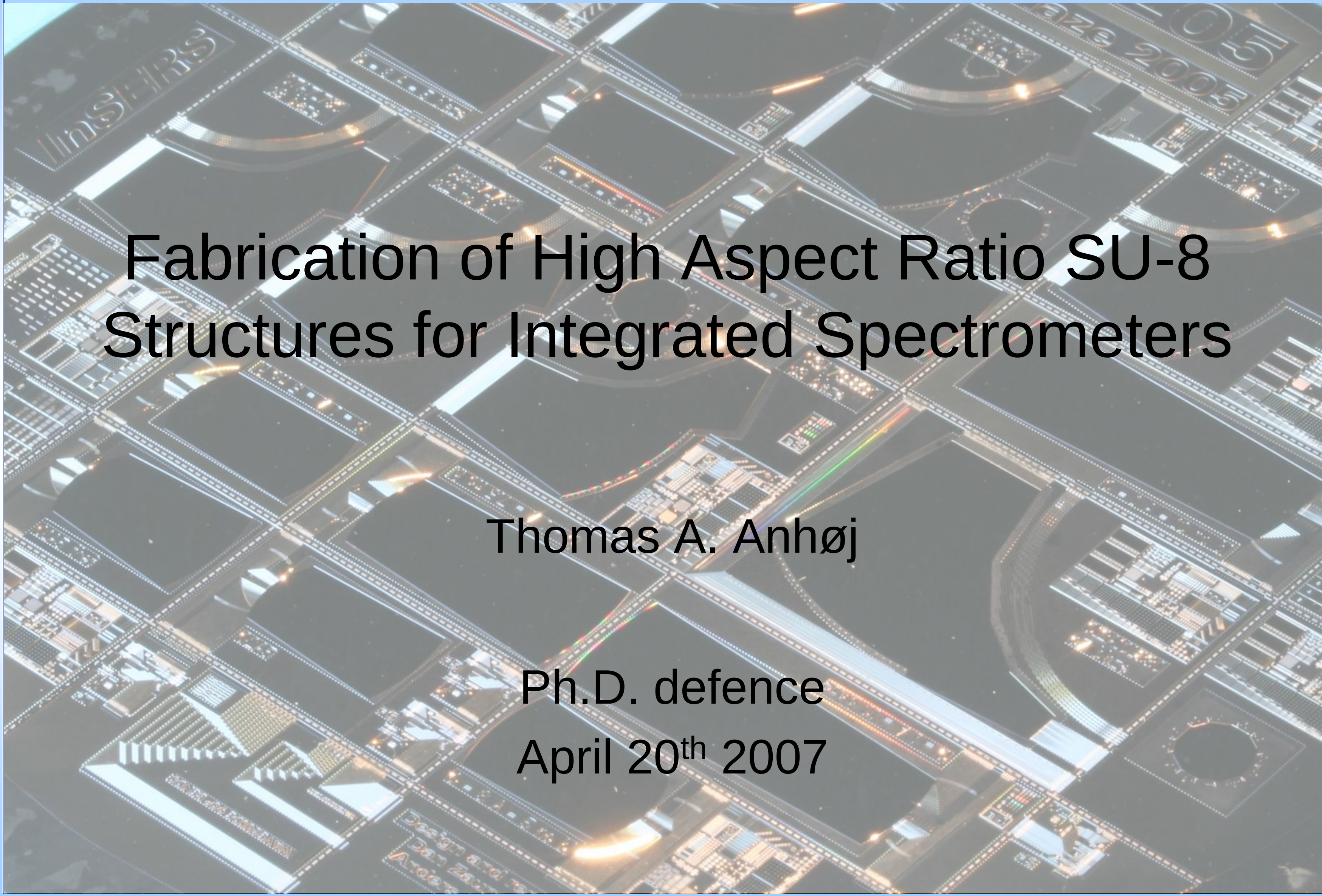


Fabrication of High Aspect Ratio SU-8 Structures for Integrated Spectrometers

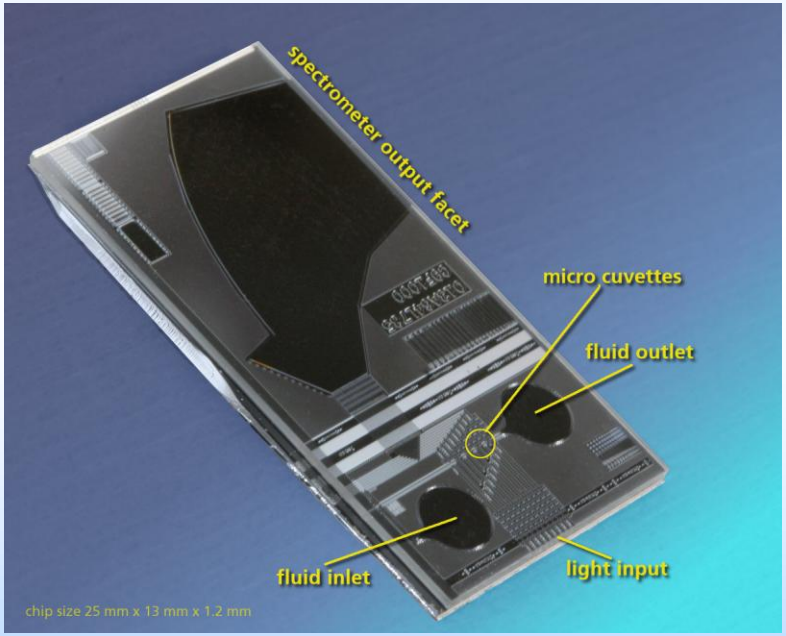
Thomas A. Anhøj

Ph.D. defence

April 20th 2007

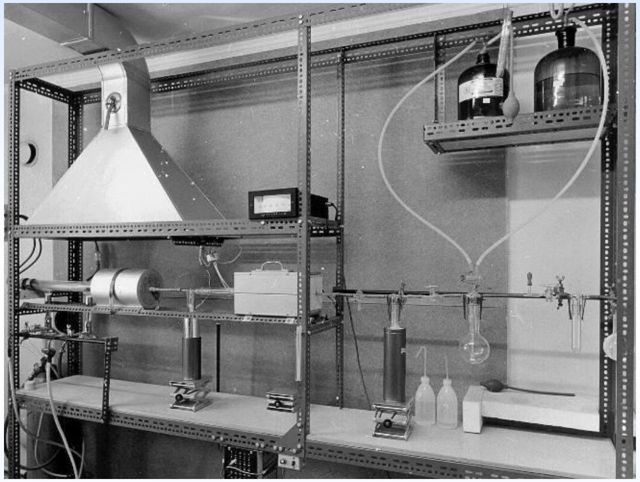
Outline

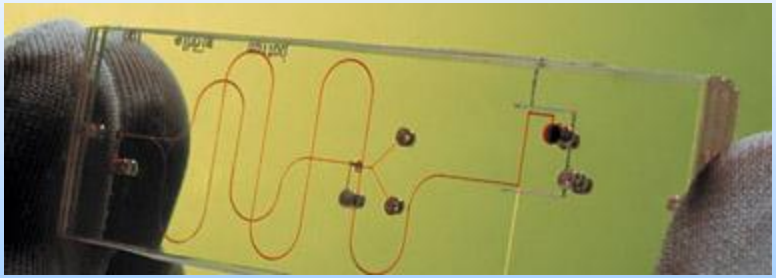
1. Introduction
2. Device fabrication
3. Device performance
4. Conclusion



Lab-on-a-chip

- The goal of lab-on-a-chip systems is to transfer the analytical capabilities of a traditional lab on to a single chip
- The benefits of integration and miniaturization are many
  - Analysis time
  - Sample and reagent consumption
  - Portability
- Sample analysis is realized in many different ways, often involving optical detection
  - Fluorescent detection
  - Absorption spectroscopy
  - Raman spectroscopy…?





