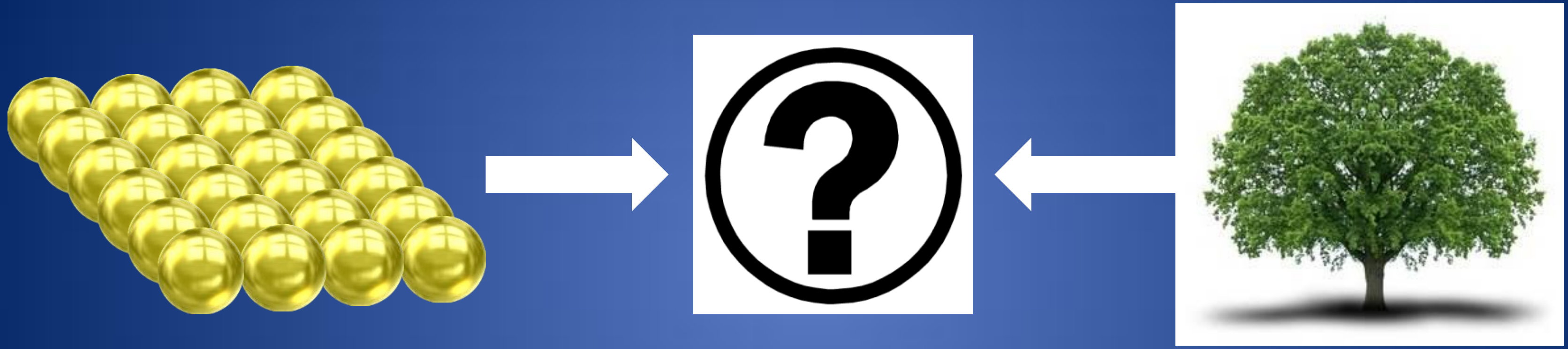
Plasmonic Trees



School of Quantum Electronics: Advances in Nanophotonics

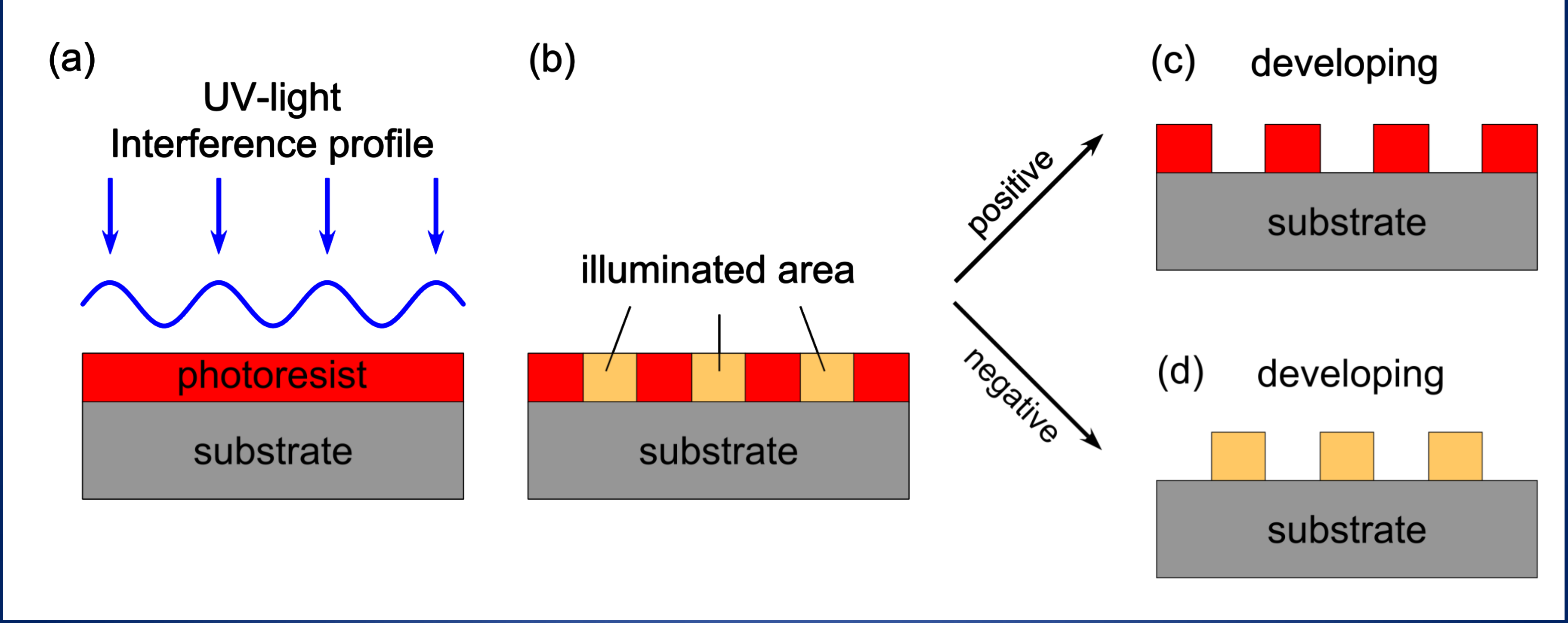
Erice, 19. July 2012

Jan Mertens

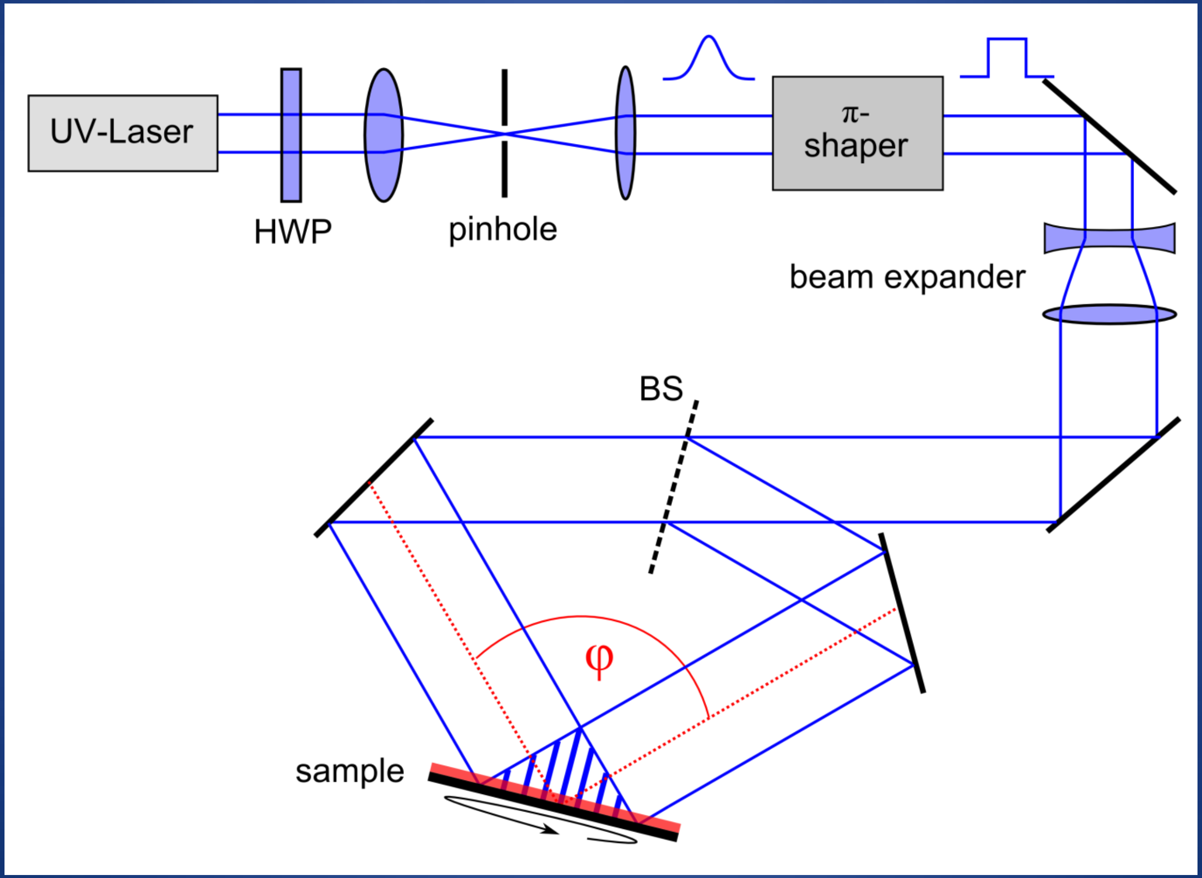
Overview

- Fabrication of trees / pillars:
  Interference lithography
- Decoration of trees / pillars:
  evaporation of gold
- Shiny trees / pillars:
  Characterisation of optical properties

Basic principle: Interference lithography

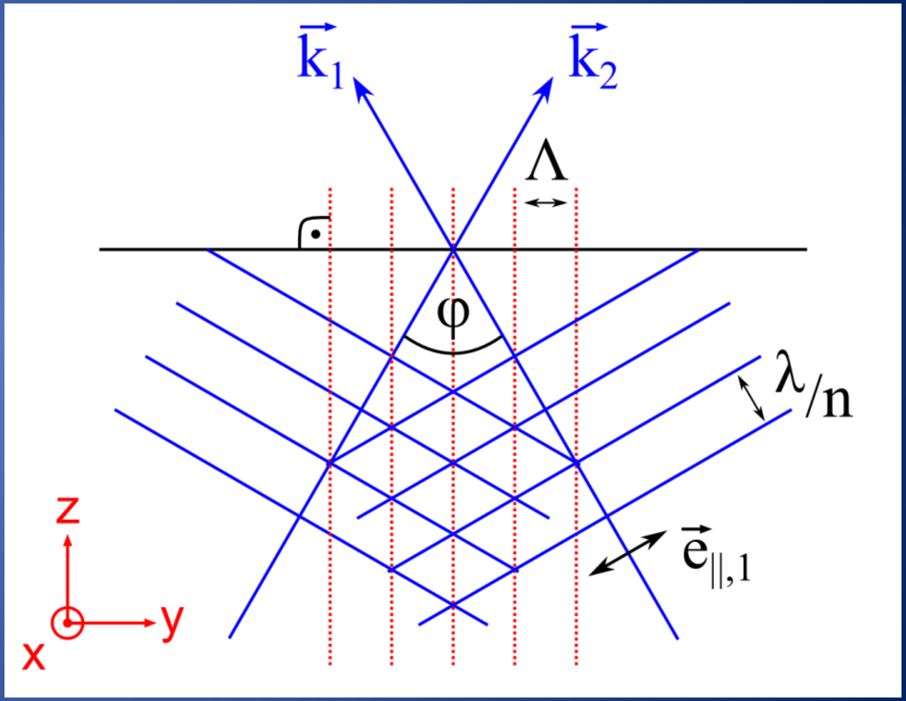


Interference Lithography Setup



Interference of plane waves

- interference of two plane waves
- interference pattern: straight lines
- periodicity: $\Lambda = \dfrac{\lambda}{2n\sin\left(\frac{\varphi}{2}\right)}$



