Advanced Research Center for Nanolithography

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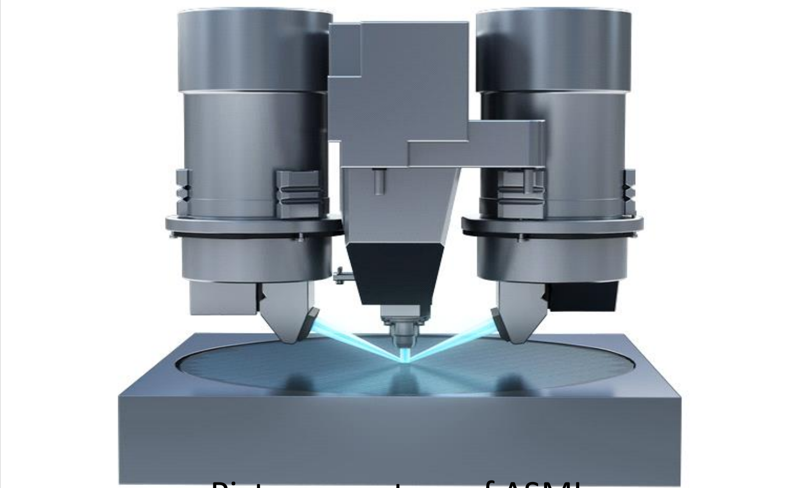
Example

Photo-acoustics for the detection of buried gratings (?)

Paul Planken

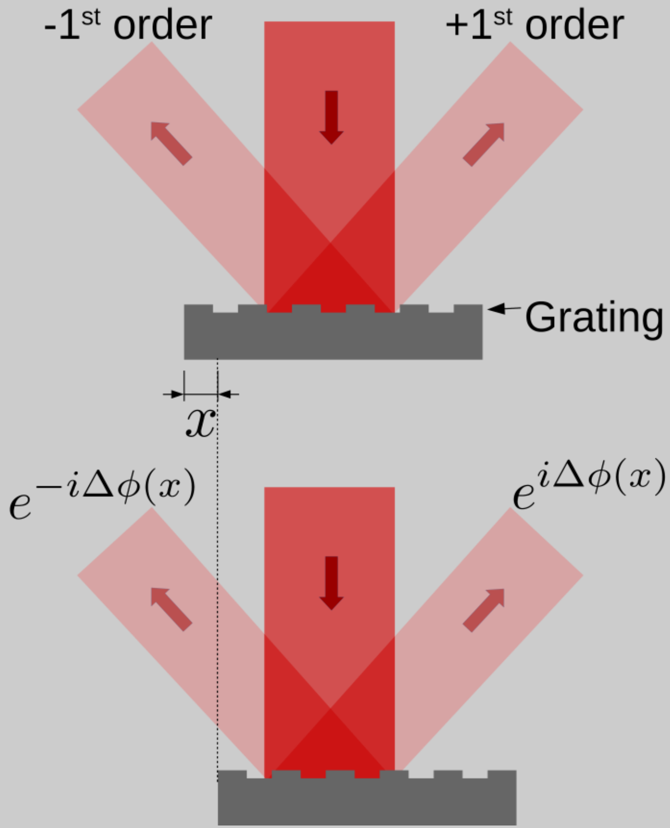
Detection of buried gratings

positioning of Si wafers
with (sub-)nm accuracy:



Picture courtesy of ASML

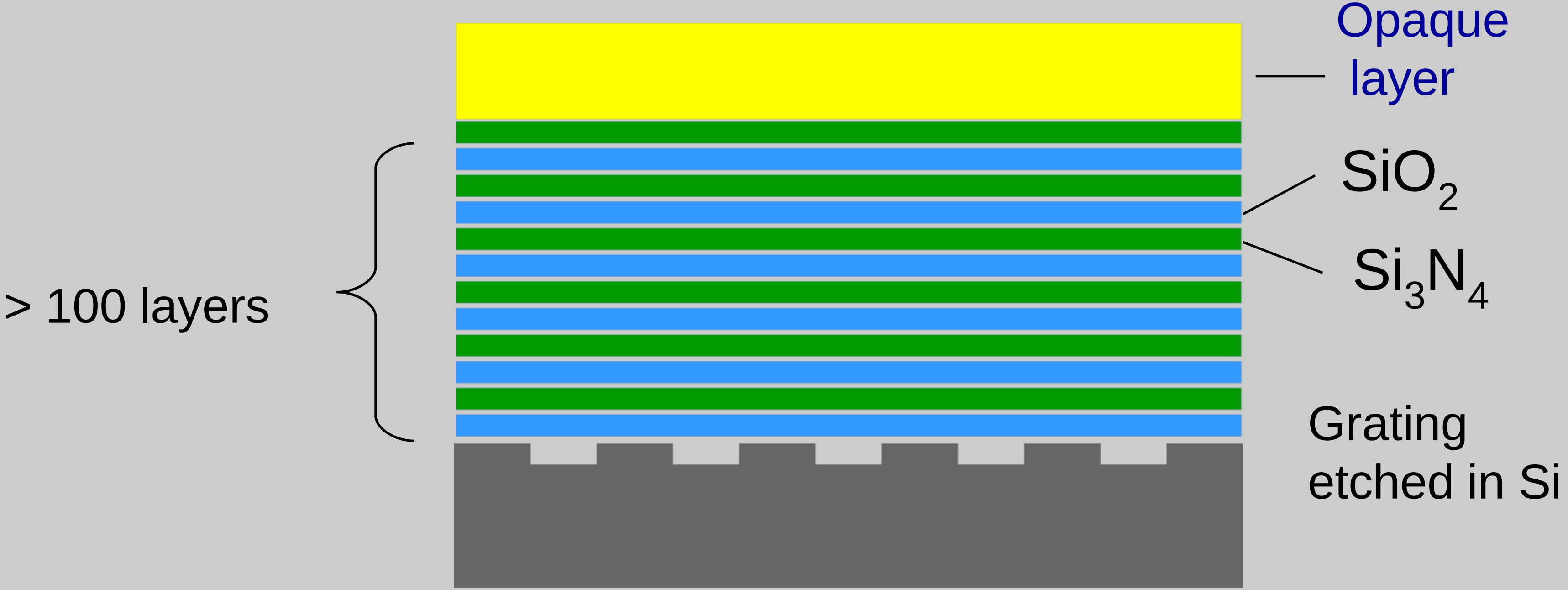
<u>Diffraction</u> from gratings on Si-wafers is used to determine position of Si wafers accurately (< 1 nm)



