SCHEDULE AT A GLANCE

55th Course Quantum Electronics, 5 October - 12 October 2014   Directors: R. Li Voti – A. Mandelis

	Sunday 5 October	**Monday 6 October** **(General Session)**	**Tuesday 7 October** **(Biomedical and Biological PA & PT)**	**Wednesday 8 October** **(Nanoscale Heat Transfer and Imaging)**	**Thursday 9 October** **(NDE&NDT – I)**	**Friday 10 October** **(NDE&NDT – II)**	**Saturday 11 October** **(Thermophysical Properties)**	**Sunday 12 October**
Breakfast (*)	Hotel or S. Rocco Cafeteria 7:00 - 9:00 a.m.	Hotel or S. Rocco Cafeteria 7:00 – 9:00 a.m..	Hotel or S. Rocco Cafeteria 7:00 - 9:00 a.m.	Hotel or S. Rocco Cafeteria 7:00 – 9:00 a.m.	Hotel or S. Rocco Cafeteria 7:00 - 9:00 a.m.	Hotel or S. Rocco Cafeteria 7:00 – 9:00 a.m.	Hotel or S. Rocco Cafeteria 7:00 - 9:00 a.m.	Hotel or S. Rocco Cafeteria 7:00 - 9:00 a.m..
Morning Session San Domenico Lecture Hall	Arrivals & Registration	Chair: S.Martellucci 10:00 – 10:15 a.m. Opening by: **A.Mandelis and R. Li Voti** 10:15 – 11.15 a.m. **C. Glorieux**	Chair: A.Mandelis 9:00 – 10:00 a.m. **G. Diebold** 10:00 – 11.00 a.m. **H. Jiang**	Chair: S.Volz 9.00 -10.00 a.m. **Y. De Wilde** 10:00 – 11.00 a.m. **G. Tessier**	Chair: C. Glorieux 9:00 – 10:00 a.m. **X. Maldague** 10:00 – 11.00 a.m. **Oral Presentations**	Chair: A. Mandelis 9:00 – 10:00 a.m. **A. Maznev** 10:00 – 11.00 a.m. **A. Oleaga**	Chair: A.Mandelis & R.Li Voti 9:00 – 10:00 a.m. **M. Wübbenhorst** 10:00 – 11:00 a.m. **A. Mandelis**	Departures
Coffee Break (*) San Domenico Terrace		11:15 – 11:30 a.m.	11:00 – 11:15 a.m.	11.00 – 11:15 a.m.	11:00 - 11:15 a.m.	11:00 - 11:15 a.m.	11:00 - 11:15 a.m.	
Morning Session San Domenico Lecture Hall		Chair: A. Mandelis 11:30 a.m. – 12:30 p.m. **B. Majaron**	Chair: B. Palpant 11:15 a.m – 12:15 p.m. **Oral Presentations**	Chair: G.Tessier 11:15 a.m. – 12:15 p.m. **Oral Presentations**	Chair: X. Maldague 11:15 – 11:45 a.m. **Oral Presentation**	Chair: A.Mendiorotz 11:15 a.m. – 12:15p.m. **Oral Presentations**	Chair: R. Li Voti **Special Session Expo15** 11:15 a.m. – 12:15 p.m **M. Franko**	
Lunch (*)	Local Restaurants	Local Restaurants	Local Restaurants	Local Restaurants	**Excursion**	Local Restaurants	Local Restaurants	Local Restaurants
Afternoon Session San Domenico Lecture Hall	Arrivals & Registration	Chair: R. Li Voti 3:00 – 4.00 p.m. **S. Volz** 4:00 – 5.00 p.m. **D. Lanzillotti Kimura**	Chair: G.Diebold 3:00 – 4.00 p.m. **M. Proskurnin** 4:00 – 5:00 p.m. **E.M. Strohm**	Chair: S.Volz 3:30 – 4.30 p.m. **J. Ordonez Miranda** 4:30 – 5:30 p.m. **C. Sotomayor-Torres**		Chair: A. Oleaga 3:30 – 4.30 p.m. **Oral presentations** 4:30 – 4:45 p.m. *Coffee Break*	Chair: M. Franko 3:00 – 5.00 p.m. **Oral presentations**	Departures
Coffee Break (*) San Domenico Terrace		5:00 – 5:15 p.m.	5:00 – 5:15 p.m.	5:30 – 5:45 p.m.		**Joint Session LENR** Chair: A. Mandelis 4:45 -5.15 p.m **F. Messa** 5.15– 6.00 p.m. **V .Violante** 6.00 – 6.30 p.m **R. Li Voti** 7.00 p.m. **FLIR prize**	5:00 – 5:15 p.m.	
Afternoon Session San Domenico Lecture Hall		Chair: C. Glorieux 5:15 – 6.00 p.m **B. Palpant** 6.00 – 7.00 p.m. **M. Baesso**	Chair: A. Mandelis 5:15 – 6.45 p.m. **Oral Presentations**	Chair: C. Sotomayor-Torres 5:45 -6.45 p.m. **Oral Presentations**			Chair: D. Todorovic 5:15 - 6.15 p.m **Oral presentations** 6.15 – 7.00 p.m **Concluding remarks**	
Dinner (*)	Local Restaurants	Local Restaurants	Local Restaurants	Local Restaurants	Local Restaurants	Social Dinner (*) 7:30 - 9:00 p.m	Local Restaurants	Local Restaurants
After dinner Session Piano Room at San Rocco	Welcome Party (*) 9:00 - 11:30 p.m.	Poster Discussion 9:00 - 11:30 p.m.	Poster Discussion 9:00 - 11:30 p.m.	Poster Discussion 9:00 - 11:30 p.m.	10.00 – 10.30 p.m. Night Session 10:30 - 11:30 p.m.. Joint Party with LENR	Poster Discussion 9:00 - 11:30 p.m.	Farewell Party (*) 9:00 - 11:30 p.m.	

(*) Accompanying person(s) may join us

Timetable of the Workshop

Sunday 5th October :

Arrivals & Registration

Lunch & Dinner: **Local Restaurants**

After Dinner: **Welcome Party** – *Piano Room San Rocco*

Monday 6th October :

Morning Session: Foundations and Techniques
San Domenico Lecture Hall

Chairperson: **S. Martellucci**

10.00 – 10.15 Opening by **A. Mandelis** and **R. Li Voti**

10.15 – 11.15 **Christ Glorieux -** KUL - Belgium
Applications of Photothermal and Photoacoustic Methods using different spatiotemporal excitation patterns

11.15 – 11.30 *Coffee Break – San Domenico Terrace*

Chairperson: **A. Mandelis**

11.30 – 12.30 **Boris Majaron -** Ljubljana - Slovenia
Photothermal Radiometry in Time Domain for temperature profiling in biological samples

12.30 – 15.00 *Lunch: Local Restaurants*

Poster Assembling

Monday 6th October :

Afternoon Session - Foundations and Techniques
San Domenico Lecture Hall

Chairperson: **R. Li Voti**

15.00 – 16.00 **Sebastian Volz -** CNRS – France
Physical Heat Conduction Mechanisms at Micro and Nanoscales

16.00 – 17.00 **Daniel Lanzillotti Kimura - CNRS – France**
Light & Sound Interactions at the Nanoscale.

17.00 – 17.15 *Coffee Break – San Domenico Terrace*

Chairperson: **C. Glorieux**

17.15 – 18.00 **Bruno Palpant -** Ecole Centrale Paris - France
Plasmonic Nanoheating: Fundamental Mechanisms and Applications

18:00 – 19.00 **Mauro Baesso -** Universidade Estadual de Maringá - Brazil
Thermal Lens to Study Transeterification Stages and Oxidative Stability: Theory and Experiments

19.00 – 21.00 *Dinner: Local Restaurants*

21.00 – 23.30 *Poster Discussion & Marsala Room*

Tuesday 7th October :

Morning Session A: Biomedical and Biological PA&PT
San Domenico Lecture Hall

Chairperson: **A. Mandelis**

9.00 – 10.00 **Gerald Diebold -** Brown University - USA
Generation of the Photoacoustic Effect by Moving Optical Sources and Thin Layers

10.00 – 11.00 **Huabei Jiang -** University of Florida - USA
Photoacoustic Imaging and Its Biomedical Applications

11.00 – 11.15 *Coffee Break – San Domenico Terrace*

Chairperson: **B. Palpant**

11.15 – 11.45 **Boris Majaron -** Ljubljana - Slovenia
Objective Characterization of Bruise Evolution using Photothermal Depth Profiling and Monte Carlo Modeling

11.45 – 12.15 **Andreas Mandelis -** University of Toronto - Canada
The Application of Ultrasound and Photoacoustic Radar Detection and Imaging for Assessment of Bone Collagen and Mineral Contents

12.30 – 15.00 *Lunch: Local Restaurants*

Tuesday 7th October :

Afternoon Session A - Biomedical and Biological PA&PT
San Domenico Lecture Hall

Chairperson: **G. Diebold**

15.00 – 16.00 **Mikhail Proskurnin -** Moskow State University – Russia
Studies of Protein and Nanoparticle Solutions in Organized Media by Thermal Lensing Along with Spectrochemical Analysis

16.00 – 17.00 **Eric M. Strohm -** Ryerson University - Canada
Photoacoustic Imaging and Characterization of Biological Structures from 1 to 1000 MHz

17.00 – 17.15 *Coffee Break – San Domenico Terrace*

Chairperson: **A. Mandelis**

17.15 – 17.45 **M. Pleitez** - Universität Frankfurt - Germany
Advances on Photothermally-based Mid-IR Spectroscopy for the Study of Human Epidermis in vivo

17.45 – 18.15 **Serge Camou –** NTT Japan
Recent Advances in Development of Noninvasive and Continuous Monitoring of Blood Glucose Levels Based on Continuous-wave Photoacoustic Protocols

18.15 – 18.45 **Timothée Labouret -** Ecole Centrale Paris - France
Ultrafast Plasmonic Heating of Single Gold Nanorods: Polarization-Controlled Photothermal Impact on a Hydrogel Medium

19.00 – 21.00 *Dinner: Local Restaurants*

21.00 – 23.30 *Poster Discussion and more*

Wednesday 8th October :

Morning Session B: Nanoscale Heat Transfer and Imaging
San Domenico Lecture Hall

Chairperson: **S. Volz**

9.00 – 10.00	**Yannick De Wilde -** Institut Langevin, ESPCI, CNRS - France *Imaging and Spectroscopy of the Near-field Thermal Emission*
10.00 – 11.00	**Gilles Tessier** - Institut Langevin, ESPCI, CNRS - France *Digital Heterodyne Holography for Thermoplasmonic Applications*
11.00 – 11.15	*Coffee Break – San Domenico Terrace*

Chairpersons: **G. Tessier**

11.15 – 11.45	**Alexei Maznev –** MIT - USA *Non-diffusive Thermal Transport by Phonons at Room Temperature*
11.45 – 12.15	**Sebastian Volz –** CNRS - France *Heat Transfer in Vacuum due to Phonons*
12.30 – 15.00	*Lunch: Local Restaurants*

Wednesday 8th October

Afternoon Session B: Nanoscale Heat Transfer and Imaging
San Domenico Lecture Hall

Chairperson: **S. Volz**

15.30 - 16.30	**Jose Ordonez-Miranda -** Ecole Centrale Paris, CNRS-France *Ultrafast Laser-Induced Heating of Dielectric Nanofilms Predicted by the Boltzmann Transport Equation: Microscopic Description of Photothermal Phenomena*
16.30 - 17.30	**Clivia Sotomayor Torres –** CINN - Spain *Phonons in Silicon Free-standing Membranes*
17.30 – 17.45	*Coffee Break – San Domenico Terrace*

Chairperson: **Clivia Sotomayor Torres**

17.45 – 18.15	**Lei Hou** - Leiden University, The Netherlands *Nanobubble Formation around a Heated Single Gold Nanosphere*
18.15 – 18.45	**Roberto Li Voti** - Sapienza Università di Roma - Italy *Thermal Characterization of Carbon Nanotubes by Photothermal Techniques*
19.00 – 21.00	*Dinner: Local Restaurants*
21.00 – 23.30	*Poster Discussion and Marsala Room*

Thursday 9th October:

Morning Session C: Non Destructive Evaluation & Testing I
San Domenico Lecture Hall

Chairperson: **C. Glorieux**

9.00 - 10.00 **Xavier Maldague -** Université Laval - Canada
Infrared Thermography for NDT and More

10.00 – 10.30 **Arantza Mendioroz** - University of the Basque Country UPV/EHU - Spain
Characterization of Vertical Cracks using Lock-in and Burst Ultrasound Excited Thermography

10.30 – 11.00 **Qining Sun and Andreas Mandelis –** University of Electronic Science and Technology of China (UESTC) and University of Toronto - Canada
Camera-based Homodyne and Heterodyne Lock-in Carrierography Imaging of Crystalline Silicon Wafers

11.00 – 11.15 *Coffee Break – San Domenico Terrace*

Chairperson: **X. Maldague**

11.15 – 11.45 **Christ Glorieux**, - KUL Leuven, Belgium
Photothermal Characterization of Layers: Experimental Issues and Solutions

12.00 – 15.00 *Lunch: Local Restaurants*

Excursion:
Bus leaving Erice Parking area around 12.00
More details will be given during the workshop

19.00 – 21.00 *Dinner: Local Restaurants*

Night Session:
San Rocco Lecture Hall

Chairperson: **S. Martellucci**

22.00 – 22.30 **Mario Bertolotti**
Celestial Messengers

22.30 – 23.30 *Joint party with LENR at Marsala Room*

Friday 10th October :

Morning Session C: Non Destructive Evaluation & Testing II
San Domenico Lecture Hall

Chairperson: **A. Mandelis**

9.00 - 10.00	**Alexei Maznev –** MIT – USA *Laser-Induced Transient Gratings for Acoustic and Thermal Measurements in Science and Industry*
10.00 – 11.00	**Alberto Oleaga -** Universidad del Pais Vasco UPV/EHU - Spain *Recent advances in the characterization of vertical cracks using lock-in thermography*
11.00 – 11.15	*Coffee Break – San Domenico Terrace*

Chairperson: **A. Mendiorotz**

11.15 – 11.45	**Peter Burgholzer -** Linz - Austria *Depth Profiling in Thermography: Fluctuations and Its Influence on Thermodynamic Limits of Spatial Resolution*
11.45 – 12.15	**Roberto Li Voti** - Sapienza Università di Roma – Italy *Photothermal Depth Profiling in Hardened Steels: New Inverse Approaches to Improve the Profile Reconstruction*
12.30 – 15.00	*Lunch: Local Restaurants*

Friday 10th October:

Afternoon Session C: Non Destructive Evaluation & Testing II
San Domenico Lecture Hall

Chairperson: **A. Oleaga**

15.30 – 16.00	**Nelson W. Pech-May**, University of the Basque Country UPV/EHU - Spain *Extending the Flash Method for Semitransparent Materials*
16.00 – 16.30	**Facundo Zaldivar Escola** - Universidad de Buenos Aires - Argentina *Characterization of Mixed Oxide Ceramics by Photothermal Microscopy*
16.30 – 16.45	*Coffee Break – San Domenico Terrace*

Friday 10th October:

Evening Joint Session: FLIR exhibition and LENR Seminars
San Domenico Lecture Hall

Chairperson: **A. Mandelis**

16.45 – 17.15	**Francesco Messa –** FLIR *FLIR exhibition & FLIR Best Presentation Award*
17.15 - 18.00	**Vittorio Violante –** ENEA Frascati - Italy *Material Science and Measurements in Low Energy Nuclear Reactions*
18.00 - 18.30	**Roberto Li Voti -** Sapienza Università di Roma – Italy *Optical & Photothermal Measurements Applied to LENR Systems*
18.30 - 19.00	*Celebration of the winner and brief talk*
19.30 – 21.00	*Social Dinner*
21.00 – 23.30	*Poster Discussion and Marsala Room*

Saturday 11st October:

Morning Session D: Thermophysical Properties
San Domenico Lecture Hall

Chairperson: **A. Mandelis & R. Li Voti**

9.00 – 10.00	**Michael Wübbenhorst –** Katholieke Universiteit Leuven - Belgium *Specific Heat Spectroscopy and Pyroelectric Depth Profiling in Ultrathin Films of Glass Forming Liquids and Polymers*
10.00 – 11.00	**Andreas Mandelis** –University of Toronto - Canada *Non-Contact Optoelectronic Diagnostics of Solar Cell Materials and Devices using Photocarrier Radiometry, Lock-in Carrierography and Termography Imaging*
11.00 – 11.15	*Coffee Break – San Domenico Terrace*

Morning Special Session in view of Expo 2015
San Domenico Lecture Hall

Chairperson: **R. Li Voti**

11.15 - 12.15	**Mladen Franko –** Nova Goriza – Slovenia *Achievements and Future Prospects in Application of Photothermal Techniques for Food Quality Control and Safety*
12.15 – 12.45	**Annamaria Giusti –** Sapienza Università di Roma - Italy *Photoacoustic Techniques Applied to Nondestructve Analysis of Phytochemicals Present in the Typical Foods of the Mediterranean Diet*
13.00 – 15.00	*Lunch: Local Restaurants*

Saturday 11st October:

Afternoon Session D: Thermophysical Properties
San Domenico Lecture Hall

Chairperson: **M. Franko**

15.00 – 15.30	**Paolo Bison**– CNR Italy *Non Invasive Detection of Marble Sulfation by Pulsed Thermography*
15.30 – 16.00	**Dragan M. Todorović -** University of Belgrade - Serbia *Photoacoustic and Photothermal Study of the Micro-Electro-Mechanical-Structures*

16.00 – 16.30 **J.A. Balderas-López -** Instituto Politécnico Nacional - UPIBI - México
Photopyroelectric Technique: Sample´s thickness scanning for Measuring Optical Properties of Pure Liquid Substances

16.30 – 17.00 **Marcus Wolff** - Hamburg University Germany
Optical Characterization of Photothermally Induced Arc Flicker in High-Intensity Discharge Lamps

17.00 – 17.15 *Coffee Break – San Domenico Terrace*

Chairperson: **D. Todorović**

17.15 – 17.45 **Alberto Oleaga** - University of the Basque Country UPV/EHU
Photopyroelectric Calorimetry Applied to the Study of Critical Behavior of KAF_3 *(A = Mn, Co, Ni)*

17.45 – 18.15 **Mario Bertolotti –** Sapienza Università di Roma - Italy
Photothermal Characterization of Thermochromic Materials for Tunable Thermal Devices

Afternoon Session: Presentation of the next events & Conclusions
San Domenico Lecture Hall

Chairperson: **A. Mandelis and R. Li Voti**

18.15 – 18.45 *Presentation of the next International Conferences:*
** 18th ICPPP Belgrade*
** 19th Symposium on Thermophysical Properties at Boulder Colorado*
** Fourth Mediterranean International Workshop on PA&PT*

18.45 – 19.00 *Concluding Remark and Round Table*

19.15 – 21.00 *Dinner: Local Restaurants*

21.00 – 23.30 *Farewell Party – Marsala Room*

Poster Disassembling

Sunday 12nd October:

Departures

Lunch & Dinner: **Local Restaurants**

POSTER SESSION

P.1
Bingzhang Chen, Dan Wu1, Jinge Yang, and Huabei Jiang
Study of Acupuncture Effect on Cerebral Blood Flow using Photoacoustic Imaging

P.2
O. Hertzberg, M. Pleitez, T. Lieblein, A. Bauer, H. von Lilienfeld-Toal and W. Mäntele
Mid-IR Photothermal Deflection Spectroscopy for in vivo Skin Measurments using a Tunable Quantum Cascade Laser

P.3
Renato Saavedra, Jorge Yañez, and César Soto
Classifying Ammunition from Gunshot Residues Using Fourier Transform Infrared Photoacoustic Spectroscopy (FTIR-PAS)

P.4
Renato Saavedra, Jorge Yañez, and César Soto
The Use of Thermal Lens Determination of Copper(II) with 5-(4-sulphophenylazo)-8-aminoquinoline

P.5
M.M. Krayushkin, Barachevsky V.A., Yarovenko V.N., Levchenko K.S., Zavarzin I.V, Chudov K.A., Kobeleva O. I., Valova T. M.
Transformations of Chromones and Their Structural Analogues into Fluorescent Products under UV-Irradiation.

