Structuring and Uniformity Improvement of Thin Film LN and Other Waveguide Materials

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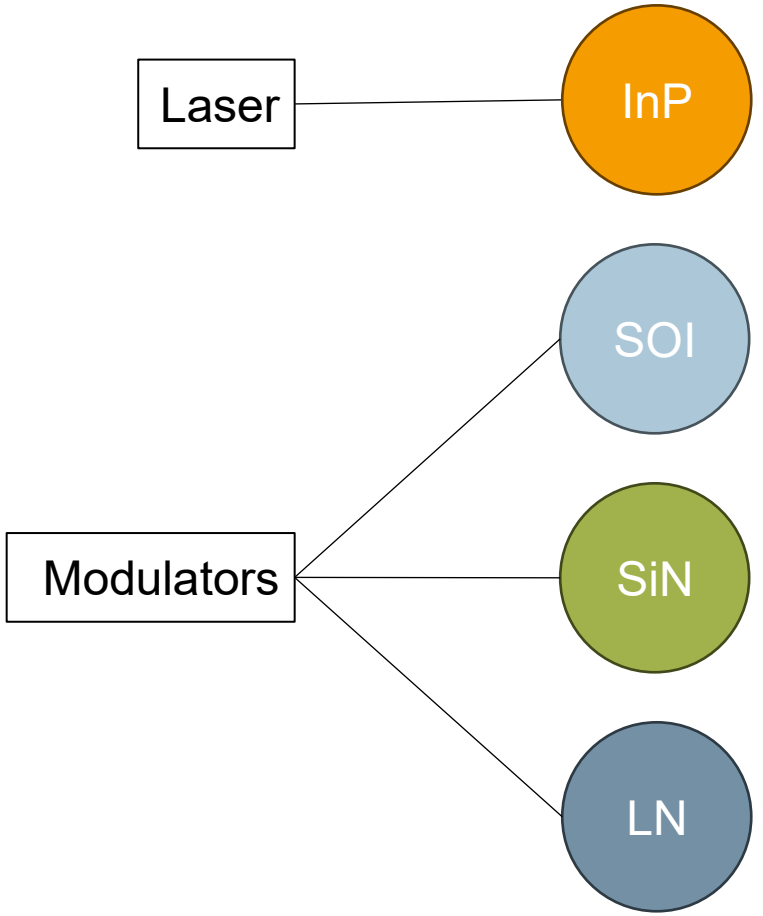
Marcel Demmler

Photonics Integrated Circuits (PICs)

- PICs represent a transformative technology with applications in:
  - Telecommunications
  - Computing
  - Healthcare
  - Sensing
- Despite their numerous advantages, PICs face several difficulties depending on their technology platforms, each with different pros and cons regarding costs, optical losses, data rates
- All platforms need good uniformity and structuring with low roughness, whereby ion beam surface processing with sub-nanometer precision is a powerful technology

Technology Platforms



About scia Systems

scia Systems is a specialist in thin-film process equipment based on advanced ion beam and plasma technologies.

We supply our customers with:

Coating, etching, and cleaning systems based on advanced **ion beam** and **plasma technologies**