Grating displacement changes optical phase of diffracted beams

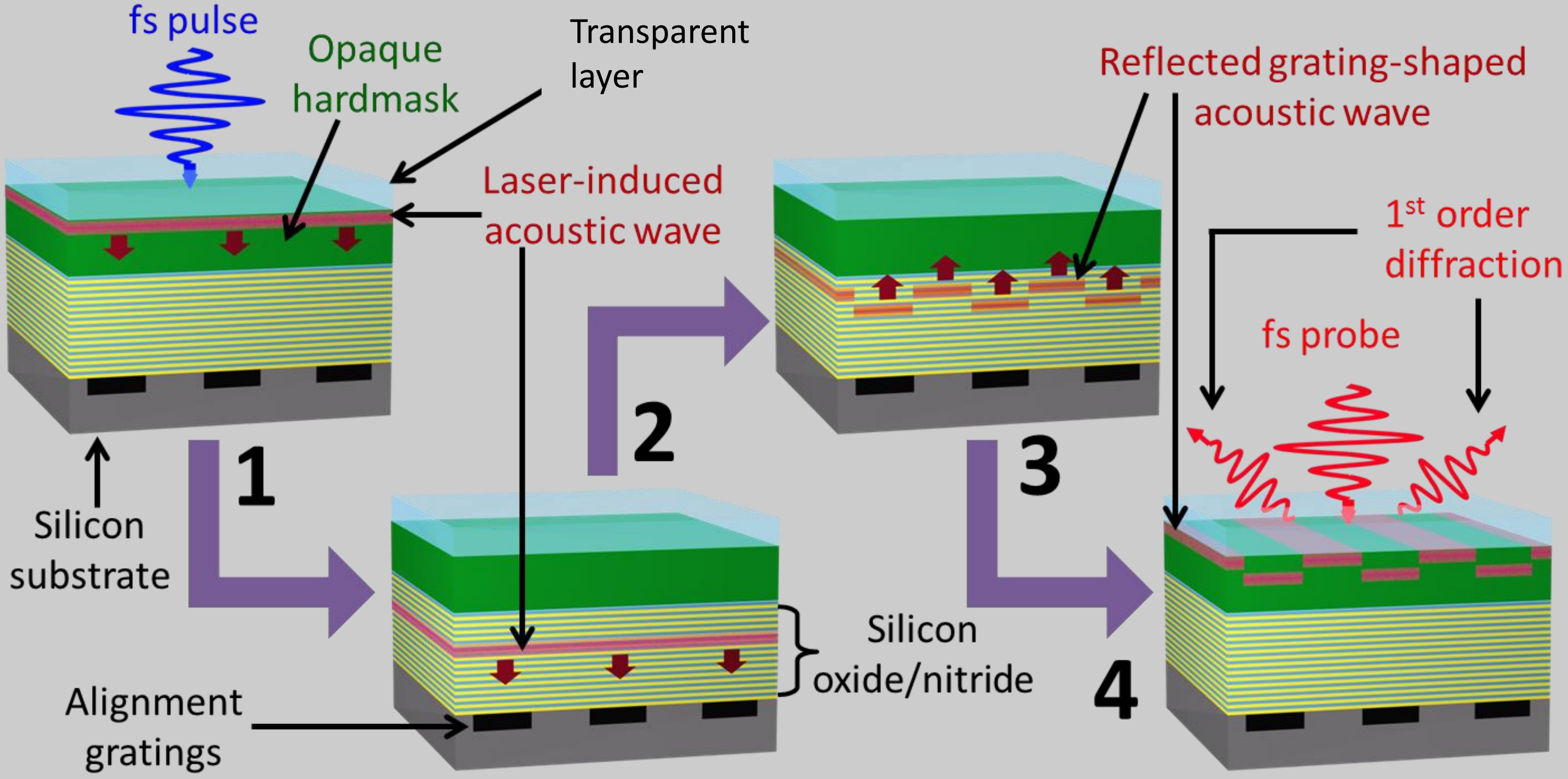
Challenge: grating covered by many layers, some opaque

Cartoon version of 3D NAND:



Difficult to "see" through opaque layers
Signal strength can be too low……

Possible solution? Photo-acoustics.....