P.6
V.A. Barachevsky, O.V. Venidiktova, O.I. Kobeleva, A.M. Gorelik, M.M. Krayushkin, O.I. Andreev, G.I. Sigeikin
Solid-Phase Photochromic Films with Polyfunctional Optical and Electric Properties

P.7
I.V. Zavarzin, M.M. Krayushkin, A.M. Bogacheva, V.N. Charushin, V.N. Yarovenko, I.A. Platonova, V.A. Barachevsky
Non-destructive Recording Media Based on FRET-effect for Operative Optical Memory

P.8
A. Giusti, G. Leahu, A.Maurizi, G.Cesarini, C.Sibilia, R. Li Voti
Nondestructve Evaluation and Testing of Apples by Photoacoustic Spectroscopy

P.9
R. Li Voti, G.Leahu, M.C. Larciprete, G.Cesarini, C. Sibilia, M. Bertolotti, I. Nefedov, I. V. Anoshkin
Photoacoustic Characterization of Randomly Oriented Silver Nanowires Films

P.10
G. Cesarini, R. Li Voti**,** G. Leahu, C.Sibilia, M.L.Grilli, A.Sytchkova
Optical and Photoacoustic Investigation of AZO/Ag/AZO Transparent Conductive Coating for solar cells

P.11

R. Li Voti, G. Leahu, M.C. Larciprete, G.Cesasini, F.Mura, I.Fratoddi, C. Sibilia and M. Bertolotti

Semiconductor-Metal Phase Transition of Vanadium Dioxide Nanostructures on Silicon Substrate: Applications for Tunable Thermal Devices

P.12

E. Marín, K. Martínez, A. Lara-Bernal, A. Calderón, G. Peña-Rodríguez, **C. Glorieux**

On Heat Losses in Photothermal Experiments

P.13

P. Vieyra Pincel, J.L. Jiménez-Pérez, A. Cruz-Orea, Z. N. Correa-Pacheco,V. Cruz-SanMartin, and **C. Glorieux**

Study of Curing Time of a Photoresin by using Photoacoustic Technique

Monday October 6th

Foundations and Techniques

T1

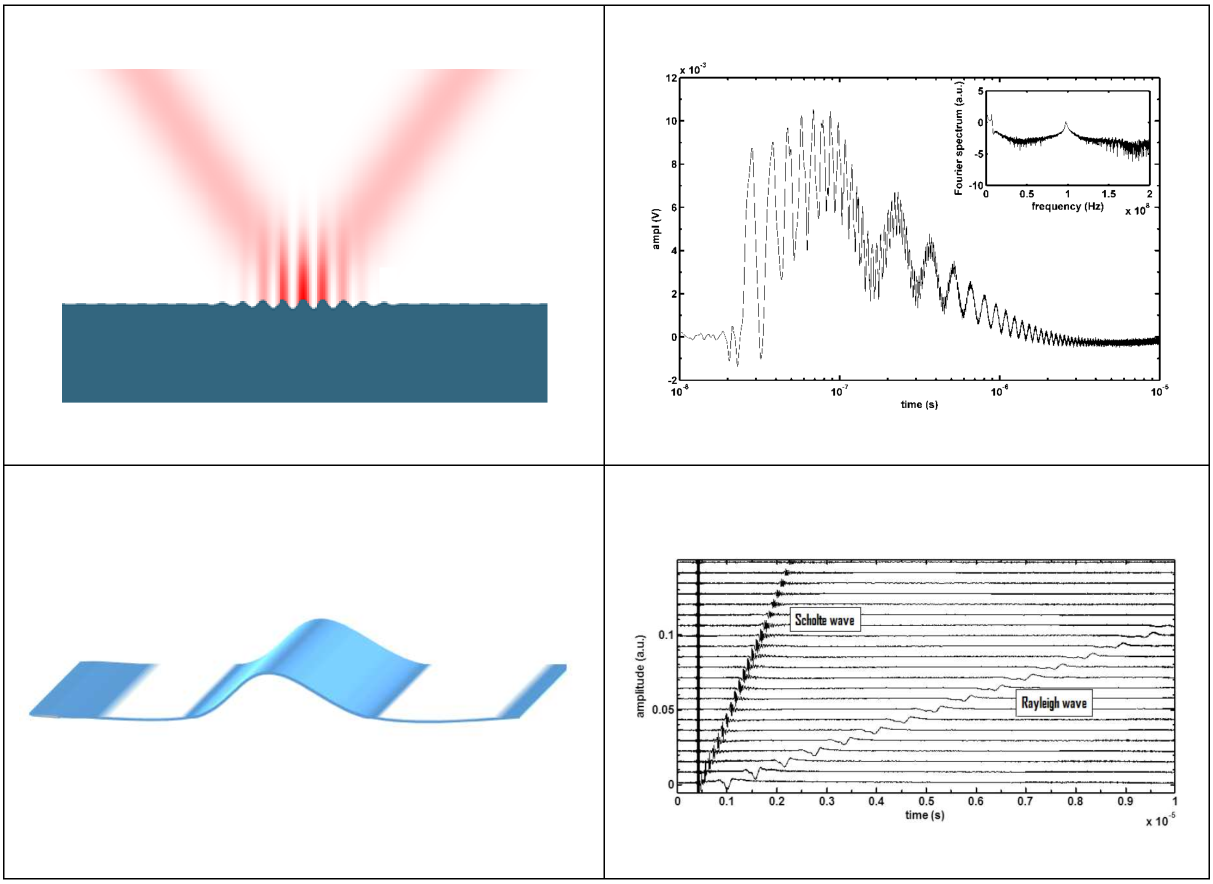
Applications of photothermal and photoacoustic methods using different spatiotemporal excitation patterns

Jan Sermeus[(a)], Bert Verstraeten[(a)], Liwang Liu[(a)], Ernesto Marin[(b)], Angel Cifuentes[(b)], Jan Fivez[(c)], Michal Landa[(d)], Pavla Stoklasova[(d)], Ken Haenen[(e)], Paulius Pobedinskas[(e)], Christ Glorieux[(a,*)]

[(a)] *Laboratory Acoustics and Thermal Physics, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D, B3001 Heverlee, Belgium*
[(b)] *Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada (CICATA), Unidad Legaria, Instituto Politécnico Nacional (IPN)Legaria 694, Colonia Irrigación, México D.F 11500, México*
[(c)] *HUB, Warmoesberg 26, B-1000 Brussel, Belgium*
[(d)] *Laboratory of ultrasonic methods,Institute of Thermomechanics,ASCR, Dolejskova 5, 182 00 Praha 8, Czech Republic*
[(e)] *Hasselt University, Institute for Materials Research (IMO), Diepenbeek, Belgium*
[*] *christ.glorieux@fys.kuleuven.be*

The determination of thermal and acoustic transport properties is typically based on the local generation of heat or elastic stress and the detection of the resulting temperature or displacement at one or more distances from the excitation region. The thermal diffusivity or acoustic wave velocity and damping can then be extracted from the spatial and temporal evolution of the measured quantity. In order to enhance the measurement accuracy, bandwidth or spatial resolution, it can be advantageous to perform measurements in frequency domain (sinusoidally modulated laser intensity) or wavenumber domain (spatially periodic grating excitation), or to work with wide bandwidth excitation, in time (pulsed laser), in space (line source), or in both.

Here we give an overview of photoacoustic and photothermal applications that make use different spatiotemporal configurations, with focus on their advantages and disadvantages in different situations. Both the excitation and detection possibilities are discussed. Different implementations are given for thermal and elastic characterization of thin layers, free-standing films, substrates, and bulk materials with frequency dependent properties. Special attention is given to the data analysis of surface acoustic wave and thermal wave dispersion curves.



Different excitation schemes and resulting signals

T2

Photothermal Radiometry in Time Domain for Temperature Profiling in Biological Samples

Boris Majaron
Department for Complex Matter, Jožef Stefan Institute, Ljubljana, Slovenia
Faculty of Mathematics and Physics, University of Ljubljana, Slovenia
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Photo-thermal radiometry in time domain (a.k.a. pulsed photothermal radiometry - PPTR) is based on measurements of transient changes in mid-infrared (IR) emission from sample surface after exposure to a single pulse of light. In addition to optical or thermal properties of homogeneous samples, light-induced temperature depth profiles can also be determined from the measured radiometric signals. Approximately 20 years ago it was first proposed that the same approach could be useful for structural characterization of biological tissues and organs.

After covering the theoretical background and experimental setup for PPTR temperature profiling, I will address specific challenges involved in solving the severely ill-posed inverse problem of temperature profile reconstruction in biological samples [1,2] and some recent advances which enabled us to achieve record-breaking depth resolution and robustness in experimental tests *in vitro* [3]. These steps include development of a custom optimization algorithm (combining the ν-method and nonnegativity constraint) [3], preconditioning of the kernel matrix (by nonuniform binning of the signals)[4], and augmentation of the forward problem formulation (by introduction of multi-spectral kernel matrix)[3].
Second part of the talk will review our recent applications of PPTR profiling *in vivo*. These include monitoring of laser tattoo removal [5], characterization of laser-tissue interaction in treatment of port wine stain (PWS) birthmarks [6], objective evaluation of a prototype laser system for skin rejuvenation (emitting at 1342 nm) [7], and development of an inovative technique for determination of maximal safe radiant exposure on individual patient basis [8]. Our most complex (and ongoing) study of hemoglobin dynamics in traumatic bruises (hematomas)[9] will be presented in a separate talk (by Vidovič *et al.*).

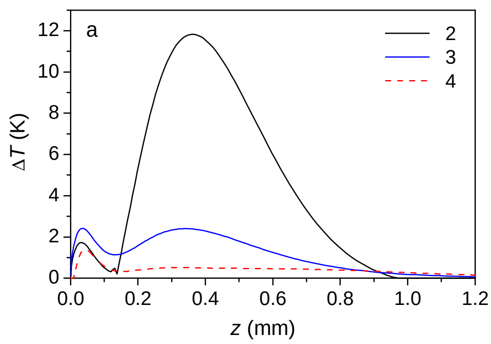

Fig. 1: Reconstructed temperature profiles in a tattoo site on a healthy volunteer prior to Nd:YAG laser treatment (*black solid line - 2*), 6 months after the treatment (*blue -3*), and 3 months after second treatment (*red dashed line -4*).[5]

[1] B. Majaron, M. Milanič, Phys. Med. Biol. **52**, 1089-1101 (2007).
[2] M. Milanič and B. Majaron, J. Biomed. Opt. **14**, 064024-1–8 (2009).
[3] M. Milanič, I. Serša, B. Majaron, Phys. Med. Biol. **54**, 2829 (2009).
[4] M. Milanič and B. Majaron, Proc. SPIE **7371**, 77310O (2009)
[5] B. Majaron and M. Milanič, Proc. SPIE **8207**, 82070G-1–12 (2012); J. Laser Health Acad. **2013**, 68–74 (2013)
[6] B. Majaron, M. Milanič, J.S. Nelson, Proc. SPIE **6632**, 66320C (2007).
[7] M. Milanič and B. Majaron, Lasers Surg. Med. **45**, 8–14 (2013).
[8] B. Majaron, L. Vidovič, M. Milanič, W. Jia, J.S. Nelson, Laser Surg. Med. **S23**, 916–917 (2011)
[9] L. Vidovič, M. Milanič, B. Majaron, Proc. SPIE vol. **8941**, 894112-1–9 (2014); J. Biomed. Opt. (submitted).

T3

Physical heat conduction mechanisms at micro and nanoscales

Sebastian Volz [(a)] and Yann Chalopin[(a)]

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Abstract: We present a short introduction on size effects on heat conduction at nanoscales and illustrate those with recent advances in the understanding of heat conduction in semi-conductor superlattices [1] and carbone based systems [2-5]. In superlattices, the effect of (i) coherence and (ii) interfaces/surfaces becoming predominant, we use a direct simulation technique -i.e. Molecular Dynamics- to estimate the thermal resistance generated by those effects but also a specific metrics to define the coherence length of phonons. In grapheme systems, several mechanics will be highlighted such as the high graphene-silica interfacial resistance, the grapheme substrate dependence of the resistance to the number of layer and the differences appearing when a suspended grapheme is deposited on a substrate.

[1] B. Latour, S. Volz, Y. Chalopin, Microscopic Description of Thermal Phonon Coherence : From Coherent Transport to Diffuse Interface Scattering in Superlattices, Phys. Rev. B., 90, 1, 014307 (2014).
[2] Y. Ni, Y. Chalopin and S. Volz, Few Layer Graphene based Superlattices as Efficient Thermal Insulators, Appl. Phys. Lett., 103, 14, 141905, (2013).
[3] Yuxiang Ni, Yuriy Kosevich, Shiyun Xiong, Yann Chalopin, and Sebastian Volz, Substrate Induced Cross-Plane Thermal Propagative Modes in Few Layer Graphene, Phys. Rev. B., 89, 20, 205413, (2014).
[4] Y. Ni, Y. Chalopin and S. Volz, Few Layer Graphene based Superlattices as Efficient Thermal Insulators, Appl. Phys. Lett., 103, 14, 141905, (2013).
[5] Yuxiang Ni, Yann Chalopin, and Sebastian Volz, Significant thickness dependence of the thermal resistance between few-layer graphenes, Appl. Phys. Lett., 103, 61906, (2013).

T4

Light and sound interactions at the nanoscale

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Abstract: The idea of trapping and manipulating light, sound and heat has fascinated mankind since ancient times. The development of micro- and nanofabrication techniques enabled the study of nanostructures where it is possible to confine photons (light) and phonons (ultrahigh frequency sound) in a single resonant cavity of about 100 nanometers, and control both the dynamics and the interactions between them. Through the engineering of semiconductor and metallic nanostructures displaying a controlled acoustic impedance modulation, a new area is growing in nanoscience: nanophononics. This area is devoted to the study of the vibrational and thermal properties at the nanometer scale, and the interaction of these engineered phonons with photons and electrons at high frequencies and reduced scales.

In the first part of this presentation I will introduce different strategies to generate and manipulate coherent phonons using femtosecond lasers [1], and will discuss experimental results obtained using engineered semiconductor nanostructures. I will discuss several acoustic devices: superlattices operate as high reflectance phononic mirrors, acoustic nanocavities confine and amplify the hypersound field both spatially and in the spectral domain, and optimized aperiodic multilayers may act as tailored phononic filters. Also, I will introduce structures based on GaAs/AlAs capable of simultaneously confine light and sound optimizing their interactions. [2-6]

Plasmonics, on the other side, has emerged as a promising field in physics, with the potential to overcome the diffraction limit in classical photonics, and to develop a myriad of applications. Spatially localized surface plasmons show strong electronic resonances that allow their use for the design of optical nanoantennas and metamaterials, enabling new ways of capturing and controlling light [7]. These resonances can be strongly dependent on polarization, allowing a selective coupling and control of the light with the nanostructures [8]. In the second part of this presentation I will show how to integrate plasmonics concepts into the field of nanophononics using metallic nanoantennas as coherent phonon generators and detectors [9].

[1] C. Thomsen, H. T. Grahn, H. J. Maris, and J. Tauc, Phys. Rev. B **34**, 4129 (1986)
[2] N. D. Lanzillotti-Kimura et al., Appl. Phys. Lett. **96**, 053101 (2010)
[3] N. D. Lanzillotti-Kimura, A. Fainstein, B. Perrin, et al, Phys. Rev. Lett. **104**, 187402 (2010).
[4] N. D. Lanzillotti-Kimura, A. Fainstein, B. Perrin, et al, Phys. Rev. B **84**, 201103 RC (2011).
[5] A. Fainstein, et al. Phys. Rev. Lett. **110**, 037403 (2013).
[6] N. D. Lanzillotti-Kimura, et al., Ultrasonics, in press (DOI: 10.1016/j.ultras.2014.05.017) (2014).
[7] S. Maier, "Plasmonics: Fundamentals and Applications", Springer, Berlin, (2007).
[8] T. Ellenbogen, K. Seo and K. B. Crozier, Nanolett. **12**, 1026 (2012).
[9] K O'Brien, N. D. Lanzillotti-Kimura, et al, Nature Communications **5**, 4042, (2014).

T5

Plasmonic nanoheating: fundamental mechanisms and applications

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Abstract: This tutorial aims at providing some take-home messages about the ability of noble metal nanoparticles to behave as effective heat nanosources when irradiated by light at their localized plasmon resonance [1]. The basics mechanisms of this conversion process will be examined. We will show how pulsed optics can help understanding them. The influence of key parameters related to both the medium (nanoparticle size, shape, number density, environment) and light (pulse duration, wavelength) will be discussed. Some selected applications in the fields of biomedicine and materials will be presented.

Fig. 1. The Lycurgus cup after light irradiation at plasmon resonance. The effect of nanoscale light-heat conversion on the macroscale material optical properties can be easily observed.

[1] B. Palpant, “Photothermal properties of gold nanoparticles”, in *Gold Nanoparticles for Physics, Biology and Chemistry*, ed. C. Louis and O. Pluchery (Imperial College Press, 2012).

T6

Thermal lens to study transeterification stages and oxidative stability: theory and experiments

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The remote nature of Thermal Lens Spectrometry (TLS) has been successfully explored in temperature scanning studies of both solids and liquids [1,2]. Glass and phase transitions of solids and photostability of biological systems have been investigated through quantitative measurements of the samples thermophysical parameters [1-2]. In this work, theory and experiments of TLS will be discussed focusing the study of transesterification stages and oxidative stability of biodiesel and oils. Measurements of samples from different stages of the transesterification reaction were performed as a function of temperature, simultaneously with the induction of fast oxidation. Vegetal oils with and without natural antioxidants were also studied. The results allowed to correlate the measured parameters with the oxidative stability. Temperature behavior of the thermal diffusivity was correlated with the molecular size, and the TLS amplitude evidenced the occurrence of oxidation. The onset temperature (T_{onset}) during the transesterification stages changed from 149ºC to 169 ºC for sunflower and from 120 ºC to 142 ºC for soybean samples. The values of the characteristic reaction time revealed the formation of intermediate compounds after ~7min for sunflower and ~10min for soybean. Additional analyses of oxidation and transesterification of both samples were performed with conventional calorimetry and Fourier transform infrared spectroscopy. The results were in agreement with those obtained by the TLS method. The TLS also allowed to distinguish natural oil from the antioxidant treated one in terms of their photostabilities. To conclude, in this presentation the theory and experiments of thermal lens method will be discussed envisaging this technique as a promising tool for different temperature studies of biodiesel and oils, and their relationship with the samples oxidative behavior. The results appear to be useful for the establishment of novel protocols for these materials certification.

[1] N.G.C. Astrath,et al Appl. Phys. Lett. **95,** 191902 (2009).
[2] N.G.C. Astrath,et al Phys. Rev. B. **21,** 214202 (2005).

Tuesday October 7th:

Biomedical and Biological PA&PT

A1

Generation of the Photoacoustic Effect by Moving Optical Sources and Thin Layers

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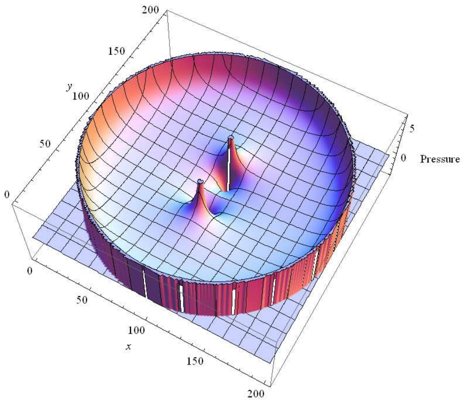
Abstract: The photoacoustic effect can be produced by moving an optical beam in a weakly absorbing medium. The character of the sound waves generated in 1, 2, and 3 dimensions is found to differ greatly. In one dimension, for example, the sound amplitude increases without bound according to linear acoustics, when the optical beam moves at the sound speed. In three dimensions a trailing wave is found as a result of reflection of a wave propagating towards the origin. In two dimensions, in addition to compressions and rarefactions that move with the light beam speed, a discontinuity in the pressure is found. Theoretical and experimental results for short pulse irradiation of thin layers is given as well.

The wave equation for pressure has a source term that is proportional to the time derivative of the heating function, which is the energy delivered by the light beam per unit volume and time to the fluid. As such, any motion of the optical source is space results in the generation of sound. It has been known for some time[1] that in a one dimensional geometry, that is, where, for instance, an optical beam moves with speed v as a line, or perhaps as a beam with a Gaussian profile, along the z axis in a channel that confines the pressure, that the pressure consists of a wave front that moves with the sound speed c, followed by a pressure decrease that moves with speed v, and a trailing wave that propagates in the negative z direction with a speed c. The wave amplitude is positive, and is proportional to 1/(c-v), which, of course, means that as v approaches c, the acoustic amplitude gets large. It can be shown that when v=c, the wave increases in amplitude as a linear function of time without bound—at least according to linear acoustics. In two and three dimensions, this is not the case as the pressure can be dissipated in directions other than the direction of propagation.

It is possible to consider theoretically the problem of a three dimensional, spherically symmetric, Gaussian optical source initially at a distance from the origin that either travels away from the origin or towards it. Again, for a radial speed v that is smaller than c, there is a wave that advances ahead of the source, and a trailing wave that propagates oppositely to the direction of motion of the source. In the case of spherical waves, there must be a reflection at the origin,



which results in a finite amplitude wave propagating outwardly and adding to the initially generated wave.

Two dimensional waves can be generated by light beams moving perpendicularly to the propagation direction of the optical beam. The case of a delta function optical source moving away from the origin with a speed v along the x axis is taken. The unusual feature of the two-dimensional wave generated in this way is that the wave that precedes the source and travels at a speed c shows a discontinuity along a circle centered at the origin, as shown in the figure.

Results for pulsed laser irradiation of thin films are presented. Here solutions to a new wave equation that takes into account thermal conduction are given and compared with the results of experiments using thin gold foils submerged in water.

[1] V. E. Gusev and A. Karabutov, *Laser Optoacoustics* (American Institute of Physics, 1993).

A2

Photoacoustic Imaging and Its Biomedical Applications

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Abstract: Principles of photoacoustic tomography (PAT) and photoacoustic microscopy (PAM) along with their hardware/software implementation will be described. In particular, quantitative photoacoustic tomography (qPAT) and photoacoustic computed microscopy (PACM) will be highlighted. These variations of photoacoustic imaging will be illustrated through their applications to detect cancer, probe inflammation and map brain activity.

Photoacoustic imaging (PAI) is an emerging biomedical imaging modality that combines the high contrast and spectroscopic-based specificity of optical imaging with the high spatial resolution of ultrasound imaging in a single modality. By listening to light, PAI detects tissue-absorbed photons ultrasonically through the photoacoustic effect. Since ultrasonic scattering is 2 to 3 orders of magnitude weaker than optical scattering in tissue, PAI breaks the 2-4mm spatial resolution limit associated with pure optical tomography such as diffuse optical tomography (DOT) for deep tissue imaging, or the ~1mm depth limit associated with confocal and multi-photon microscopy and optical coherent tomography (OCT). In PAI, tissue is excited with a short (typically a few nanoseconds) laser pulse (focused or unfocused) and the subsequent laser-induced transient photoacoustic waves in the range of 1-100MHz, due to the transient thermoelastic expansion of light-absorbing components in tissue, are detected by wideband unfocused or focused ultrasound transducer(s). Unique advantages of PAI are that functional or biochemical parameters such as deoxy-hemoglobin (HbR), oxy-hemoglobin (HbO_2), water (H_2O), and lipid, etc along with vasculature and blood flow can be imaged in high resolution. In addition, highly specific molecular PAI can be realized through the use of molecular contrast agents. Finally, PAI can be made portable for bedside applications, is economical, and uses non-ionization radiation.

PAI has found its potential clinical applications in several areas. In breast imaging, PAI offers the submillimeter-resolution ability to quantitatively image the high optical contrast generated through the presence of blood, water, and lipid which are the predominate transformations associated with malignancy. Clinical studies conducted at multiple institutions and countries have repeatedly shown that there exist 2:1 and higher absorption contrasts in breast cancers that can be imaged by PAI. These studies suggest that PAI has the potential to detect breast tumors at early stages. Application of PAI to joint imaging has been recently explored, offering an opportunity for early detection and monitoring of progressive diseases including osteoarthritis and rheumatoid arthritis. In this case, the optical contrast is produced through the degraded articular cartilage, and the increased water content and turbidity in the synovial cavity. Other clinical applications of PAI also start to appear including intravascular imaging and intraoperative imaging during cancer treatment.

While brain imaging and electrophysiology play a central role in neuroscience research and in the evaluation of neurological disorders, a single noninvasive modality that offers both high spatial and temporal resolution is currently not available. PAI may become such a neuroimaging modality at least in animals. I show in this lecture in an acute epilepsy rat model that PAI can noninvasively track seizure brain dynamics with both high spatial and temporal resolution, and at a depth that is clinically relevant. The noninvasive yet whole surface and depth capabilities of PAI allow to actually see what is happening during ictogenesis in terms of seizure onset and spread.

A3

Objective Characterization of Bruise Evolution using Photothermal Depth Profiling and Monte Carlo Modeling

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Forensic examiners are frequently asked to estimate the age of traumatic bruises. This procedure is currently based on subjective assessment of the bruise color, which however depends strongly on the depth of vascular injury, natural skin tone, ambient light conditions, etc. Limited control of these factors prevents an accurate and reliable determination of the time of the injury.

Optical techniques, such as diffuse reflectance spectroscopy (DRS), were recently applied to objective analysis of the bruise healing process [1,2]. However, DRS signals lack information on geometry of the specific skin site, as well as on depth distribution of relevant chromospheres. Consequently, the key parameters governing the bruise healing process assessed from inverse analysis of DRS spectra are likely not very accurate.

Pulsed photothermal radiometry (PPTR) allows noninvasive determination of laser-induced temperature depth profiles in strongly scattering biological tissues [3,4]. We have applied this technique to quantitative characterization of the bruise healing process. By combining an analytical model of bruise evolution with numerical (Monte Carlo) simulation of PPTR measurement, we can objectively fit the PPTR signals obtained from human volunteers at various times after incidental injury [5]. This approach eliminates reconstruction of the corresponding depth profiles, which avoids the controversies related to its non-uniqueness, and reduces the computational complexity. The above step is preceded by similar analysis of a nearby healthy site, which allows us to assess the local values of epidermal thickness, melanin content, and concentration of blood in intact dermis.

The described approach enables us to determine the values of hemoglobin mass diffusivity and biochemical degradation rate, which were controversial in literature and have not been measured directly. In addition, temporal variations of the hemoglobin dynamics parameters can be assessed for the first time. Access to such information is imperative for future development of objective techniques for bruise age determination.

