New materials and techniques for channeling of relativistic particles

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Geneva,9 December 2005

Outline

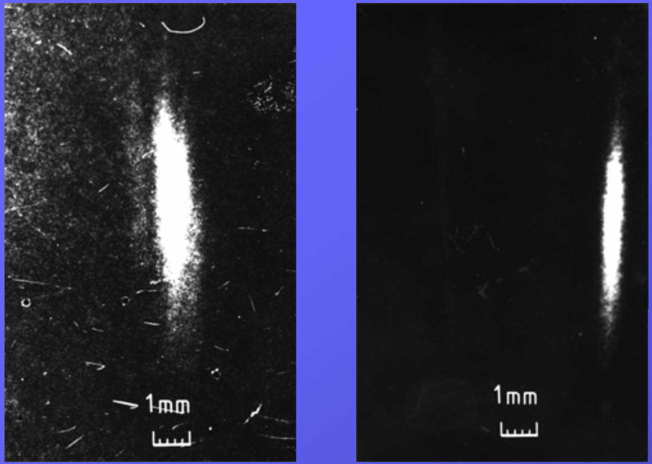
- Crystal fabrication
- Sample characterization
- Film with internal stress
- Novel materials for channeling
- Conclusions

Crystal preparation

Defects are induced by a dicing saw (a surface layer as thick as 30 μm is rich in scratches, dislocations, line defects and anomalies)

The samples are chemically polished by wet planar etching (HF,HNO_3,CH_3COOH).

70-GeV proton beam deflected by bent silicon crystals

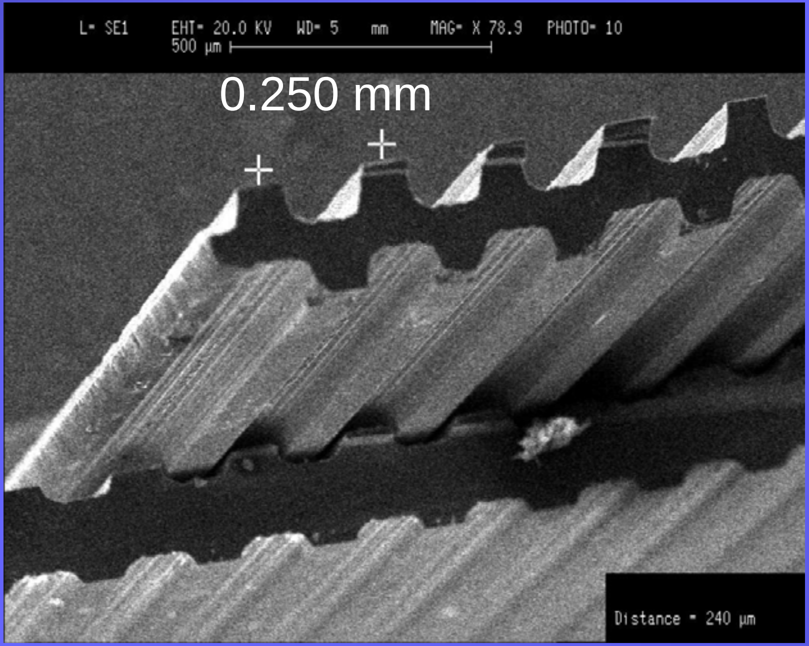


Mechanically polished

Chemically etched

Crystal Dicing

Samples are achieved by dicing a Silicon wafer



Dicing at various speed and with different grain size of the diamond powders results in samples with diverse features

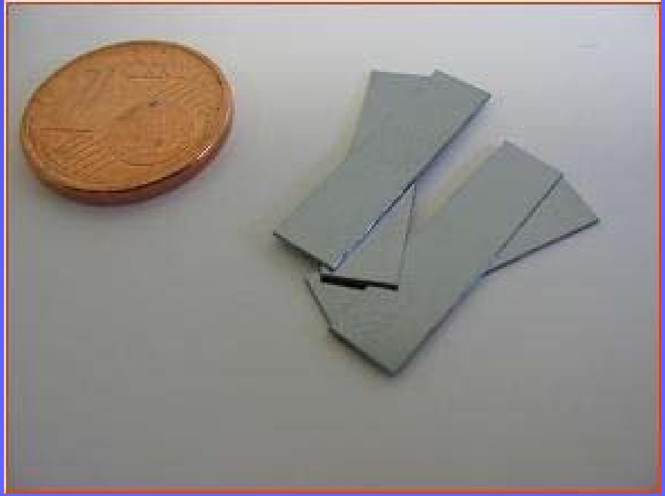
New lapping-polishing facility

Logitech lapping-polishing machine PM5

Logitech six-inch bonding station

Sample fabrication

Wafer dicing.....