Interference of plane waves

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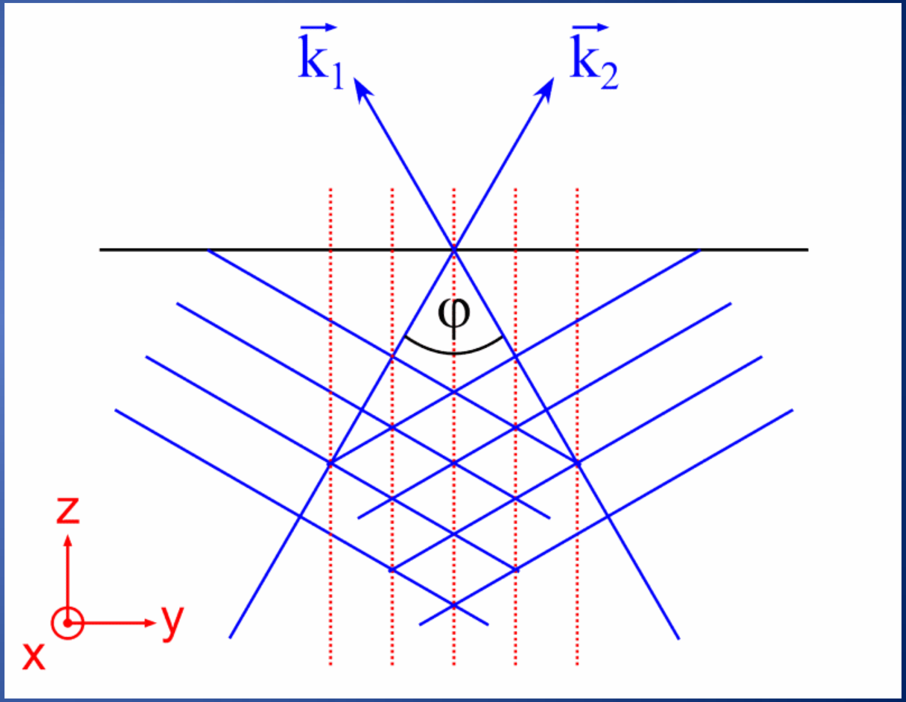
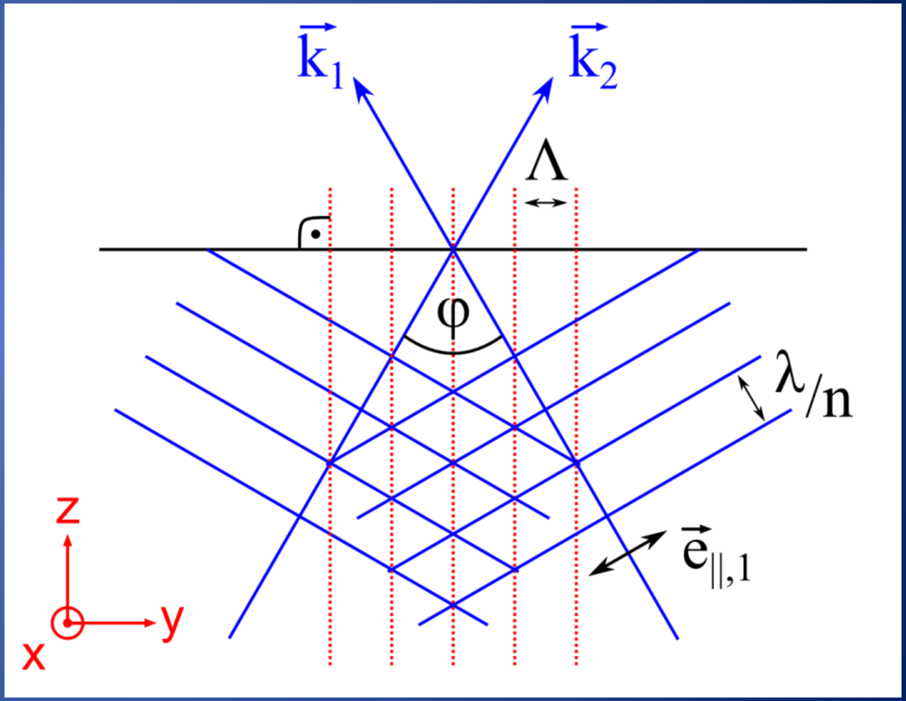
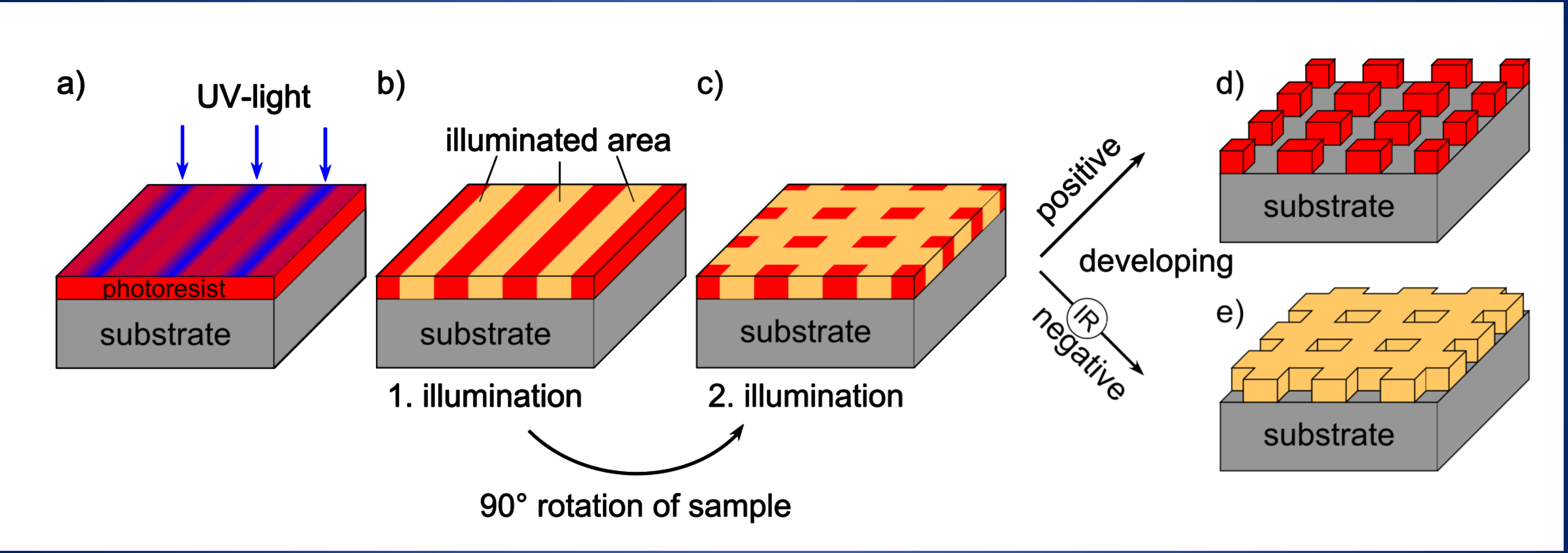


Interference of plane waves

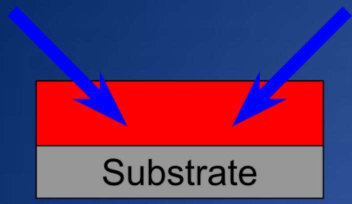
- interference of two plane waves
- interference pattern: straight lines
- periodicity: $\Lambda = \dfrac{\lambda}{2n\,\sin\left(\frac{\varphi}{2}\right)}$
- lithography: wavelength λ fixed, angle φ variable
- peridicity limits: $\Lambda \approx 250\text{nm}$



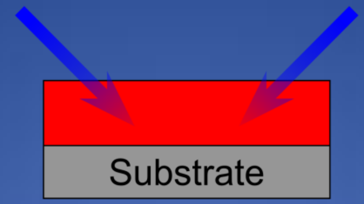
Fabrication of pillar structures



Simulation of Interference Pattern



+

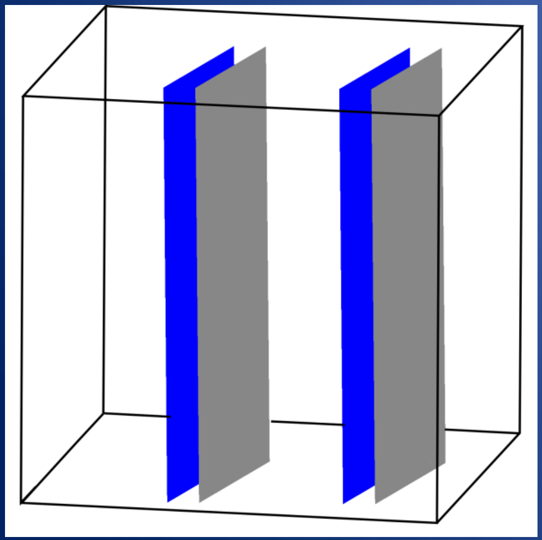


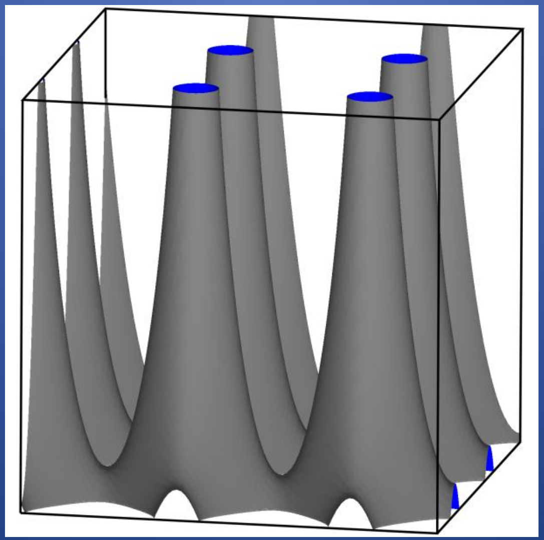
+

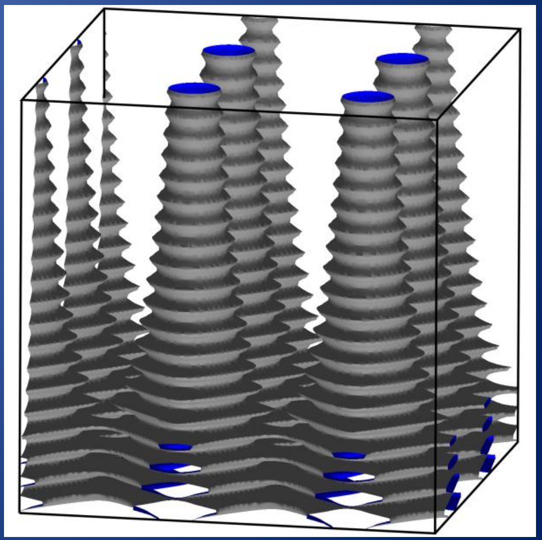
$$I = \left|\vec{E}_1(\vec{r},0°) + \vec{E}_2(\vec{r},0°)\right|^2 + \left|\vec{E}_1(\vec{r},90°) + \vec{E}_2(\vec{r},90°)\right|^2$$

$$I(z) = I_0 e^{-\alpha \cdot z}$$

$$I_{total} = I_{in} + I_{refl}$$

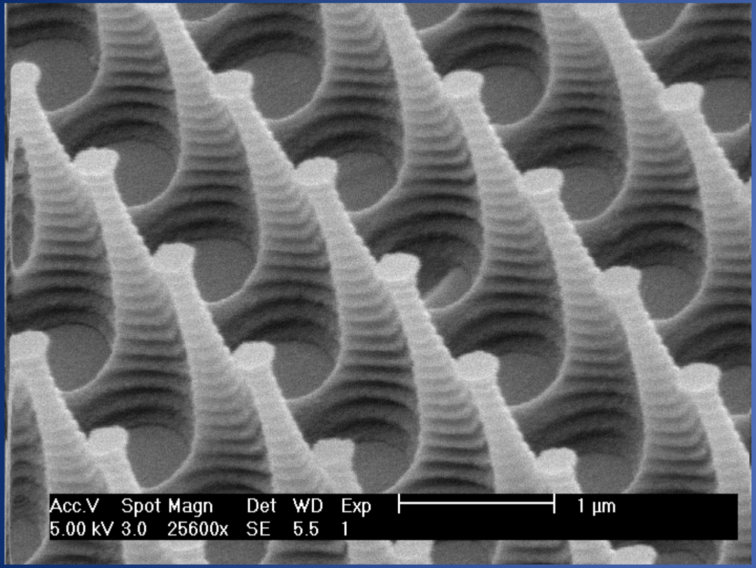






Photoresist pillars on glass

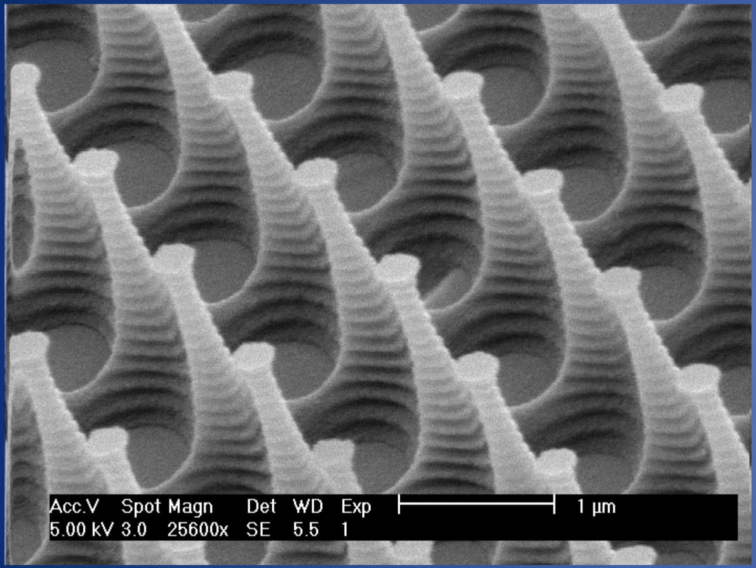
- properties:



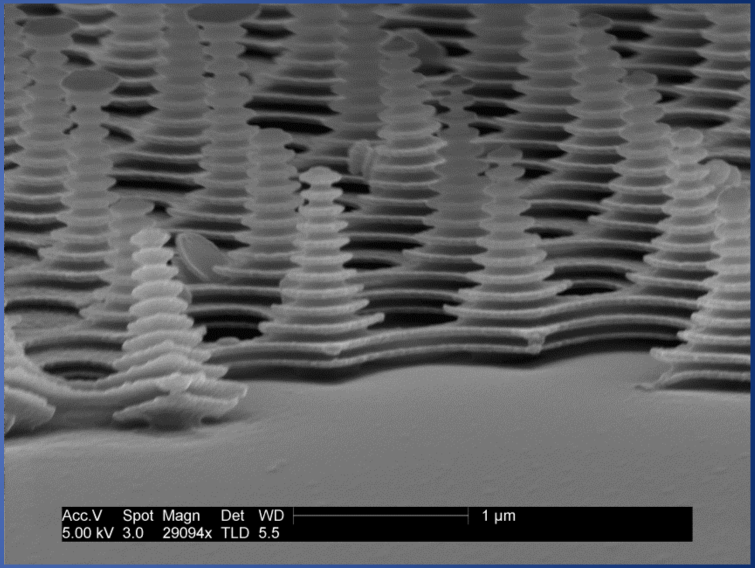
low reflectivity
➡ weak corrugation amplitude