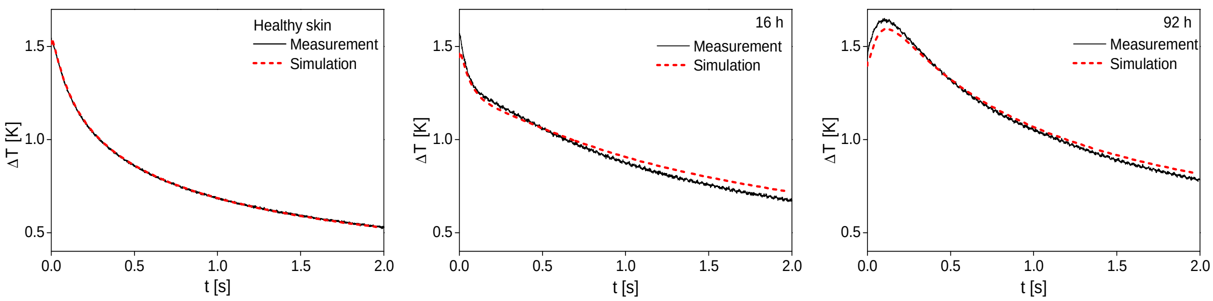

Fig. 1: Measured and best fitting simulated PPTR signals in healthy (*left*) and bruised skin 16 (center) and 92 hours after incidental injury (*right*).

Table 1: Parameters of the bruise evolution model as assessed from the data in Fig. 1.

		t = 16 h	t = 92 h
Hemoglobin mass diffusivity	[10^{-4} mm^2/h]	6.61 ± 0.07	6.2 ± 0.2
Depth of blood extravasation	[mm]	0.466 ± 0.003	0.478 ± 0.007
Hemoglobin decomposition time	[h]	51 ± 5	81 ± 3
Duration of blood spill	[h]	> 16	38 ± 3

[1] L.L. Randeberg *et. al*., Laser Surg. Med. **38**, 277–289 (2006).
[2] B. Stam *et al.*, Med. Biol. Eng. Comput. **48**, 911–921 (2010).
[3] M. Milanič, I. Serša, B. Majaron, Phys. Med. Biol. **54**, 2829 (2009).
[4] M. Milanič, B. Majaron, Lasers Surg. Med. **45**, 8–14 (2013).
[5] L. Vidovič, M. Milanič, B. Majaron, Proc. SPIE vol. **8941**, 894112-1–9 (2014).

A4

The Application of Ultrasound and Photoacoustic Radar Detection and Imaging for Assessment of Bone Collagen and Mineral Contents

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Osteoporosis is a major public health problem in many countries. This talk will examine the backscattered ultrasound (US) and back-propagating photoacoustic (PA) signals from trabecular bones, and their variations with reduction in bone minerals and collagen content. While the collagen status is directly related to the strength of the bone, diagnosis of its condition using US remains a challenge. For both PA and US methods, coded-excitation signals and matched filtering were utilized to provide high sensitivity of the detected signal. The PA signals were generated with an 805-nm CW laser used for optimally deep optical penetration depth. The detector for both modalities was a 2.2-MHz US transducer with lateral resolution of ~1 mm at its focal point. Bone decalcification and decollagenization were induced with mild ethylenediaminetetraacetic acid (EDTA) and sodium hypochlorite solutions, respectively. The PA and US signals were measured on bovine bones, and apparent integrated backscatter/back-propagating (AIB) parameters were compared before and after demineralization and decollagenization. Using a lateral pixel size much larger than the size of the trabeculae, raster scanning generated PA images related to the averaged values of the optical and thermoelastic properties, as well as density measurements in the focal volume. US backscatter yielded images related to mechanical properties and density in the focal volume. The depth of interest was selected by time-gating the signals for both modalities. The raster scanned PA and US images were compared with micro-computed tomography (μCT) images averaged over the same volume to generate similar spatial resolution as US and PA. The comparison revealed correlations between PA and US modalities with the mineral volume fraction of the bone tissue. Various features and properties of these modalities such as detectable depth, resolution and sensitivity are discussed.
The results show that both PA and US are sensitive to mineral changes. In addition, PA is also sensitive to changes in the collagen content of the bone, but US is not significantly sensitive to these changes.

A5

Analysis of Protein and Nanoparticle Solutions in Organized Media by Thermal Lensing Along with Spectrochemical Analysis

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Abstract: State-of-the-art research trends look somewhat similar for studies in biomedicine and in various case s of nanomaterial assessment in technology. Sometimes, early studies in artificial mixtures (for technology) or purely *in vitro* studies (for biomedicine) quickly jump to actual application environments or *in vivo* studies. However, such a quick 'long' jump changes too many parameters of the system in question and one cannot say *a priori* that the behavior of the test entity in artificial conditions will be replicated in real systems. As well, not all the parameters of the system in question can be readily monitored *in vivo* or in a real application with ease. Thus, a test platform, which can be considered as an intermediate step between initial *in vitro*/test studies and *in vivo*/real applications, is of a great value [1, 2]. Such intermediate (or *ex vivo*) platforms are known to be based on organized media of hydrophilic polymers—either micellar or structural—polyethylene glycols, various membranes, or hydrogels [3-6]. The polymer modification of the solution stabilizes and mildly fixes nanoparticles, micelles, or cells in place and provides the overall physicochemical properties closer to the intended real application of the test entity.

On the other hand, the field of application of photothermal spectroscopy for heterogeneous materials (solid and liquid), including dynamic heterogeneities, develops rapidly and extensively. This includes sensing and analysis of various nanoparticles, biologically active complexes, and cells. As the photothermal signal strongly depends on the parameters of the solution, it could change advantageously and crucially if an aqueous medium contains nanoparticles, micelles, or polymers. Thus, polymer-based organized media can provide very sensitive and distnict measurement of test entities with photothermal spectroscopy in various environments. Moreover, due to its intrinsic sensitivity, versatility, and non-destructivity, photothermal spectroscopy can be a valuable assessment/probing unit of such a test polymer-based platform.

The examples of this study will include use of several polymer and surfactant-based organized media for the photothermal (thermal-lens) detection and investigation of carbon nanomaterials (unmodified fullerenes and detonation nanodiamonds) and some (heme) proteins and their supramolecular complexes with metal chelates, lipids, etc. The applications of photothermal spectroscopy for the quantification and size estimation of these test materials will be discussed. The data obtained by photothermal spectroscopy will be compared with the data from other relevant analytical methods, mainly of spectrochemical analysis.

Acknowledgements: The work is supported by The Russian Scientific Foundation, grant no. 14-23-00012.

[1] M. Yuan et al, Sens. Actuat. B, **190**, 707–714 (2014).
[2] D. Zhai et al, ACS Nano, **7**, 3540–3546 (2013).
[3] N. Sahiner, Prog. Polym. Sci., **38**, 1329–1356 (2013).
[4] N. Sahiner and L. Sagbas, J. Power Sources, **246**, 55–62 (2014).
[5] E. Mansfield, T.L. Oreskovic, N.S. Rentz and K.M. Jeerage, Nanotoxicology, **8**, 394–403 (2014).
[6] S. Hernandez, J.K. Papp and D. Bhattacharyya, Ind. Eng. Chem. Res., **53**, 1130–1142 (2014)

A6

Photoacoustic imaging and characterization of biological structures from 1 to 1000 MHz

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Photoacoustics is an emerging imaging modality that combines the high contrast of optical imaging with the high resolution of ultrasound imaging. When tissue is illuminated with a laser, the absorption of optical energy causes a rapid thermoelastic expansion, resulting in the emission of a pressure wave that can be detected with ultrasound receivers. Both endogenous contrast (such as melanin or hemoglobin) or exogenous contrast (such as dyes and nanoparticles) can be used as optical absorbers to facilitate photoacoustic wave emission. Specific parts of the cell or tissue can be examined by selecting appropriate chromophores and interrogating optical wavelengths. The resulting photoacoustic wave intensity can be used to generate high resolution images from the absorbing structures. The thermoelastic expansion generated upon absorption of optical energy creates pressure waves with frequencies in the MHz to GHz range, depending on the structures examined. A quantitative analysis of the frequency content of the signals can be used to extract the composition or functional information about the cells or tissue that cannot be obtained through other means. These properties can give insight into the health of the cells and tissue, including the presence of disease such as cancer. In this presentation, recent advances in biomedical photoacoustic research using frequencies from 1-1000 MHz will be presented. This includes the clinical range (1-15 MHz) for small animal imaging and tissue characterization, high frequency (20-80 MHz) for tumor and blood vessel characterization, and photoacoustic microscopy (over 100 MHz) for the analysis of single cells.

A7

Advances on Photothermally-based Mid-IR Spectroscopy for the Study of Human Epidermis *in vivo*

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The study of the composition, structure, and function of the human epidermis is a clear example where photothermally-based spectroscopy shows a remarkable advantage over the traditional spectroscopy methods. When mid-IR spectroscopy is applied, these advantages are further enhanced because, in this spectral region, the efficiency of the production of the phototermal effects is extremely high. Furthermore, in the mid-IR, the biomolecules present their most characteristic spectral features. Additionally, the application of photothermally-based spectroscopic methods has been recently boosted by the introduction of broadly tunable quantum cascade lasers. As a consequence, several authors have already published results using these powerful light sources in combination with the photothermal approach. Sigrist *et al.*, for instance, reported the measurement of the mid-IR absorption spectra of skin *in vivo* by means of CW photoacoustic spectroscopy[1]. We have also recently reported the use of a windowless ultrasound resonator for non-invasive glucose monitoring in human skin *in vivo* by pulsed photoacoustic spectroscopy[2,3]. Another example is provided by Mandelis *et al.* who have proposed the use of differential photothermal radiometry in human skin for non-invasive glucose monitoring[4].

In this event we are discussing, with an oral presentation, the most recent advances on the application of photoacoustic spectroscopy as well as photothermal deflectometry in the study of the structure and composition of human epidermis *in vivo,* in a non invasive way, as well as its relevance in the understanding of its function in wound healing, drug delivery, and non-invasive glucose monitoring.

[1] J. Kottmann, U. Grob, J.M. Rey, and M.W. Sigrist, Sensors **13**, 535 (2013).

[2] M.A. Pleitez, T. Lieblein, A. Bauer, O. Hertzberg, H. von Lilienfeld-Toal, and W. Mäntele, Rev. Sci. Instrum. **84**, 084901 (2013).

[3] M.A. Pleitez, T. Lieblein, A. Bauer, O. Hertzberg, H. von Lilienfel-Toal, and W. Mäntele, Anal. Chem. **85**, 1013 (2013).

[4]X. Guo, A. Mandelis, and B. Zinman, Biomed. Opt. Express **3**, 3012 (2012).

Recent advances in development of noninvasive and continuous monitoring of blood glucose levels based on continuous-wave photoacoustic protocols.

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The regular monitoring of blood glucose levels have been a burden for all the diabetic patients worldwide in order to decrease this condition consequence in the long-term. With recent advances, portable and relatively low cost devices have been developed and commercialized by several companies, which provides accurate and fast measurements anywhere, anytime, and by anyone. However, the technique requires blood sampling usually through finger-pricking, which causes pain and potential infection, which in turn affect patients' compliance, and cannot provide continuous monitoring [1]. Without a doubt, the noninvasive technique remains the perfect alternative to the standard protocol for continuous and painless long-term monitoring [2]. So far, none of the proposed approaches have been able to reach the market place due to stringent regulations and complexity of human body. In order to propose an alternative to this need, we then chose the continuous-wave photoacoustic (CW-PA) technique among the several techniques available, and already developed two protocols: the frequency shift (FS) [3,4] and the optical power balance shift (OPBS) [5,6]. Figure 1 shows the experimental setup, where FS requires only one light source while OPBS needs two for differential measurements.

Despite using the same technique, the two approaches focus on different aspect of the sensing mechanism and therefore exhibit specific characteristics. On the one hand, FS monitors the shift of the resonant frequency. This is a scalar parameter that doesn't depend on neither optical wavelength nor the cavity size dimension. It can also provide high sensitivity to any change in sample solution composition. However, FS is equivalent to an acoustic velocity measurement, and thus exhibits no specificity to glucose. On the other hand, OPBS uses two optical sources to perform measurement equivalent to differential optical coefficients monitoring. This protocol enables one to cancel out the background signal generated by water absorption and provides dependence to compound strongly influenced by the choice of optical wavelengths pair. Figure 2 shows experimental results performed at 1382nm-1610nm pair with pure glucose and pure albumin aqueous solutions. Those results are in good agreement with spectroscopic data. The later method then opens the door to selective measurements of glucose by multiplexing optical wavelengths.

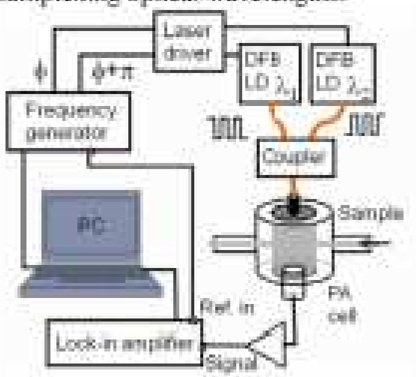

Fig. 1. Schematic view of the experimental setup required to perform FS (one light source) and OPBS (two light sources) measurements.

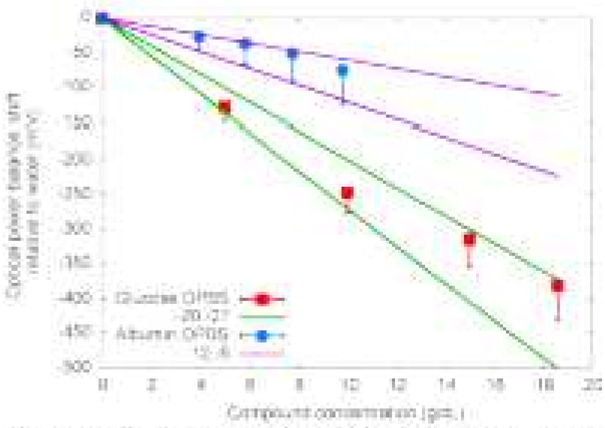

Fig. 2. OPBS-based measurements of glucose and albumin aqueous solutions inside fluidic cell without control of temperature (errorbars).

[1] J.K. Kirk and J. Stegner, J. Diabetes Sci. Technol., Vol. 4 (2), 435-439 (2010).
[2] J. Wagner, C. Malchoff, and G. Abbott, Diabetes Techn. & Therapeutics, Vol. 7 (4), 612-619 (2005).
[3] S. Camou, Y. Ueno, and E. Tamechika, *in proceeding of* IEEE Sensors 2010, Oct. **2010**, Hawaii, USA
[4] S. Camou, T. Haga, T. Tajima, and E. Tamechika, Anal. Chem., Vol. 84 (11), 4718-4724 (2012).
[5] S. Camou, Y. Ueno, and E. Tamechika, *in proceeding of* IEEE Sensors 2011, Oct. **2010**, Limerick, Ireland.
[6] S. Camou, chapter in *Pervasive and mobile sensing and computing for healthcare*, S.C. Mukhopadhyay and O.A. Postolache, eds. (Springer, 2012).

A9

Ultrafast Plasmonic Heating of Single Gold Nanorods: Polarization-Controlled Photothermal Impact on a Hydrogel Medium

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Abstract: Gold nanoparticles exhibit strong absorption of light around a particular wavelength, due to the excitation of a collective oscillation of conducting electrons in the metal. This phenomenon, known as localized surface plasmon resonance (LSPR), strongly depends on the size, shape and environment of the nanoparticle. Gold nanoparticles can act as nanoscale sources of heat through photothermal conversion at their LSPR. This feature enables various biomedical applications including bioimaging, photothermal therapy and drug delivery[1].

High aspect ratio gold nanorods, in particular, show unusual high resonance in the infrared (tunable to the therapeutic window). This resonance is associated with a long-axis (longitudinal) oscillation of electrons, thus depending on the alignment of the nanorod relative to the incident electric field [2]. While gold nanorods and their plasmon dynamics have been extensively studied experimentally, there is very little experimental evidence on photothermal heating of an aqueous medium from a single gold nanorod under ultrafast excitation.

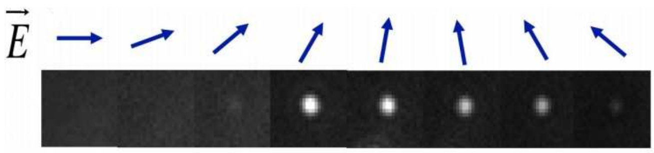

Fig. 1. Polarization-dependent optical backscattering response of a single irradiated gold nanorod

We will present the ultrafast plasmonic heating of single 10-by-67-nm gold nanorods embedded in a hydrated chitosan hydrogel thin film. An infrared femtosecond-pulsed laser beam with controlled linear polarization strongly excites the longitudinal LSPR of the nanorods. Photothermal heating is transferred to the hydrogel medium with various outcomes. Using fluorescence lifetime imaging microscopy and backscattering imaging, supported by heat transfer simulations, we will show polarization-dependent non-thermal damage on a large area around the nanorods. We will discuss the physical mechanisms most likely involved, including nanobubble generation, chemical damage and plasma formation.

[1] E.C. Dreaden, A.M. Alkilany, X. Huang, C.J. Murphy and M.A. El-Sayed, Chem. Soc. Rev. **41**, 2740-2779 (2012).
[2] H. Ma, P.M. Bendix and L.B. Oddershede, Nano Lett. **12** 8, 3954-3960 (2012).

Wednesday October 8th

Nanoscale Heat Transfer and Imaging

B1

Imaging and spectroscopy of the near-field thermal emission

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We present the coupling of a Fourier transform infrared spectrometer (FTIR) and a scanning probe microscope to perform imaging and spectroscopy measurements with sub-wavelength spatial resolution in the mid-infrared spectral range. In contrast with a regular scanning near-field optical microscope which requires the use of an external laser source, the originality of our set-up is that it is based on the detection of the sole near-field thermal emission (NFTE) produced by the sample, which is scattered by a nanosized tip. This mode is called thermal radiation scanning tunnelling microscopy (TRSTM) [1]. As it probes the NFTE, it provides information regarding the spatial and spectral variations of the electromagnetic local density of states (EM-LDOS) [1-4].

We achieve a spatial resolution of hundreds of nanometers in the mid-infrared range ($\lambda \approx 10$ µm) for imaging, FTIR spectroscopy, and hyperspectral imaging [5]. As an example, figure 1 shows hyperspectral line scans performed across a boundary between silicon carbide (SiC) and gold (Au). The transition between intense quasi-monochromatic peaked spectra on SiC, due to the surface phonon polaritons resonance [4], and low intensity broadband spectra on Au, occurs within ~ 300nm. Besides the non-Planckian behavior of some materials, this demonstrates that spatially super-resolved spectroscopy is achieved with our method with a resolution nearly two orders of magnitude beyond the diffraction limit. Various applications of the TRSTM will be discussed during this talk.

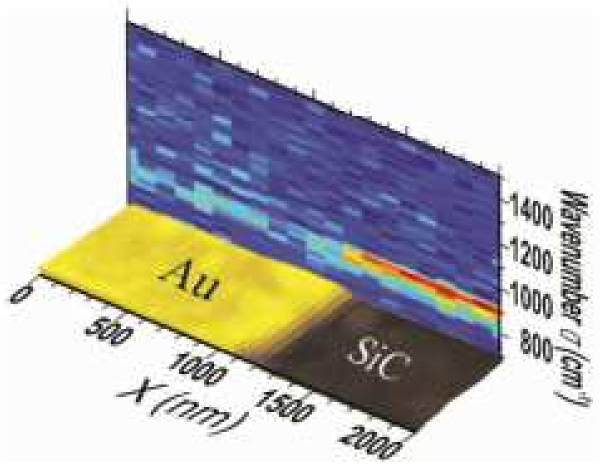

Fig. 1: Hyperspectral TRSTM line scan. Near-field thermal emission spectra are recorded each 100 nm along a straight line crossing a boundary between SiC and Au. A quasi-monochromatic near-field thermal emission is observed on SiC due to the contribution of surface phonon-polaritons [5].

Work performed thanks to a fruitful collaboration with:
F. Peragut, V. Krachmalnicoff, R. Carminati (Institut Langevin) ; K. Joulain (Institut P') ; J.-J. Greffet (Labo. Charles Fabry- Institut d'Optique) ; P. Roy, J.-B. Brubach (Synchrotron SOLEIL) ; P.-O. Chapuis (Centre d'Energétique et de Thermique de Lyon) ; S. Collin, N. Bardou (Labo. Photonique et Nanostructures).

[1] Y. De Wilde, F. Formanek, R. Carminati, B. Gralak, P.-A. Lemoine, J.-P. Mulet, K. Joulain, Y. Chen, J.-J. Greffet, Nature, 444, 740 (2006).
[2] A. C. Jones and M. B. Raschke, Nano Letters, 12, 1475 (2012).
[3] K. Joulain, P. Ben-Abdallah, P.-O. Chapuis, Y. De Wilde, A. Babuty, C. Henkel, Journal of Quantitative Spectroscopy & Radiative Transfer, 136, 1 (2014).
[4] A. Babuty, K. Joulain, P.-O. Chapuis, J.-J. Greffet, Y. De Wilde, Physical Review Letters, 110, 146103 (2013).
[5] F. Peragut, J.-B. Brubach, P. Roy, Y. De Wilde, submitted (2014).

B2

Digital heterodyne holography for thermoplasmonic applications

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Abstract: Like most interferometric methods digital holography is able to record the amplitude and phase of optical waves. Associated to heterodyning, it is also adapted to the measurement of modulated phenomena. We present here applications to temperature imaging in metallic nanosystems, where plasmonic excitation is associated to ohmic heating, and can therefore be used to characterize and optimize plasmon resonance.

In metals displaying ohmic losses, the electron oscillation which is characteristic of plasmonic phenomena induces heating. Such localized heat sources can be used in e.g. cancer cell destruction, to design optimized bolometers or to optimize photo-thermo-voltaic devices. Conversely, heating can be detrimental to applications of plasmonic resonators to medical diagnosis, where sensitivity is ultimately limited by the optical power which can be withstood by the analyte or the antenna without risking destruction. In any case, this heating can be considered a fingerprint of plasmonic phenomena, and a way to characterize them. It can be used as a way to detect nanoparticles [1], or to characterize plasmonic resonances in nanostructured systems [2]. Here, we present a non contact, full field imaging method based on digital heterodyne holography [3,4], which measures variations in the light scattered by the structures as a result of refractive index changes related to local heating. A variety of nanodisc chains with different disc numbers, spacings and diameters were fabricated on glass substrates by e-beam lithography.

A heterodyne phase modulation of a low power probe beam (λ= 785 nm, P = 50 mW) allows the retrieval of high frequency changes induced by the modulation of an excitation beam (F_{Heat} = 1 kHz, λ= 532 nm, P < 1W) at a low frequency compatible with a slow CCD camera (F_{CCD} = 16 Hz). In collaboration with R. Carminati (Institut Langevin), a Green function - based analytical approach allowed us to show that the recorded signals are directly proportional to the temperature increase.

Clear photothermal signal were observed when the excitation beam is polarized parallel to the axis of the structures, allowing nanoantenna excitation. The photothermal signal is typically 4 times lower for a perpendicular polarization at identical laser fluence. This is an indication that a plasmonic resonance involving the whole disc chain, efficiently excited by an electric field along its axis, is the dominant dissipative source in this case, while the perpendicular polarization mostly excites individual disc modes.