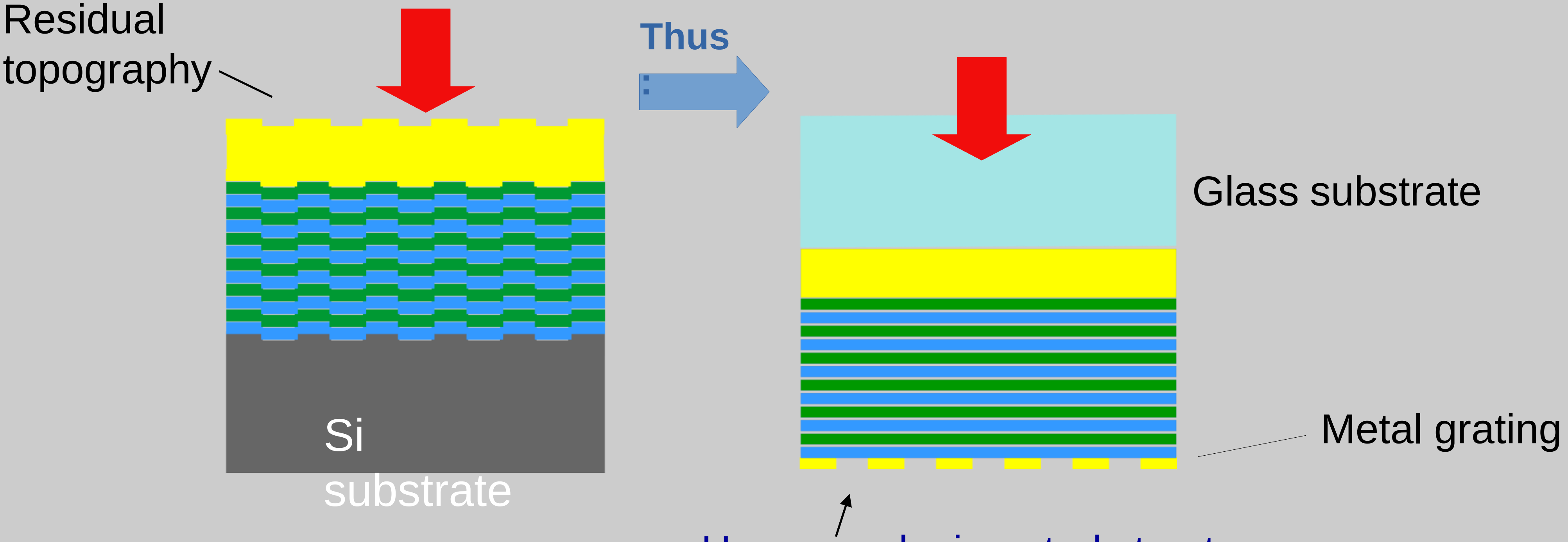


From light to sound, to light again

For a clean experiment: need samples without "residual topography"