Photoresist pillars on…

glass



silicon



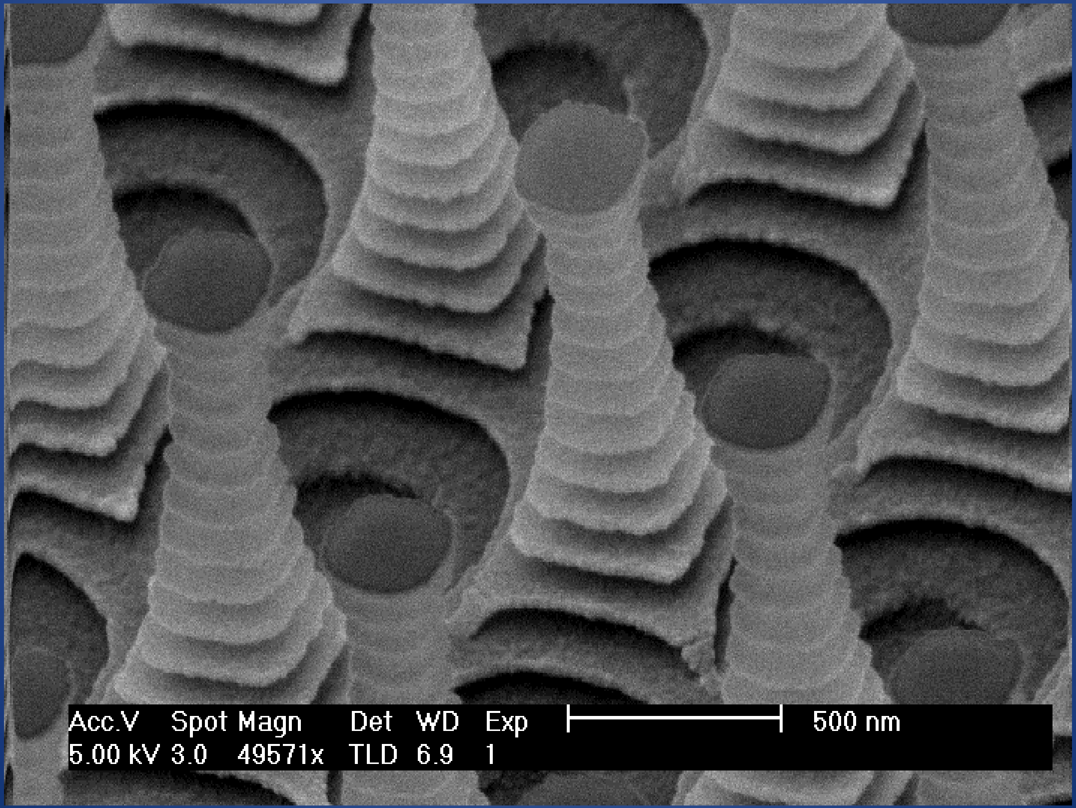
periodicity of corrugation:
~120nm

low reflectivity
➡ weak corrugation amplitude

high reflectivity
➡ strong corrugation amplitude

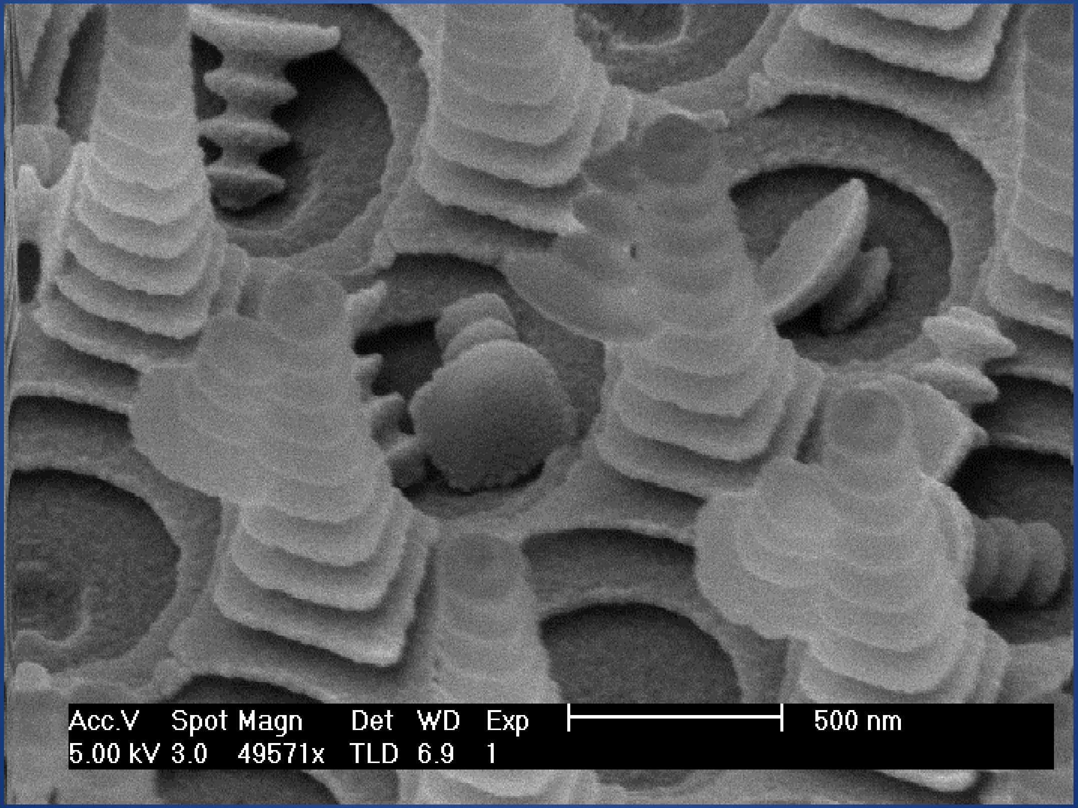
Photoresist pillars on silicon

- strong corrugation leads to stability problems



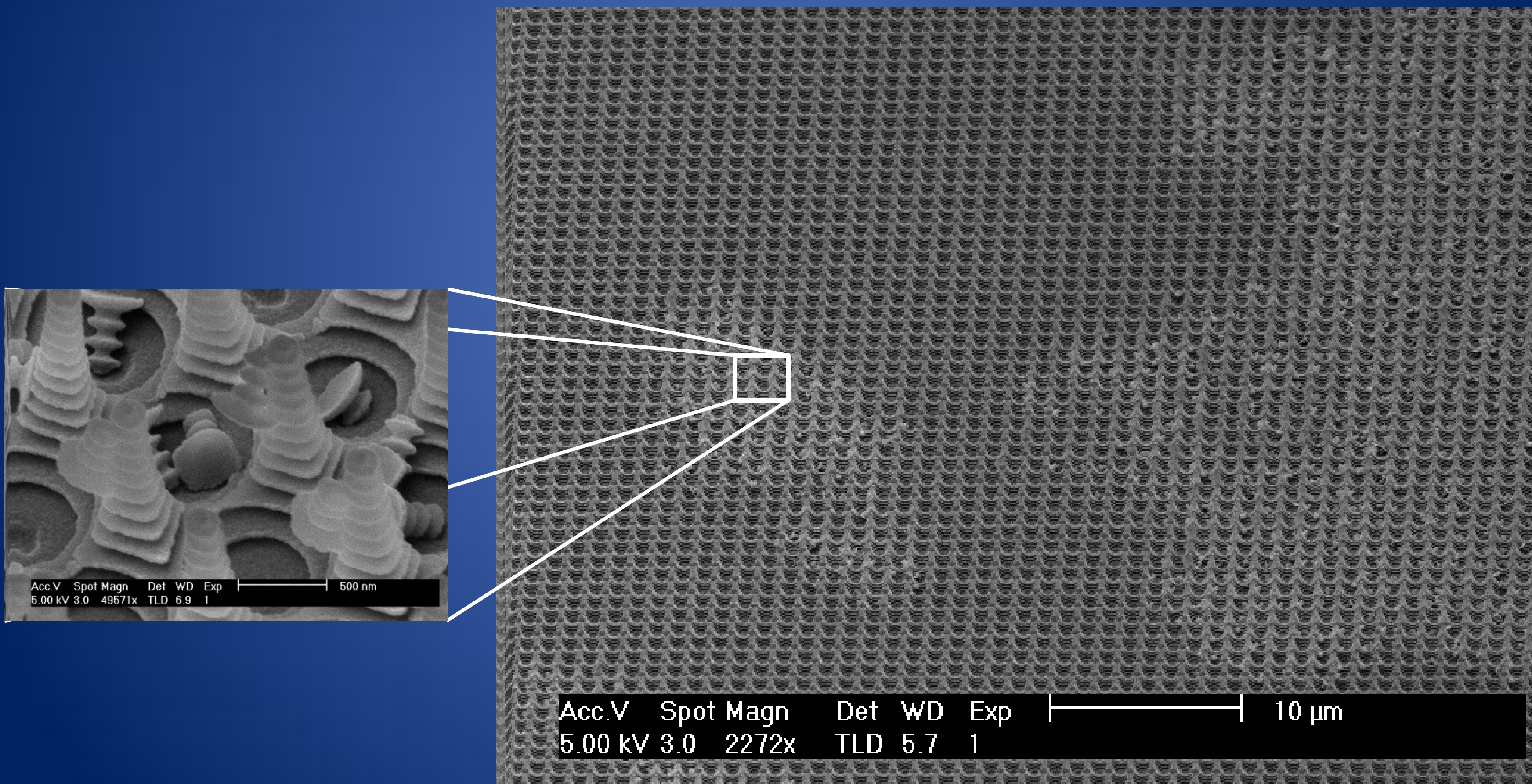
Photoresist pillars on silicon

- strong corrugation leads to stability problems



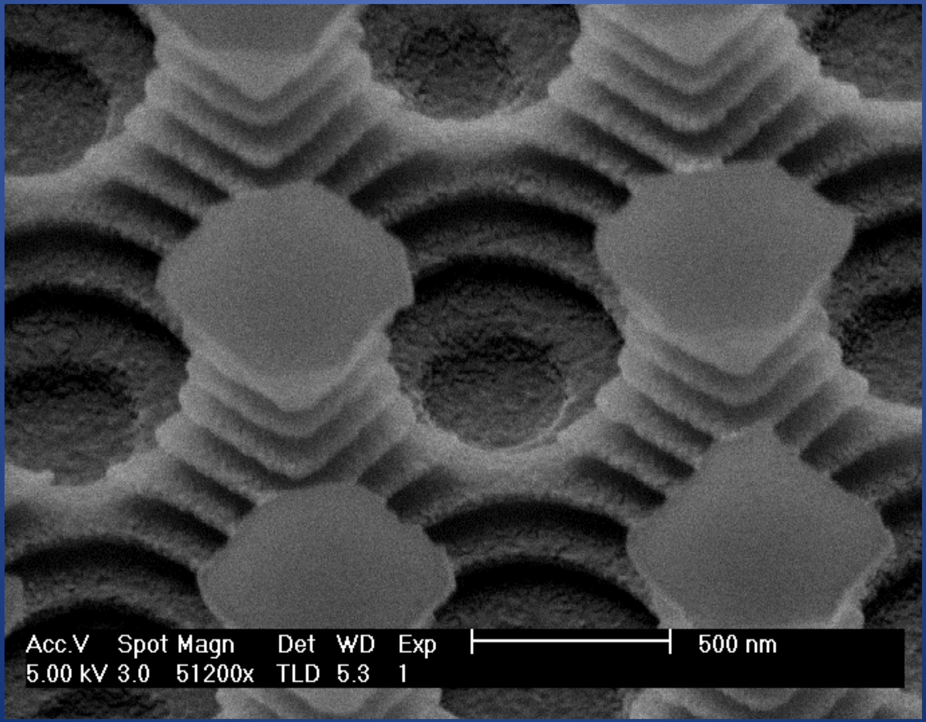
Photoresist pillars on silicon

- strong corrugation leads to stability problems



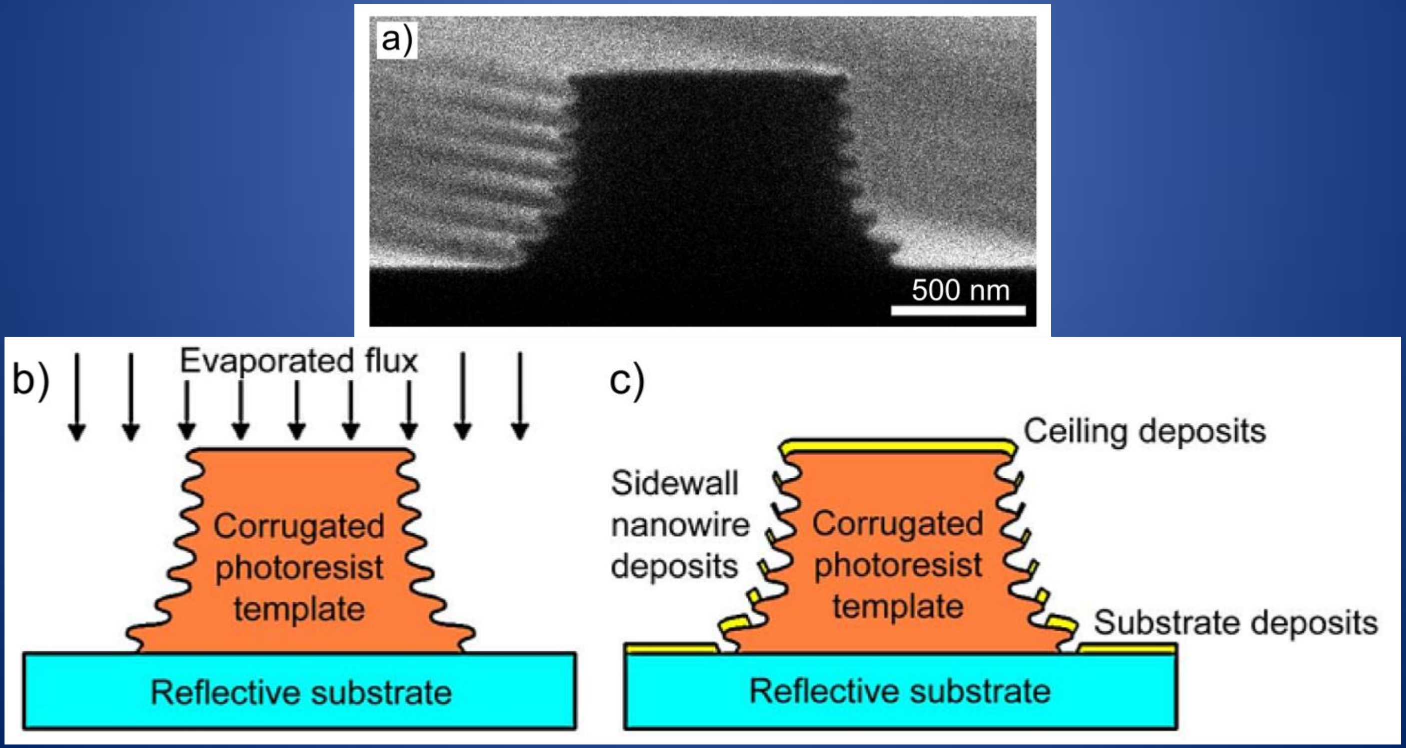
Photoresist pillars on silicon

- strong corrugation leads to stability problems
- possible solution: supercritical drying
- for the moment: shorter pillars ($1\mu m$)



Evaporation of gold

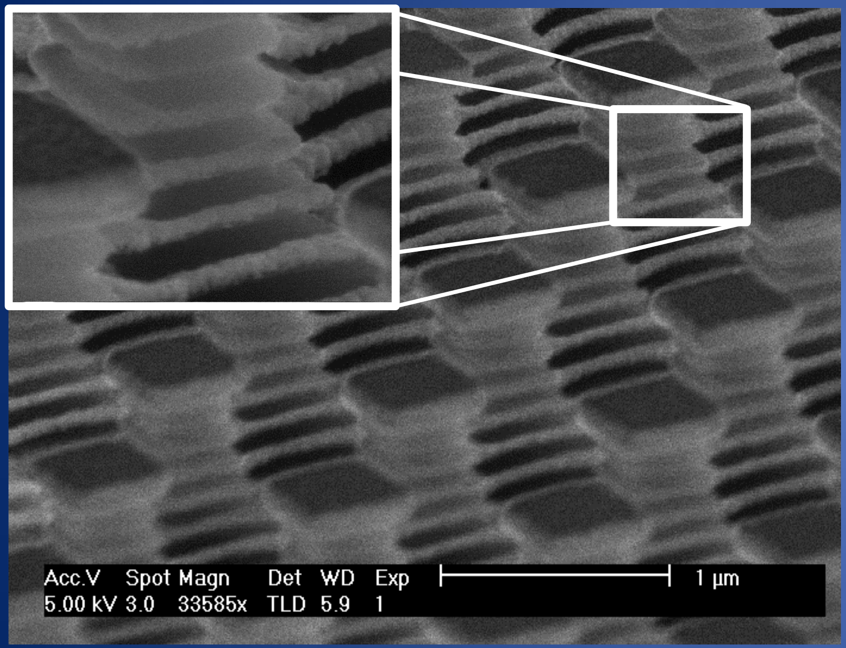
- thermal evaporation: directed evaporation flux
- shadowing effect: gold deposits only at edges of each level
- presented by: Kostovski et al. (2008)



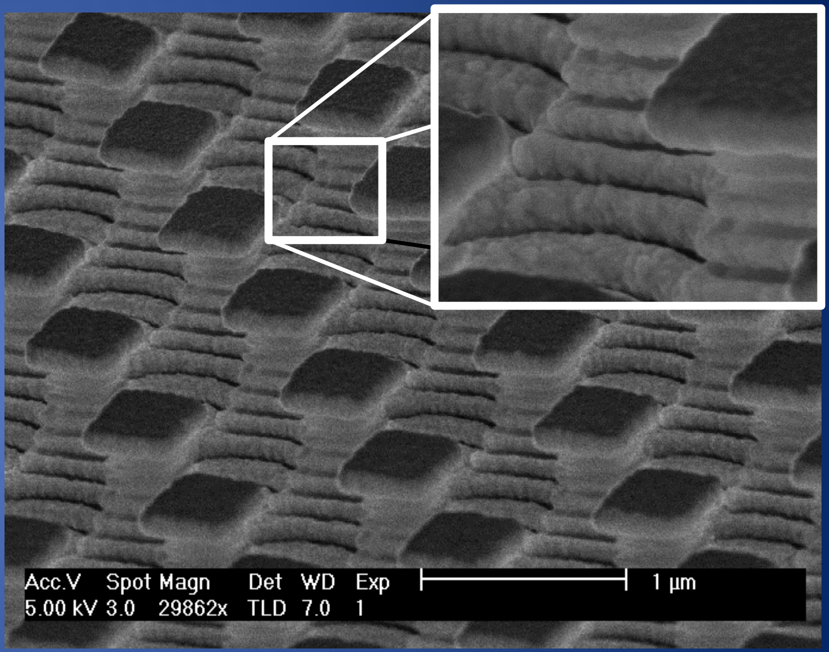
Kostovski et al. (2008) (DOI: 10.1063/1.2939563)

Formation of gold rings: silicon substrate

50nm Au



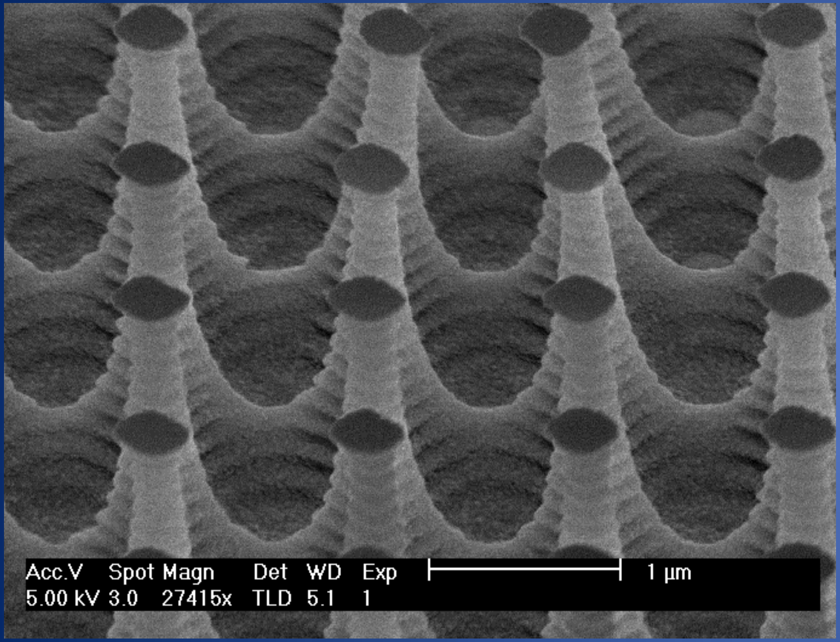
80nm Au



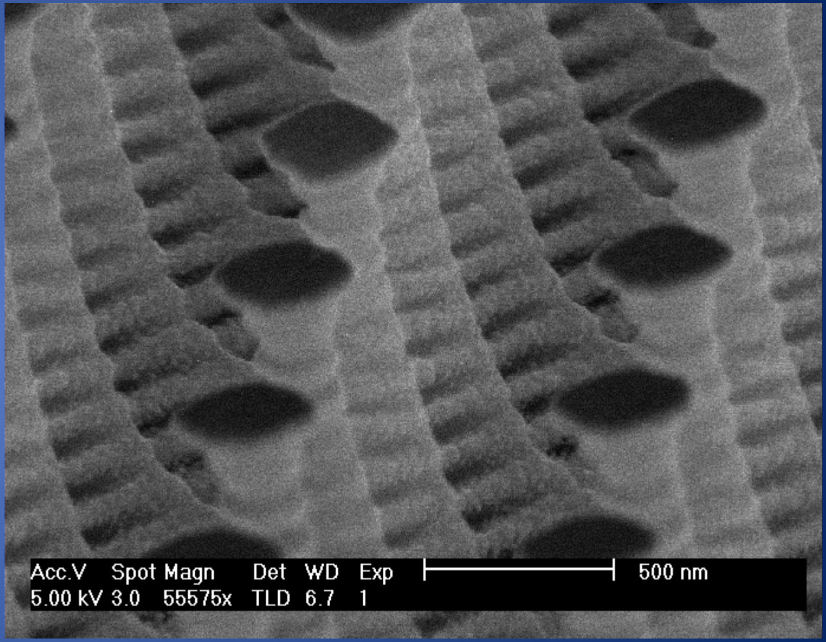
- ring diameter at pillar top: ~ 500nm
- thin gold layer: large gap
- 80nm Au: gold rings almost in touching contact: gap size <10nm