Motivation

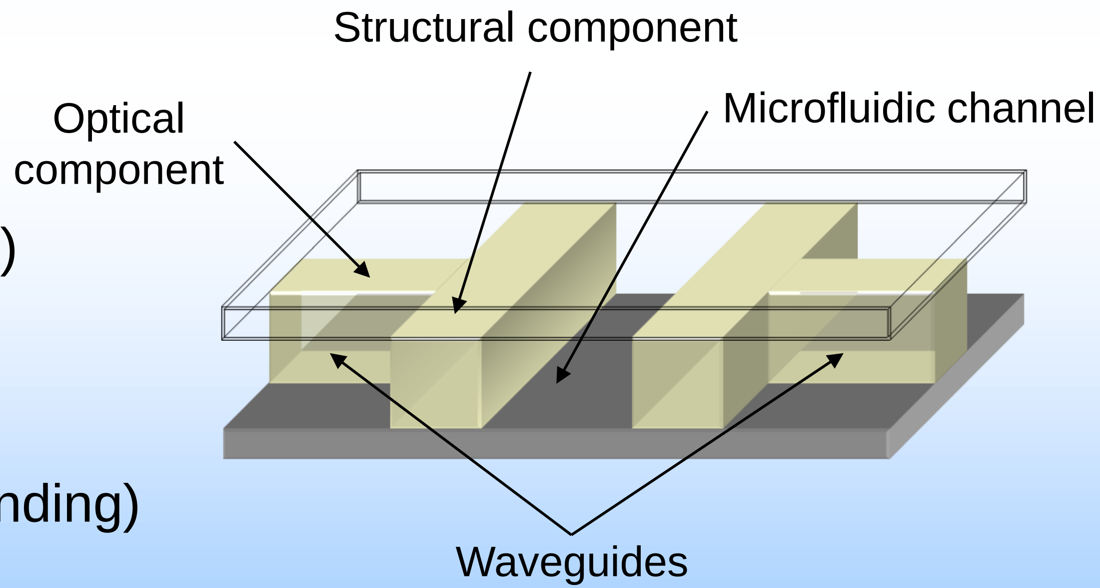
→ Raman spectroscopy: SERS-on-a-chip

→ Integrated optical system and microfluidic system

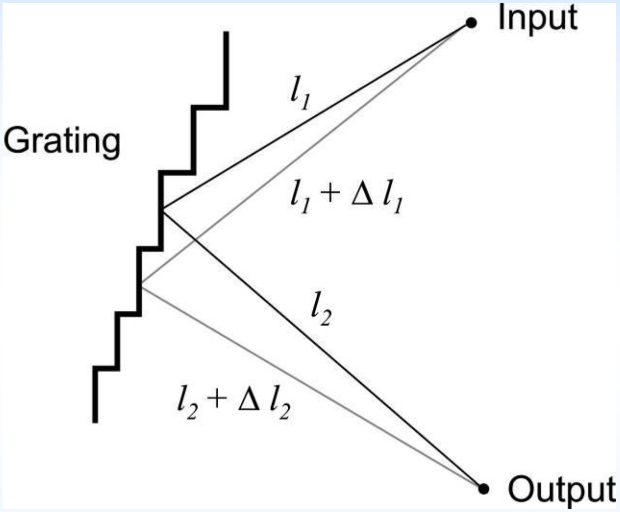
→ On-chip spectrometer

Platform:

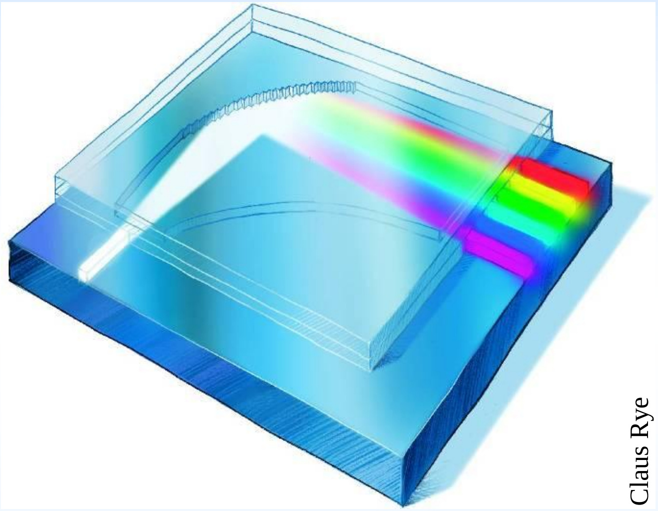
- 40 µm epoxy-based photoresist (SU-8 25)
- Thermally oxidized silicon substrate
- Glass lid (adhesive PMMA bonding)



Integrated spectrometers



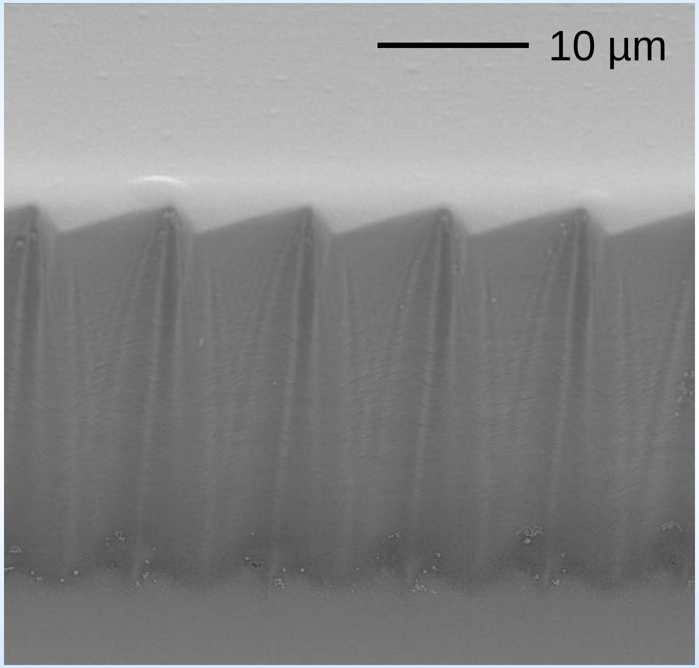
At the output:
$m\lambda = \Delta l_1 + \Delta l_2$



- Design parameters:
  - Diffraction order
  - Wavelength
  - Focal length
  - Linear dispersion
- Important characteristics:
  - Transmission loss
  - Resolution
  - Free spectral range
  - Linear dispersion