Negative antennas, i.e. series of holes in a continuous metallic films are interesting candidates to minimize heating : the gold layer can act as an efficient heat dissipator while, according to Babinet's principle, optical properties are in some respect expected to be similar to those of positive antennas, i.e. series of gold disks on glass substrates. We have carried out a detailed scanning near-field microscopy (SNOM) characterization of these negative structures in order to compare evaluate the validity of the comparison to their positive counterparts, and a photothermal studies of their thermal properties. We will present a systematic study of the dependence of photothermal signals on disc number, size and gap, as well as photothermal measurements on other types of plasmonic structures.

Finally, we will present finite element simulations of simple plasmonic structures showing that, for a given density of metal per unit surface, a fine tuning of the aspect ratio of elongated gold nanodiscs allows an optimization of the absorption by the structure, paving the way for efficient light to heat conversion taking advantage of plasmonic resonances.

This work is funded by the ANR NATO, and by LABEX WIFI (Laboratory of Excellence within the French Program "Investments for the Future") under references ANR-10-LABX-24 and ANR-10-IDEX-0001-02 PSL*.

[1] D. Boyer, P. Tamarat, A. Maali, B. Lounis, and M. Orrit, Science **297**, 1160-1163 (2002).
[2] Baffou, G., C. Girard, and R. Quidant. Phys. Rev. Lett. 104 (13), 1–4 (2010).
[3] E. Absil, G. Tessier, M. Gross, N. Warnasooriya, S. Suck, M. Coppey-Moisan, D. Fournier, Opt. Exp. 18, 2, 780 (2010).
[4] S. Y. Suck, S. Collin, N. Bardou, Y. De Wilde, and G. Tessier, Optics Letters 36, 6, 849, (2011).

B3

Non-Diffusive Thermal Transport by Phonons at Room Temperature

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Abstract: Phonon-mediated thermal conductivity is expected to follow the diffusion model as long as the heat transfer distance is large compared to the phonon mean free path (MFP). The “textbook” value of the phonon MFP in Si at room temperature (RT) is about 40 nm, with even shorter MFPs listed for most other materials. Consequently, we used to believe that deviations from the Fourier law of heat conduction could only be observed on the tens of nanometers scale. However, describing phonon transport in solids by a single MFP value is an extremely poor model as the MFP varies greatly over the phonon spectrum. Recent first-principles calculations [1] indicated that low-frequency phonons with MFP exceeding 1 μm contribute about 50% to the thermal conductivity of Si at RT, contrary to what the entrenched textbook MFP value may suggest. We will discuss a recent experiment [2] that demonstrated that the Fourier law indeed breaks down at distances much greater than previously thought. The laser-induced transient grating (TG) technique was used to set up a spatially periodic temperature profile in a thin silicon membrane and monitor its decay. By changing the thermal grating period, the heat transport distance was varied within the range ~1-10 μm. A deviation from the quadratic dependence of the decay time on the TG period demonstrated the deviation from the diffusion model in a clean and model-independent manner. Furthermore, the simplicity of the experimental geometry enabled an analysis of the phonon transport with the Boltzmann transport equation [3,4] that showed a reduction in the effective thermal conductivity due to the suppression of the contribution of the low-frequency phonons with MFP exceeding the heat transfer distance. We will discuss the implications of these findings for our understanding of the phonon-mediated heat transport at small distances.

[1] K. Esfarjani, G. Chen, and H. T. Stokes, Phys. Rev. B **84**, 085204 (2011).

[2] J.A. Johnson, A.A. Maznev, J. Cuffe, J.K. Eliason, A.J. Minnich, T. Kehoe, C.M. Sotomayor Torres, G. Chen, and K.A. Nelson, Phys. Rev. Lett. **110**, 025901 (2013).

[3] A.A. Maznev, J.A. Johnson, and K.A. Nelson, Phys. Rev. B **84**, 195206 (2011).

[4] K. C. Collins, A. A. Maznev, Z. Tian, K. Esfarjani, K. A. Nelson, and G. Chen, J. Appl. Phys. **114**, 104302 (2013).

B4

Heat transfer in vacuum due to phonons

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Abstract: We tackle the mechanism of radiation at small scales. When the gap distance between two emitting bodies decreases below the Wien's photon wavelength, direct electrostatic interactions between charges yield an exalted heat transfer larger than the one predicted Stefan's Law. We show that the proposed Maxwell equation approach remains limited to gaps larger than about 10nm and we highlight that charge-charge interactions predominate below this distance down to a few Angstroëms [1]. We also prove the existence of a guided radiated heat flux along polar nanowires that can be larger than the one transported through lattice vibrations. This flux can be estimated with the quantum of thermal conductance at ambient temperature [2].

[1] S. Xiong, K. Yang, Y.A. Kosevich, Y. Chalopin, R. D'Agosta, P. Cortona, S.Volz, Classical to quantum transition of heat transfer between two nanoparticles, Phys. Rev. Lett. 112, 114301 (2014)C. van Tiger, Phy. Rev. Lett. 14, 741-755 (1997).

[2] J. Ordonez -Miranda, L. Tranchant, B. Kim, Y. Chalopin, T. Antoni and S. Volz, Quantized Thermal Conductance of Nanowires at Room Temperature due to Surface Phonon-Polaritons, Phys. Rev. Lett., 112, 055901, (2014).

B5

Ultrafast Laser-Induced Heating of Dielectric Nanofilms Predicted by the Boltzmann Transport Equation: Microscopic Description of Photothermal Phenomena

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Abstract: The blossoming of nanotechnology involving the miniaturization of devices with enhanced rates of operation requires a profound understanding of their thermal performance. This is particularly critical in nanomaterials, in which the heat transport is not necessarily described by the Fourier's law of heat conduction.

In this work, a nonlocal theory for heat conduction across dielectric nanofilms under high frequency temperature fields is developed and applied to explain the reduction of their thermal conductivity observed in recent experiments. This theory is a novel and analytical solution of the Boltzmann transport equation for phonons in a dielectric film subjected to periodic heating at the surface. By considering that the mean free path (MFP) and mean free time (MFT) of phonons are independent of the temperature and the phonon frequency, explicit expressions for the temperature and the heat flux are derived and analyzed as a function of the film thickness and modulation frequency. It is shown that: 1) For a film thickness much greater than the MFP (diffusive regime) and for frequencies much smaller than the inverse of the MFT, the amplitude and phase of the temperature field exhibit the classical diffusive behavior predicted by the Fourier's law. By contrast, as this thickness becomes comparable to or smaller than the MFP (ballistic regime), these signals display attenuated oscillations, which strengthen as the film thickness reduces to nanoscales or the modulation frequency increases from GHz to THz. 2) The diffusion length is still a meaningful concept in the ballistic regime and its value is given by $\mu = l/\sqrt{6\omega\tau}$, where l and τ are the MFP and MFP respectively, and ω is the modulation frequency. 3) The cross-plane thermal conductivity k of a dielectric film increases with the ratio λ between the film thickness and the phonon MFP and is given by

$$k = \frac{k_0}{1 + \frac{4\beta(\lambda)}{3\lambda}}, \qquad (1)$$

which reaches its bulk value k_0 at the limit $\lambda \to \infty$. The explicit determination of the parameter $\beta(\lambda)$ is provided by our approach, which makes of equation (1) an accurate extension of previous formulas reported in the literature [1,2].

Our theory facilitates the understanding of heat conduction at high frequencies, and it could be used as the theoretical model to perform the microscopic characterization of nanofilms, through the determination of the MFP and MFT of phonons.

[1] A. Majumdar, ASME J. Heat Transfer **115**, 7-16 (1993).
[2] G. Chen, Phys. Rev. B **57**, 14958-14973 (1998).

B6

Phonons in silicon free-standing membranes

Emigdio Chavez-Angel[(a)], J Sebastian Reparaz[(a)], Bartolomiej Graczykowski[(a)], Francesc Alzina[(a)], Jordi Gomis-Bresco[(a)], Marianna Sledzinska[(a)], Markus R Wagner[(a)], Andrey Shchepetov[(b)], Mika Prunnila[(b)], Jouni Ahopelto[(b)] and Clivia M. Sotomayor Torres [(a,c)*]

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Abstract: In this talk we will review the current understanding of phonons in ultra-thin membranes with special attention to thermal transport. The main message is that the thermal conductivity decreases with membrane thickness in accordance to observation of electronic device heating as dimensions are reduced. Here we explore the physics underpinning this increasing thermal management issue.

We will present dispersion relations of acoustic phonons and how they are affected by stress. We will discuss phonon lifetime measurements of selected modes and reconcile them with scattering mechanism the strength of which depends on frequency and extrinsic scattering such as boundary scattering.
The connection to thermal conductivity will be made both based on simulations which use a modified Akhieser mechanism and on experiments, including results of a technique developed in-house, namely, the Two-laser Raman thermometry.

Two further examples associated with confined phonons will be briefly discussed: Our experiments on1D phononic crystals with a mode in the gap combined with a photonic crystal (optomechanical or phoXonic crystals) and phonons in 2D phononic crystals, in particular the transition form ordered to disordered crystals, in terms of phonon localisation.

Bibliography:

[1] C. M. Sotomayor Torres et al., *Physica status solidi (c)* **1** (11) 2609-2612 (2004).
[2] J. Groenen et al., *Phys Rev B*, **77**, 045420 (2008).
[3] J. Cuffe et al., *Nano Letters* **12** (7) 3569-3573 (2012).
[4] A. Shchepetov et al., Appl Phys Lett **102,** 192108 (2013).
[5] E. Chávez et al., *JPCS*, **395**(2012), 012105.
[6] J. Cuffe et al, *Phys Rev Lett.* **110** (9) 095503 (2013)
[6] A. Johnson et al., Phys Rev Letts **110** (2) 025901 (2013).
[7] J. S. Reparaz et al., Review of Scientific Instruments **85** 034901 (2014).
[8] E. Chavez Angel et al., Appl Phys Lett Materials **2** (1) 012113 (2014)
[9] B. Graczykowski et al., Applied Physics Letters **104** (12) 123108 (2014) (MS Nr L13-11492R2)
[10] B. Graczykowski et al., New Journal of Physics **16** 073024 (2014)
[11] J Gomis-Bresco et al., Nature Communications **5** 4452 (2014)

Acknowledgements:

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B7

Nanobubble formation around a heated single gold nanosphere

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Gold nanoparticles (NP) absorb light strongly, and the absorbed energy is dissipated as heat into the local environment. When the temperature of the NP's surrounding medium, for instance water, reaches the pressure-dependent boiling point, a vapor shell forms around the particle [1]. This vapor shell or nanobubble affects the particle's optical response (spectrum, absorption) [2]. To follow the dynamics of bubble formation, we use both the photothermal and a fast pump-probe detection method to investigate the formation and dynamics of the plasmon-assisted "nanobubble" [3]. Our first results indicate that the boiling temperature at which a nanobubble forms is about 200 °C because of the increased Laplace pressure in the bubble. Rich dynamics can be observed in this nanobubble system, even under CW laser heating (see Figure 1).

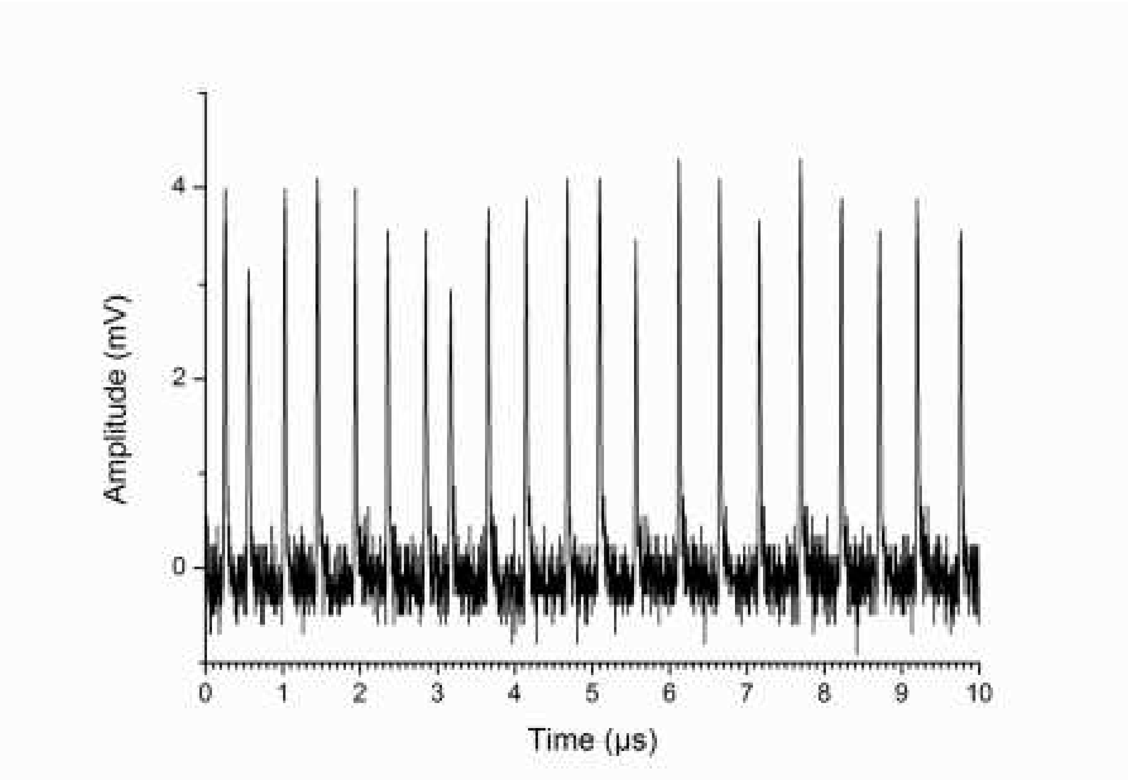

Fig. 1: Direct probe detection of a nanobubble under constant heating just above the boiling threshold. The signal shows quasi-periodic bursting behavior, with each burst lasting for a few tens of ns.

[1] Merabia, S., Keblinski, P., Joly, L., Lewis, L. & Barrat, J.-L. Critical heat flux around strongly heated nanoparticles. *Physical Review E* **79**, 021404, (2009);
[2] Fang, Z. *et al.* Evolution of Light-Induced Vapor Generation at a Liquid-Immersed Metallic Nanoparticle. *Nano letters* **13**, 1736-1742, (2013);
[3] Lukianova-Hleb, E. Y. & Lapotko, D. O. Experimental techniques for imaging and measuring transient vapor nanobubbles. *Applied Physics Letters* **101**, 264102, (2012).

B8

THERMAL CHARACTERIZATION OF CARBON NANOTUBES BY PHOTOTHERMAL TECHNIQUES

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Carbon nanotubes (CNT) are multifunctional materials commonly used in a large number of applications in electronics, sensors, nanocomposites, thermal management, actuators, energy storage and conversion, and drug delivery.

Despite recent important advances in the development of CNT purity assessment tools and atomic resolution imaging of individual nanotubes by scanning tunnelling microscopy and high-resolution transmission electron microscopy, the macroscale assessment of the overall surface qualities of commercial CNT materials remains a great challenge. The lack of quantitative measurement technology to characterize and compare the surface qualities of bulk manufactured and engineered CNT materials has negative impacts on the reliable and consistent nanomanufacturing of CNT products

In this paper we show how photothermal and photoacoustic techniques represent useful non-destructive tools to study the thermal properties of carbon nanotubes films. The photoacoustic spectroscopy (PAS) is used for a direct measurement of the absorbance spectra of CNT showing many advantages with respect to the standard optical spectra measurements which are usually affected by relevant scattering phenomena. We applied PAS in the UV/VIS range from 250 to 650 nm by using 400 W Arc Xe lamp. On the other side photothermal radiometry (PTR) has been applied by using an Ar^{++} pump laser beam, modulated at a frequency in the range 1Hz -100 kHz, and a MCT infrared detector, in order to measure the effective thermal parameters, the IR emission properties from CNT thin films, and evaluate the average thermal boundary resistances at the film/bulk interface.

We investigated two set of CNT; in the first group the nanostructures are aligned ("*forest*") and deposited onto a silicon substrate. The diameter of the nanotubes ranges from 20-50nm, and the total thickness of the CNT film ranges from 70μm to 240μm. In the second group the CNT are randomly oriented in plane, and the CNT film is deposited on different transparent substrate (PET and quartz).

Experimental results show how both PAS and PTR represent an excellent tool for quantitative measurement of the thermal properties of CNT thin films.

Thursday October 9th :

Non Destructive Evaluation & Testing I

C1-I

Infrared Thermography for NDT and More

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Abstract: This presentation intends to present Infrared Thermographic in the context of NonDestructive Testing (IRT-NDT). After a brief theoretical overview, both schemes, of passive and active are introduced including current image processing approaches. More specifically, the talk will address the following points:

- electromagnetic spectrum and the Planck's law;
- deployment;
- practical approaches (pulsed, modulated, eddy current, vibro-thermography);
- infrared image processing;
- review of some NDT applications.

Aircraft industry is one of the leading field for advanced IRT-NDT thanks to recent POD (Probability of Detection) studies which formalize the capabilities and limits of the technique. It demonstrates that image processing enables to push further the limit of detection. For instance phase images enable to probe deeper defects. Robotized deployment allows the routine inspection of complex composite parts.

Another growing field is cultural heritage where IRT-NDT enables to assess historical facts, detect sources of degradation. Clever stimulation approaches such as solar loading can be used with profit, for instance to reveal internal building structure even under thick masonry.

Additionally, passive applications will be presented as well: cattle monitoring, parking lot surveillance, night vision driving, etc.

C2-I

Characterization of Vertical Cracks using Lock-in and Burst Ultrasound Excited Thermography

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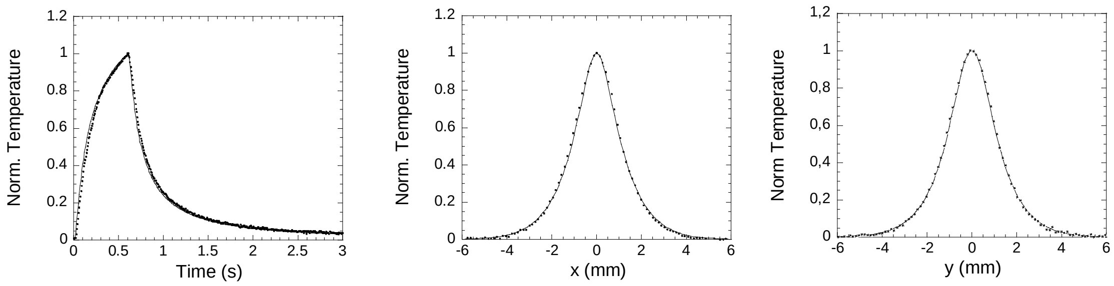
Ultrasound (US) excited infrared thermography or vibrothermography has emerged as a promising technique to detect and characterize closed cracks. It is based on the detection of the surface temperature distribution of parts that arise as a consequence of the heat produced at the defects under ultrasonic excitation, mainly because of friction between the crack surfaces or stress concentration at the crack tips. The technique has been developed in to two temporal regimes of the excitation: (a) a short burst of constant US intensity in which case the surface temperature is monitored as a function of time in both the heating and cooling periods [1] and (b) an amplitude modulation of the US intensity together with a lock-in analysis of the images sequence giving rise to amplitude and phase thermograms [2]. Lock-in vibrothermography has proven to be a useful tool to characterize vertical cracks [3]. However, being burst excitation much faster in terms of data taking, there is not much work published on the characterization of vertical cracks using this type of excitation. In this work we calculate the time evolution of the surface temperature distribution corresponding to rectangular vertical cracks in the burst regime. Simulations indicate that the temperature distribution obtained at the time corresponding to the end of the burst together with the time evolution of the temperature at the center of the thermogram may contain enough information to retrieve the width, height and depth of the rectangular vertical crack.



(a) (b) (c)

Fig.1: Experimental (dots) and fitted (continuous line) temporal evolution of the temperature at the center of the thermogram (a), and central profiles obtained at the end of a 300 ms burst perpendicular to the crack (b) and along the crack (c) corresponding to a 1 by 1 mm square vertical crack buried 0.6 mm bellow the sample surface.

In order to check the predictions of the theory, we have performed burst vibrothermography experiments on samples containing calibrated vertical cracks and have found a very good agreement between experimental data and the results of the simulations. Moreover, by performing a simultaneous fitting of two perpendicular temperature profiles obtained at the end of the burst together with the temperature evolution at the center of the thermogram we have been able to retrieve the dimensions and depth of the calibrated crack (see Fig. 1). Results from lock-in and burst vibrothermography are compared. These results open the possibility of characterizing vertical cracks from burst vibrothermography data in a fast manner.

ACKNOWLEDGMENTS

This work has been supported by the Ministerio de Ciencia e Innovación (MAT2011-23811 and MTM2010-16917), by Gobierno Vasco (IT619-13), by University of the Basque Country (UFI 11/55) and by Diputación General de Aragón.

[1] L. D. Favro, X. Han, Z. Ouyang, G. Sun, H. Sua, and R. L. Thomas, Rev. Scientific Instr. **71**, 24182000 (2000)
[2] A. Dillenz, T. Zweschper, G. Riegert, and G. Busse, Rev. Sci. Instr. **74**, 4172003 (2003)
[3] A. Mendioroz, A. Castelo, R. Celorrio, and A Salazar, NDT&E International **66**, 8-15 (2014)

C3-I

Camera-based Quantitative Lock-in Carrierographic Imaging of Crystalline Silicon Wafers

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Abstract: Photoluminescence (PL) has been highly developed and widely used for characterization of silicon wafers and solar cells. Photocarrier Radiometry (PCR) [1], a form of frequency-domain dynamic PL technique using carrier diffusion waves, has been demonstrated to be an effective quantitative methodology for carrier transport parameter determination (bulk lifetime, carrier diffusivity, and surface recombination velocities) and carrier density imaging. Lock-in carrierography (LIC) [2], the camera-based imaging extension of the single-element detector PCR, has been introduced in both low-frequency homodyne and high-frequency heterodyne modes for imaging characterization of crystalline Si wafers. For homodyne LIC, phase images at several modulation frequencies and a simplified model based on PCR theory are used to construct the effective carrier lifetime image from the phase-frequency dependence [3]. However, due to the low frame rate of today's near-infrared cameras and poor signal-to-noise ratio (SNR) at short exposure times, the imaging frequency range of LIC is highly limited. This limitation hinders LIC from high frequency imaging which is the key to resolving the foregoing four transport parameters and realizing depth-selective/resolved imaging. A heterodyne lock-in imaging scheme [4,5] has been introduced to overcome the camera speed limitations and poor SNR, thereby generating high-frequency LIC images of crystalline Si wafers up to 10 kHz [6]. The idea is to construct a slow enough beat frequency component through frequency mixing. Heterodyne LIC produces shallow, carrier-density-wave diffusion-length-controlled images of Si wafers at high frequencies. A heterodyne theoretical model has been established for fitting the experimental frequency scans from associated PCR data to extract the major carrier transport parameters [6]. Good agreement was found between the heterodyne and conventional homodyne PCR measurements, and between LIC and μ-PCD effective lifetime imaging results. The very close similarity between PCR and heterodyne LIC pixel frequency responses over a broad range (100 Hz – 10 kHz) renders the heterodyne method suitable for simultaneous quantitative imaging of transport properties of semiconductor substrates and devices.