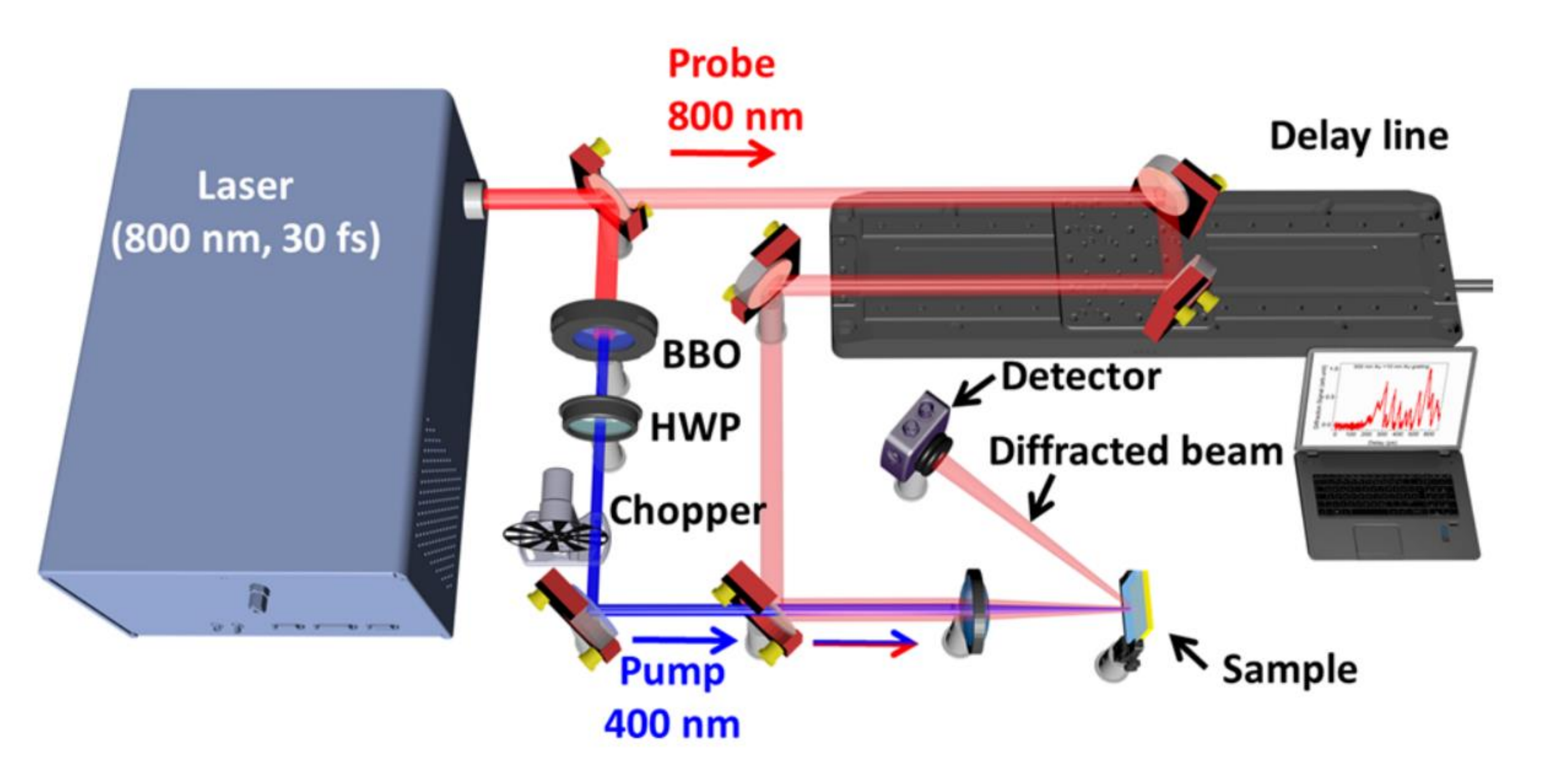
Real-world samples

Home-made samples



- Home-made, <u>inverted</u> structures
- Illumination from the glass side

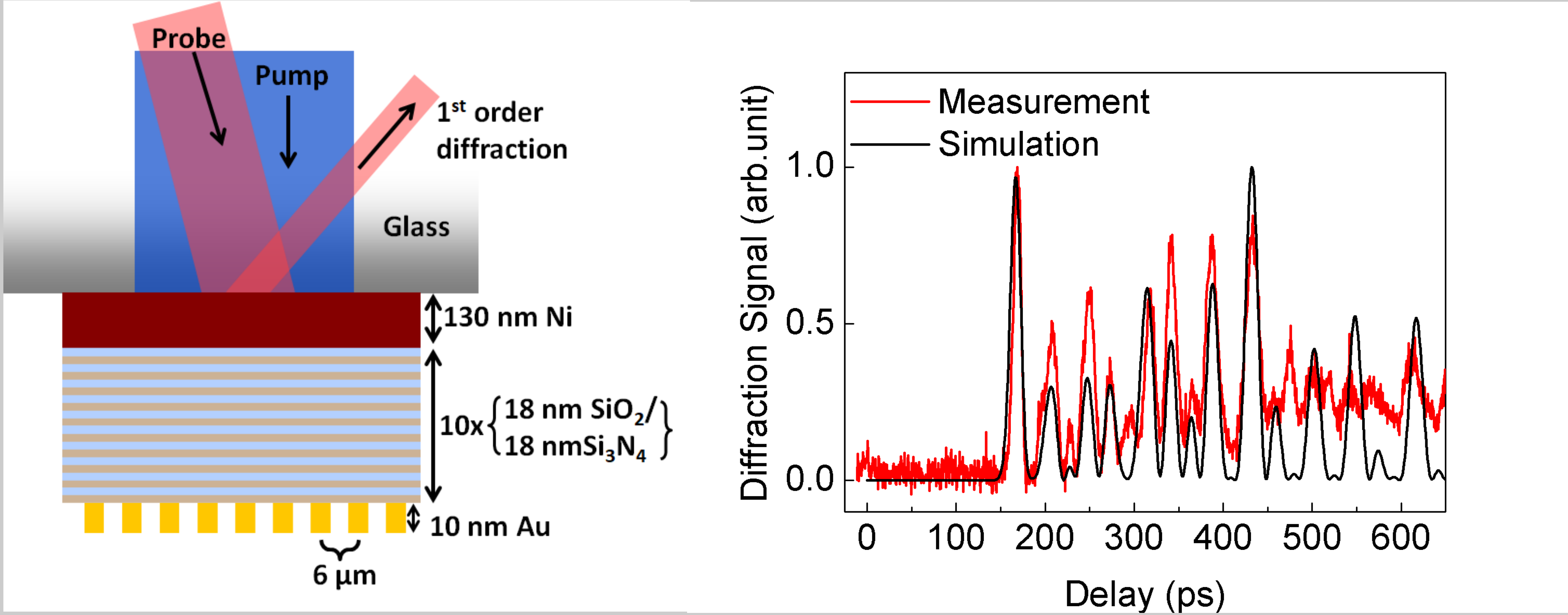
Setup



Probe
800 nm
Laser
(800 nm, 30 fs)
Delay line
BBO
HWP
Chopper
Detector
Diffracted beam
Sample
Pump
400 nm

Home-made multi-layer sample

> 20 layers



Grating still observed through multiple dielectric layers

- Phys. Rev. Appl. 14, 014015 (2020)
- Opt. Express 28, 23374 (2020)
- Phys. Rev. Appl. 13, 014010 (2020)
- Appl. Phys. Lett. 117, 051104 (2020)
- Appl. Opt. 59, 9499 (2020)

So, it works…………or does it?