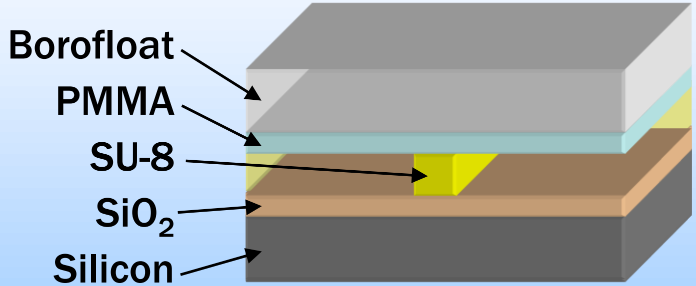
Integrated spectrometers

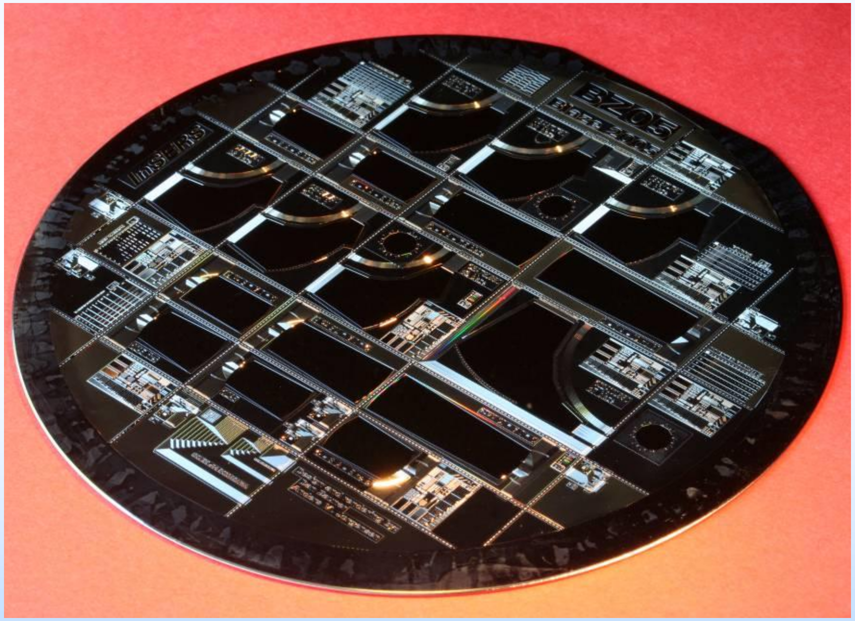
- Challenges in the photolithographic fabrication process
  - Line broadening
  - Corner effects
  - Sidewall angle
- Consequences
  - Increased transmission loss
  - Decreased resolution



Device fabrication

- Substrate preparation
- Spin coating
- Pattern transfer
- Bonding
- Dicing

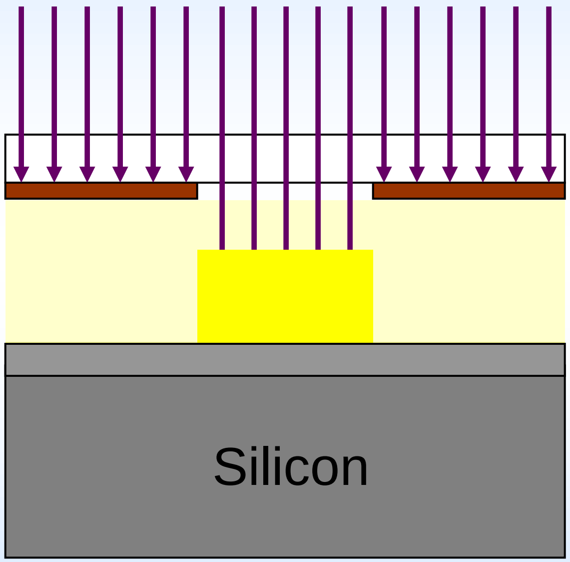




SU-8 processing

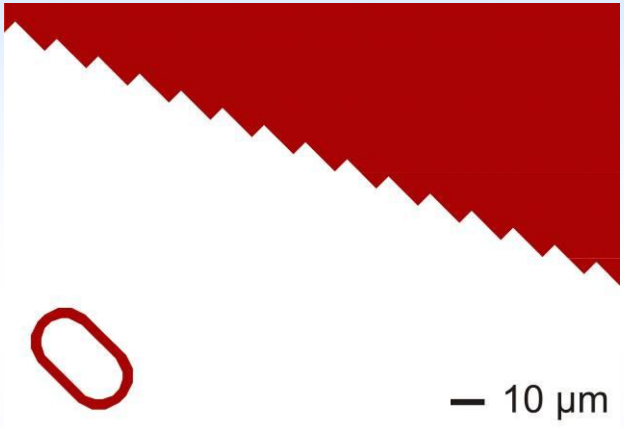
SU-8 is a chemically enhanced, negative tone photoresist.

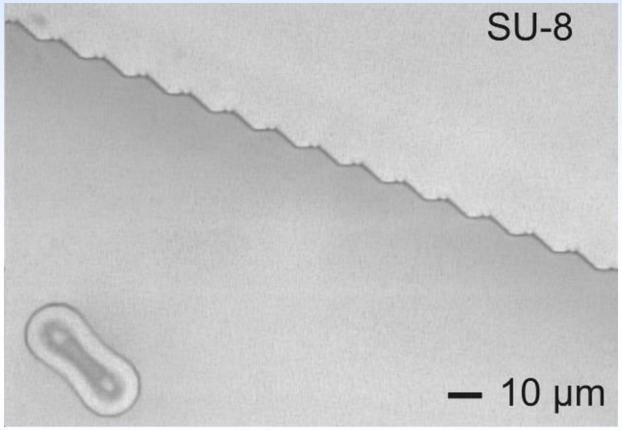
Cross-linked SU-8 is transparent in the visible and near-infra red wavelength range, and has a high refractive index (1.6 @ 633 nm)



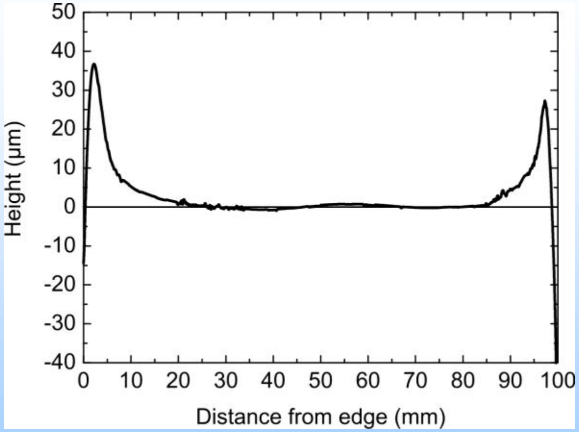
- Spin coat
- Soft bake
- Exposure
- Post-exposure bake
- Development of non-cross linked SU-8

SU-8 processing



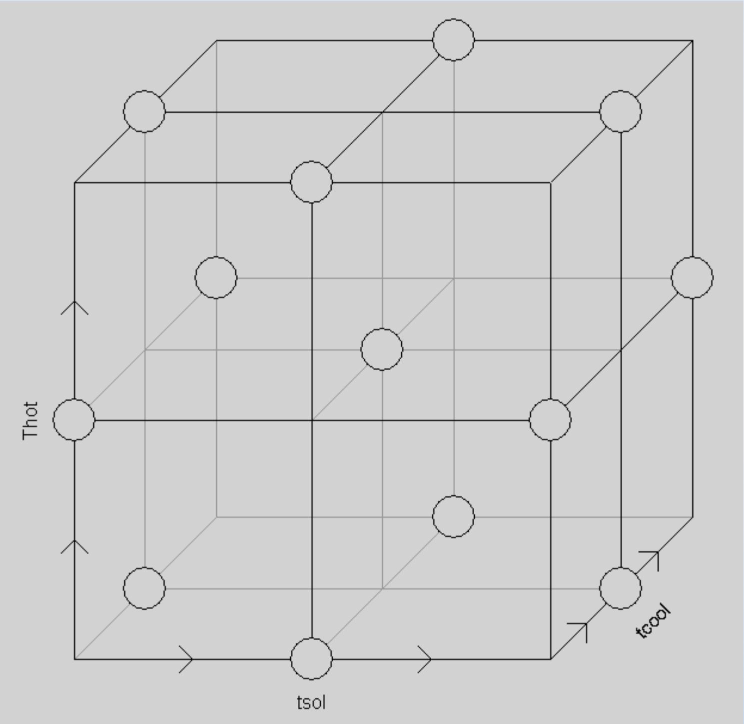


- Line broadening and corner effects due to proximity effect caused by the edge bead
- Solution:
  - Remove edge bead
  - Optimize process parameters