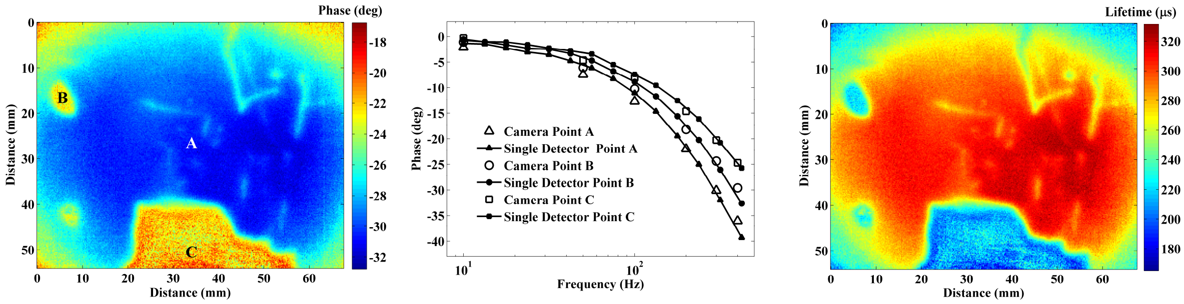

Fig. 1: Homodyne LIC of a c-Si wafer (a) 300 Hz phase image; (b) phase-frequency dependence; (c) effective lifetime image

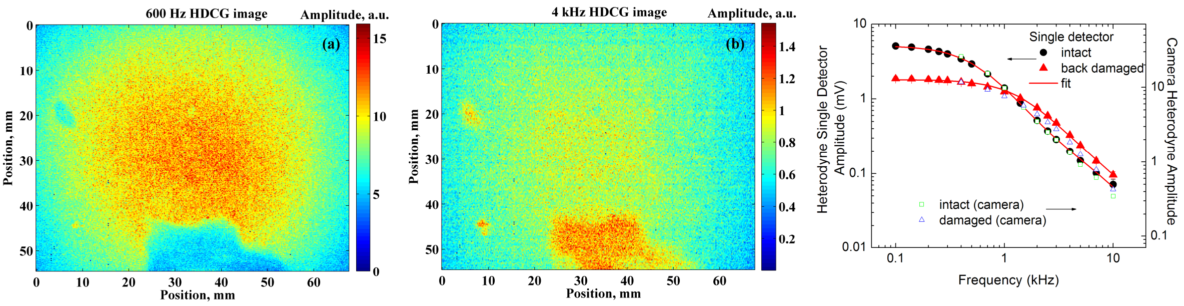

Fig. 2: Heterodyne LIC of the same wafer (a) at 600 Hz; (b) at 4 kHz; (c) amplitude-frequency dependence. Notice the amplitude contrast inversion at high frequencies.

[1] A. Mandelis, J. Batista and D. Shaughnessy, Phys. Rev. B **67**, 205208 (2003).
[2] A. Melnikov, A. Mandelis, J. Tolev, P. Chen, and S. Huq, J. Appl. Phys. **107**, 114513 (2010).
[3] Q. M. Sun, A. Melnikov, and A. Mandelis, Appl. Phys. Lett. **101**, 242107 (2012).
[4] A. Melnikov, P. Chen, Y. Zhang, and A. Mandelis, Int. J. Thermophys. **33**, 2095 (2012).
[5] Q. M. Sun, A. Melnikov, and A. Mandelis, Int. J. Thermophys., available online (2014).
[6] Q. M. Sun, A. Melnikov, and A. Mandelis, Appl. Phys. Lett., submitted (2014).

C4-I

Photothermal characterization of layers: experimental issues and solutions

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In measurement techniques for determining thermal transport parameters, the thermal conductivity or thermal diffusivity of a material are determined by analyzing the steady state (thermal conductivity) or dynamic (thermal diffusivity) thermal gradient over a sample layer, which is resulting from a given heat input. The accuracy of the method then depends on the accuracy of the involved quantities: the temperature, the distance over which the temperature gradient is determined, and, in some cases, the input power. Photothermal techniques offer the advantage that, by choosing the frequency range of the used light intensity modulation, the the thermal diffusion length can be tuned to the region of interest, avoiding the estimation or modeling of influences of heat exchange on other locations, which are not of interest. Moreover, the measurement configuration and frequency range can be chosen to determine specific thermal parameters or combinations thereof with optimum accuracy. One-dimensional standard configurations have been proposed (research groups of A.Salazar/A.Oleaga, Bilbao, A. Mandelis, Toronto, M. Marinelli/U.Zammit/F.Mercuri/S.Paoloni, Rome, S. Longuemart, Dunkerque, D. Dadarlat, Cluj-Napoca, E. Marin, Mexico City, A.Orea, Mexico City, M. Chirtoc, Reims, J. Philip, Cochin, R. Li Voti, Rome, A. Guimaraes, Darcy Ribeiro, C. Glorieux/J.Thoen, Leuven, and many others in the photothermal community [1]) for the determination of thermal effusivity, thermal diffusivity, thermal conductivity/effusivity and specific heat capacity.

In this paper, we discuss the main challenges that need to be overcome when designing or performing photothermal experiments that are intended to determine the thermal properties of layered samples, and solutions that have been recently proposed:

(i) Control and accurate measurement of the layer thickness and parallelity
(ii) Heat losses due to convection and radiation
(iii) Effects of thermal wave reflections
(iv) Effects of pick-up noise in case of very weak signals
(v) Determining thermal diffusivity of thermally thick layers (substrates)

For each challenge, solutions and measures will be proposed.

[1] Proceedings of the 15th International Conference on Photoacoustic and Photothermal Phenomena (ICPPP15) 19–23 July 2009, Leuven, Belgium, http://iopscience.iop.org/1742-6596/214/1, last viewed on 28/9/2014

Friday October 10th :

Non Destructive Evaluation & Testing II

C5-II

Laser-Induced Transient Gratings for Acoustic and Thermal Measurements in Science and Industry

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Abstract: In transient grating (TG) photoacoustics, crossed laser pulses are used to excite spatially periodic acoustic and thermal responses which are monitored via diffraction of a probe laser beam. The TG technique is particularly advantageous for studying elastic and thermal transport properties of thin films and near-surface layers of bulk samples. This lecture will provide a comprehensive review of the state of the art of TG photoacoustics including instrumentation, methodology and applications ranging from fundamental science to industrial metrology.

The TG method is greatly enhanced by the optical heterodyne detection which not only improves the signal-to-noise ratio but also enhances the information content of the measurements. In particular, we will see how the heterodyne phase control enables the isolation of the thermoreflectance component of the signal from the surface displacement contribution which is important for the interpretation of the thermal transport measurements in opaque materials.

The use of diffractive optics and small lasers enabled the implementation of the heterodyned TG technique in a compact apparatus with the automated control of the TG period that has been implemented in a commercial metrology system for semiconductor industry. While the main industrial application has been the metal film thickness control, the technique has great potential for measuring elastic properties and thermal conductivity for a variety of applications ranging from low-k dielectrics in microelectronics to materials for future fusion reactors.

Apart from practical applications, the TG method helped produce a number of interesting results related to the fundamental aspects of wave propagation in surface phononic crystals and locally resonant metamaterials. In another recent study, the TG technique was used to measure thermal conductivity of free-standing silicon membranes down to 15 nm in thickness, which enabled a reconstruction the “mean free path distribution” of the thermal conductivity in Si. We will conclude by discussing trends and prospects such as that of TG measurements in the X-ray range.

C6-II

Recent Advances in the Characterization of Vertical Cracks Using Lock-in Thermography

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Early detection of vertical cracks is a challenging task to prevent failures in working structures. This kind of crack can be easily detected using IR thermography based techniques provided an asymmetry in the heat flux is produced. This can be achieved by illuminating the sample with a laser beam which is focused close to the crack (see Fig. 1a). This produces a discontinuity in the temperature field at both sides of the crack due to its thermal resistance, which partially blocks the heat flux. In the last decades the "flying spot" method, based on heating the sample with a moving laser spot and detecting the surface temperature with an infrared detector, has been developed to detect cracks in a fast manner [1]. In the last years several approaches to characterize the geometrical parameters of the crack (depth, length and width) have been published [2,3].

The aim of this work is to characterize vertical cracks accurately using lock-in thermography. In the case of infinite vertical cracks an analytical solution for the surface temperature is obtained. The effect of the experimental parameters (a, d, f) on the temperature discontinuity at the crack position is analyzed. Measurements on samples containing calibrated cracks have been performed using an infrared camera. A least square fit of the amplitude and phase of the surface temperature is used to retrieve the thickness of the crack. A very good agreement between the nominal and retrieved thickness of fissure is found, even for widths down to 1 μm, confirming the validity of the model (see Figs. 1b and c).

In the case of finite cracks there is no analytical solution. Moreover, classical continuous finite elements fail when dealing with narrow cracks. To overcome this problem, we have developed a new method based on discontinuous finite elements, which allows dealing with very narrow cracks. The surface temperature of steel samples containing calibrated semi-infinite cracks has been measured using a lock-in thermography setup. A least square fit of the amplitude and phase of the surface temperature is used to retrieve the width and depth of the semi-infinite crack. Measurements on finite rectangular cracks are now in progress.

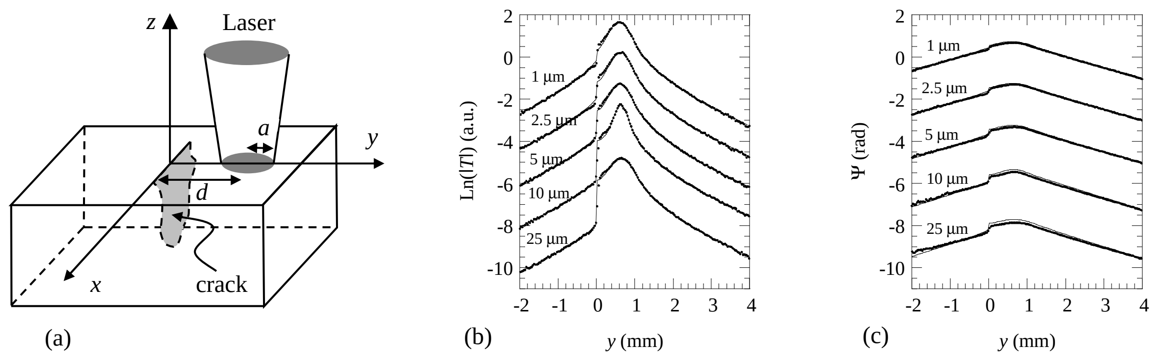

Fig. 1: (a) Diagram of the vertical crack of arbitrary shape. (b) Experimental natural logarithm of the surface temperature amplitude and (c) phase profiles along the *y* axis for several crack widths, for infinite cracks. Dots correspond to experimental data and continuous lines to the fit to theory (for the sake of clarity data have been shifted vertically).

Acknowledgements: This work has been supported by the Ministerio de Ciencia e Innovación (MAT2011-23811 and MTM2010-16917), by Gobierno Vasco (IT619-13), by UPV/EHU (UFI 11/55), by Diputación General de Aragón, by CINVESTAV Unidad Mérida and by CONACYT beca mixta.

[1] Y.Q. Wang, P.K. Kuo, L.D. Favro and R.L. Thomas, *Springer Series in Optical Science, Photoacoustic and Photothermal Phenomena II* **62**, 24-6 (1990).

[2] J. Schlichting, Ch. Maierhofer and M. Kreutzbruck, NDT&E Int. **45**, 133-40 (2012).

[3] M. Streza, Y. Fedala, J.P. Roger, G. Tessier and C. Boue, Meas. Sci. Technol. **24**, 045602 (2013).

C7-II

Depth profiling in thermography: fluctuations and its influence on thermodynamic limits of spatial resolution

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Abstract:

In macroscopic systems behavior is usually reproducible and fluctuations, which are deviations from the typically observed mean values, are small. But almost all inverse problems in the physical and biological sciences are ill-posed and these fluctuations are highly “amplified”. Using stochastic thermodynamics we describe a system in equilibrium kicked to a state far from equilibrium and the following dissipative process back to equilibrium. From the observed value at a certain time after the kick the magnitude of the kick should be estimated, which is such an ill-posed inverse problem and fluctuations get relevant. For simple model systems (kicked Ornstein-Uhlenbeck process or kicked harmonic oscillator) the time-dependent probability distributions, the information loss about the magnitude of the kick described by the Kullback-Leibler divergence of these distributions, and the entropy production derived from the observed mean values are given. The equality of information loss caused by fluctuations and mean entropy production is shown for general kicked dissipative processes from stochastic thermodynamics following the derivation of the Jarzynski and Crooks equalities.

For real-world heat diffusion processes having complicated phonon – atoms interactions, the distributions describing the temperature fluctuations are mostly unknown and can be only approximated by Gauss distributions “near” to equilibrium. But the mean value equation, which is the heat diffusion equation and therefore the mean entropy production is known. The equality to the Kullback-Leibler divergence and its information-theoretical interpretation (Chernoff-Stein Lemma) allows us to describe the influence of the fluctuations without knowing their distributions just from the heat diffusion equation and thus to derive very applicable results, e.g. by giving thermodynamic limits of spatial resolution for depth profiling in thermography.

Experimentally a graphite bar heated at certain locations was used to get a nearly one dimensional heat transfer. Beside the unavoidable thermodynamic fluctuations the influence of additional noise (electronic noise, shot noise,…) on the spatial resolution for depth profiling is evaluated.

C8-II

PHOTOTHERMAL DEPTH PROFILING IN HARDENED STEELS: NEW INVERSE APPROACHES TO IMPROVE THE PROFILE RECONSTRUCTION

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Nondestructive testing of mechanical components subjected to hardness processing is a topic of fundamental importance, both in the field of automotive and aerospace systems. The lack of cementation, the burns in the steels, and the decarburisations of the power gears, and the statoric and rotoric equipments may cause catastrophic failures with serious repercussions. The industry and the companies responsible for the hardening processes as well as for the quality control of the mechanical components are continuously seeking for improvements in the standard destructive tests performed by Vicker or Brinell durometer where one mechanical component is chosen for random testing.

Since 1996 the use of IR systems based on photothermal radiometry for the non-destructive determination of the hardness profiles in steels has been deeply studied and discussed by several groups both in Europe in the framework of European Thematic Networks (BRRT-CT97-5032) [1], in North America [2], and in Asia [3] as shown by the huge numbers of papers presented in the past ICPPP editions.

In this paper we introduce a new PTR compact system, integrable with mechanized and robotic arms for industrial needs, which use a simple Ge lens for collecting the IR radiation from the sample to the detector. The inverse problem to reconstruct the diffusivity profile D(z) from the PTR signal in the frequency domain S(f) has been linearized and solved by the Singular Value Decomposition by using a new approach [4,5,6]. The hardness depth profile HV(z) is eventually calculated thanks to the calibration curve hardness/diffusivity. Preliminary results on AISI9310 hardened steel gears show accurate hardness profile reconstructions in comparison with the hardness measurements by standard Vicker test[.

REFERENCES

[1] H. G. Walther, D. Fournier, J. C. Krapez, M. Luukkala, B. Schmitz, C. Sibilia, H. Stamm, and J. Thoen, Analytical Sciences. 17, s165–s168 (2001).
[2] M. Munidasa, F. Funak, and A. Mandelis, J. Appl. Phys. 83, 3495–3498 (1998).
[3] C. Wang, A. Mandelis, H. Qu, and Z. Chen, J. Appl. Phys. 103, 043510 (2008).
[4] R. Li Voti, C. Melchiorri, C. Sibilia, M. Bertolotti, Use of the genetic algorithms in the photothermal depth profiling, Analytical Sciences 17 pp.s410-s413 (2001).
[5] R. Li Voti, C.Sibilia, M. Bertolotti, Photothermal depth profiling: comparison between genetic algorithms and thermal wave backscattering, Rev.Sci. Instrum. vol. 74, pp. 372 (2003).
[6] R. Li Voti, G.Leahu, C.Sibilia, S.Milletari and S Giunta. Invited lecture at the 17ICPPP, Shuzou China (2013)

C9-II

Extending the flash method for semitransparent materials

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The flash technique on the back configuration is one of the standard techniques used for the determination of thermal diffusivity in solids [1], however the flash method in the front face configuration have been attracting attention in the last decade, due to its versatility for characterizing parts, mainly in service, whose back surface is hard to access [2]. In order to improve the applicability of the flash technique (in both front and rear faces configurations) in this work we make an extension to semitransparent slabs, which allows simultaneous evaluation of the thermal diffusivity and optical absorption coefficients, at both exciting and infrared (IR) wavelengths, from the same experimental data. This is achieved by introducing a theoretical model that considers plane illumination on one surface of the semitransparent slab, transparency to visible and IR wavelengths, multiple reflections of the light beam at the slab surfaces, and heat losses to the surrounding atmosphere by convective and radiative mechanisms at the boundaries of the slab. The duration of the light pulse is also included in the model.

Analytical expressions for the temperature at the front and rear surfaces are obtained in the Laplace domain. Then, numerical Laplace inversions are performed using the Stehfest algorithm [3]. We make curve fittings from the experimental data, using the Levenberg-Marquardt algorithm [4]. Five parameters have been used in the fittings: Q_o/K, D, α, β, and h/K, where Q_o is the energy of the heating pulse, K is the thermal conductivity of the material, D is the thermal diffusivity of the slab, α and β are the optical absorption coefficients to exciting and IR wavelengths, respectively, and h is the combined convective-radiative heat transfer coefficient.

Several materials covering a wide range of thermal diffusivity and optical absorption coefficient values have been measured in order to validate the proposed models. Good agreement between experimental data and theoretical models is obtained, as indicated by the low residuals values shown in Figure 1. Most importantly, for all the materials analyzed in this work the retrieved D and α agree with literature values.

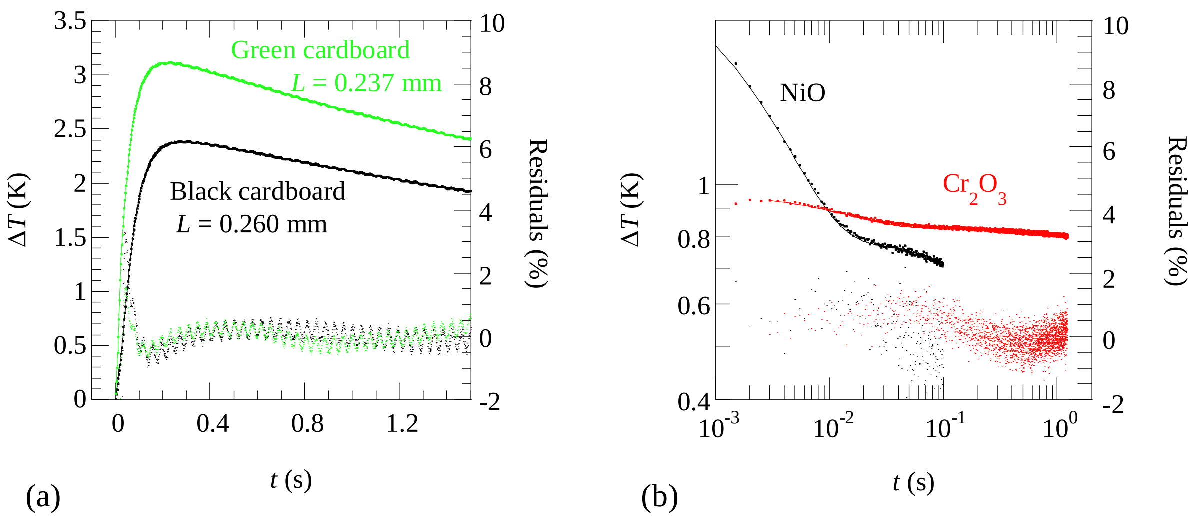

Fig. 1. Results obtained from both front and back flash methods. Experimental results are shown by dots and continuous lines represent the curve-fittings obtained from the models. (a) Classical (back configuration) flash method results in cardboards. (b) Front face configuration results for magnetic oxides that are semitransparent to IR wavelengths.

[1] W.J. Parker, R.J. Jenkins, C.P. Butler and G.L. Abbott, J. Appl. Phys. **32**, 1679 (1961).
[2] P. Bison, F. Cernuschi, E. Grinzato, S. Marinetti and D. Robba, Infrared Phys. Technol. **49**, 286 (2007).
[3] H. Stehfest, Commun ACM **13**, 47 (1970).
[4] D. W. Marquardt, J. Soc. Ind. Appl. Math. **11**, 431 (1963).

C10-II

Characterization of Mixed Oxide Ceramics by Photothermal Microscopy

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In this work we show how a newly developed accessory for metallographic microscopes can be used for the characterization of sintered mixed oxides, providing a microscopic map of the thermal diffusivity and also a concentration map and homogeneity quantitative determination.

The method relies on the measurement of the surface curvature appearing as a consequence of the thermal expansion induced by the modulated pump beam [1]. This is accomplished by a quasi confocal configuration for the collection of the reflected probe beam, which results modulated at the pump modulation frequency due to a change in the reinjected power produced by the defocusing from a curved surface. The scheme used in this work is a modification of the suggested scheme presented in Ref. [2]. The changes were introduced to be able to add the device as an accessory of a commercial optical microscope.

A modulated beam heats the surface and a second probe beam collinear with the pump detects the change in surface curvature due to the material expansion. The frequency dependence of such expansion provides information on the thermal diffusivity of the sample at the impinging location. Scanning the beams allows the retrieval of a thermal diffusivity map (Fig. 1). This new setup resulted more stable, reliable and precise than the photodeflection technique used before for the characterization of similar samples [3]. The thermal transport properties are strongly correlated to the composition, allowing the detection of clusters of pure (unmixed) oxides, and the determination of the concentration distribution. Histograms of the thermal diffusivity provide information on the homogeneity of the interdiffusion (Fig. 2). Detailed frequency scans at fixed locations provide more accurate absolute values of the thermal diffusivity. Tests on Urania/Gadolinea and Urania/Dysprosia mixtures are presented. A microscopic image of a sample is shown in Fig 3.

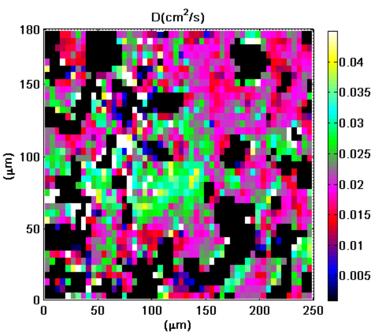

Fig. 1: Thermal diffusivity Map.

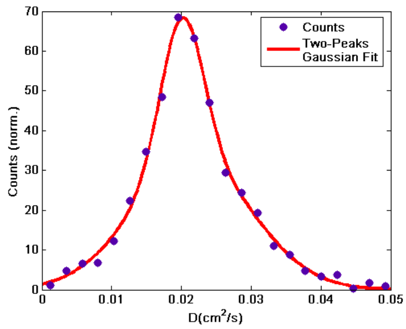

Fig. 2: Histogram of the thermal diffusivity.

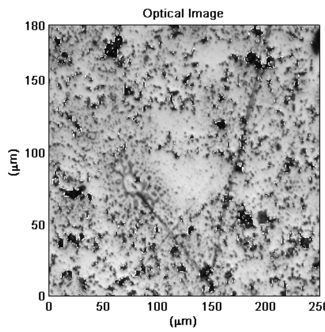

Fig. 3: Optical image with a camera.

[1] N. Mingolo, O. E. Martínez. Focus shift photothermal method for thermal diffusivity mapping. J. Appl. Phys. 111, 123526 (2012).
[2] N. Mingolo, O. E. Martínez. Thermal expansion recovery microscopy: Practical design considerations. Review of Scientific Instruments 85, 014903 (2014).
[3] F. Zaldivar Escola, O. E. Martínez, N. Mingolo, R. Kempf. 2013. Photothermal microscopy applied to the characterization of nuclear fuel pellets. Journal of Nuclear Materials 435, 17–24.