Formation of gold rings: glass substrate

20nm Au



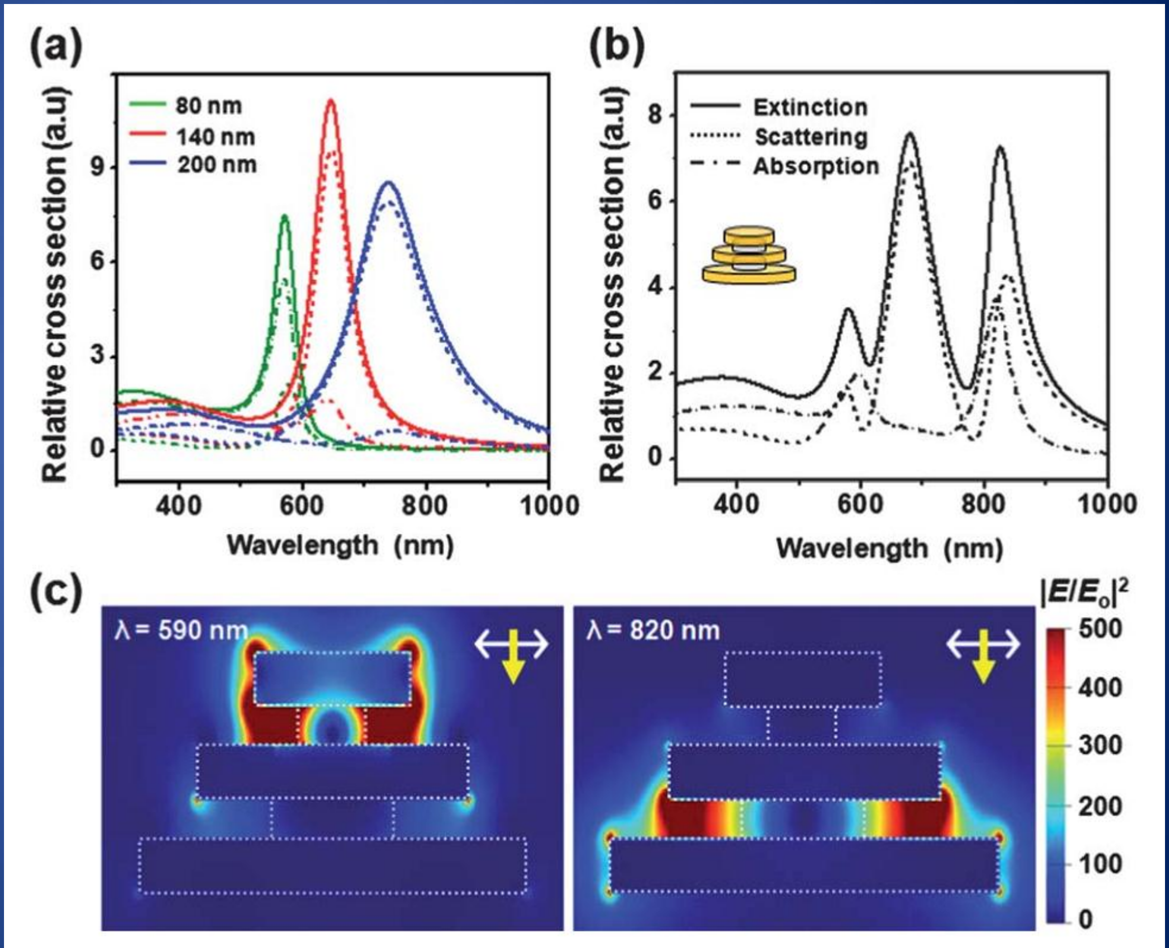
50nm Au



- rings do not seem to be separated from each other

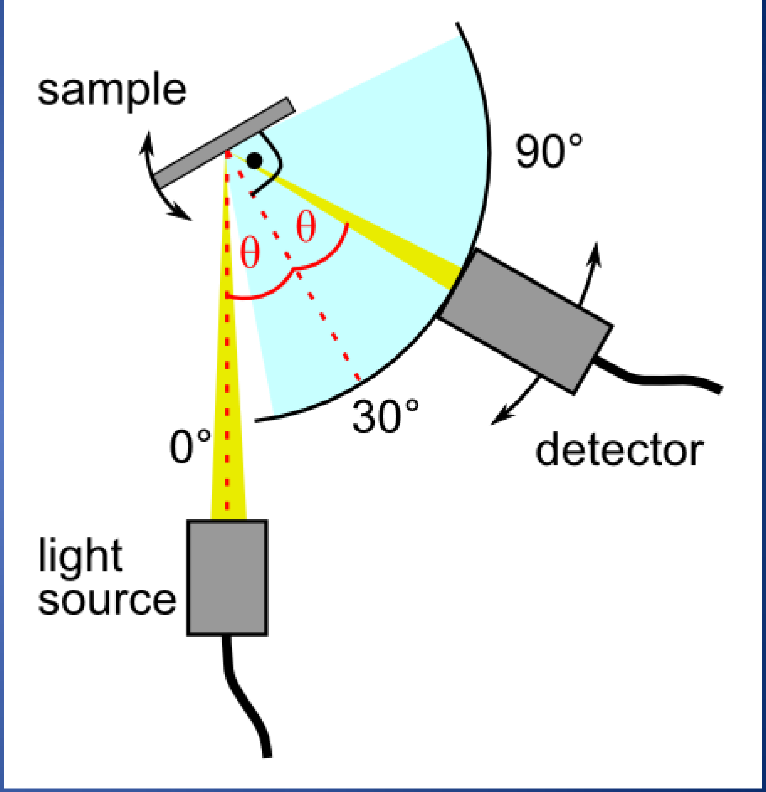
Plasmonics: Expectations

- stacked Au nano-disk structure (Wi et al. 2012)
- disk thickness: 20nm
- disc diameters: 80nm, 140nm, 200nm
- FDTD simulation



Wi et al. 2012 (DOI: 10.1039/C2NR30179B)

Goniometer measurements

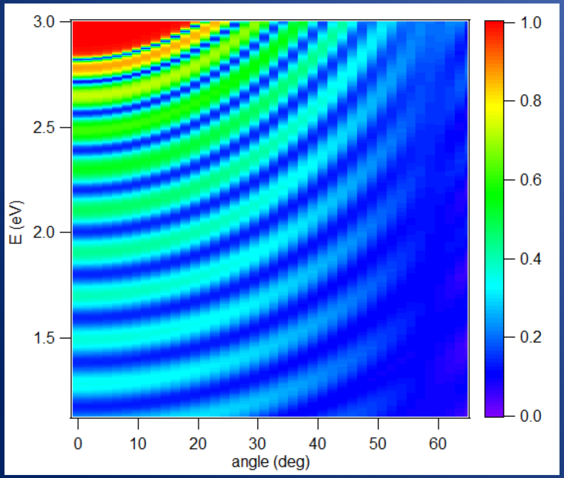


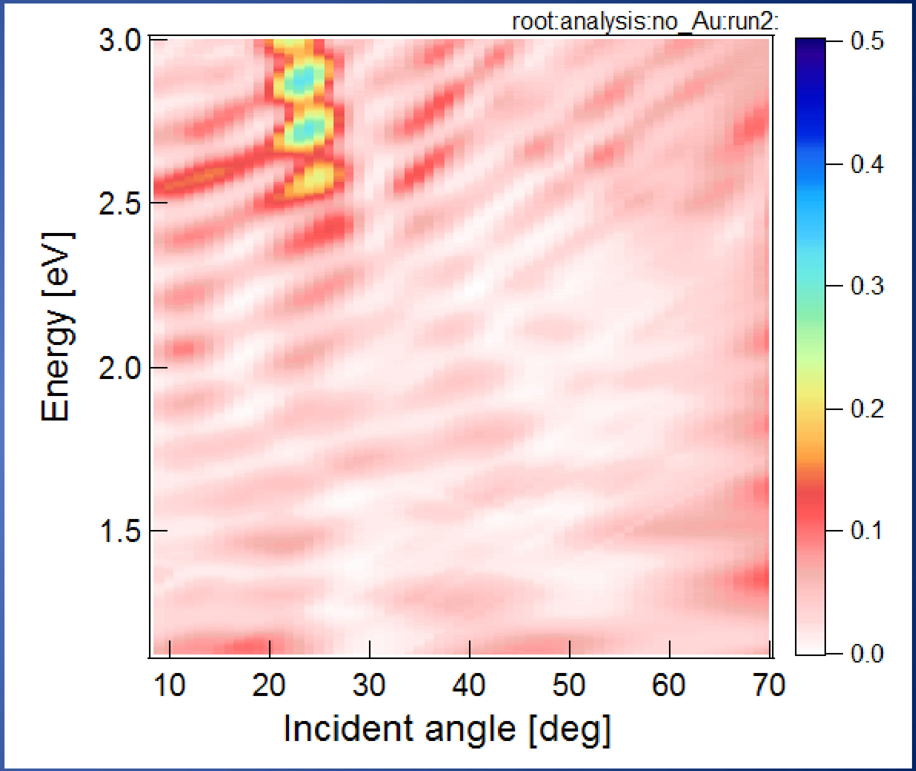
Goniometer measurements

- photoresist pillars on silicon
- **no** gold coating

- multilayer interference modes

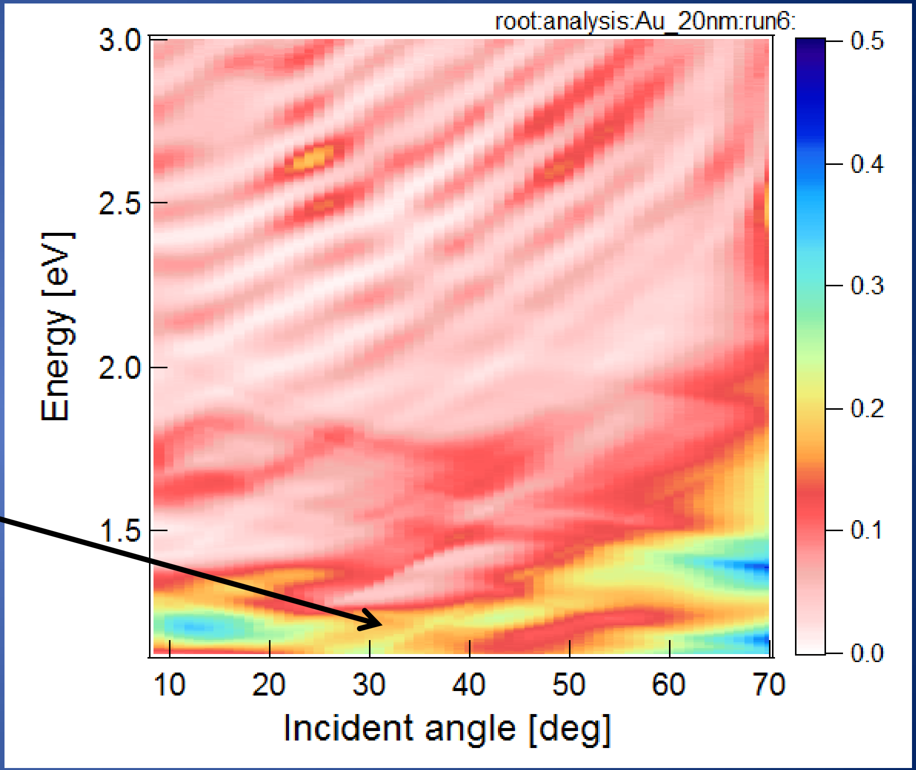
- calculation for a DBR with $n_{resist} = 1.655, n_{air} = 1$





Goniometer measurements

- photoresist pillars on silicon
- **<u>20nm</u>** gold coating
- multilayer interference modes
- weak modes appearing