Experimental approach

- Investigations and optimization is carried out using design of experiments (DOE)
- Once suitable ranges of the involved parameters have been chosen, the experiment is designed using commercial software (MODDE 6.0 from Umetrics, Sweden)
- The result of the experiment is modelled and the models are used to optimize the process



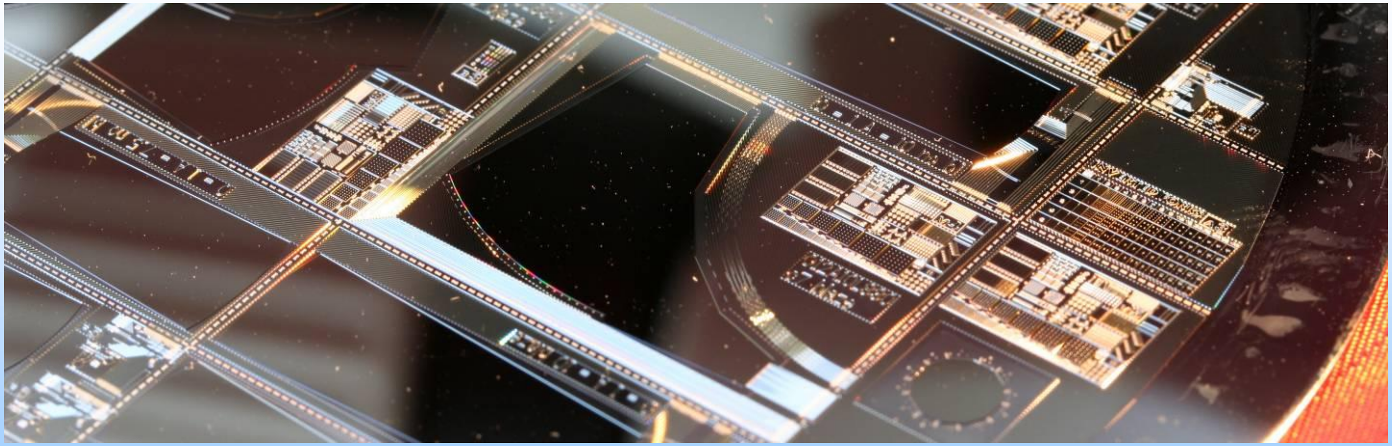
Experimental approach

Edge bead removal

- 8 variables
- Response surface modeling including both second order and interaction terms
- 54 wafers

Parameter optimization

- 6 variables, 6 responses
- Response surface modeling including both second order and interaction terms
- 76 wafers

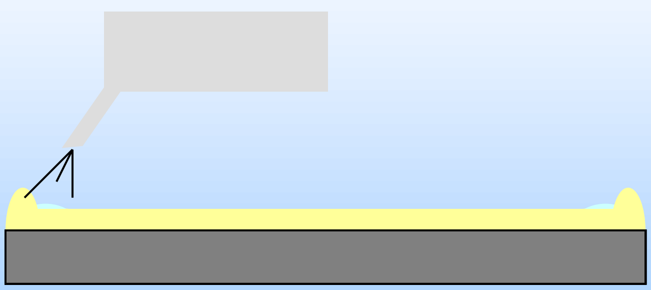


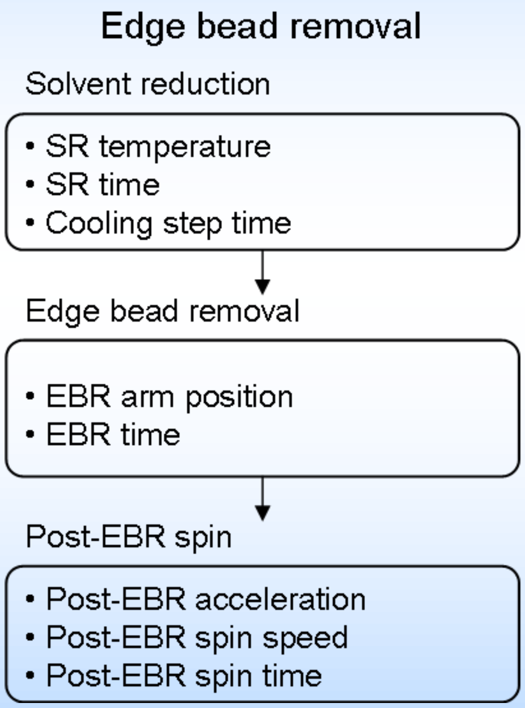
Edge bead removal

When a wafer is spin coated with resist, a surplus of material builds up at the edge of the wafer.

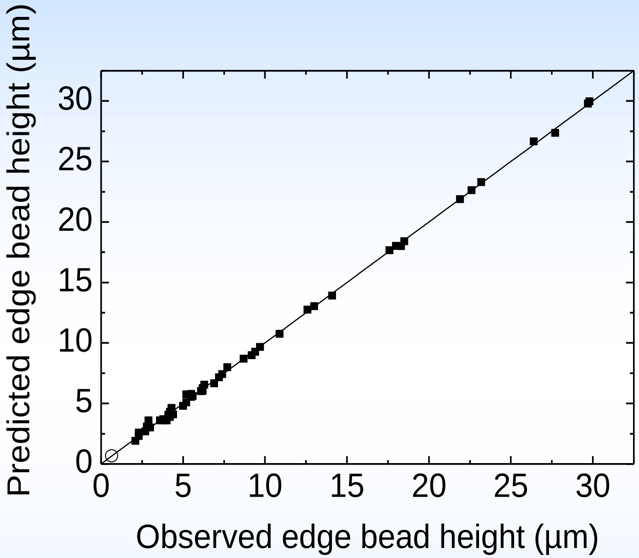
This effect is called ‘edge bead’.

The edge bead has a negative effect in the photolithographic process, as well as in the bonding process.

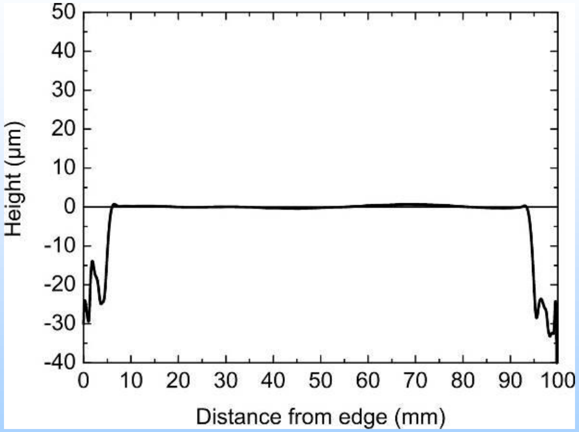




Edge bead removal



- The application of the solvent during EBR (position and duration) is the most significant factor in the model
- The model is used to optimize the EBR process

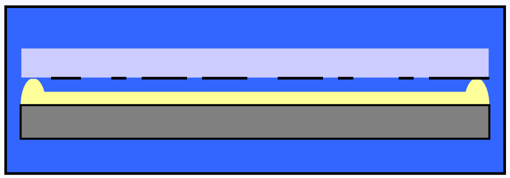


Optimized process:
- Solvent reduction 9:23 min @ 50 ºC;
- Edge bead removal (PGMEA) 40 s, 5 mm from edge;
- Post-spin 28 s @ 1440 rpm.