In-house **technology** and **process development**

Extensive **project expertise**

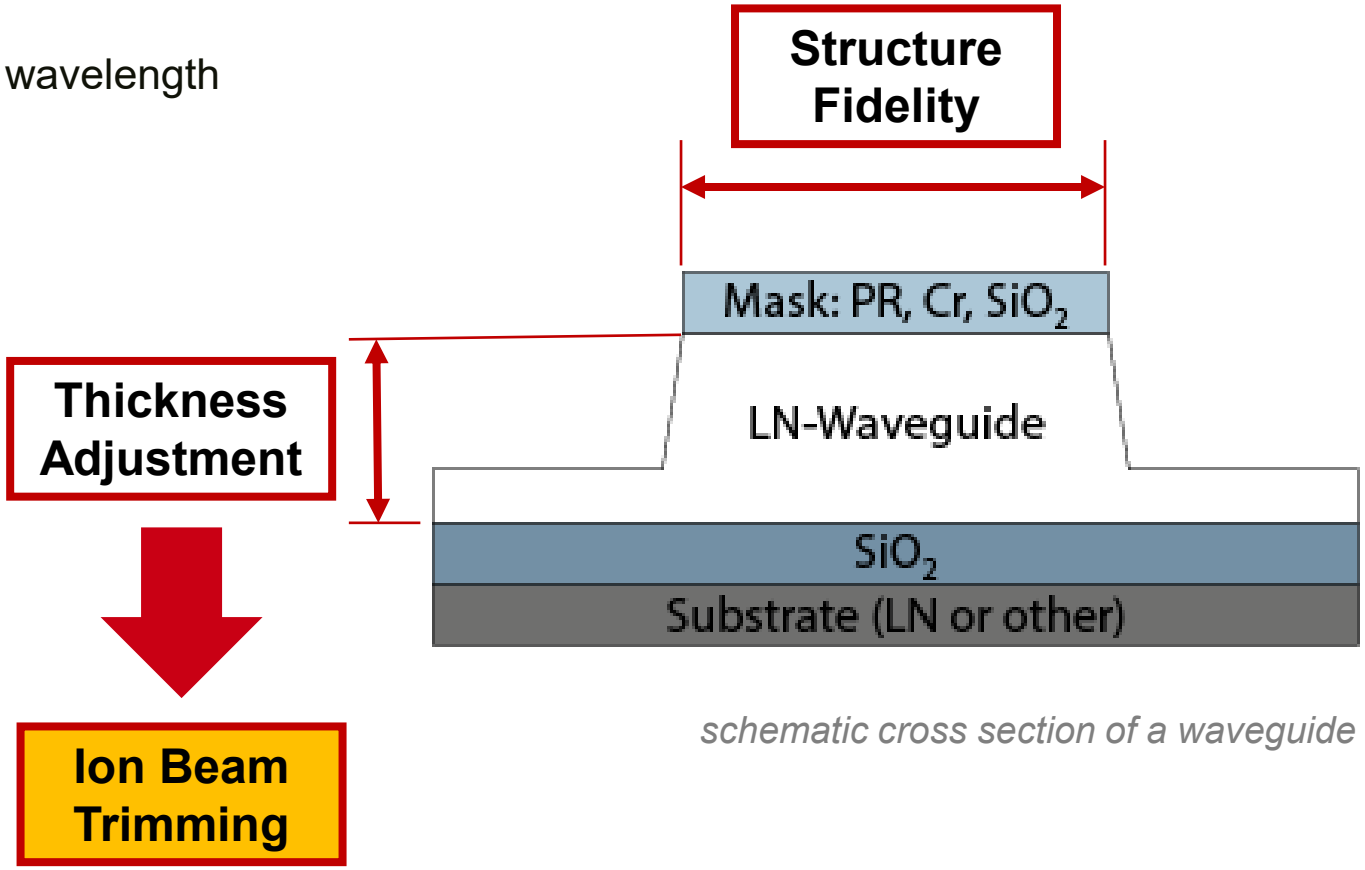
Global sales and **service** network

The key components are developed and **manufactured inhouse**

PIC Waveguide Performance

Requirements

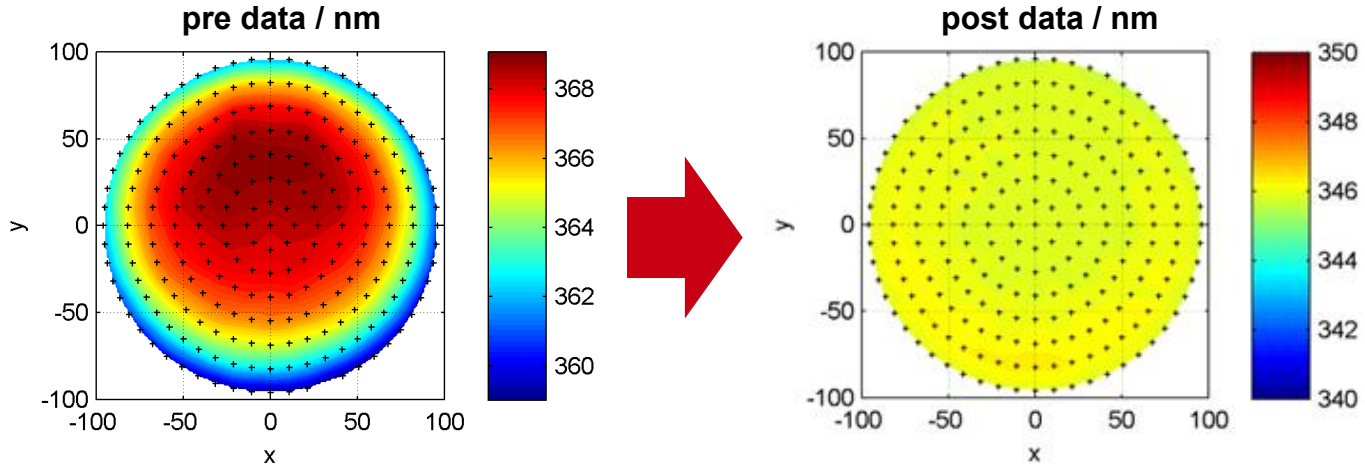
- (Nonlinear) optical material
- Optimized light transmission
- Dimensions have to fit to the wavelength
- Lowest losses
  - Low absorption
  - Low scattering
- High yield on wafers



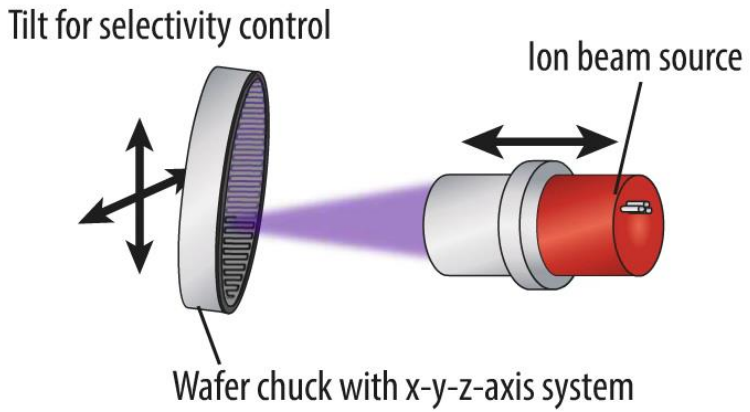
schematic cross section of a waveguide