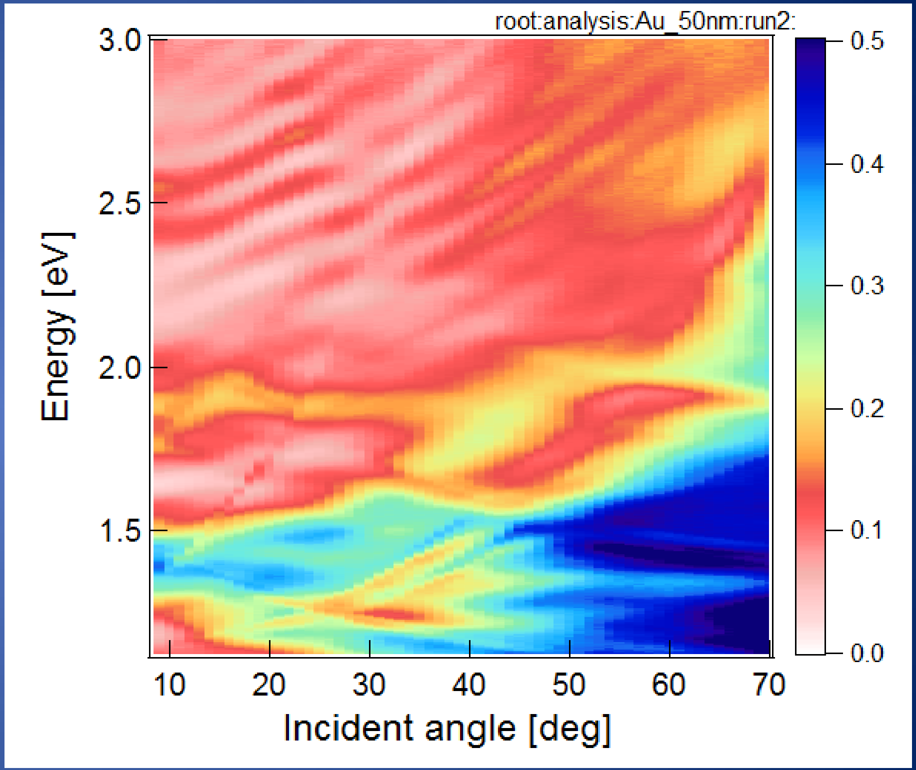


Goniometer measurements

- photoresist pillars on silicon
- **<u>50nm</u>** gold coating

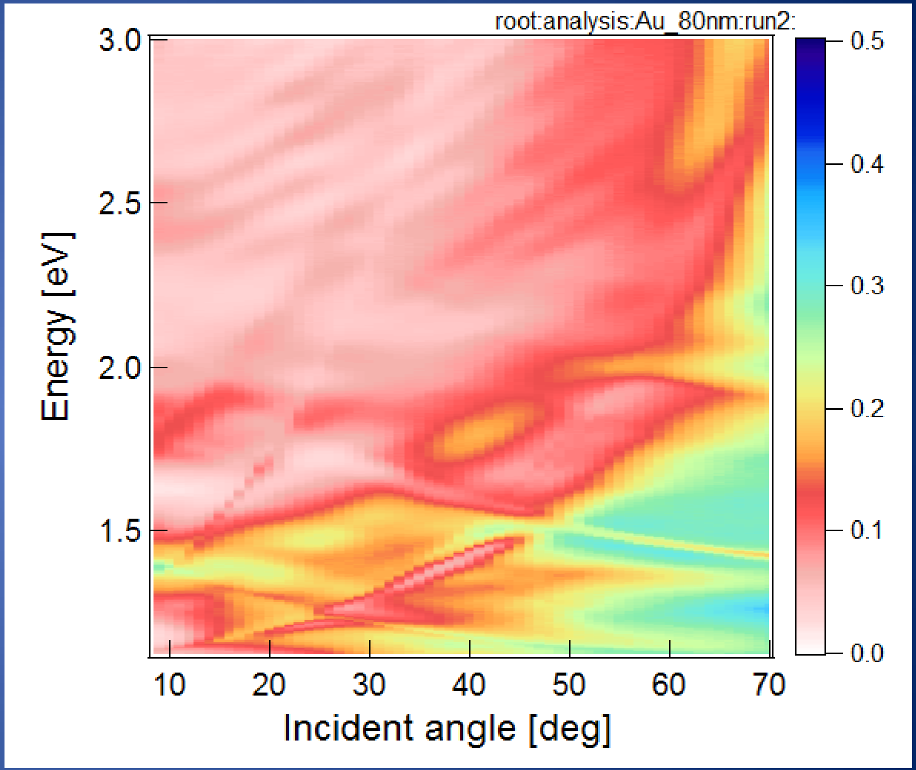
- multilayer interference modes

- modes become stronger pronounced



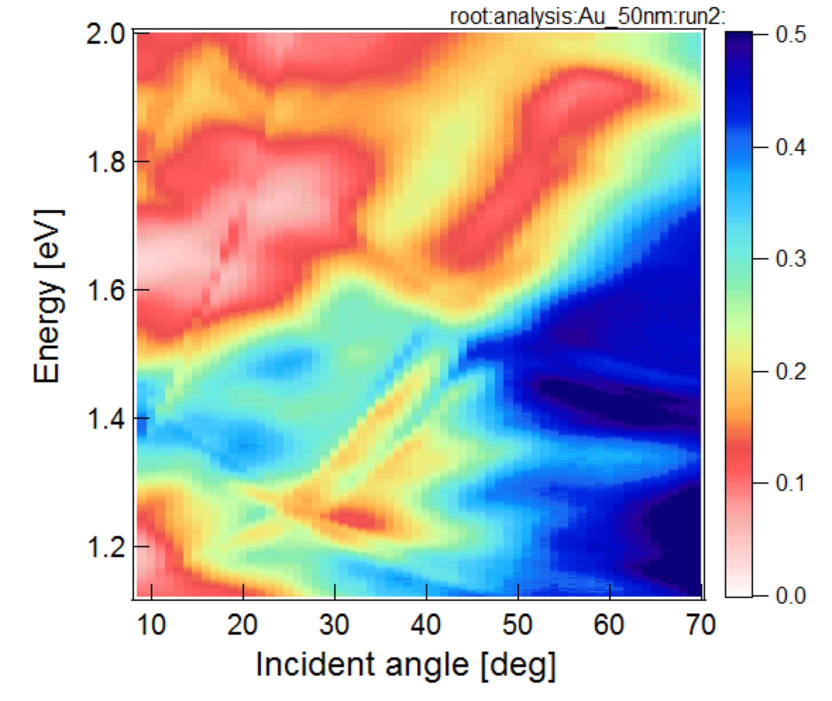
Goniometer measurements

- photoresist pillars on silicon
- **<u>80nm</u>** gold coating
- multilayer interference effect vanishes
- strongly pronounced modes visible in IR regime
- overall low reflectivity

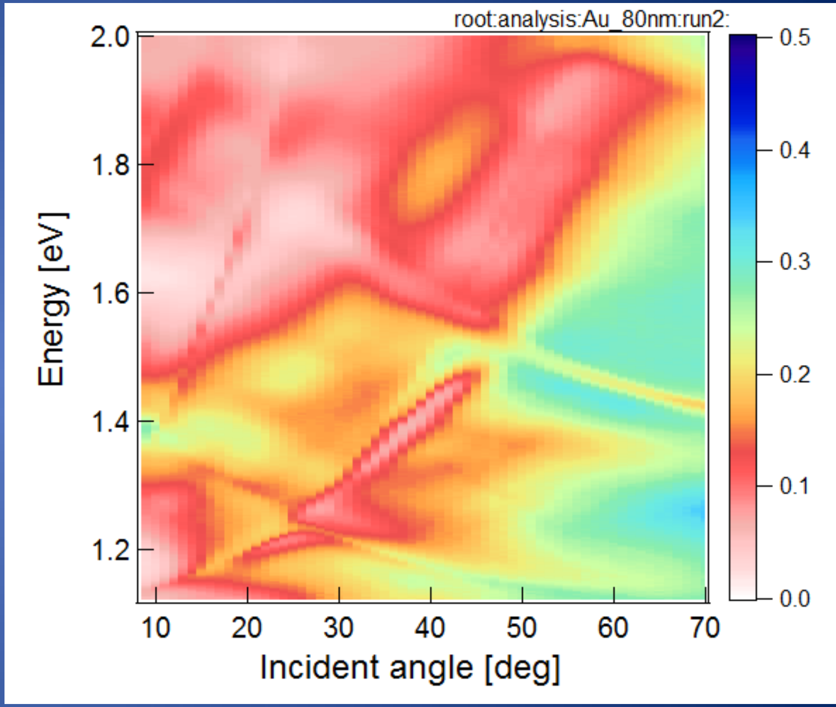


Goniometer measurements

50nm Au

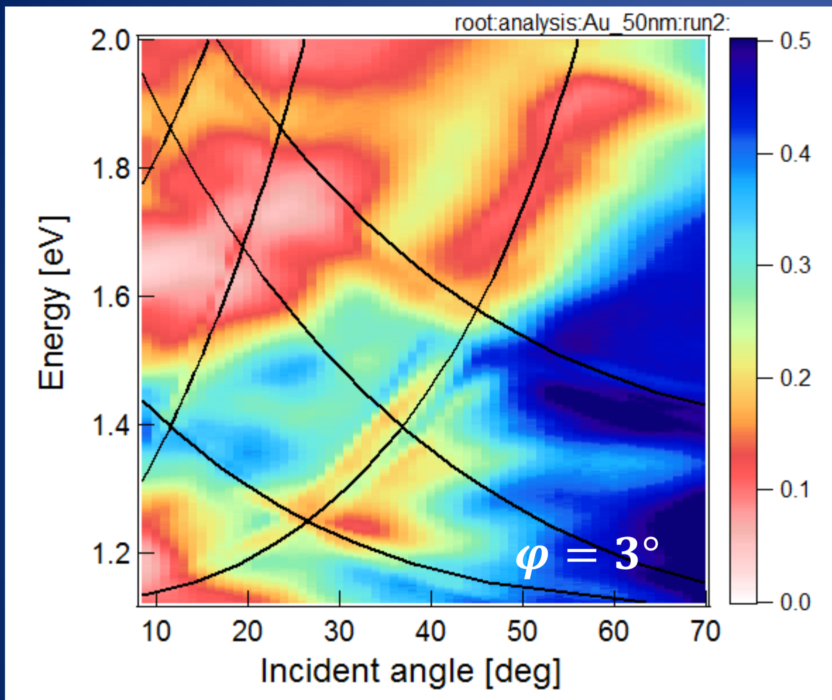


80nm Au

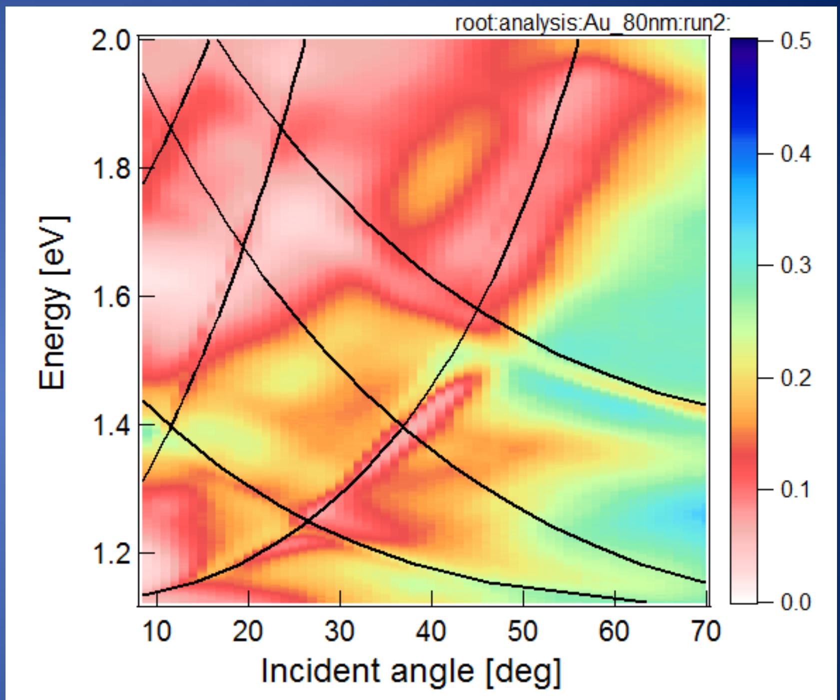


Goniometer measurements

50nm Au



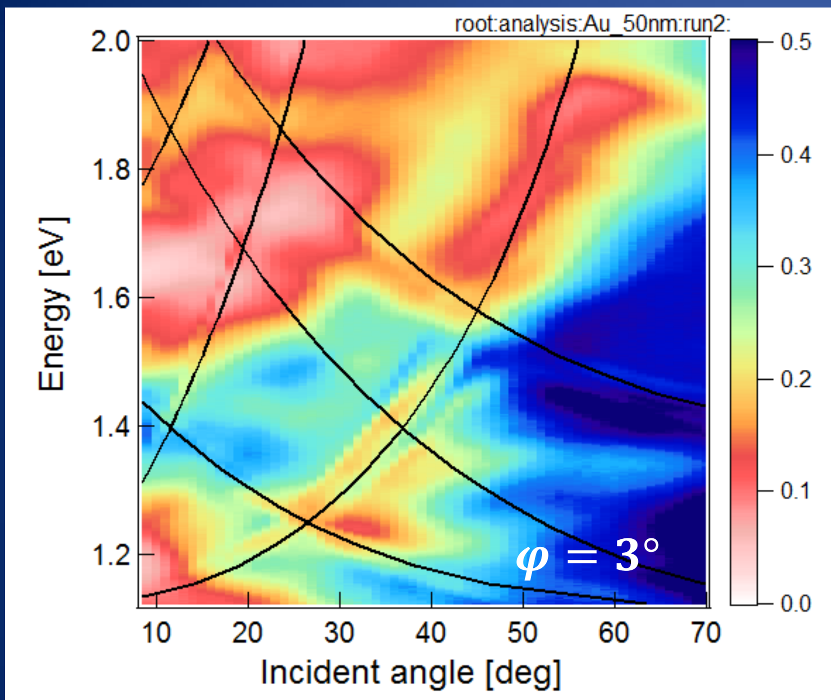
80nm Au



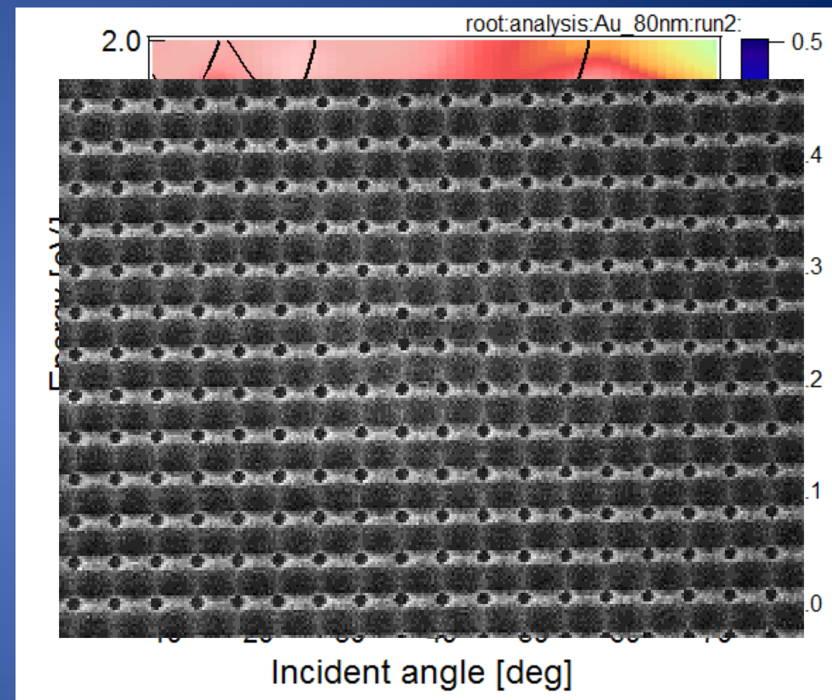
- modes correspond to photonic band structure of a 2D grating