Strain-wave-induced grating amplitudes < 1 pm - 300 pm

➡ Diffraction efficiencies < 1.0×10^{-7}

Low values, too small for practical applications…….

Can we enhance the photo-acoustic signals?

Use optical <u>resonances</u>

- Etalon resonances (no grating, just reflection!)
- Surface Plasmon Polariton resonances

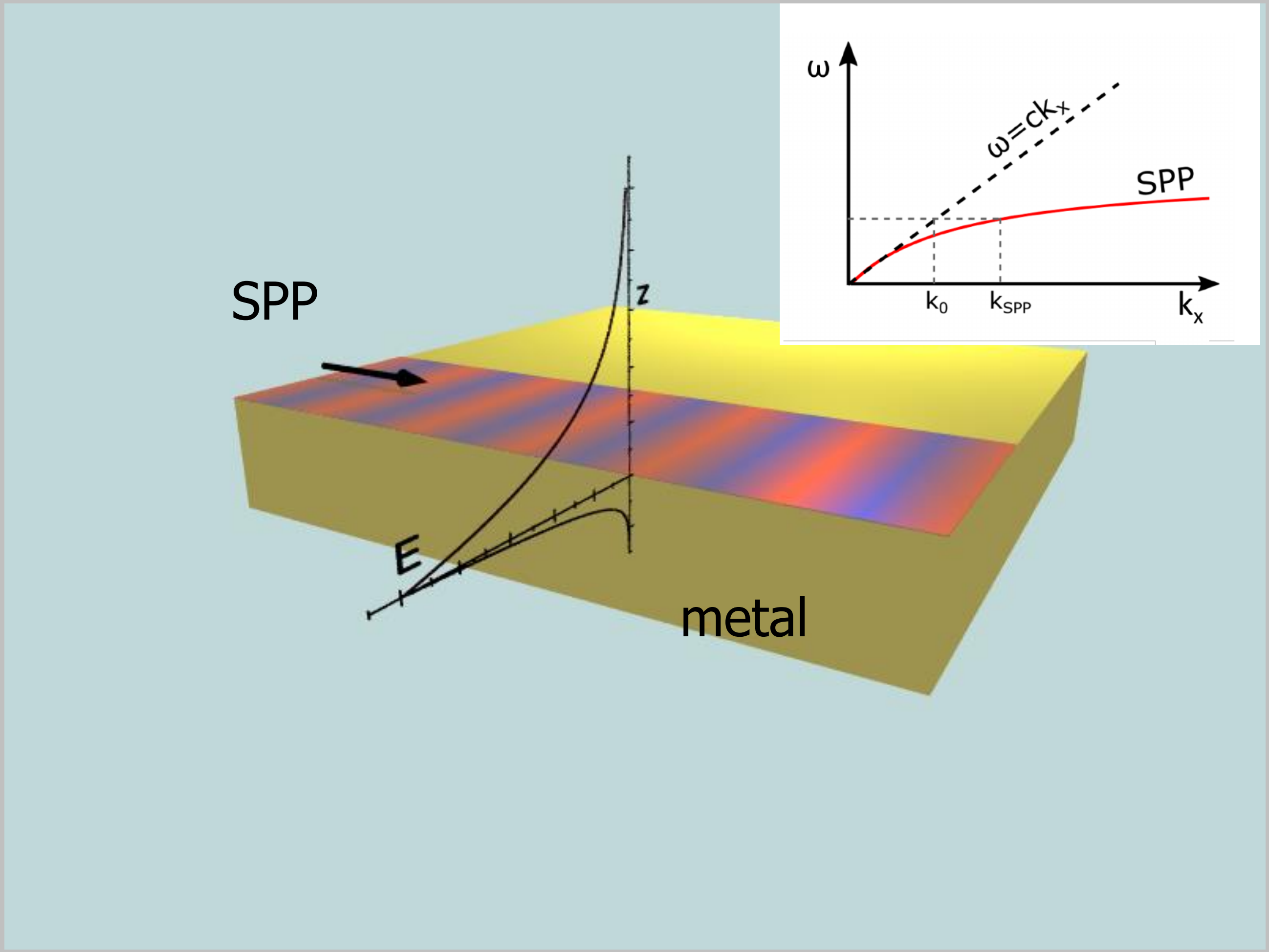
Surface plasmon polariton resonances

<u>Plasmon</u>:

-EM-wave bound at the interface between a metal and a dielectric

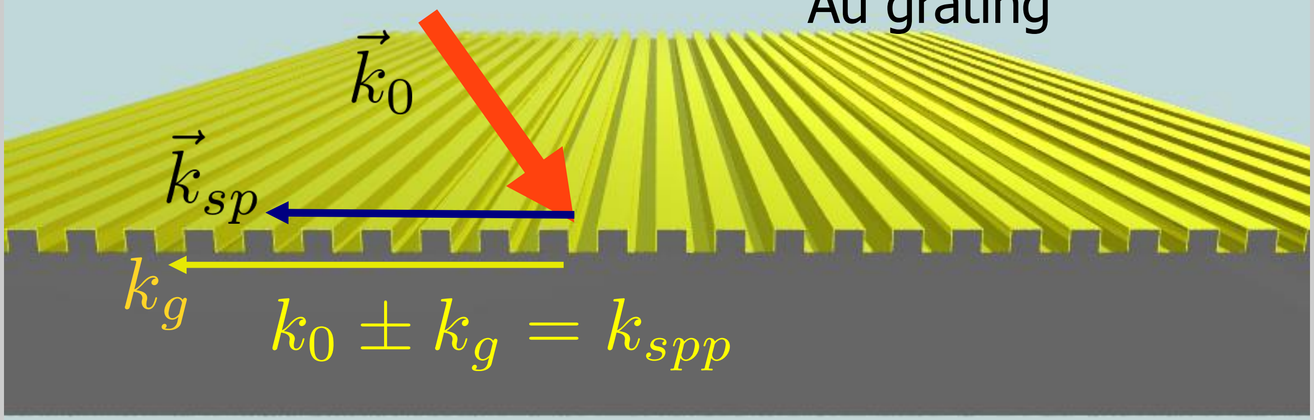
-Field is strongest at surface

-Field is evanescent in z-direction



Excite SPPs using periodic surface structures

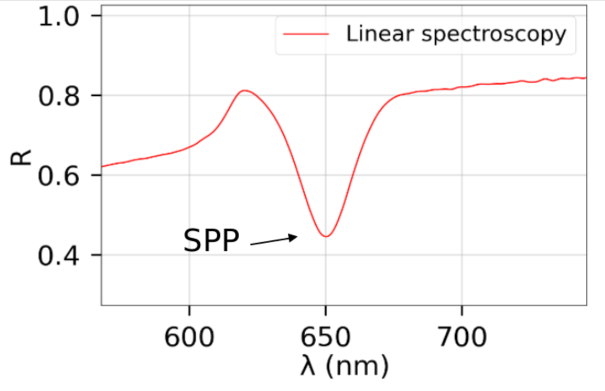
Use periodic structure to excite surface plasmons



Appl. Opt. **60**, 7304 (2021)

AIP Advances **12**, 025227 (2022)