Basic Principle - Ion Beam Trimming (IBT)

- Localized dimensional (mostly thickness) correction by focused broad ion beam
- Contactless high vacuum process with depth resolution close to single atom layers
- Removal controlled by local dwell time of the ion beam at certain wafer positions
- Dwell time adjustment handled by pre-calculated velocity map in raster scan pattern
- Better thickness uniformity leads to higher yield for many applications



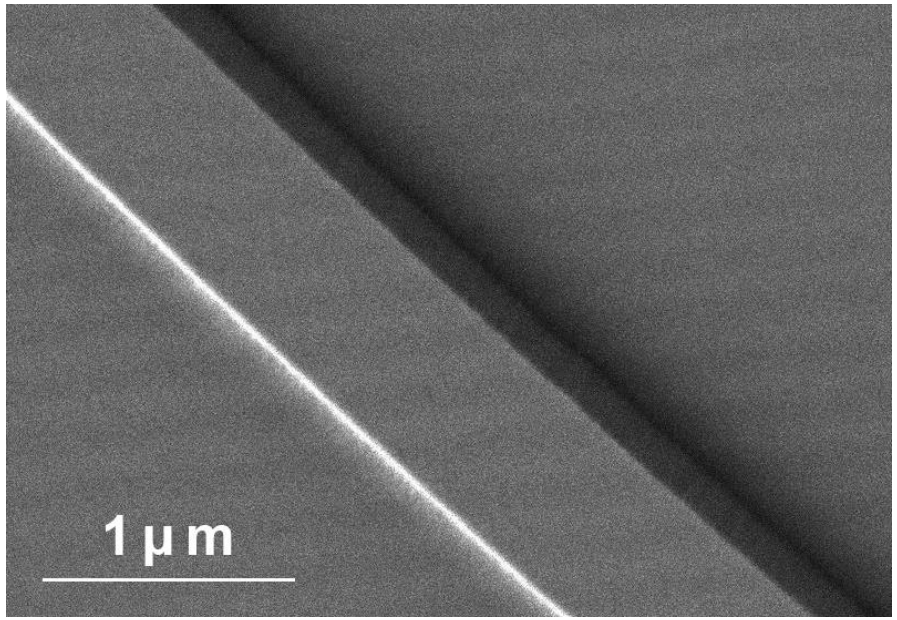
Thickness data before (3.0 nm RMS) and after (0.13 nm RMS) ion beam trimming