Optical and Photothermal Measurements applied to Low Energy Nuclear Reaction Systems

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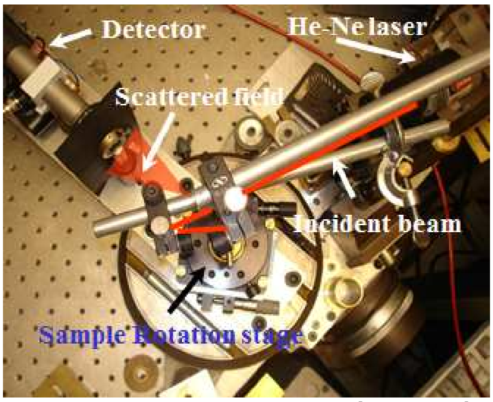
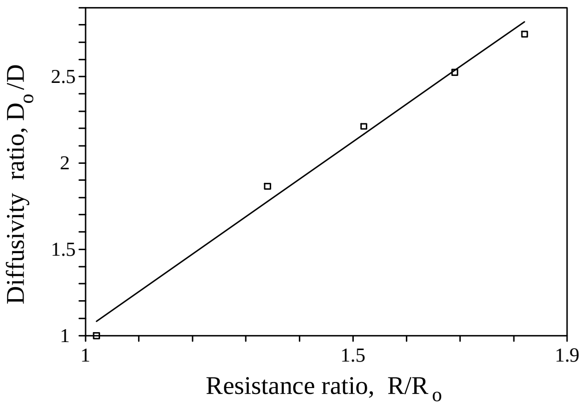
Researchers working with the Low Energy Nuclear Reaction Systems have always been interested to apply new nondesctructive techniques for the characterization of the palladium-hydrogen compounds. One of the main request is to find a simple methodology to reveal the amount of hydrogen loaded in the system (loading ratio), to identify simple quality parameters to describe if the surface morphology is adapted for an efficient loading process, for triggering plasmons in the structures, and finally to produce efficient excess of heat. In this article we present a compact laser device that has been designed and realised for nondestructive optical and morphological characterization of some rough palladium samples subjected to an electrolytic process (i.e. cold fusion) [1]. Such a characterization was a crucial and challenging task of a joint collaboration among Sapienza Università di Roma, ENEA Frascati, and Energetics LLc, to explore possible correlations between the surface optical properties and the measured excess of heat. The laser device measures the in plane scattered intensity in the whole range of scattering angle [-89°, +89°] (0° is for normal incidence) coming out from rough palladium samples. The scattered light detected by the Si-photodiode is finally analysed by a dedicated software which allows to invert the experimental data, reconstruct the statistical properties of the surface, and eventually detect the presence of surface patterning and surface plasmons (figure 1). We applied also photothermal deflection techniques for measuring the thermal diffusivity of different palladium samples with different concentration of Hydrogen (loading ratio). Generally the presence of Hydrogen could inhibit the heat conduction and diffusion, as well as electrical conductance because of the production of defects and dislocations. In this sense the thermal diffusivity may be correlated to the hydrogen concentration providing a supplementary information about the quality of the loading processes. In figure 2 we report some experimental results on different palladium compounds. We display the inverse of the thermal diffusivity of the compound normalized to the standard palladium diffusivity (D_o/D) vs the electrical resistance ratio R/R_o.. A clear correlation between thermal and electrical properties is found. By looking at the different scales of D_o/D and R/R_o one could conclude that the thermal diffusivity measurements could be very sensitive to the loading process, more than the electrical resistance.





Figs.1 exp.setup: Fig.2: correlation curve between the diffusivity ratio and the electrical resistance ratio

1. R. Li Voti G.L. Leahu, S. Gaetani, C. Sibilia, M. Bertolotti, V. Violante, E. Castagna, JOSA B Vol. 26, 2009.A.
2. De Ninno, A. La Barbera, V. Violante - Journal of Alloys and Compounds 253-254 (1997);

Saturday October 11st :

Thermophysical Properties

D1

Specific Heat Spectroscopy and Pyroelectric Depth Profiling in Ultrathin Films of Glass Forming Liquids and Polymers

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The thermo-physical properties of supercooled liquids and glasses show often deviations from their (equilibrium) bulk properties when they are confined to structures at nanometer dimensions. Typical properties being susceptible to *size*- or *confinement* effects are the glass transition temperature, T_g, the melting and crystallization temperature/kinetics, density, transport properties and others, which are documented in a large body of scientific literature from the last two decades. The physical characterization of nano-confined systems such as ultrathin films and nano-porous structures is often challenging, since proven bulk techniques might encounter problems arising from unfavorable scaling relations (probing length scales >> e.g. sample thickness, too small sample mass). Here, photothermal techniques, utilizing "slowly" propagating thermal waves, represent a promising approach for studying thermo-physical properties in nano-confined materials.
This presentation focuses on the characterization of ultrathin glassy films by means of thermal wave based methods.
In the first part, we will address ultrathin films of H-bonded liquids that were vapor deposited well below their bulk-T_g to form low-enthalpy "stable" glasses [1]. These films of a typical thickness of 50 nm were studied by a combination of chip-based ac-calorimetry and dielectric spectroscopy in an OMBD setup. Glycerol films revealed a peculiar dynamics after recovery of the liquid state that manifests as a slow-down in the dielectric structural relaxation time [2]. In contrast, specific heat spectroscopy in an overlapping frequency range is lacking this effect and also confirmed the gradual recovery of bulk-like c_p during various structural transformation events. Clear "stable glass" behavior was found for vapor deposited glasses of 2-Ethyl-1-Hexanol, which will be discussed as the 2nd example.

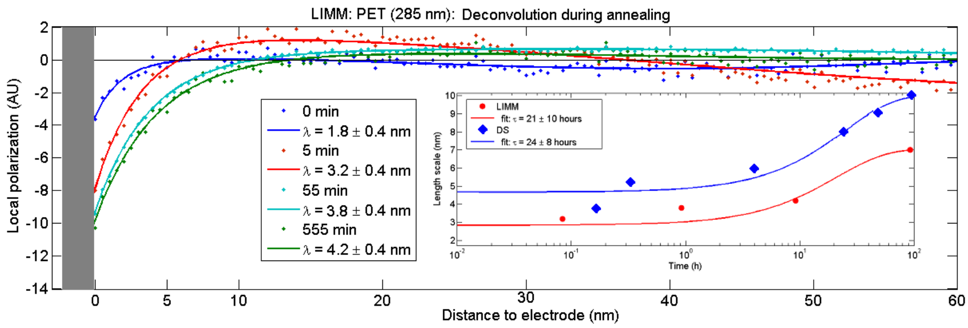

Fig. 1: Pyroelectric surface profiles on PET thin films measured by LIMM as function of sample annealing time.

Size and surface induced effects in polymeric thin films will be subject of the second part. Thermal annealing of thin films of polyethylene terephthalate (PET) leads to irreversible adsorption of parts of the polymer chain to a solid substrate. The resulting absorbed layer shows a reduced mobility that manifests as by a decrease in the dielectric strength of the film. A first visualization of this adsorbed layer is obtained via washing experiments, revealing a Guiselin brush structure, where the polymer backbones are oriented perpendicular to the substrate plane. To confirm the predicted chain conformation, ultimately resulting in a surface-induced polarization, we have studied the metal (aluminum) / PET interface by means of a pyroelectric depth profiling technique, also known as Laser Intensity Modulation Method (LIMM, [4]). Experiments were done using high frequency thermal waves excited in the range from 25 kHz to 25 MHz. The pyroelectric profile was obtained by both a scale transform approximation and by applying an innovative Monte-Carlo algorithm. The latter finally yielded an exponential-type surface polarization profile of PET with nanometer resolution, see Figure 1, the temporal evolution of which was found to correlate greatly with the growth dynamics of the irreversibly adsorbed PET layer as confirmed by independent adsorption experiments.

[1] S.F Swallen, K.L Kearns, et al., Science **315**, 353 (2007)
[2] S Capponi, S Napolitano, M Wübbenhorst Nature communications **3**, 1233, 9, 2012.
[3] S. Napolitano and M. Wübbenhorst, Nat. Communications. **2**, 260 (2011).
[4] B. Ploss, Proc. ISE 11, Melbourne, Australia, 177-180, (2002).

D2

NON-CONTACT OPTOELECTRONIC DIAGNOSTICS OF SOLAR CELL MATERIALS AND DEVICES USING PHOTOCARRIER RADIOMETRY, LOCK-IN CARRIEROGRAPHY AND THERMOGRAPHY IMAGING

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In this work a combined theoretical and experimental approach is developed for determining the current-voltage characteristics of silicon solar cells by use of quantitative lock-in carrierographic (LIC [1], also described as frequency-domain photoluminescence, LIP) and lock-in thermographic (LIT) imaging [2]. The optoelectronic (LIC) and thermoelectronic (LIT) imaging modalities are used for non-destructive, non-contact measurements of the electrical parameters of industrial solar cells from images obtained at various external load resistances. The measured values were found to be in very good agreement with electrical measurement. A photogenerated carrier radiative recombination current flux equation was developed which links the optical and electrical characteristic of solar cells. Based on that equation, estimation of the current-voltage characteristic of silicon solar cells by use of contactless LIC image measurements under variable illumination intensity becomes possible at all stages of solar cell fabrication before electrode deposition. Contactless LIC measurement was found to be in good agreement with standard electrical measurements.

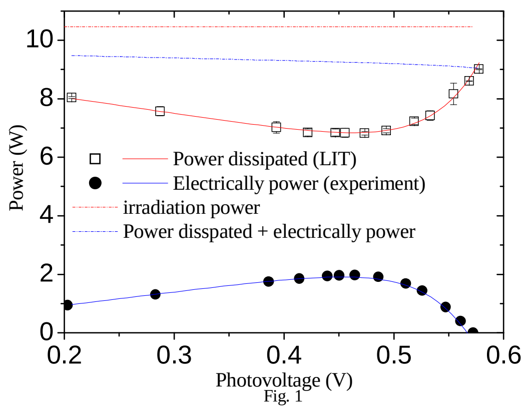

Fig. 1

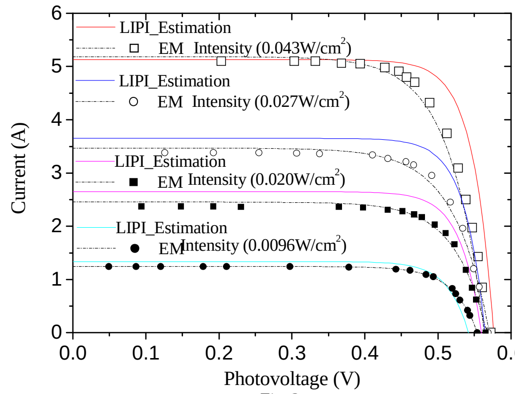

Fig. 2

Fig. 1 The determination of a mc-Si solar cell power dissipated by using LIT. Fig. 2 The estimation of current-voltage characteristic of the solar cell using contactless LIC

REFERENCES

[1] A. Melnikov, A. Mandelis, J. Tolev, P. Chen and S. Huq, J. Appl. Phys, 107, 114513 (2010).

[2] O. Breitenstein, M. Langenkamp, O. Lang and A. Schirrmacher, Sol. Energy Mater. Sol. Cells 65, 55 (2001).

D3

Achievements and Future Prospects in Application of Photothermal Techniques for Food Quality Control and Safety

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Abstract: Over the past decades photothermal techniques had undergone important development in instrumentation and have found numerous applications including monitoring of food processing and particularly food quality and safety control, mainly due to their inherent high sensitivity. Applications in the food sector are extensively reviewed in references listed below [1-6] and include mainly three groups of photothermal techniques: 1) photopyroelectric techniques (PPE) for thermal characterization and measurements of properties such as thermal diffusivity, effusivity and determination of phase transition temperatures, 2) photoacoustic spectroscopy (PAS) for detection of gasses in the process of food storage, as well as for characterization of powder samples (e.g. flours), and 3) thermal lens spectrometry (TLS), which was extensively used for chemical analysis of foodstuffs in combination with other analytical techniques such as liquid chromatography (HPLC), flow injection analysis (FIA) or bioanalytical assays engaging enzymes or antibodies (ELISA).

In addition to measurements of thermal parameters by PPE, which are relevant for optimization of food processing (e.g. cooking temperature), PAS was mainly used for determination of ethylene and other gases important in storage of vegetables and fruits or ammonia as indicator of meat spoilage. Other indicators of food spoilage or hygienic conditions can be biogenic amines formed by microorganisms also in processes such as food fermentation. Such compounds were determined by FIA-TLS, which was also used in combination with bioanalytical assays for determination of allergens in food or organophosphorous and carbamate pesticides in vegetables and juices. HPLC-TLS found applications mainly in determination of carotenoids as antioxidants and indicators of adulteration of olive oils or fruit juices but also in investigations of their role as antioxidants in physiological processes in human body. Other important applications of HPLC-TLS include determination of neonicotinoids as representatives of third generation pesticides in vegetables.

Current trends are oriented particularly into development of fast screening methods to analyse large numbers of samples in shortest time possible. Important progress in this field has been recently made by advancement of thermal lens microscopy (TLM) and introduction of µFIA-TLM [7]. It was for example demonstrated by determination of carcinogenic chromate in water that up to 15 sub µL samples per minute can be analysed using this technique, which still provides limits of detection lower than conventional transmission mode spectophotometry.

[1] D.D. Bicanic, J. Mol. Struct. **993**, 9–14 (2011)
[2] C.D. Tran , M. Franko, *Thermal Lens Spectroscopy*, In Encyclopedia of analytical chemistry, R.A. Meyers, ed. (John Wiley: Chichester., 2010)
[3] M. Franko, *Bioanalytical Applications of TLS*, In: Thermal wave physics and related photothermal techniques: Basic principles and recent developments, E. Marin, ed. (Research Signpost Press, 2009)
[4] M. Franko , Appl. Spectrosc. Rev. **43**, 358-388 (2008)
[5] M. Franko, Talanta, **54,** 1-13 (2001)
[6] D. Bicanic, M. Franko, J. Gibkes, E. Gerkma, J.P. Favier, H. Jalink, *Applications of photoacoustic and photothermal non-contact methods in selectedareas of environmental and agricultural sciences*, In: Life and earth sciences, Progress in photothermal and photoacoustic science and technology, vol. 3. A. Mandelis, P. Hess, Peter, eds. (Bellingham: SPIE Optical Engineering Press, 1997) pp. 131-186
[7] M. Liu, M. Franko, Crit. Rev. Anal. Chem. **44**, 328-353 (2014)

D4

Photoacoustic techniques applied to non-destructive analysis of phytochemicals present in typical foods of the Mediterranean Diet

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Fruits and vegetable have long been regarded as having considerable beneficial effects on health due in part, to the presence of bioactive compounds or phytochemicals. Some of these molecules, such as chlorophylls, carotenoids and anthocyanins are responsible for the organoleptic qualities of fruit and vegetables. In addition, they are implicated in numerous physiological processes of the plants, being produced in response to different types of abiotic and biotic stress. In particular, chlorophylls and carotenoids, widely found in the skins of fruits like apples, are involved in the photosynthesis process, while anthocyanins together with carotenoids, play an important role in protecting the fruits from photo-damage induced by UV irradiation. Thanks to these properties, the mentioned pigments play an important role as biomarkers of nutritional, healthy and commercial quality, so in this respect they receive great interest not only from nutritionists, but also from the agro-food industry.

In apples, chlorophylls, carotenoids and anthocyanins undergo to the changes during ripening and storage of fruits and their direct determination by a non-destructive analytical approach make it possible to correlate the content of these pigments with the degree of ripeness, freshness and shelf life of fruits. Eventually, non-destructive analysis could allow to standardize the quality parameters to meet the needs of both consumers and market.

In recent years, the photoacustic non-destructive technique (PA) have had a great acceleration in food analysis, since is not affected by scattering of light in turbid media, as occur for traditional spectroscopic techniques. Moreover, PA require little or no manipulation of the sample, nor require extraction procedures, so it can be employed for the direct optotermic characterization of the molecules contained in complex matrices such foods.

PA measurement were carried out on the apple peels of two cultivars: Golden Delicious and Royal Gala. The results revealed that PA signals were in agreement with the presence of chlorophylls (a and b), carotenoids and anthocyanins in different side of apple according to the different colour of the portion of apple peel analysed.

The quantitative standardization of the system will allow to correlate the concentration and the proportion of chlorophylls, carotenoids and anthocyanins with ripening state of the fruits in order to provide indication on optimum harvest date of apple fruits.

D5

Non Invasive Detection of Marble Sulfation by Pulsed Thermography

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Abstract: Air pollution is one of the most serious factors of degradation of carbonate stones, which compose some of the most important monuments and artifacts in the world. Although in recent years pollution has decreased considerably in European urban areas, there are still concentrations of pollutants, such as sulfur dioxide, one of the most dangerous chemical compound involved in the deterioration of calcareous stones. Sulfur dioxide can react with calcium carbonate, producing an external layer of gypsum. This process greatly depends on the structure of the stone and on the presence of moisture. This work aims to estimate, in a nondestructive way, the thickness of the gypsum layer grown on the marble surface by sulfation.

Recently, considerable improvements in infrared camera technology have allowed the use of thermography as a nondestructive testing method [1], [2], [3]. For the sake of historical importance of monuments, we propose a new method that permits to estimate the thickness of the gypsum layer formed on the marble surface, heating by a light pulse the surface area where the gypsum layer is located, while an infrared (IR) camera monitors the surface temperature. This technique is non-disruptive, non-invasive and non-contact. It is based on both pulsed infrared thermography and a mathematical model to reconstruct the profile of the effusivity and the thickness of the gypsum. Laboratory tests drew attention to the translucency of gypsum and marble at wavelengths of the visible to near IR. For this reason a model taking into account this aspect is adopted in the inversion procedure.

[1] X.P.V. Maldague; Nondestructive Evaluation of Materials by Infrared Thermography; Springer-Verlag, London (1993).

[2] S.M. Shepard, J.R. Lhota, B.A. Rubadeux, D. Wang, T. Ahmed; Reconstruction and enhancement of active
thermographic image sequences;
Opt. Eng. 42 (5), 1337-1342 (2003); doi: 10.1117/1.1566969

[3] S.M. Shepard, J. Hou, J.R. Lhota, J.M. Golden; Automated processing of thermographic derivatives for quality assurance;
Opt. Eng. 46 (5), 051008 (2007); doi: 10.1117/1.2741274

D6
Photoacoustic and Photothermal Study of the Micro-Electro-Mechanical-Structures

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Abstract
The development of microsystem technologies (surface and bulk micromachining) resulted in the production of miniature sensors, actuators, resonators and electromechanical parts. The photoacoustic (PA) and photothermal (PT) science and technology extensively developed new methods for the investigation of micro – electro – mechanical - systems (MEMS). The PA and PT effects can be important also as driven mechanisms for optically excited micromechanical structures.

The basic concept, development and application of the PA and PT elastic vibration methods are presented. The amplitude and phase of the PA and PT elastic vibration spectra (the PA and PT signals vs. the modulation frequency of the excitation optical beam) for various types of micromechanical structures (the cantilevers, membranes, plates) were measured and analyzed.

The PA and PT elastic vibration methods enable to investigate the different micro-electro-mechanical-structures (MEMS). This investigation is important for analysis of the influence of the different technological processes to the vibrations of the optically driven micromechanical structures, i.e. how the technological processes change the characteristics of micromechanical structures for sensors and actuators.

D7

Photopyroelectric Technique: Sample´s thickness scanning for Measuring Optical Properties of Pure Liquid Substances

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Abstract: The useful of Photopyroelectric technique, in the transmission configuration, for measuring optical properties of pure liquid substances is shown. The analytical scheme involves the scanning of the photopyroelctric signal as function of the sample´s thickness. Optical absorption coefficient, at 980 nm, was measured for distilled water and a series of linear alcohols (methanol and ethanol among them). An interesting relationship between this optical parameter and the molecular weight of the linear alcohol was found.

Optical properties are widely used for identification (especially in the infrared region) and quantification (usually in the UV region) of pure substances or their mixtures. Optical absorption coefficient, β, is required for the second purpose. This optical parameter, defined for a substance in a mixture as $\beta=c\varepsilon$, where c is the concentration and ε, the molar extinction coefficient (or absorptivity), depends on the wave-length and characterize how fast monochromatic light is absorbed across the sample. Beer-Lambert´s law establishes an exponential decay for the light passing through the sample by means of the equation $I=I_0\exp(-\beta l)$, where I_0 is the initial light intensity and I is the one after passing through the sample, with thickness l. When applies, a dimensionless parameter, named absorbance, defined as $A=-\log(I/I_0)$, is related with β through the equation $A=\beta l\log(e)$. Absorbance is measured by means of a spectrometer which just measure, for a constant thickness, the light passing through the sample and the corresponfing one for a reference sample, lacking of experimental criteria for verifying validity of Beer-Lambert model calibration curve, establishing linear relation between c and A, is required for establishing this relation. This experimental scheme does not apply, however, for a pure substance and commercial spectrometers are not useful in this case. Photopyroelectric (PPE) technique in transmission [1], taking the sample´s thickness as variable, results ideal instead, and figure 1 is a cross section of the PPE experimental setup. If the sample´s behaves in the thermally thick regime and taking sample´s thickness as the only variable it has been shown that PPE signal, $V(l)$, can be written as [1]

$$V(l) = C\exp(-\beta l) \qquad (1)$$

where C is a complex constant. This equation establishes that if Beer-Lambert´s model applies PPE amplitude decrease exponentially while PPE phase remains constant.

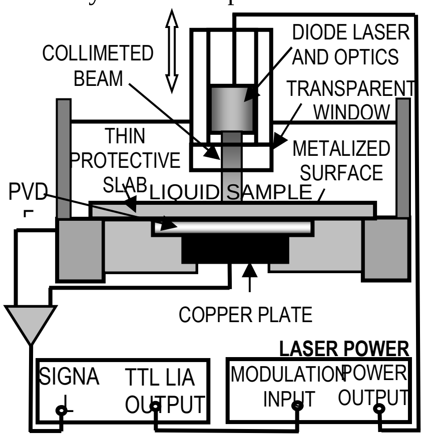

Fig. 1 Cross section of the Photopyroelectric setup.

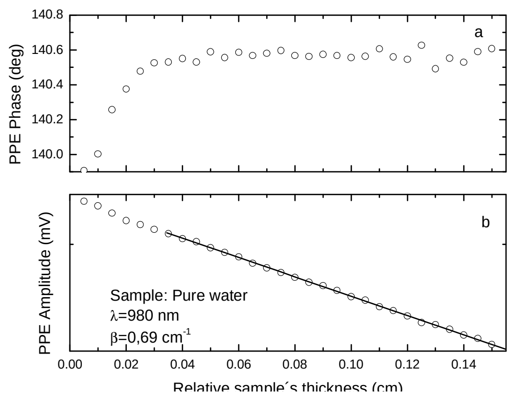

Fig. 2 Photopyroelectric (PPE) signal, as a function of the sample´s thickness, for pure water. a. PPE phase. b. PPE amplitude. The continuous line in b is the best linear fit for obtaining the optical absorption coefficient.

Figure 2 shows experimental results for pure water, at 980 nm, showing the constant PPE phase (a), which validates the Beer-Lambert model in this case, and the corresponding PPE amplitude, which decrease exponentially. The corresponding optical absorption coefficient is obtained from Eq. (1) as the slope of the best linear fit, shown in Fig. 2b as the continuous line. The optical absorption coefficient for six linear alcohols: methanol, ethanol, 1-prophanol, 1-buthanol, 1-penthanol and 1-octhanol were also measured and an interesting relation between this optical property and the molar weight was found.