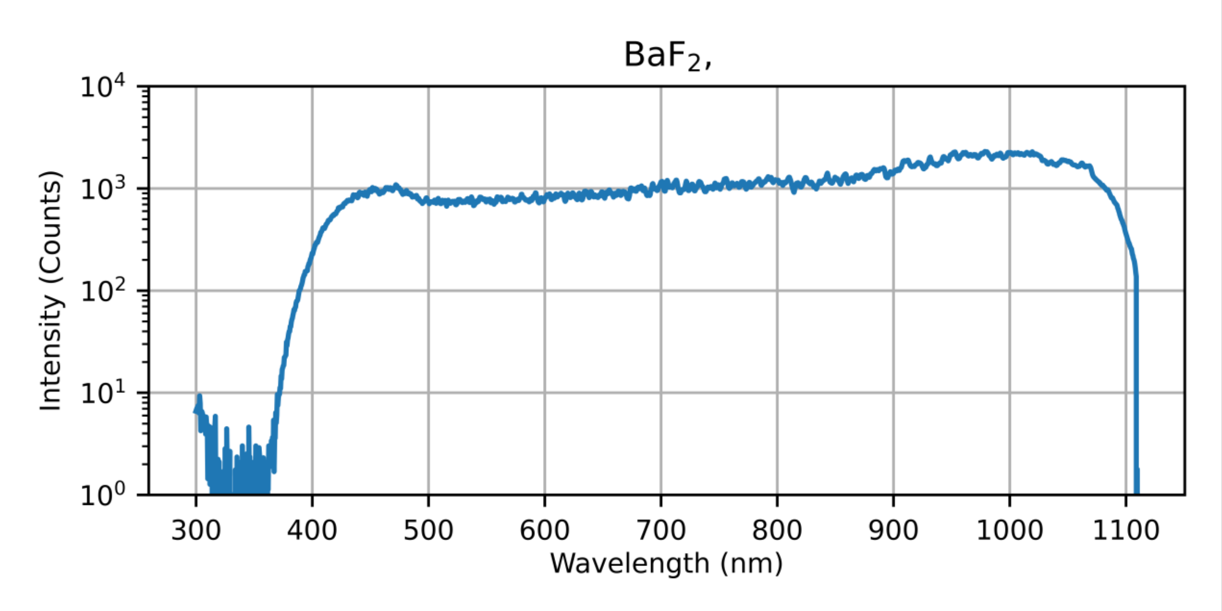
SPP shows up as Absorption dip



- Tune laser to slope of resonance
- Enhanced reflection changes

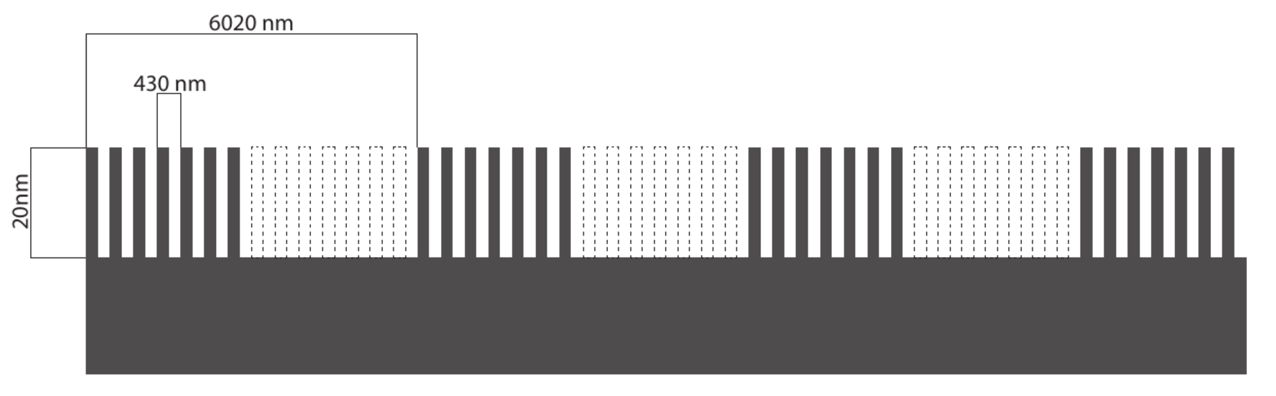
Pump / White-light probe

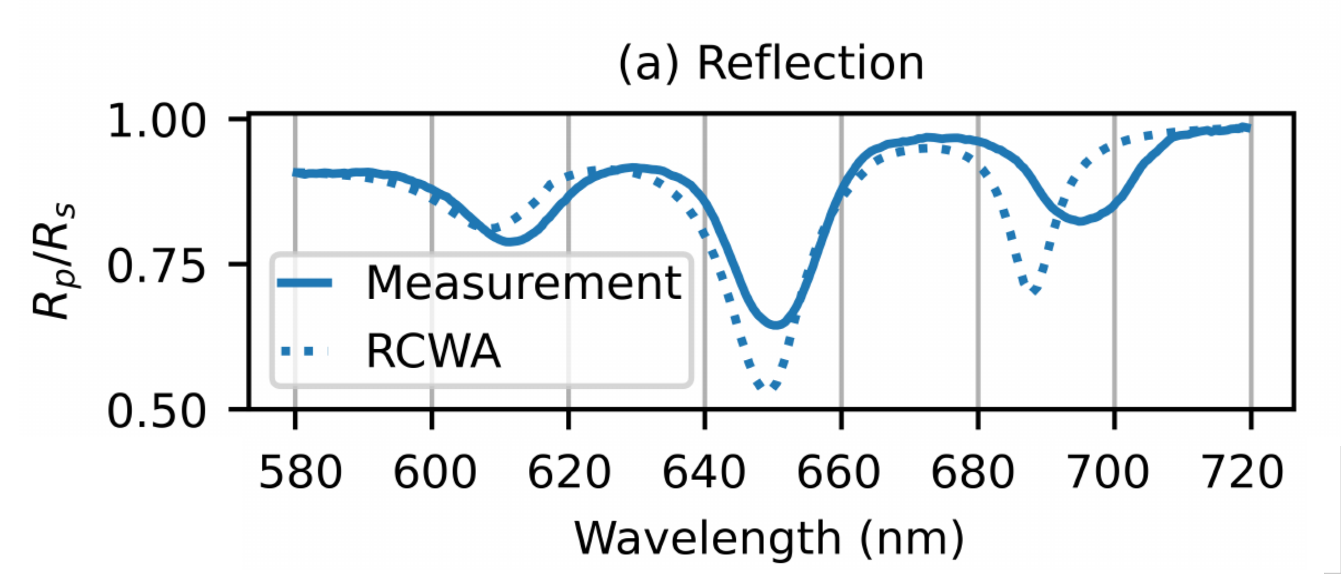
- Probe pulse is now a white-light continuum pulse (~ 5 ps long)
- Generated by 50 fs, 1300 nm pulse using continuum generation in BaF_2