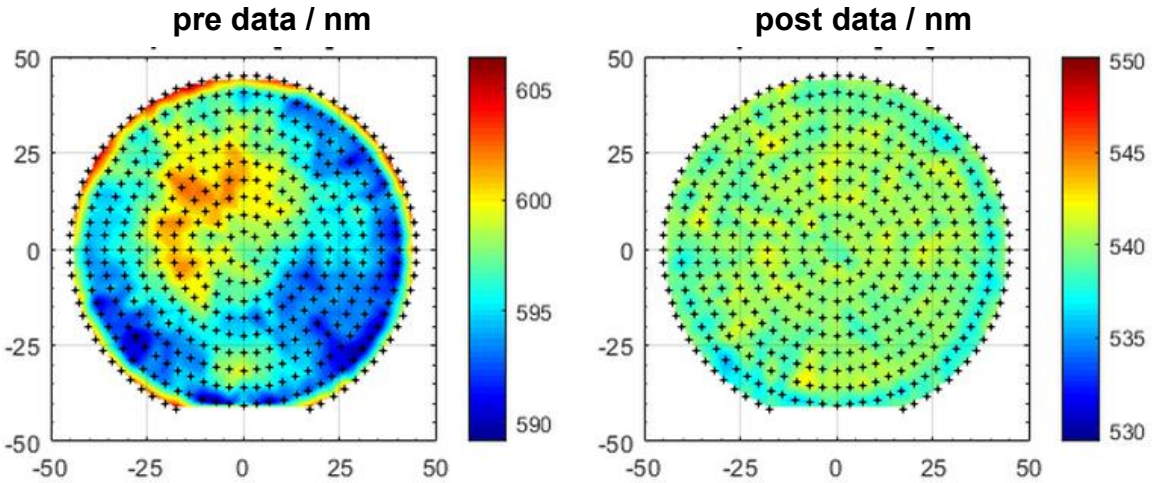
Principle of ion beam trimming by scia Trim 200

LN Waveguide Trimming

- Precise adjustment of waveguide structures
- < 0.1 % thickness uniformity possible
- POI wafers (LN or LT on Silicon), Si_3N_4, SiO_2, Si and other material possible



Waveguide structures with adjusted thickness by ion beam trimming and patterned by ion beam etching, in $LiNbO_3$



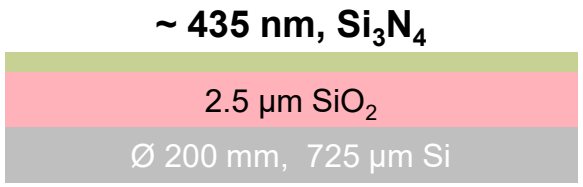
Pre and post thickness distribution of $LiNbO_3$-Structure

Standard deviation	*Pre:*	*3.84 nm* →	*Post:*	*1.32 nm*
Thickness	*Pre:*	*579 nm* →	*Post:*	*539.8 nm*