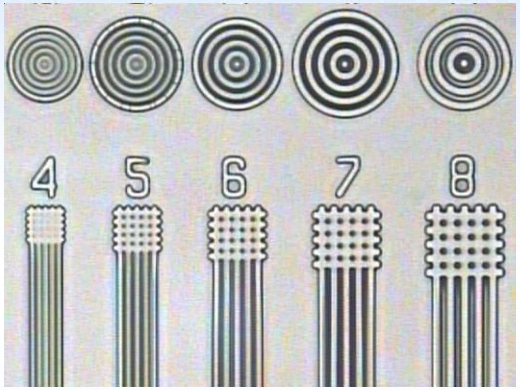
Result:
Edge bead height < 1 µm, i.e. practically gone.

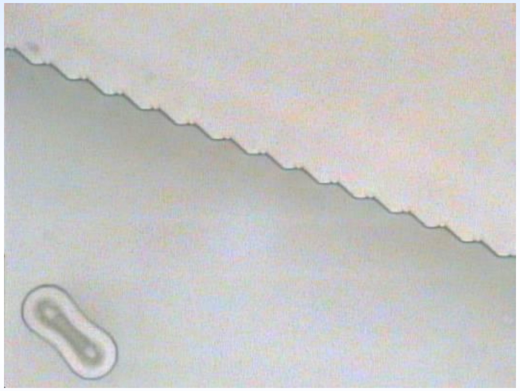
Edge bead removal results

With edge bead

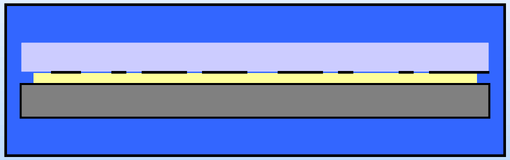


7 µm trenches

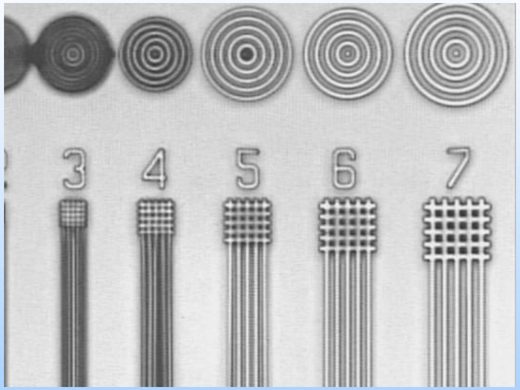


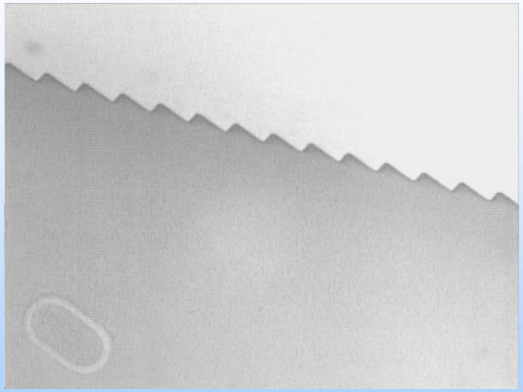


Without edge bead



4 µm trenches



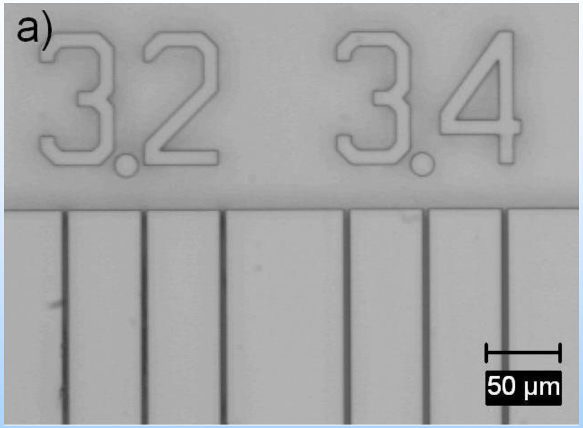


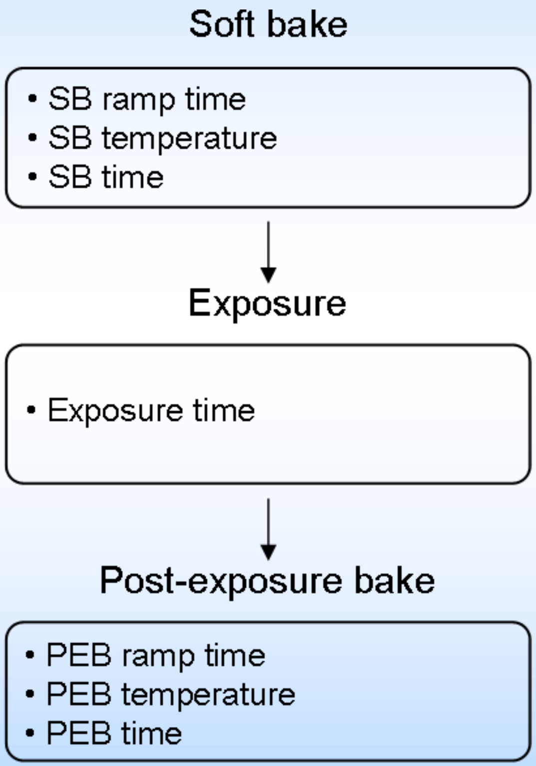
Process parameter optimization

With the edge bead gone the lithographic resolution has improved significantly. This makes it possible to study the effect of process parameters.

Cracks are an issue, especially in the large spectrometer slab, but also in waveguides and in the fluidic channel.

Response monitors
– trenches
– ridges
– cracks



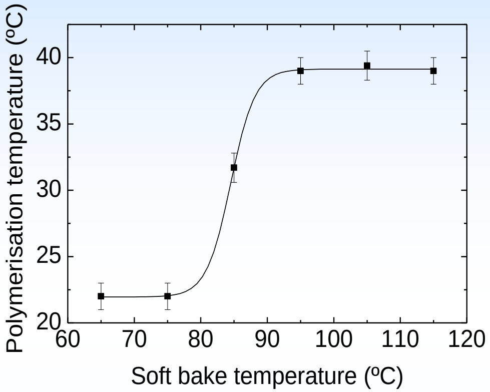


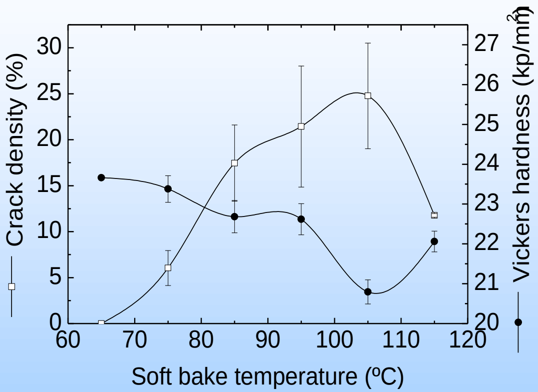
Process parameter optimization

Starting point	Optimized recipe
• Soft bake:	
– 30 min @ 95 °C	– 5 min @ 65 °C
• Exposure:	
– 25 s @ 9 mW/cm^2	– 20 s @ 9 mW/cm^2
• Post-exposure bake:	
– 4 min @ 95 °C	– 30 min @ 65 °C
– 10.5 trench aspect ratio	– 11.4 trench aspect ratio
– 5.1 ridge aspect ratio	– 8.8 ridge aspect ratio
– 1-9 % cracks	– No cracks!