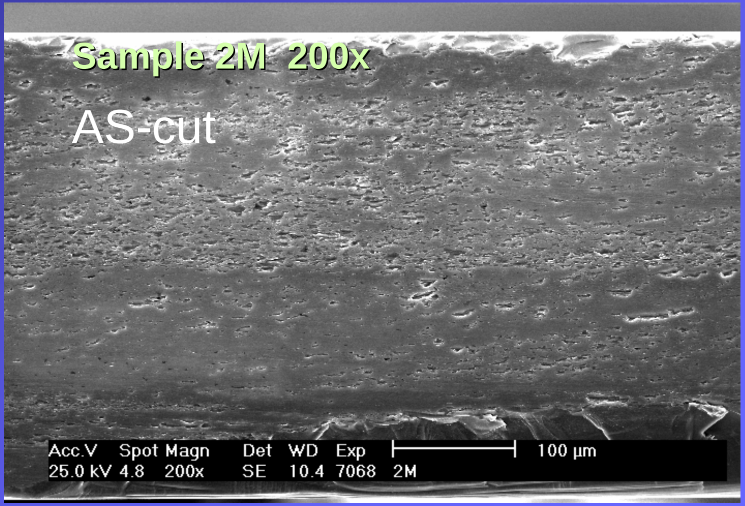


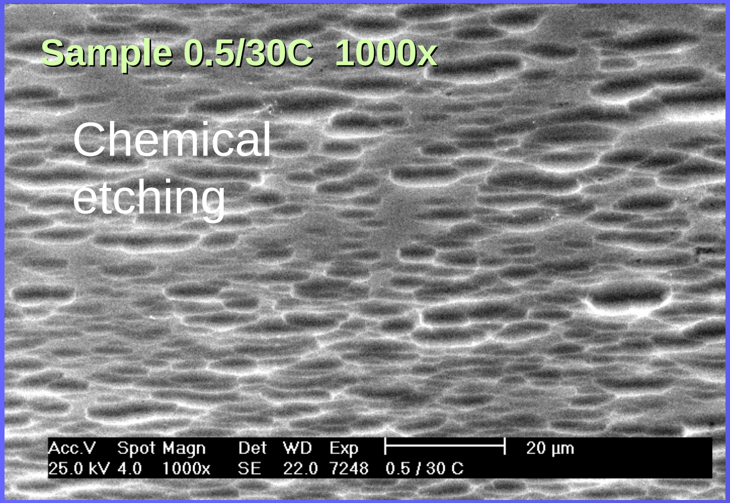
....assembling....

....mechanical treatment...