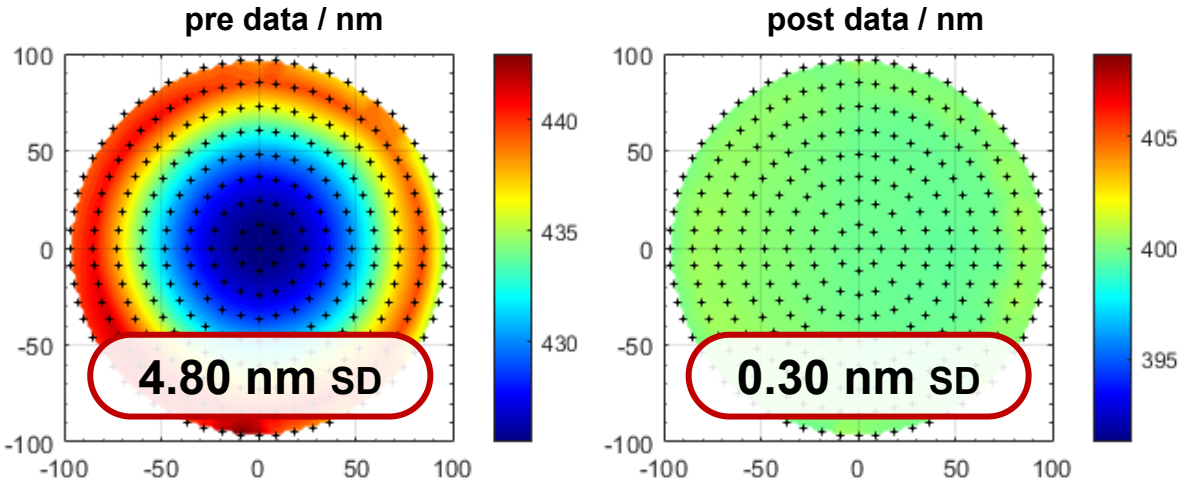
3.84 nm SD → **1.32 nm SD**

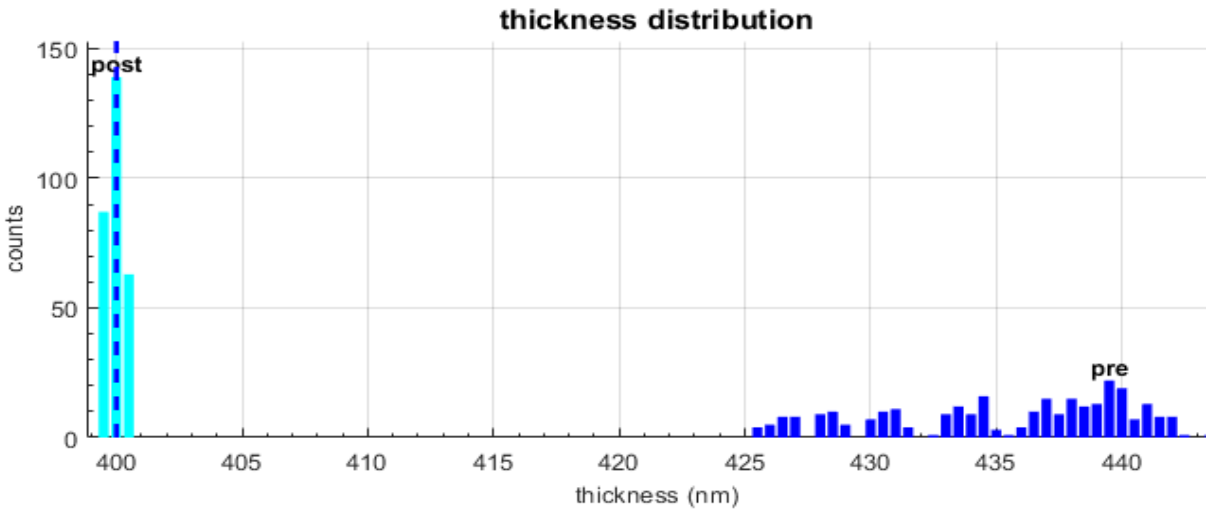
SiN Trimming for Waveguides

- Trimming of **Si_3N_4 layer** before waveguide pattering



Pre and post properties of Si_3N_4 layer				
Standard deviation	Pre:	4.80 nm →	Post:	**0.30 nm**
Thickness	Pre:	435 nm →	Post:	400 nm
RMS roughness	Pre:	0.3 nm →	Post:	0.3 nm
Refractive index	Pre:	2.023 →	Post:	2.023