The effect of soft bake temperature

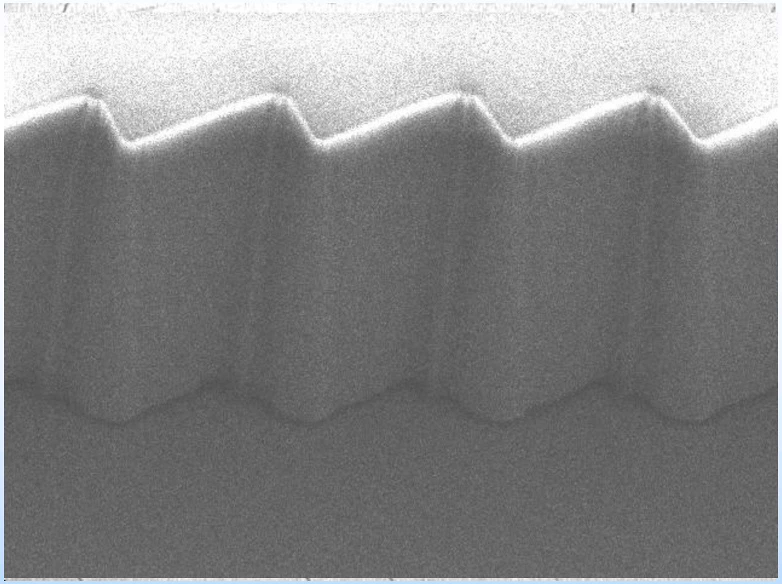
- The soft bake temperature has the biggest effect in several of the second DOE models.
- Soft bake effects
  - Polymerization
  - Resist sensitivity
  - Resulting material strength
- May be explained by
  - Solvent dependent photoinitiation
  - Solvent dependent polymerization