- 1 kHz rep. rate
- High dynamic range camera measures probe spectra

Here: segmented grating

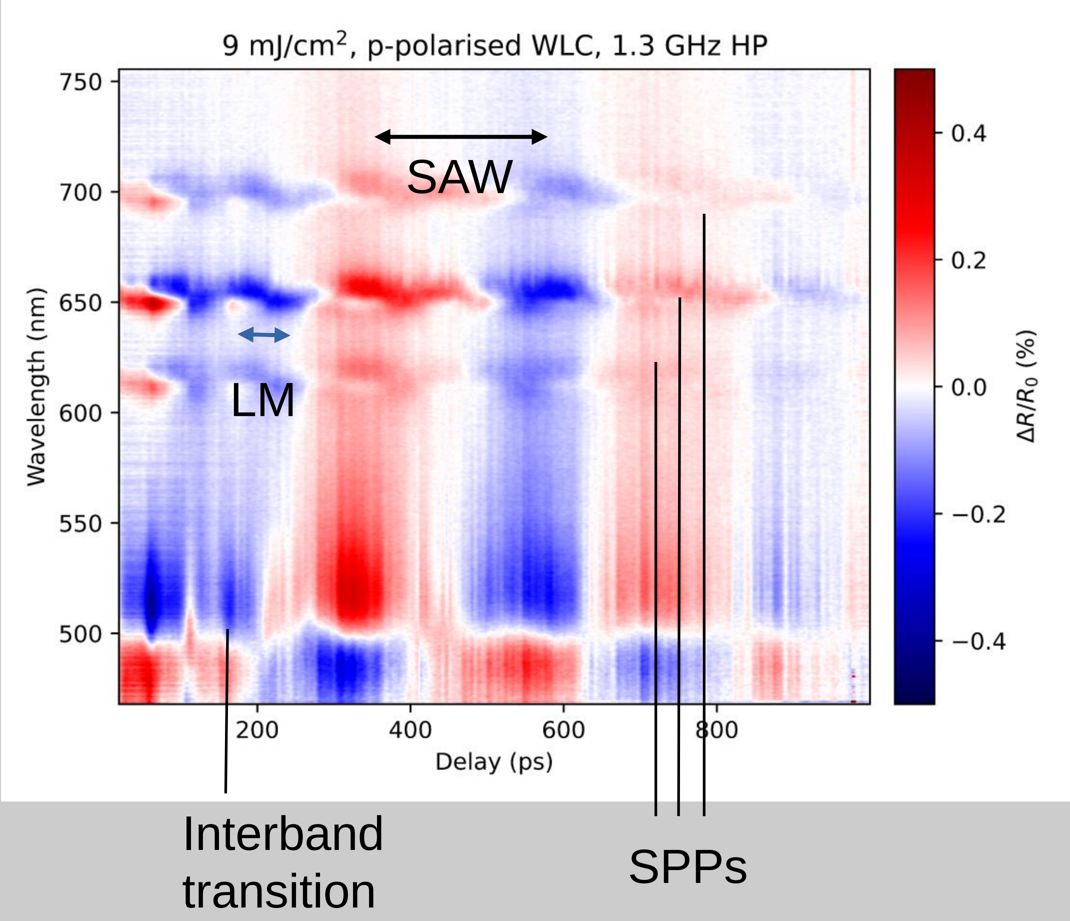




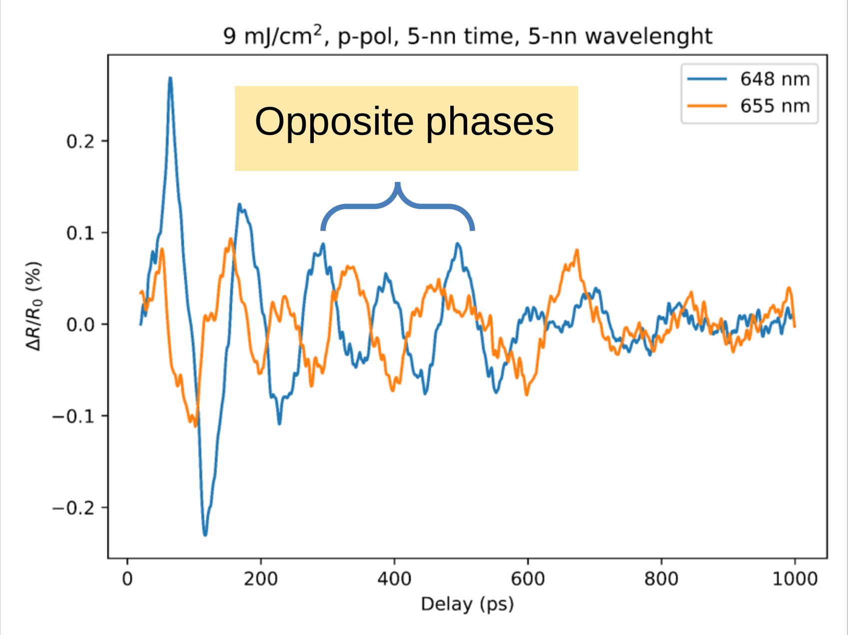
- Segmented grating has three SPP resonances
- Plasmonic grating is "amplitude modulated"
- Spatial frequency **sidebands**

Photoacoustics **31**, 100497 (2023)

Reflection signals: background removed



Only longitudinal mode:



- Rapid oscillations are longitudinal strain waves
- Also enhancement around interband transition (~521 nm)

Outlook

Signal enhancement works, but is

(a) not enough yet
(b) requires deposition of materials
(c) requires surface grating

What's next?
(a) Enhance signal strength (rep. rate tuning)
(b) Use surface as end mirror of small etalon in air? (no deposition needed)
(c) Optically create temporary ε-grating at surface for SPP resonance (no topography grating needed!)

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