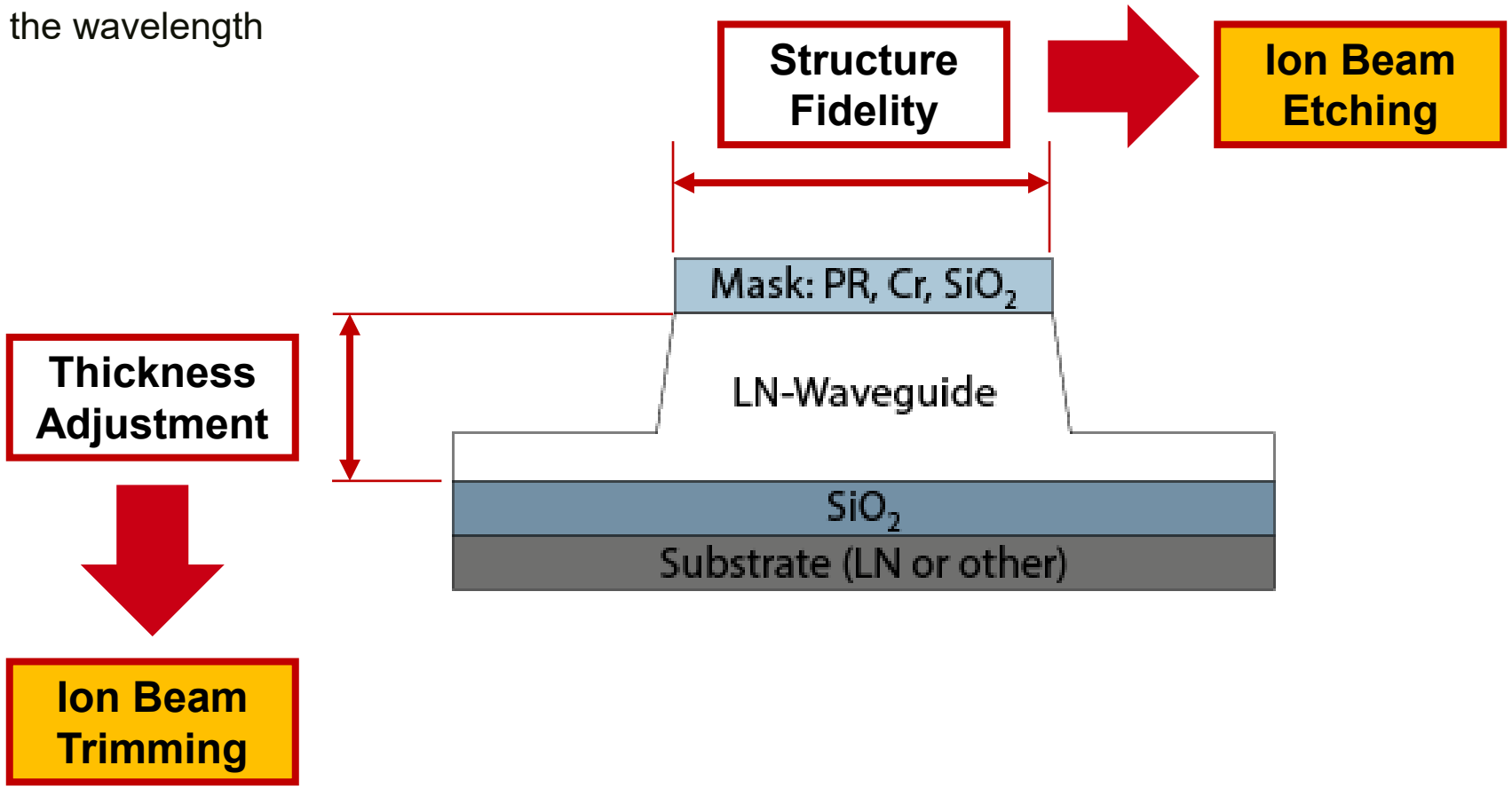


- **Improvement** of **Si_3N_4 thickness** standard deviation by factor of **~16x**
- **No change** in **roughness** or **refrefractive index**
  → **No increase in optical losses**