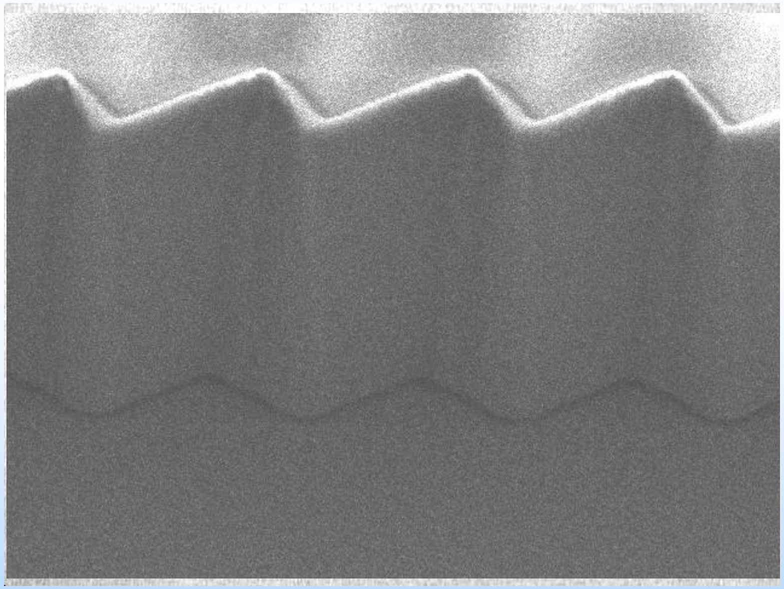


Parameter optimization results

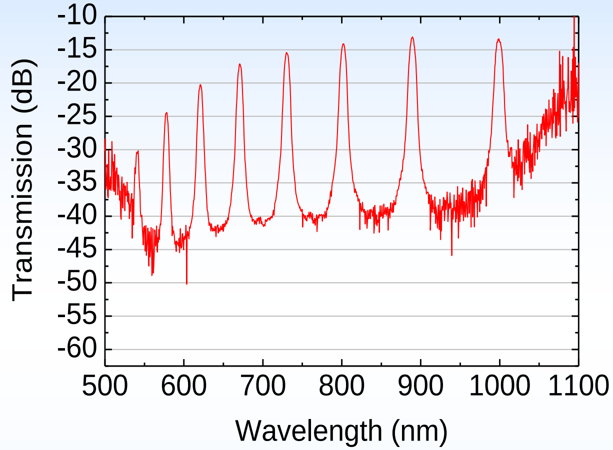
Starting point



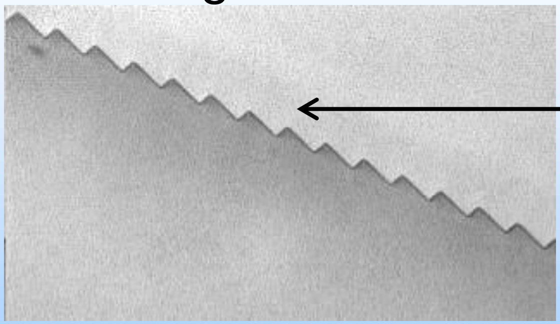
Optimized recipe

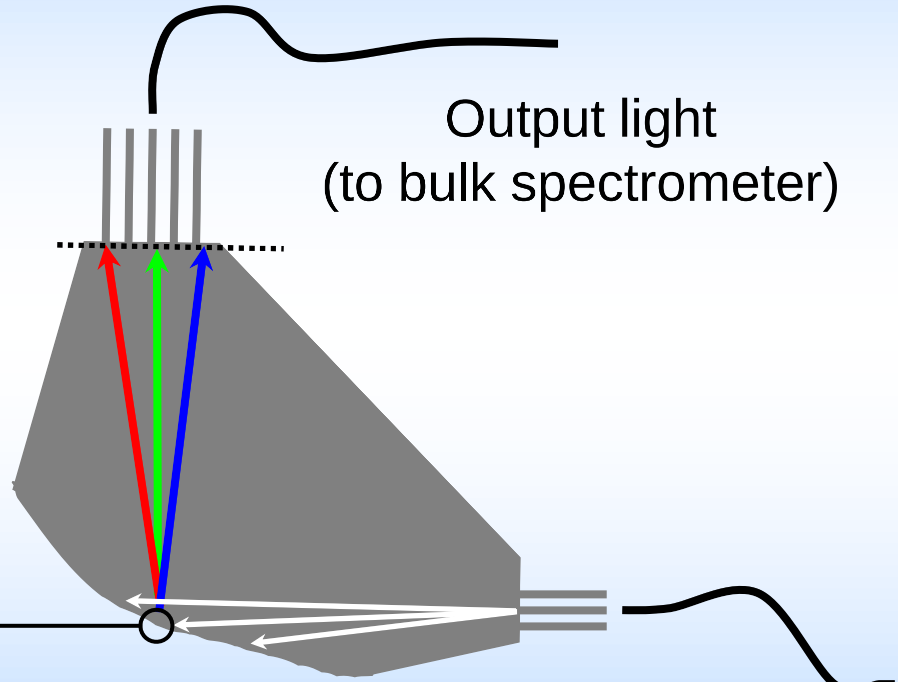


Spectrometer characterization

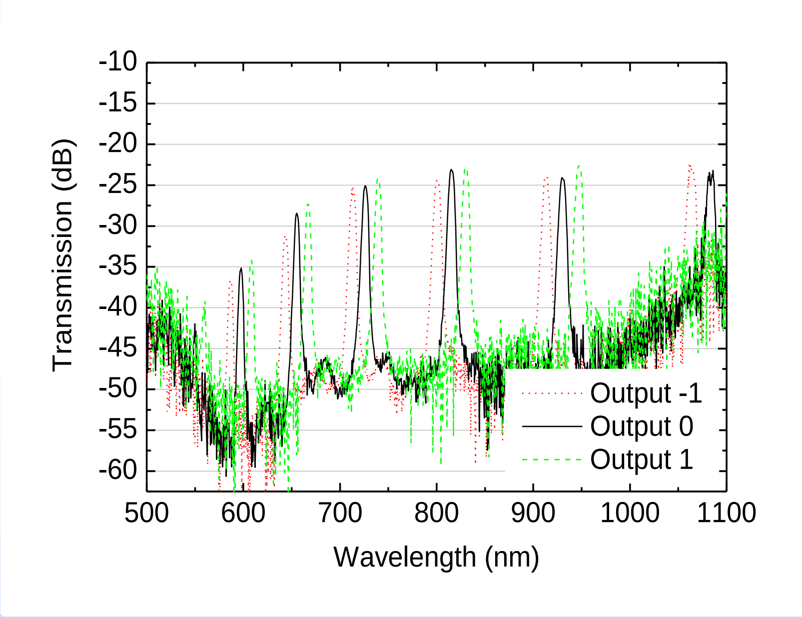


Grating



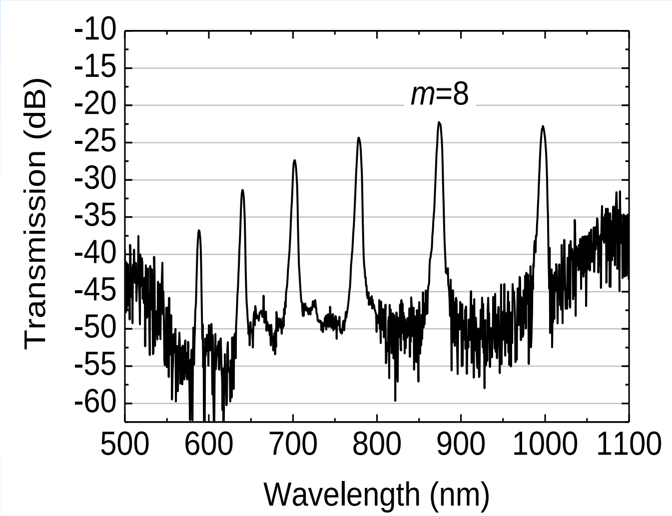


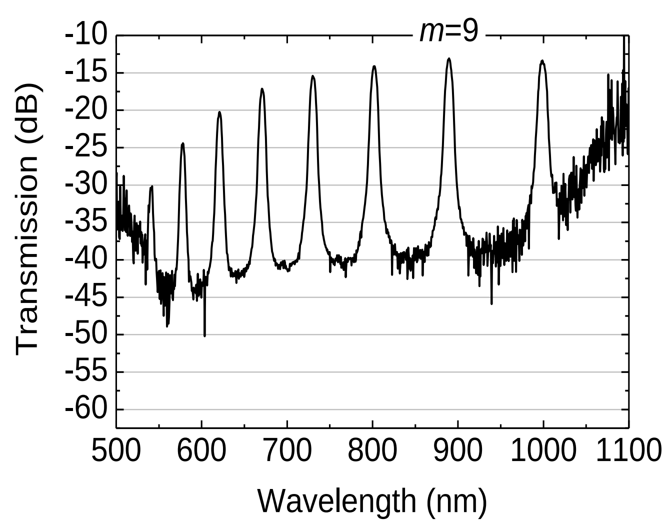
Spectrometer performance



- Order:
  - m=9 (m_0=9)
- Wavelength:
  - 726 nm (730 nm)
- FSR:
  - 89.2 nm (91.3 nm)
- Linear dispersion:
  - 7.5±0.2 µm/nm (7.5 µm/nm)