Goniometer measurements

50nm Au



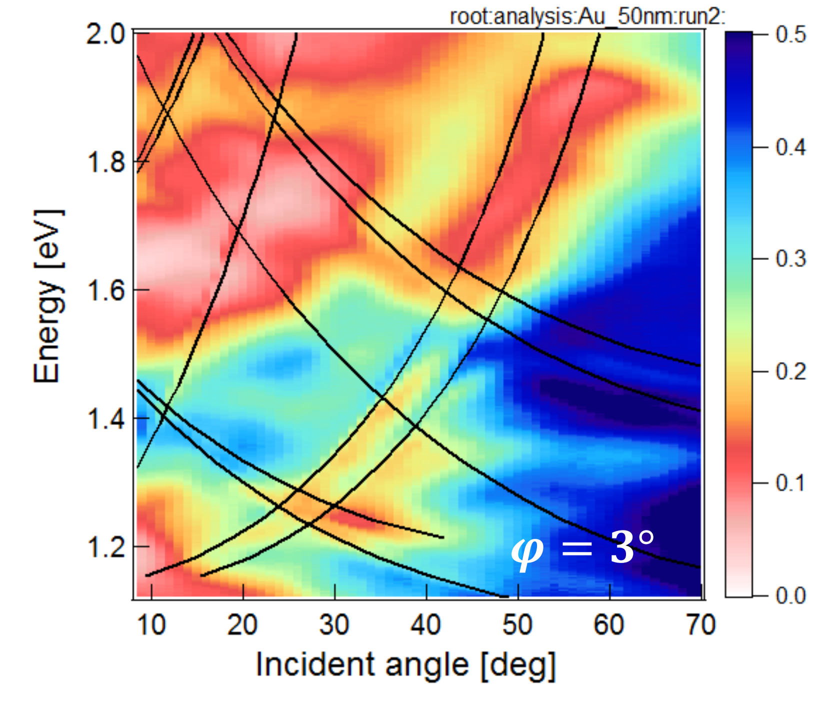
80nm Au



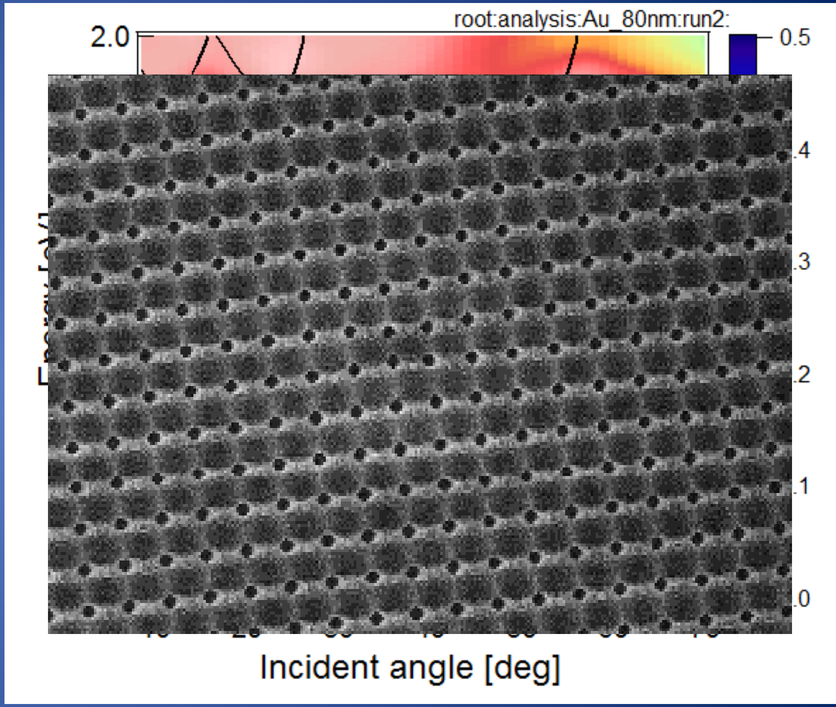
- modes correspond to photonic band structure of a 2D grating

Goniometer measurements

50nm Au



80nm Au



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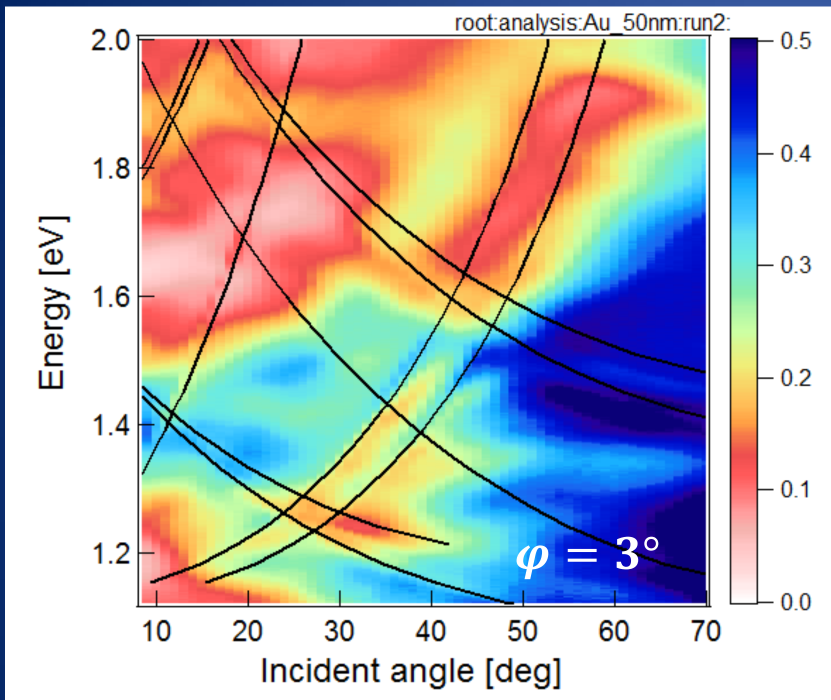
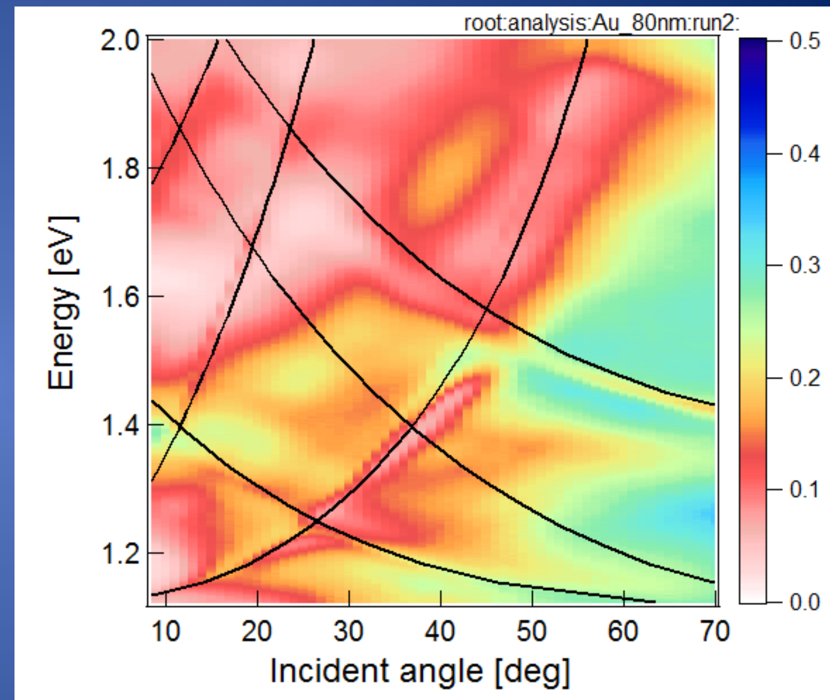
Goniometer measurements

50nm Au



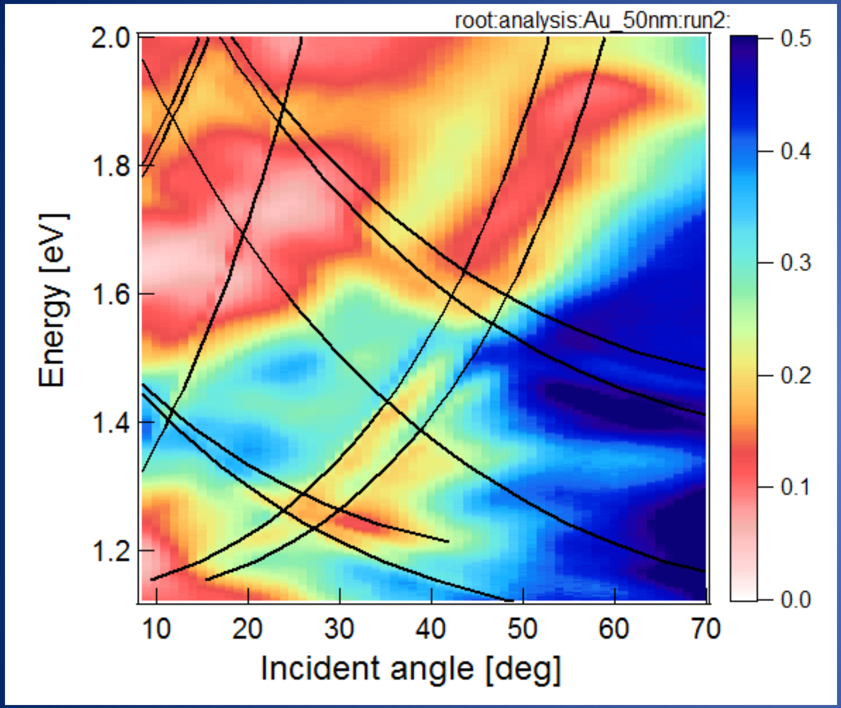
80nm Au



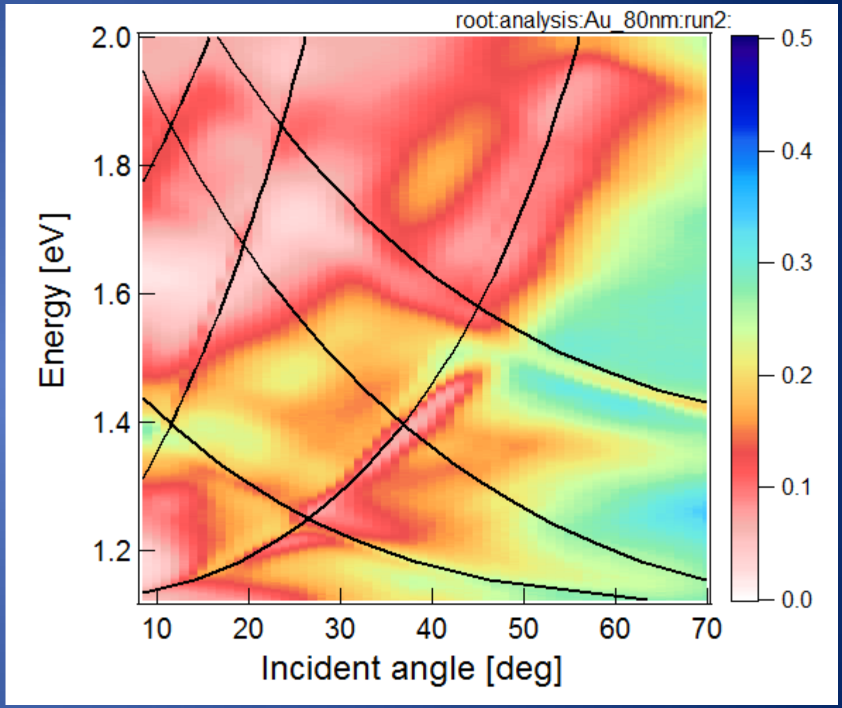
- modes correspond to photonic band structure of a 2D grating

Goniometer measurements

50nm Au



80nm Au

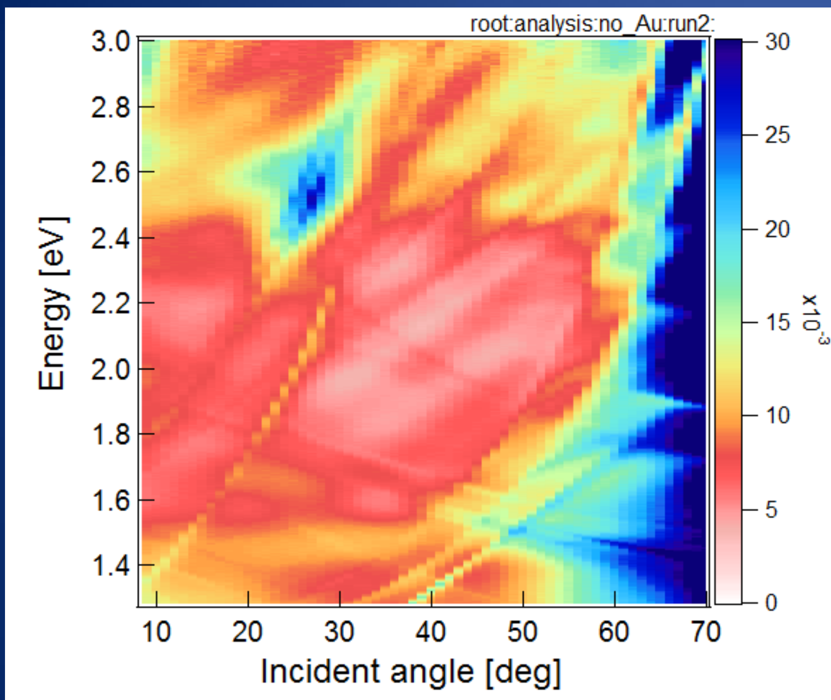


- modes correspond to photonic band structure of a 2D grating
- plasmonic effects?