PIC Waveguide Performance

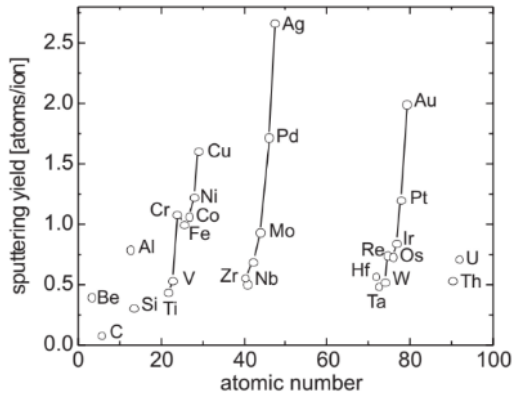
Requirements

- Optimized light transmission
- Dimensions have to fit to the wavelength
- Lowest losses
  - Total reflection
  - Low absorption
  - Low scattering
- High yield on wafers

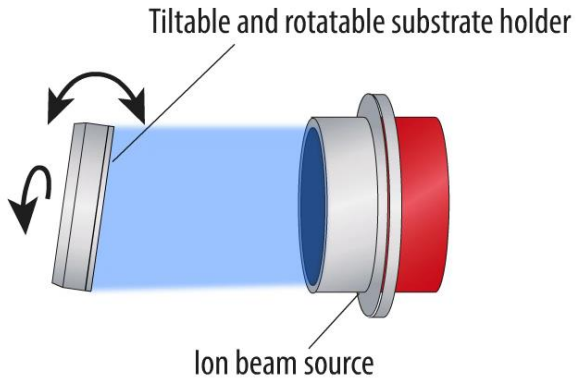


Basic Principle – Ion Beam Etching (IBE)

- Generation of ion beam by broad ion beam source
- Atoms of material are ejected by bombardment of high energetic ions
- Any material with a sufficient high melting point can be etched
  as well as multilayer stacks containing films with different chemical etch rates
- Ion Beam Milling (IBM)/Ion Beam Etching (IBE)
  by (mostly) noble gases and resulting physical sputter process
- Reactive Ion Beam Etching (RIBE)
  where reactive gas is directly supplied to ion beam source
  and combined physical and chemical process
- Chemically Assisted Ion Beam Etching (CAIBE)
  the reactive gas is injected as background gas and reactions
  driven by ions activating absorbed reactive gas species



Periodic dependency of the sputter yield for fixed ion energy (Ar^+, 400 eV)



Process arrangement of scia Mill 200

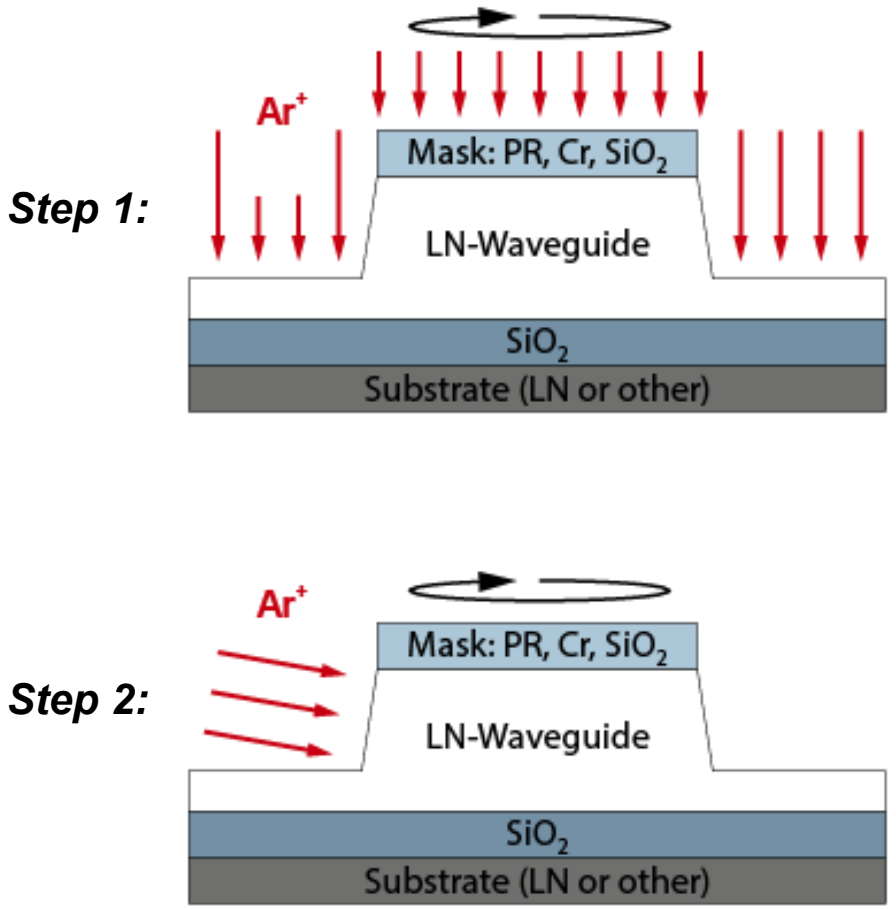
Photonic Waveguide Processing – Patterning of LN