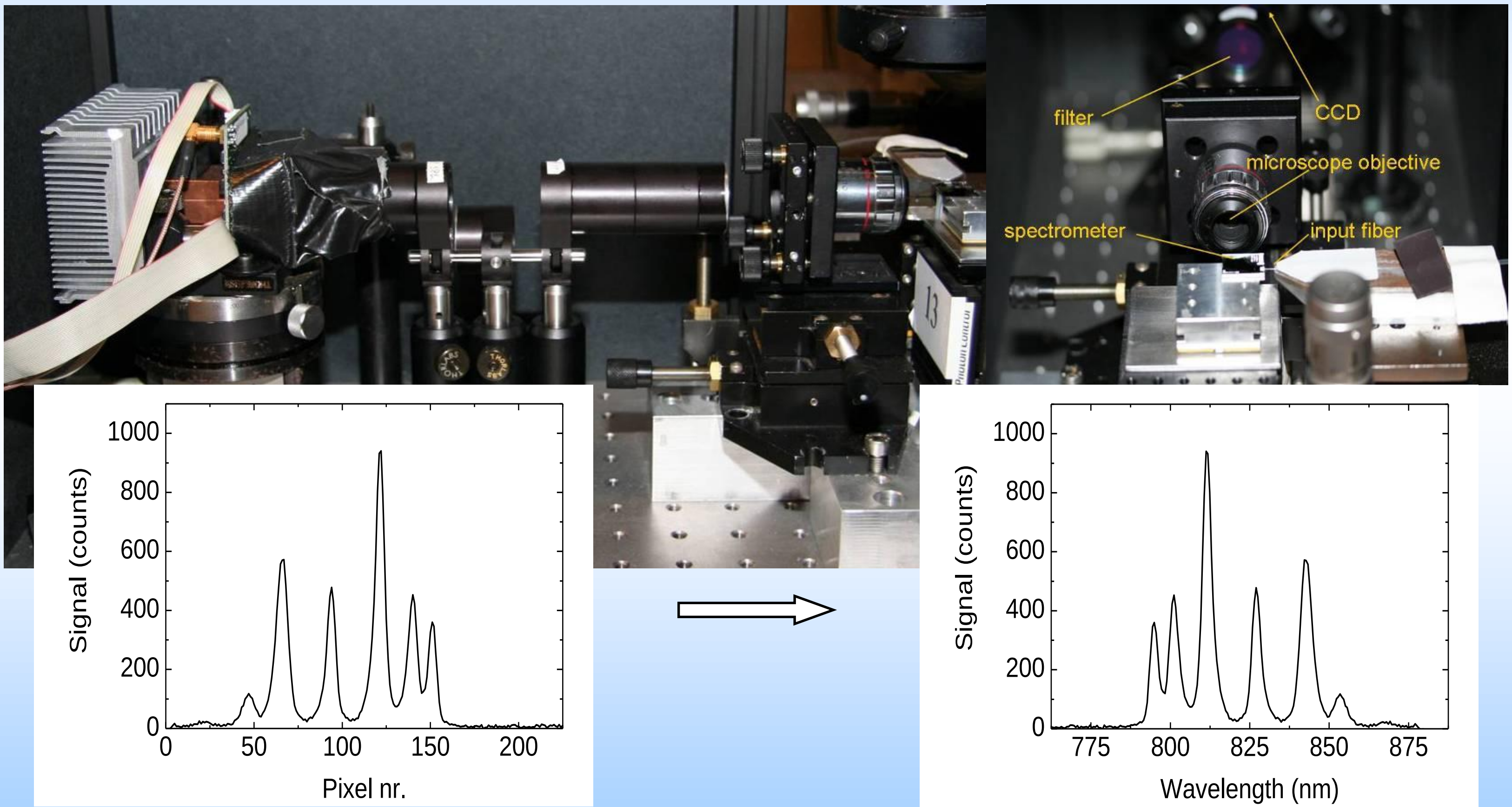
Result of optimization



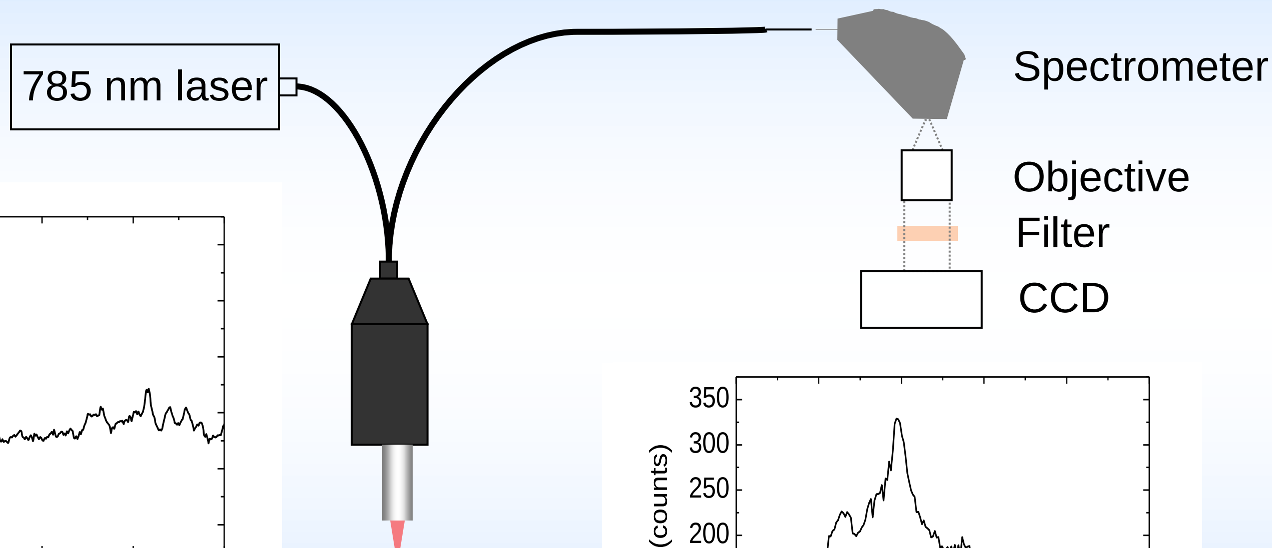


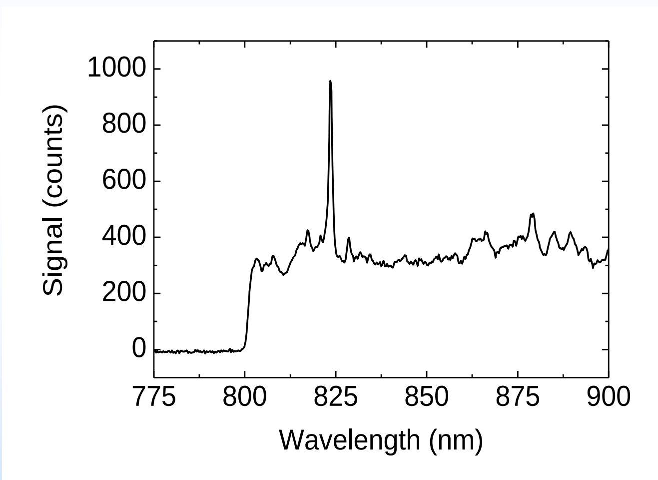
- Loss: 22.3 dB 13.1 dB
- FWHM: 5.8 nm 7.5 nm
- The transmission increase due to the optimized fabrication is 7.5 dB
- The intrinsic spectrometer transmission loss is estimated to 9.8 dB

Using the spectrometer

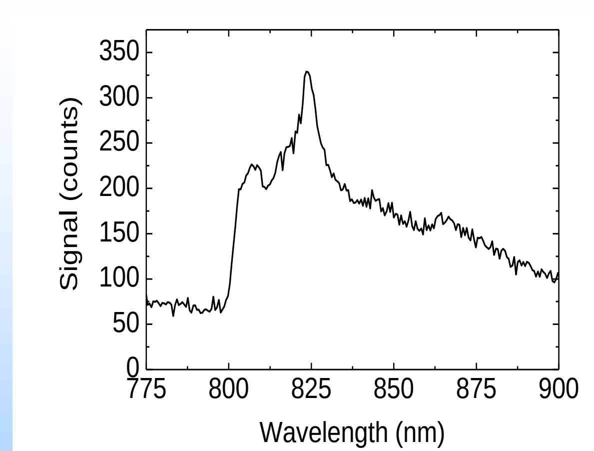


Using the spectrometer





Commercial spectrometer

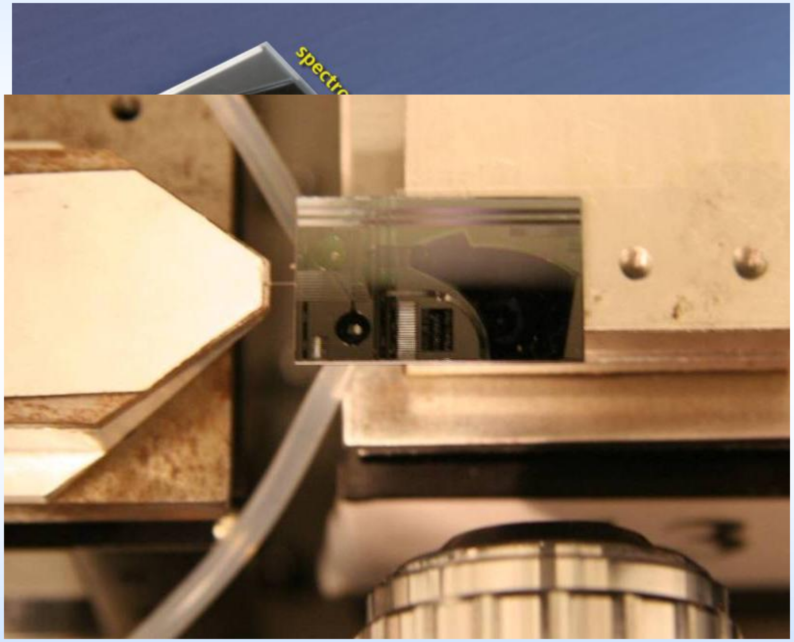


Integrated spectrometer

Conclusion

- Trench aspect ratio increased from 6 to above 11
- Cracks eliminated
- Spectrometer transmission increased six-fold

- Outlook
  - Proof of concept
  - SERS active surface
  - Blazed spectrometer design



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- B98 and Co.
- Christoph
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