[1] Balderas-López J. A., Meas. Sci. Technol., **23** (2012) 065501 (10 pp.)

D8

Optical Characterization of Photothermally Induced Arc Flicker in High-Intensity Discharge Lamps

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High-intensity discharge (HID) lamps comprise a translucent vessel called arc tube, in which a plasma discharge arc between two electrodes is established. These lamps combine high lumen efficacies with excellent color qualities. Operating HID lamps at a high-frequency (20 – 300 kHz) would reduce cost and increase energy efficiency of the lamp-driver system compared to the currently used low frequency 400 Hz [1]. However, tuning the alternating current (AC) frequency of the electronic driver to the high-frequency range bears the risk of stimulating acoustic eigenmodes of the arc tube which leads to arc flicker. More recently, the mechanism behind this phenomenon has been identified [2]: The AC represents a periodic heat source that implies temperature and pressure oscillations. The standing pressure waves induce forces with non-zero time average that arise from the bulk viscosity of the plasma. This effect is called acoustic streaming [3]. The additional force field superimposes the buoyancy-driven velocity field and can cause unstable plasma arcs that result in visible light flicker. However, the acoustic streaming effect can also be used to straighten the discharge arc and, thus, to significantly enhance the lamp efficiency [4].

This work presents experimental investigations at different excitation frequencies and modulation depths in order to characterize arc flicker. Light fluctuations of the discharge arc have been detected with a photodiode. Simultaneously, the operating voltage as function of time has been recorded. A transformation of the measuring results into the frequency domain shows that the arc motion represents a superposition of sinusoidal oscillations. Additionally, a photodetector array has been used to obtain two-dimensional information about the light intensity distribution. These results are compared to the photodiode measurements. In a second step shape, position, and length of the discharge arc are identified and the range of motion at different excitation frequencies and modulation depths are determined.

[1] G. A. Trestman, 28th Annual Conf. of the Ind. Electron. Soc., (IEEE, Piscataway, NJ, 2002), pp. 1214-1218.
[2] F. Afshar, Journal of the Illum. Eng. Soc. **5**, 27-38 (2008).
[3] J. Lighthill, Journal of Sound and Vibration **61**, 391-418 (1978).
[4] K. Stockwald, H. Kaestle, H. Ernst, IEEE Trans. on Ind. Applicat. **50**, 94-103 (2014).

D9

Photopyroelectric Calorimetry Applied to the Study of Critical Behavior of K*A*F3 (*A* = Mn, Co, Ni)

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Critical behavior of the paramagnetic to antiferromagnetic transition in single crystals of $KNiF_3$ and $KCoF_3$ has been studied by means of a high resolution ac photopyroelectric calorimetry and compared with our previous measurements in $KMnF_3$. From the phase of the photopyroelectric signal, thermal diffusivity is extracted and from the combination of phase and amplitude, specific heat and thermal conductivity can be obtained. The three thermal magnitudes are presented for the three samples. The transitions take place at 245.1 K for $KNiF_3$, 115.2 K for $KCoF_3$ and 86.6 for $KMnF_3$. For both $KMnF_3$ and $KNiF_3$ the transition is purely magnetic but for $KCoF_3$ the spin-orbit interaction leads to orbital ordering at the same time as the magnetic ordering takes place, distorting the crystal lattice from cubic to tetragonal.

Figure 1 shows specific heat (c_p) for both $KNiF_3$ and $KCoF_3$ in the near vicinity of their respectives Néel temperatures T_N. In the near vicinity of the transition, the critical behavior of specific heat can be expressed through the well known equation

$$c_p = B + Ct + A^{\pm}\left|t\right|^{\alpha}\left(1 + E^{\pm}\left|t\right|^{0.5}\right) \qquad (1)$$

where $t = (T-T_N)/T_N$ is the reduced temperature, and α, $A^{\pm}$, B, C and $E^{\pm}$ are adjustable parameters. In the case of $KNiF_3$, the value of the critical exponent has been found to be α =-0.110±0.003 and the ratio of the coefficients A^+/A^-=1.30, agreeing quite well with the 3D-Heisenberg isotropic model, which is compatible with the magnetic structure of the sample. This result has been confirmed applying a similar procedure to D and 1/K. Concerning $KCoF_3$, the critical exponent is α =-0.078±0.008 while the ratio of the coefficients gives A^+/A^-=1.28. The deviation from the theoretical Heisenberg value (-0.115) arises from the fact that there is orbital as well as magnetic ordering, which affects the Hamiltonian describing the system.

These results are compared to the case of $KMnF_3$, where α =-0.111±0.002 and A^+/A^-=1.41 [1] and the differences in the parameters are discussed as a function of the magnetic anisotropies appearing as a result of the change of transition metal.

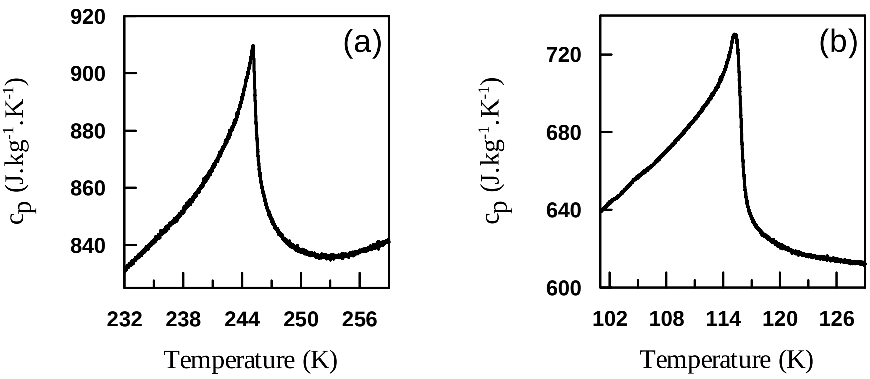

Fig. 1: Specific heat for $KNiF_3$ (a) and $KCoF_3$ (b) in the vicinity of the magnetic transition

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[1] A. Salazar, M. Massot, and A. Oleaga, Phys. Rev. B **75,** 224428 (2007).

D10

PHOTOTHERMAL CHARACTERIZATION OF THERMOCHROMIC MATERIALS FOR TUNABLE THERMAL DEVICES

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The optical and infrared properties in thermochromic materials have been deeply investigated in the last years due to the large variety of photonic devices that can be realised thanks to the metal/insulator phase transition: "*smart*" windows which autonomously control sun rays into a room, thermally controllable localized-plasmon, hysteresis enhancement of a phase transition by nanoparticulation, optical memory by the means of phase transition, and ultrafast switching of the photonic stop band in photonic crystals.

Among the thermocromic materials (niobium dioxide, vanadium sesquioxide etc..) vanadium dioxide (VO_2) represents the most widely used for many applications [1]. Its crystalline lattice exhibits an abrupt semiconductor-to-metal phase transition at a temperature of about $T_C \approx 68°C$, characterized by a change of the crystalline cell from monoclinic to tetragonal, and consequently by an ultrafast change in the optical and IR properties (i.e. reflectivity and emissivity).

In this paper we show how photothermal techniques may represent a useful non-destructive and non contact tool to study the optical and thermal properties changes of vanadium dioxide thin films (both single layer and multilayers deposited onto a silicon substrate [2,3]) during the phase transition. We have performed the standard optical and infrared measurements of reflectance, transmittance, and emittance by changing the temperature of the vanadium dioxide film from 20°C (below T_c) to 90°C (above T_c) so to determine the entity of the thermal hysteresis loops and compare the refractive index in both metallic and semiconductor states with respect to the reference values [4]. We have applied photothermal radiometry (PTR) by using a diode laser modulated at a frequency in the range 1Hz -100 kHz, and a MCZT infrared detector, in order to measure the effective thermal parameters of the structure, as well as the induced emissivity changes from the vanadium dioxide film [5].

Experimental results show how PTR represent an good tool for a quantitative measurement of the thermal properties of vanadium dioxide thin films.

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REFERENCES

[1] M.Soltani, M.Chaker, E.Haddad, R.Kruzelecky, J.Margot, P.Laou, and S.Paradis, *J.Vac.Sci.Technol.A* 26(4) Jul/Aug (2008)

[2] LI VOTI R., LARCIPRETE M. C., LEAHU G., SIBILIA C., and BERTOLOTTI M., *J. Nanophotonics* **6**, (2012) 061601.

[3] LI VOTI R., LARCIPRETE M. C., LEAHU G., SIBILIA C., and BERTOLOTTI M., *J. Appl. Phys*. **112**, (2012) 034305.

[4] G. Leahu, R. Li Voti, C. Sibilia, M. Bertolotti, Applied Physics Letters, 103 (23), 231114 (2013). [5] G. L. Leahu, R. Li Voti, M. C. Larciprete, A. Belardini, F. Mura, I. Fratoddi, C. Sibilia, and M. Bertolotti AIP Conference Proceedings 1603, 62 (2014); doi: 10.1063/1.488304

Posters

Study of Acupuncture Effect on Cerebral Blood Flow using Photoacoustic Imaging

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Abstract: Acupuncture has been a powerful clinical tool for treating brain diseases. A research proposed that the neural system generates neural electrical signals evoked by acupuncture [1]. Another study indicated that acupuncture produces an effect by regulating the nervous system [2]. Hui observed that acupuncture can activate the limbic system and produce relevant responses with the sensorimotor system [3]. However, there is currently no appropriate method to clarify the therapeutic effect of acupuncture. Here, we use photoacoustic tomography (PAT) to study the effect of acupuncture by imaging cerebral vasculature and blood flow in small animals. Ten healthy mice were stimulated with acupuncture needles on Yongquan acupoints, and PAT images of mouse brain were concurrently obtained. Compared to control group, the mice with acupuncture showed significant changes in cerebral blood flow especially in the middle cerebral artery (MCA) and branch vessels, as see in Fig. 1. Data were analyzed after the experiment on ten mice using a *t*-test. The criterion for significance was $p < 0.05$. This pilot study shows the potential of PAT as a visualization tool for illuminating the mechanism of acupuncture and promoting its clinical applications.

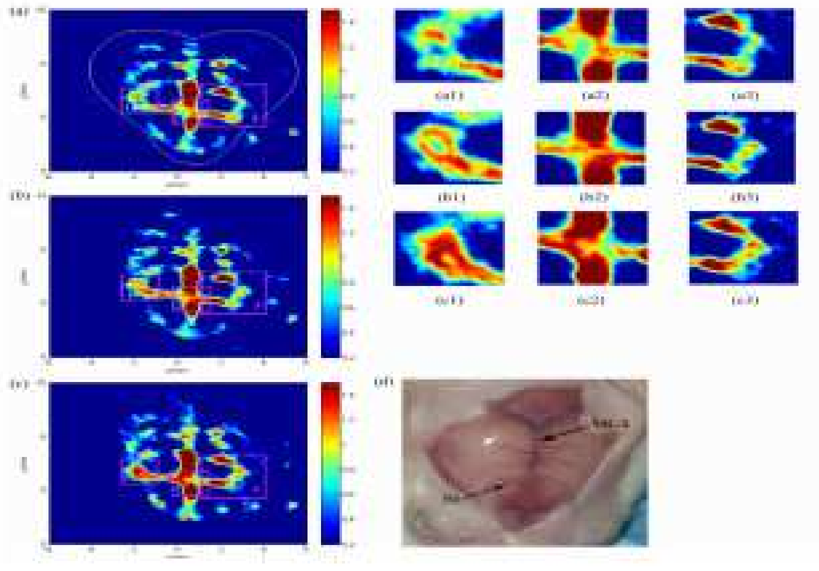

Fig. 1: Noninvasive PAT imaging of a mouse brain at a wavelength of 532nm with skin and skull intact. Photoacoustic image acquired (a) before acupuncture (at the 3 minutes), (b) after acupuncture (at the 8 minutes), (c) after rotation of the needle (at the 13 minutes). (a1)-(a3) is the magnified image of box 1,2 and 3 in (a). (b1)-(c3) are acquired similarly in (b) and (c). (d) Photograph of the small mouse brain obtained after the PAT experiment.

[1] C. X. Han, J. D. B. Wang, Y. Guo, Y. Y. Liu, J. Tianjin University **44**(5), 412-416 (2011).
[2] J. S. Han, L. Terenius, Annu. Rev. Pharmacol Toxicol. **22**(1), 193-220 (1982).
[3] K. K. Hui, V. Napadow, J. Liu, M. Li, Q. Marina, E. E. Nixon, J. D. Claunch, L. LaCount, T. Sporko, K. K. Wong, J. Vis. Exp. **8**(38), 1190-1197 (2010).

P2

Mid-IR Photothermal Deflection Spectroscopy for *in vivo* Skin Measurments using a Tunable Quantum Cascade Laser

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Middle infrared (mid-IR) photothermal spectroscopy provides a promising method for non-invasive spectral analysis of the human epidermis. This is due to the high specificity and sensitivity of biomolecular absorption, as for example for glucose, in this spectral range[1]. There are already several successful approaches measuring the IR spectra of the human epidermis[2]. Additional, these approaches allow the determination of epidermal glucose concentrations using an acoustic resonator in the ultrasound range[3].

Here we propose a mid-IR photothermal deflection spectrometer, which makes the recording of skin spectra possible. The experimental array can be described as a pump-probe beam detection system. By using a mid-IR/VIS transparent material as a sample holder, the alignment of the probe beam to samples with not defined shape, especially liquids and soft tissue (e.g. skin), is simplified due to the establishment of a defined flat sample surface. The mid-IR pump laser, a tunable quantum cascade laser (QCL), is irradiating the sample, while the probe beam passes above the irradiated spot and is deflected. This deflection of the probe beam is a consequence of the change of refractive index induced by the generated thermal wave.

With this setup we were able to perform depth profiling of the human epidermis by measuring *in vivo* skin spectra at different modulation frequencies of the QCL. Also, *in vitro* measurements of several aqueous glucose solutions in the physiological range (50mg/dl to 500 mg/dl) were carried out to prove, if the system offers enough sensitivity for detecting typical concentrations of this analyte regarding non-invasive glucose determination in human skin. The results of these measurements give a promising perspective for further applications as sensing technique in the biomedical filed.

[1] H. von Lilienfeld-Toal, M. Weidenmüller, A. Xhelaj, and W. Mäntele, *Vib. Spectrosc.* vol. 38, no. 1–2, pp. 209–215, Jul. 2005.

[2] M. a Pleitez, T. Lieblein, A. Bauer, O. Hertzberg, H. von Lilienfeld-Toal, and W. Mäntele,*Rev. Sci. Instrum.*, vol. 84, no. 8, p. 084901, Aug. 2013.

[3] M. A. Pleitez, T. Lieblein, A. Bauer, O. Hertzberg, H. von Lilienfeld-Toal, and W. Mäntele, *Anal. Chem.*, vol. 85, no. 2, pp. 1013–20, Jan. 2013.

P3

Classifying Ammunition from Gunshot Residues Using Fourier Transform Infrared Photoacoustic Spectroscopy (FTIR-PAS)

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Abstract: The Gunshot Residue (GSR) particles have extensive significance in forensic examination of cases involving suspected use of firearms. The GSR can consist of both unburned and partially burnt combustion products from primer or powder components, and can be used to link to the types ammunition, or eventually help in identifying the firer. Identification of propellant powders in evidential materials can provide useful information especially when both the cartridge and projectile are absent. In this study, we present an approach to classify GSR from different propellant handgun ammunition by FTIR-PAS. For these measurements, the sample collection is by ‘‘taping’’ the hands of the shooter with adhesive tapes immediately after the firearm discharge. A total of seven ammunition brands were studied for classification purposes. Ammunition was supplied by Policía de Investigaciones de Chile. The tapes were directly subjected to spectral measurement in a FTIR spectrometer (Nicolet 450, USA) equipped with a cantilever-enhanced photoacoustic cell (PA301 GASERA, Finland). Placing the tape in the cell holding cup and purging the cell with dry He, 50 scans were recorded in the range of 500-4000cm^{-1} and resolution of 8cm^{-1}. A carbon reference was used for spectra-intensity normalization. Multivariate data analysis such as Principal Components Analysis (PCA) was used to reveal the separation between spectra in the score space and compared also with **k** nearest neighbors (KNN), SIMCA and PLS-DA. This work demonstrated that FTIR-PAS is a sufficiently sensitive to detect and classify GSR from different types of ammunition brand. Collection of residue is quite simple and easily carried out in the field. The taping method can be directly applied to the surface (skin or other material) to be tested. The methodology allows a fast and simple photoacoustic measurement in which additional sample preparation methods and chemical extractions are not required.

P4

The Use of Thermal Lens Determination of Copper(II) with 5-(4-sulphophenylazo)-8-aminoquinoline

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Abstract: Thermal Lens Spectrometry (TLS) had shown to be an effective technique in the field of analytical chemistry. Successful application in environmental and biochemical samples has been reported, specially because of its extreme sensitivity. We report the results obtained in the quantitative determination of copper by using TLS. The work is part of an investigation on metal complexes determined by photothermal methods. We explore thermal lensing sensitivity in comparison with conventional spectrophotometric methods. We developed preliminary studies for determining Cu(II) in water samples and is meant to be applied in mineral residuals and natural water impacted by the mining activity.

The method is based on Cu(II)-5-(4-sulphophenylazo)-8-aminoquinoline (SPA) complex colorimetric reaction. The characterization and optimization of the Cu(II)-SPA complex in aqueous solution was analyzed under both TLS. Cu(II) reacts with SPA at room temperature and it forms a high molar absorptivity brown-red complex. The complex absorption is not affected by the buffer addition. A TL spectrometer was set up with He-Ne laser (20mW) as both the probe and the excite sources at wavelength of 632.8 nm. The sample solution was introduced into a 10 mm photometric quartz cell. By measuring, the signal from the detector over time was acquired for each sample and then TL signal was calculated. Under optimum conditions for copper complex formation (10 mL dilution volume, SPA 1 10^{-3} mol/L, 3 mL Buffer pH 11.5, 5 mL methanol), the TLS calibration is linear up to 130 μg/L and the limit of detection (LOD) of copper resulted 3.7 μg/L. The relative standard deviation (R.S.D.) of the method for the calibration is nearly 5% at 63.5 μg/L (n=5).
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P5

Transformations of Chromones and Theis Structural Analogues into Fluorescent Products under UV-Irradiation

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At present, optical information recording in the modern ODs is based on thermoinduced transformation processes of substances that change the reflection properties under light. Prospects for increasing the information capacity of ODs are related to the development of multilayered light-sensitive recording media based on organic compounds that being irradiated experience irreversible photochemical transformations of the initial non-fluorescing compound into a fluorescent photoproduct [1-3]. Multilayered ODs provide the realization of the three-dimensional (3D) optical memory with the recording density higher than 1 TB due to layer-by-layer processes of two-photon information recording and reproduction [2].

It has recently been shown that UV-irradiated acylchromones I that do not manifest fluorescence are irreversible rearranged to fluorescent furano[3,4-b]chromenones II [3-5]. Based on the latter, we are developing multilayered detection media for ODs of the WORM archive type [3]. This work is devoted to development of methods for synthesis and the study of the photochemical properties of compounds I and the fluorescence properties of photoarrangement products II.

In addition the synthesis of structural analogues III and their behavior under UV-irradiation are presented.

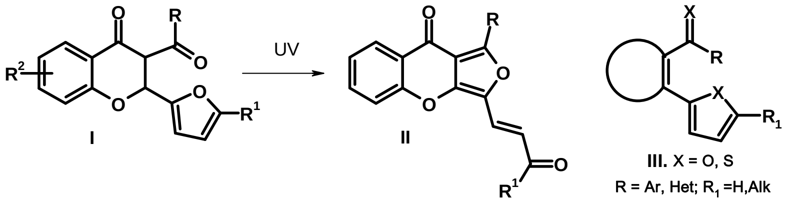

Figure 1 shows the typical photoinduced changes in the absorption and fluorescence spectra of chromone **Ia** in toluene.

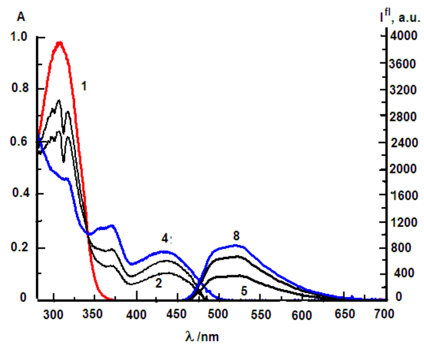

Fig. 1. Absorption spectrum of compound **Ia** ($R=R_1=R_2$; X=O) in toluene (1) and the absorption (2–4) and fluorescence (5–8) spectra of its photoproduct formed after UV irradiation through the UFS-1 light filter. The fluorescence spectra were measured after light excitation with the wavelength of 440 nm.

All studied chromones are characterized by a high Stokes shift that provides their practical application both in light-sensitive recording media with fluorescence readout of optical information and other fields due to the achievement of a high contrast of the fluorescence signal. The value of quantum yields depends on both the structure of chromones and the nature of substituents in their fragments.

1. V. A. Barachevsky, M.V. Alfimov, V.B. Nazarov, *Opt. Mem. & Neur. Networks*, 7 (3), (1998), 205.
2. A. S. Dvornikov, E. P., Walker, P. M. Rentzepis, *J. Phys. Chem.*, 113 (2009), 13633.
3. V. A. Barachevsky, O. I. Kobeleva, T. M. Valova, A. O. Ait, A. A. Dunaev, A. M. Gorelik, M. M. Krayushkin, K. S. Levchenko, V. N. Yarovenko, V. V. Kyiko, E. P. Grebennikov, *Opt. Mem. & Neur. Networks*, 19 (2010), 187.
4. I. S. Semenova, K. S. Levchenko, V. N. Yarovenko, M. M. Krayushkin, V. A. Barachevski, O. I. Kobeleva,, T. M. Valova, *Russ. Chem. Bull*., 2012, № 9, 1745.
5. K. S. Levchenko, I. S. Semenova, V. N. Yarovenko, M. M. Krayushkin, *Tetrahedron Letters*, 53, (2012) 3630–3632.

P6

Solid-Phase Photochromic Films with Polyfunctional Optical and Electric Properties

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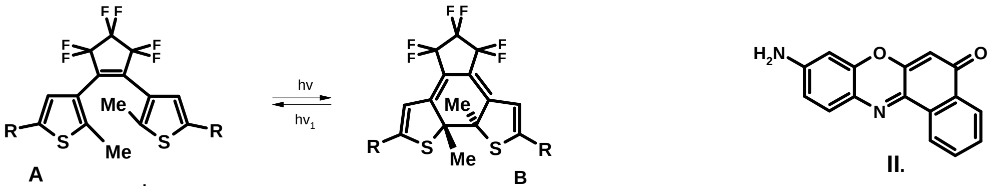
Abstract: With the use of photochromic nanoparticles based on thermally irreversible photochromic diarylethenes, organic fluorophores, Ag nanoparticles as well as CdSe/ZnS quantum dots new photocontrolled thin film elements simultaneously and reversibly changing optical (absorption, fluorescence) and electric (conductivity) properties under light were first created.