Requirements:

- Patterning of Lithium Niobate ($LiNbO_3$) Waveguides
- Smooth sidewall, free of redeposition

Approach:

- 2-step etching process with
  - Step 1: Vertical LN etching
  - Step 2: Sidewall redeposition removal at lower incident angle
- Flexibility of IBE or RIBE dependent on process optimization
  - Inert process: Ar^+
  - Reactive process: CHF_3



2-step etching process for patterning of LN Waveguides

Photonic Waveguide Processing – Patterning of LN

Customer requirements:

- Etch LN waveguides using PR mask
- Sidewall >75°
- Low sidewall roughness, no redeposition

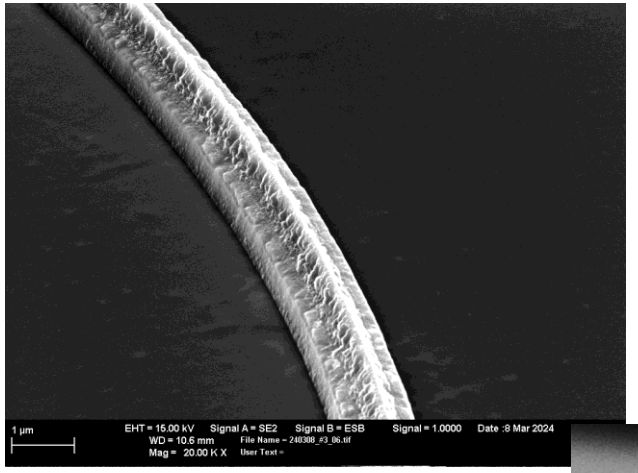
Challenge:

- Thermally unstable resist

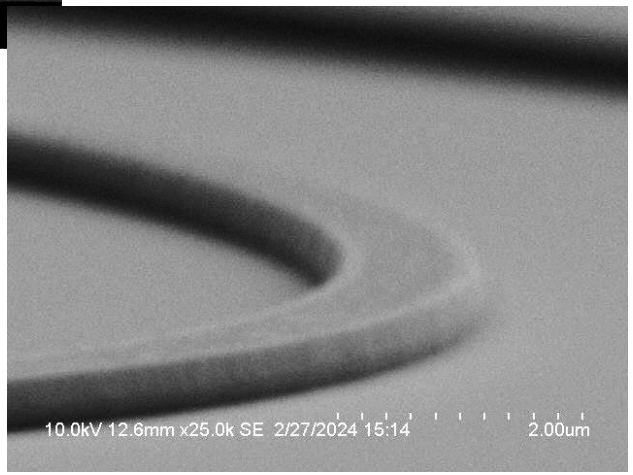
  → Mask reflows/shrinks

Final:

- Resist bake-out + cooling
- Recipe optimization



Patterned LN with reflow resist mask



LN structure after PR removal

How scia Systems Can Improve Your PIC

- Ion Beam Processing of a wide range of PIC-relevant materials, including dielectric films, compound semiconductors, high refractive index materials, and hybrid structures without defects or impairment of optical performance

scia Trim 200

Ion Beam Trimming of thin film $LiNbO_3$ or Si_3N_4 waveguides and SOI wafers

scia Mill 200

Reactive Ion Beam Etching for structuring of $LiNbO_3$ and Si_3N_4 waveguides

Visit us at SEMICON Europe
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Thank you!

scia Systems GmbH
Clemens-Winkler-Str. 6c
09116 Chemnitz
Germany

+49 371 33561-0
info@scia-systems.com

www.scia-systems.com