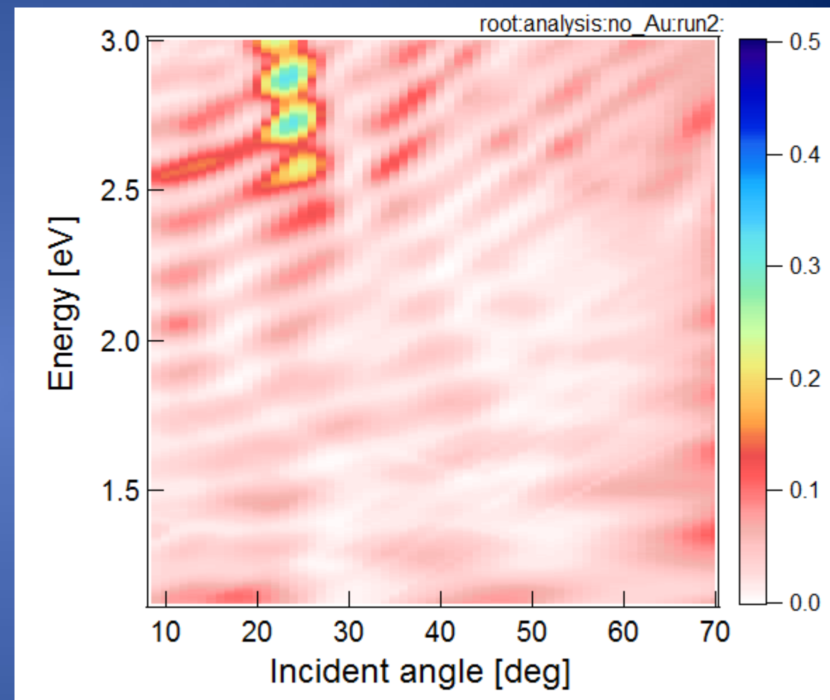
  ➡ hard to identify

Comparison: pillars on glass – silicon: no gold

glass



silicon

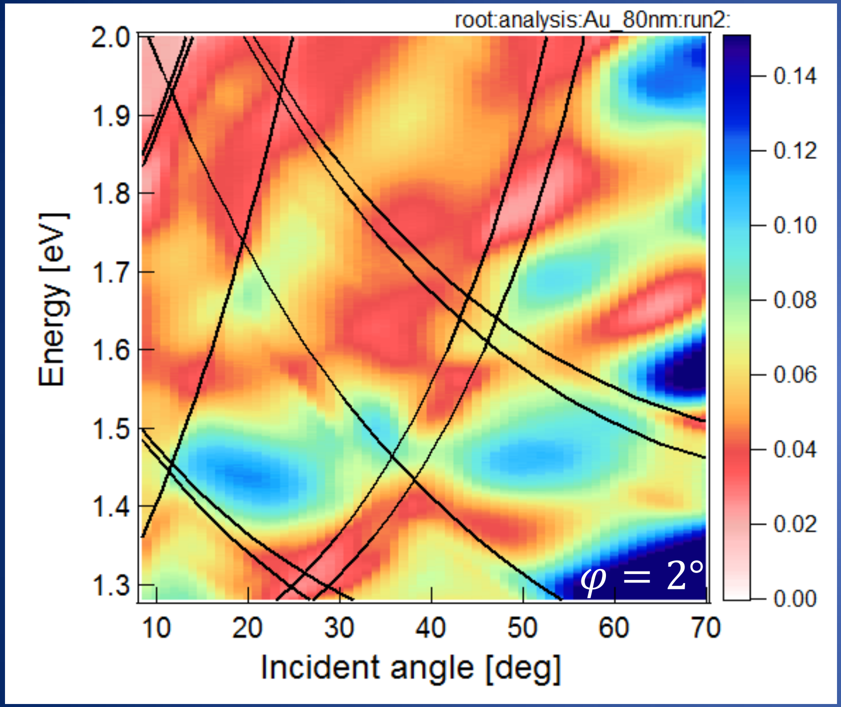


- no multilayer interference
- photonic crystal modes visible

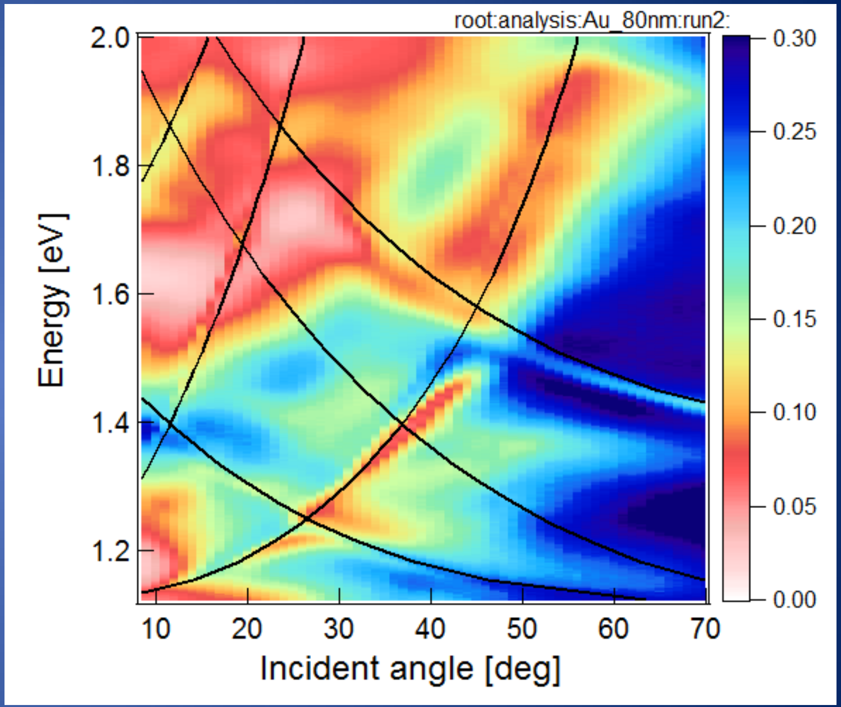
- multilayer interference
- no photonic crystal modes

Comparison: pillars on glass – silicon: 80nm gold

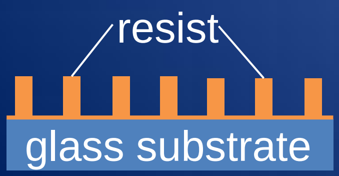
glass

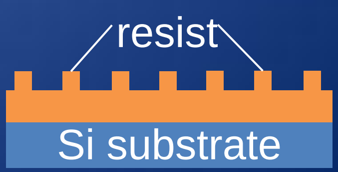


silicon



- normalised to 80nm Au film on glass
- normalised to 80nm Au film on silicon





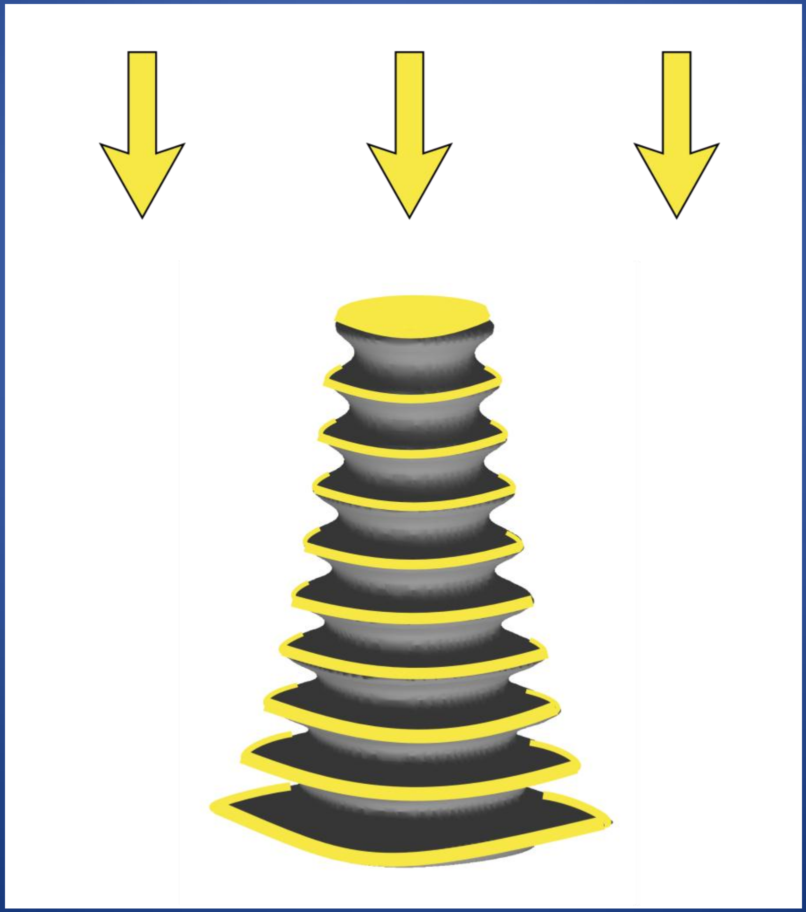
Conclusion

- ring formation works
- plasmonic effects not obvious

- possible problems:
  - structure is too large
    - smaller pillars (diameter) can be fabricated ➡ smaller ring diameter
  - pillars on silicon short, process not optimised, yet

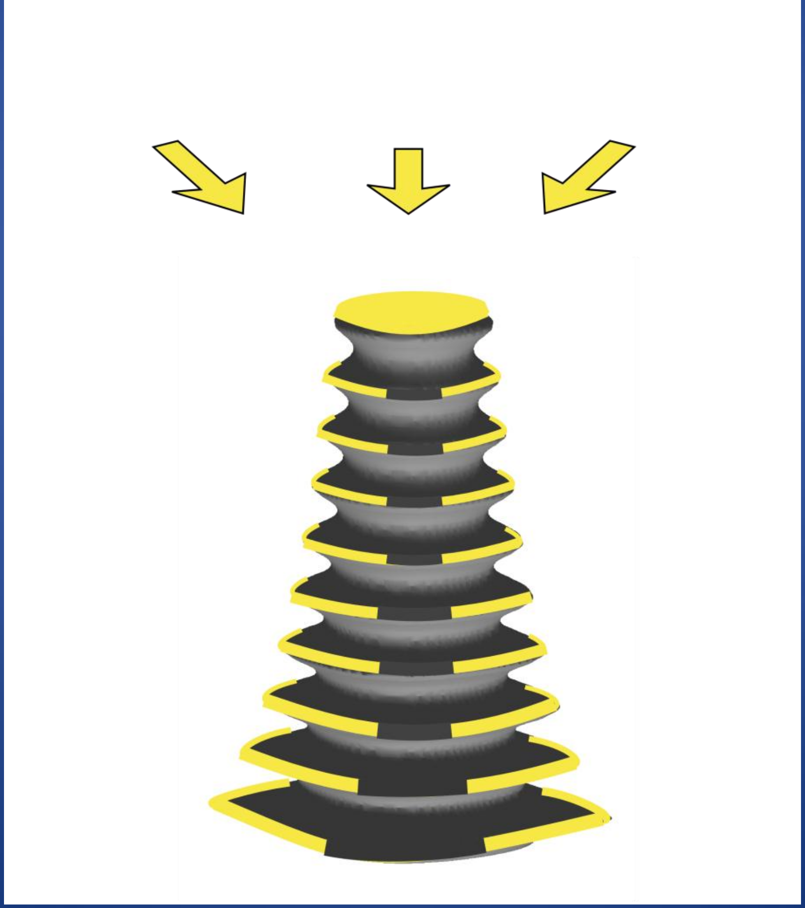
Future work

- fabrication of stacked gold rings: evaporation along surface normal



Future work

- fabrication of stacked split rings: angled evaporation



Thank your for your attention!

Questions?