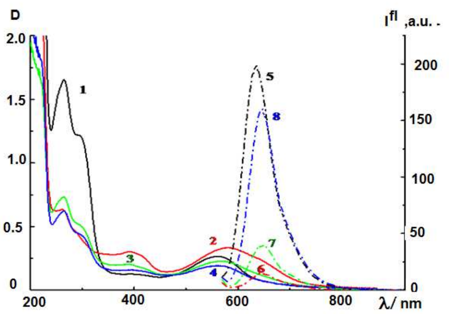
Nanophotonics progress demands the improvement of the element base for creation of smart devices of new generation. In this regard photocontrolled elements on a basis of photochromic nanoparticles are of special interest. In the given report the first results on creation of multifunctional photochromic solid-state films which at the same time reversibly change absorption, fluorescent and electric propertiesunder light are discussed.

Photochromic nanoparticles have been created on the basis of Ag nanoparticles and CdSe/ZnS quantum points. As photochromic components were used thermally irreversible diarylethenes (I), testing repeated reversible valence isomerization between A and B forms under only activating radiation. For reception a nondestructive photoinduced fluorescent signal in photochromic layers on the basis of Ag nanoparticles organic fluorophores, in particular oxazine II, were used. In layers based on CdSe/ZnS quantum dots they served as fluorophores. Solid-phase layers were put on the "edge" aluminium electrodes made by a method of vacuum evaporation of metal through a mask on a glass substrate.



I. R = Alk, Ar, Hal, CHO, CO_2Alk

The prepared solid-phase photochromic film based on one from diarylethene (R=CHO), nanoparticles Ag and oxazine II as a fluorophore showed reversible photoinduced changes of absorption and fluorescent (Fig.1) as well as conductivity (Fig.2). The szme results were received for the solid-phase photochromic film containing the same diarylethene and quantum dots CdSe/ZnS.



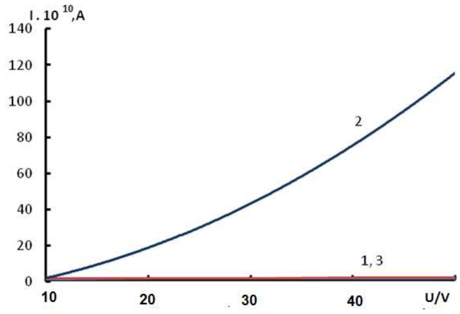


Fig.1 Absorption (1-4) and fluorescence (5-8) spectra for the solid-phase film containing diarylethene I, oxazine II and nanoparticles Ag before (1,5), after UV (2,6) and subsequent visible irradiation (3,4,7,8).
Fig.2. Volt-Amper characteristics for the same film before (1), after UV (2) and subsequent visible irradiation (3).

Thus, as a result of the study thin solid-phase optical nanostructured films simultaneously and reversibly changing optical (absorption, fluorescence) and electric (conductivity) properties under light were first created. This study opens perspectives for the development of a new generation of photocontrolled polyfunctional optical elements acceptable for creation optical integrated shemes.
This study was supported by RFBR (the project N 13-03-00964a) and Presidium of RAS.

P7

Non-destructive Recording Media Based on FRET-effect for Operative Optical Memory

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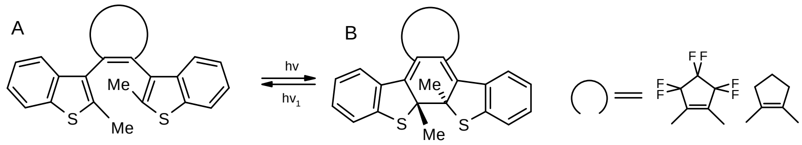
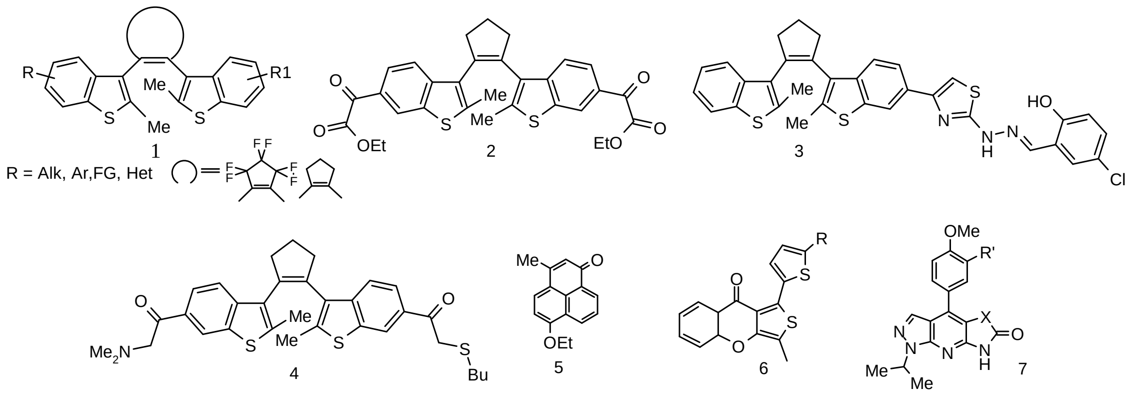
Photochromic 1,2-dithienylethenes containing cyclopentenes as a linking bridge are considered as promising components of light-sensitive recording media [1]. Under UV- and Viz- Irradiation these compounds can repeatedly undergo, without decomposition, photochemical transformations to form thermally stable open (A) and cyclic (B) forms.



We developed methods for the synthesis of a wide range of new cyclopentene photochromes of 1-4 types [2,3] and showed that these compounds can be used for the design of non-destructive recording media with the photoinduced fluorescent readout of optical information. Unsymmetrical cyclopentene photochromes 2 with different functional groups may be also of interest as linkers for nanothechnology, and photochromic coordination ligands.

A large number of fluorescent compounds such as products 5-7 were synthesized as well [4,5].

Composite materials for reversible optical memory devices using the FRET effect were created. For this goal binary mixtures of photochromes and fluorescent components were prepared. The absorption bands of photochromes 1-4 are located in the 400-600 nm range; they reliably coincide with the emission bands of fluorophores 5-7.



Using such composites provides nondestructive optical data reading out.

[1]. M.M. Krayushkin and M.A. Kalik, Syntheses of Photochromic Dihetarylethenes. In: Katritzky, editors: *Advances in Heterocyclic Chemistry*, Vol. 103, Oxford: Academic Press; 2011, p. 1-59.
[2]. M.M. Krayushkin, V.N. Yarovenko, L.V. Christoforova, A.S. Shashkov, E.P. Grebennikov, A.G. Devyatkov, G.E. Adamov, K.S. Levchenko, P.S. Shmelin, V.A. Barachevsky, T.M. Valova, O. I. Kobeleva. *Russ. Chem. Bull.*, 2011, № 12, 2487-2494.
[3]. A. M. Bogacheva, V. N. Yarovenko, K. S. Levchenko, O. I. Kobeleva, T. M. Valova, V. A. Barachevsky, M. I. Struchkova, P. S. Shmelin, M. M. Krayushkin, V. N. Charushin. *Tetrahedron Lett*. 2012, *53*, 5948–5951.
[4]. A. N. Komogortsev, B. V. Lichitsky, A. A. Dudinov, K. S. Krylov, A. M. Bogacheva, O. I. Kobeleva, V. A. Barachevsky, M. M. Krayushkin. *Mendeleev Commun*., **2013**, *23*, 222-223.
[5]. M. M. Krayushkin, A. M. Bogacheva, A. N. Komogortsev, B. V. Lichitsky, A. A. Dudinov, K. S. Levchenko, O. I. Kobeleva, T. M. Valova, V. A. Barachevsky, V. N. Charushin; *J. Sulfur Chem*., 2013, *34*, No. 6, 580–587.

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P8

Photoacustic (PA) and Phototermic (PT) techniques applyed to non-destructive analysis of phytochemicals present in typical foods of the Mediterranean Diet

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Many epidemiological studies suggest that a diet rich in fruits and vegetables, like the Mediterranean diet, offers protection against some common diseases of the Western world, such as cardiovascular events, obesity, diabetes, cancer and other age-related degenerative diseases. Fruits an vegetable have long been regarded as having considerable beneficial effects on health, due in part, to the presence of bioactive compounds or phytochemicals. These compounds include tens of thousands of molecules belonging to various chemical classes and botanical families also very distant from each other such as carotenoids, tocopherols, glucosinolates and polyphenols. They are produced as secondary metabolites by plants and play a key role in complex biotic and abiotic interaction. In fact, the bioactive compounds are essential for plants survival, because are produced, as signal molecules, in response to various stimuli including stress (UV, temperature, hydric stress).

Their amount and composition in plant foods is strongly dependent on a number of factors as genotype, ripening, environmental conditions, climate, cultivation practices, harvesting modalities and storage methods. Moreover, many of them are responsible for the organoleptic characteristics of foods such as colour, aroma and taste. In the human organism, the phytochemicals, through different mechanisms, defend our cells and tissues from free radicals attack, helping to neutralize or reduce the oxidative processes. In particular, due to their chemical structure, the phenolic compounds may exert strong antioxidant activity, in addition these molecules are involved in several other cellular processes, for example, are able to interact and modulate multienzymatic systems, to inhibit platelet aggregation, to counteract the carcinogenesis, to reduce the formation of inflammatory molecules. The daily and continuous introduction of these substances is of particular importance for human health.

All these properties confer to phytochemical an important role as biomarkers of nutritional, healthy and commercial quality. Nowadays, both the food industry and the agricultural sector need of rapid screening tools that make it possible the quality control along the whole chain of production (from farm to finished product). In this respect is desirable a non-destructive analytical approach, which allows to correlate the information obtained from direct analysis of bioactive compounds content in plant foods with the stadium of ripeness, freshness, shelf life of products.

In the recent years, the PA and PT techniques have been applied to the quantitative analysis of phytochemicals present in fruits and vegetables. In particular, these techniques have allowed the direct quantitative analysis of carotenoids (α- and β-carotene, lycopene) and flavonoids (mainly anthocyanins) in fresh produce products such as tomatoes, carrots, brassicaceae, oranges, cherries, apricots, grapes, wine, etc, with little or no manipulation of the sample.

In particular we obtained preliminary data (figure 4) from PA signals measurements in peel of apple fruits belonging to two different varieties: Golden Delicious and Royal Gala. The results revealed that PA signals were in agreement with the presence of chlorophylls (a and b), carotenoids and anthocyanins in different side of apple according to the different colour of the portion of apple peel analysed.

P9

PHOTOACUSTIC CHARACTERIZATION OF RANDOMLY ORIENTED SILVER NANOWIRES FILMS

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Metallic nanowires have cross-sectional diameters included between few to hundreds nanometers, while their lengths span from several to some hundreds microns. Metallic nanowires films show peculiar optical properties, such as high optical transmittance in the visible range, connected to the extremely reduced dimension of wires diameter, while still allowing for good electrical conduction, thus being suitable for those applications where transparent electrodes are required. As a consequence, metallic nanowires mesh, both randomly of systematically oriented, can be employed to tune the effective optical constants of the resulting film, and get peculiar spectral absorbance properties.

In this work we present the photoacustic characterization in the UV/VIS range of randomly oriented silver nanowires films deposited onto either quartz or polymeric substrate. This study was performed over a set of films differing in both metallic nanowires' dimensions, as well as metal content.

Samples were prepared using suspensions of Ag-nanowires in isopropanol (IPA) (25 mg/ml), purchased from Seashell Technology, differing by both nanowires' length and diameter. The starting IPA dispersion was added to de-ionized water, and then ultrasonicated for few minutes, filtrated and transferred onto the substrate by drop casting. The obtained films were characterized by scanning electron micrography (SEM images), thus the metal filling factor was retrieved with a matlab software based on visual method [1].

Following the morphological characterization, we employed photoacoustic spectroscopy (PAS) to investigate in details the absorbance spectra of silver nanowires films, in order to evidence their peculiar ab sorbance properties in the UV/VIS range. The us of PAS is particularly useful to investigate film that my display relevant scattering phenomena, as for silver nanowires films. We applied PAS in the UV/VIS range from 250 to 650 nm by using a low modulation frequency from 1Hz to 100Hz. The experimental results show that the choice of metal filling factor may affect the absorbance spectra of the resulting mesh.

ACKNOWLEDGMENTS
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REFERENCE

[1] M. C. Larciprete, A. Albertoni, A. Belardini, G. Leahu, R. Li Voti, F. Mura, C. Sibilia, I. Nefedov, I. V. Anoshkin, E. I. Kauppinen, A. G. Nasibulin, JOURNAL OF APPLIED PHYSICS, 083503-1- 083503-6 (2012)

P10

Optical and Photoacoustic Investigation of AZO/Ag/AZO Transparent Conductive Coating for Solar Cells

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Great attention has been paid recently to transparent conductive oxides TCO because of their application in optoelectronic devices, flat panel displays, solar cells, and anti-static coatings.
For photovoltaic applications, the reduction of the material cost, and the cost of its processing are key factors in the production process. Al-doped ZnO meets the requirements for contacting thin film solar cells, thanks to its good optoelectrical properties, low cost and higher resistance to Hydrogen-reach plasmas.

Recently many papers analyse innovative AZO based TCO structures where a thin layer of Silver is introduced in the TCO so to increase the electrical conductance without loosing transparency.

In this work first we simulate the transparency of a multilayer AZO/Ag/AZO as a function of the silver thin layer, by optimizing the AZO thicknesses, discussing some typical figure of merit.

Then we have prepared some multilayer coatings by RF sputtering not optimized yet.

The optical and thermal performances of the realized AZO/Ag/AZO multilayers were investigated by optical and photoacoustic spectroscopy. The thickness of the layers was determined by ellipsometry characterization.

REFERENCE

[1] M.L. Grilli, A. Sytchkova, S. Boycheva, A. Piegari, "Transparent and conductive Al-doped ZnO films for solar cells applications", Phys. Status Solidi A 210, No 4, 748-754 (2013)

P11

SEMICONDUCTOR-METAL PHASE TRANSITION OF VANADIUM DIOXIDE NANOSTRUCTURES ON SILICON SUBSTRATE: APPLICATIONS FOR TUNABLE THERMAL DEVICES

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Abstract.
We present a detailed infrared study of the semiconductor-to-metal transition (SMT) in a vanadium dioxide (VO2) film deposited on silicon wafer. The VO2 phase transition is studied in the mid-infrared (MIR) region by analyzing the transmittance and the reflectance measurements, and the calculated emissivity. The temperature behaviour of the emissivity during the SMT put into evidence the phenomenon of the anomalous absorption in VO2 which has been explained by applying the Maxwell Garnett effective medium approximation theory, together with a strong hysteresis phenomenon, both useful to design tunable thermal devices to be applied for the thermal control of spacecraft. We have also applied the photothermal radiometry in order to study the changes in the modulated emissivity induced by laser. Experimental results show how the use of these techniques represent a good tool for a quantitative measurement of the optothermal properties of vanadium dioxide based structures.
Keywords: Emissivity; Phase transition; Photothermal radiometry; Thermochromic materials.
PACS: 42.79.Ta, 64.60.an, 78.20.Ci

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REFERENCES
[1] M.Soltani, M.Chaker, E.Haddad, R.Kruzelecky, J.Margot, P.Laou, and S.Paradis, *J.Vac.Sci.Technol.A* 26(4) Jul/Aug (2008)
[2] LI VOTI R., LARCIPRETE M. C., LEAHU G., SIBILIA C., and BERTOLOTTI M.,
J. Nanophotonics **6**, (2012) 061601.
[3] LI VOTI R., LARCIPRETE M. C., LEAHU G., SIBILIA C., and BERTOLOTTI M.,
J. Appl. Phys. **112**, (2012) 034305.
[4] G. Leahu, R. Li Voti, C. Sibilia, M. Bertolotti, Applied Physics Letters, 103 (23), 231114 (2013).
[5] G. L. Leahu, R. Li Voti, M. C. Larciprete, A. Belardini, F. Mura, I. Fratoddi, C. Sibilia, and M. Bertolotti AIP Conference Proceedings 1603, 62 (2014); doi: 10.1063/1.488304

P-12
On heat losses in photothermal experiments

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Analysis of convection-radiation heat losses (CRHL) in frequency domain photothermal experiments is scarce. In this work a simple analysis demonstrates that CRHL can be neglected for modulation frequencies at which the thermal resistance against these mechanisms exceeds the heat diffusion thermal impedance. A frequency dependent *M*-number has been introduced in order to give a mathematical criterion for this, namely $M = ZH << 1$, where *Z* is the real part of the sample´s thermal impedance and *H* the CRHL's heat transfer coefficient. It is somewhat analogous to the Biot's number for stationary phenomena. A simple experiment has been designed to demonstrate the above hypothesis. A disc shaped sample is periodical heated at one of its surfaces at different frequencies using an amplitude modulated laser beam, and the temperature at the rear surface is monitored as a function of time using an infrared sensor. Amplitude graphs as a function of frequency are then compared with a theoretical model with and without CRHL consideration. It has been found that at low modulation frequencies the conventional model without CRHL does not fit well the experimental data, while using the proposed modifications a good agreement was found. From this comparison the sample´s thermal diffusivity has been obtained straightforwardly. We hope that the here presented results should be helpful not only for researchers in the field of photothermal techniques, but also for those dealing with any phenomena involving periodical modulated heating.

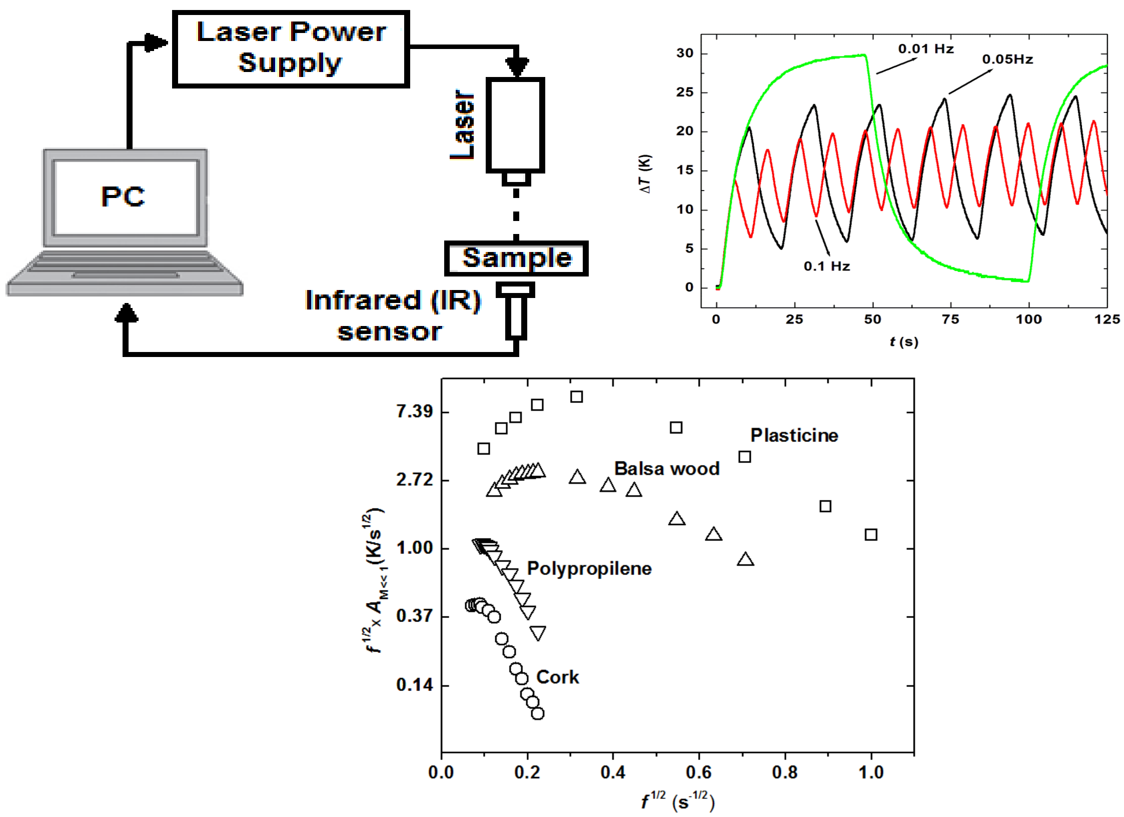

Figure: Top left: experimental setup. Top right: typical IR signals. Bottom: frequency dependence of IR radiometry signals of different samples, containing features due to convective and radiative heat losses.

P-13
Study of curing time of a photoresin by using photoacoustic technique

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This research studies the curing of a photoresin by the presence of UV laser radiation, as the excitation source. The optical absorption band for the curing of the resin ranged from 300 to 405 nm. A UV laser radiation, operated at $\lambda = 405$ nm with an output power of 20 mW, was the light source to study the curing of the resin as a function of time and the open photoacustic cell (OPC) was used to characterize the curing process and characteristic curing time for different resin thicknesses. The average values of curing time were $\tau = 10.43$, 20.99, 30.18, 45.84, 67.59 and 89.55 s and the resin thicknesses were 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 cm, respectively, showing a parabolic behavior of resin thickness as a function of the characteristic curing time. Also UV-vis Spectroscopy and Infrared Fourier Transform Spectroscopy (FTIR) techniques were employed to characterize the resin in order to study the optical absorption and the chemical bonds, respectively. Our study has applications in the manufacture of 3D printing parts for uses in medicine.

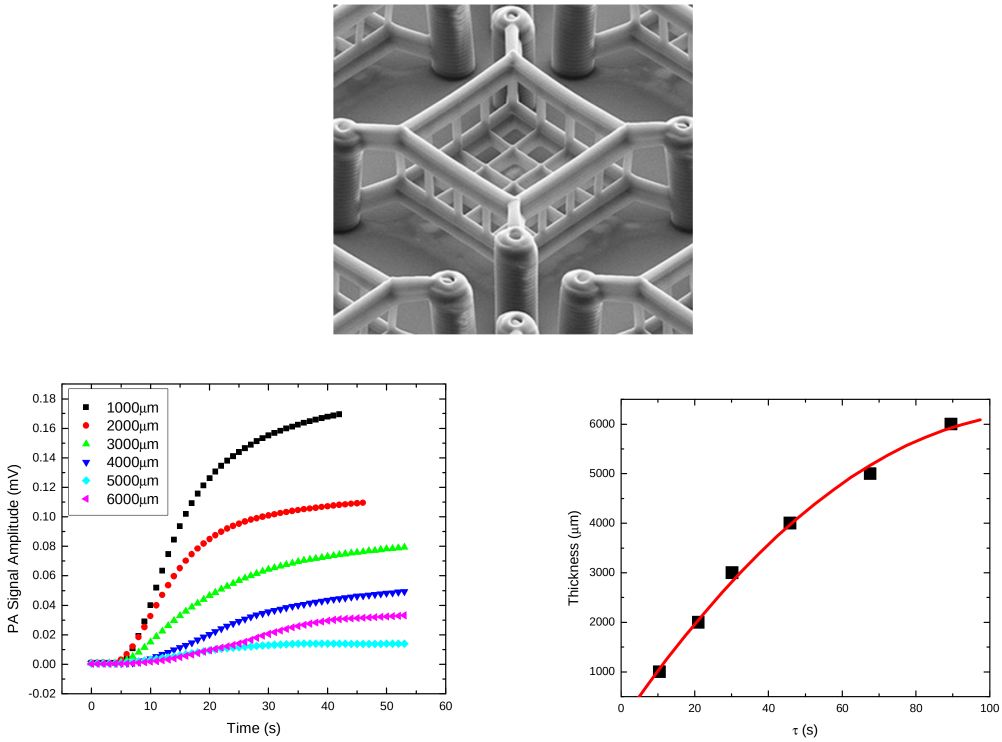

Figure: Top: 3D resin structure. Bottom left: PA signals recorded during curing for different curing thicknesses. Bottom right: evolution of thickness with curing time