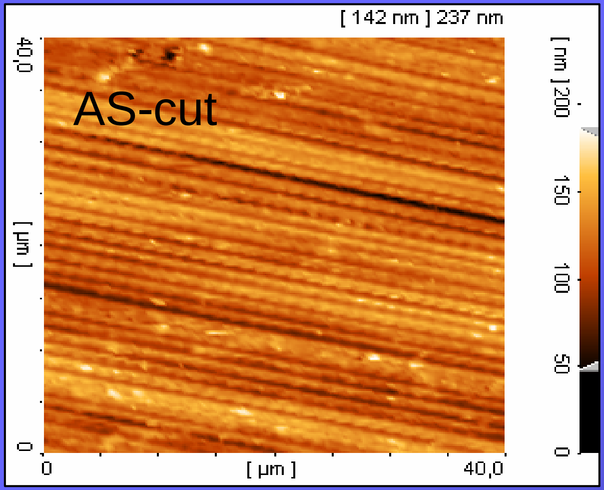
Chemical treatment

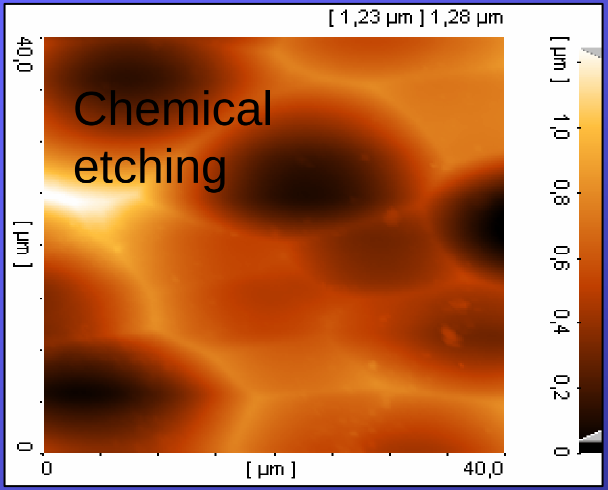
SEM and AFM- measurements



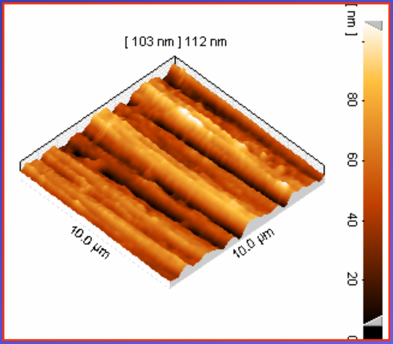


Chemical etching appears not to be performing…

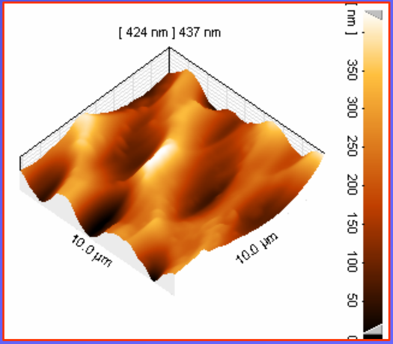




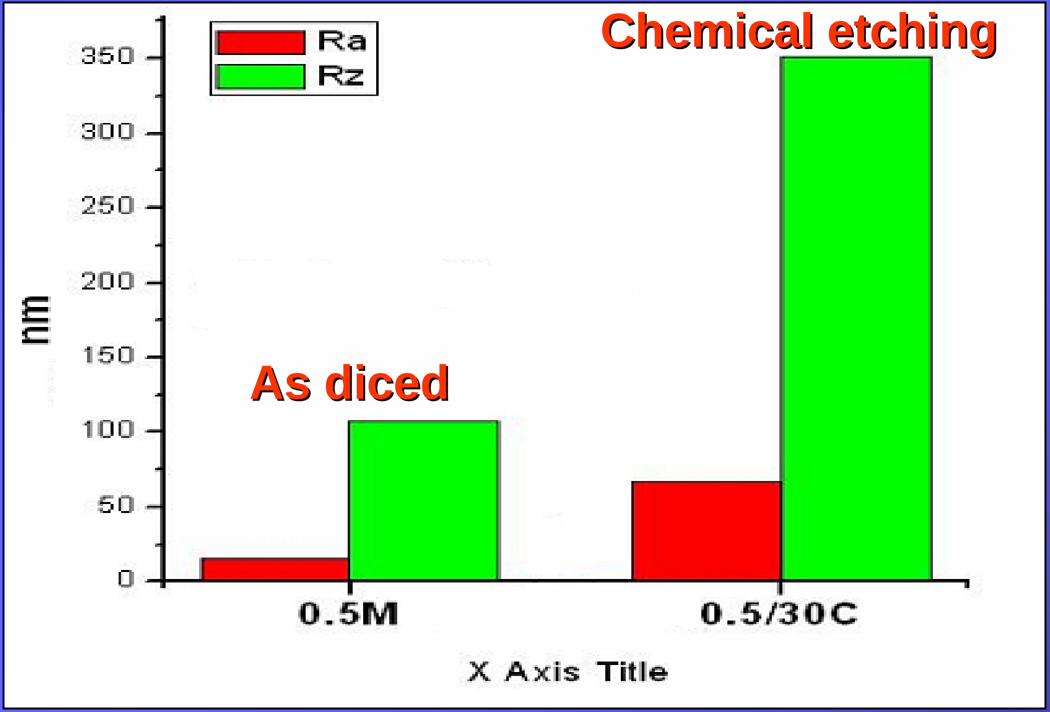
Morphological characterization



As diced

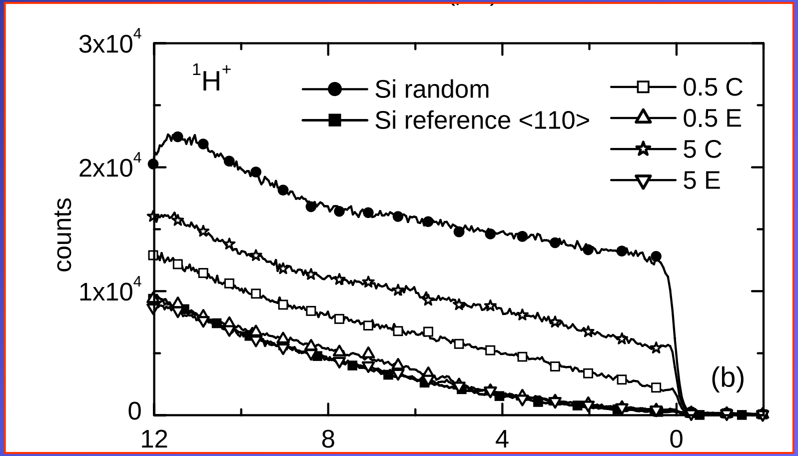


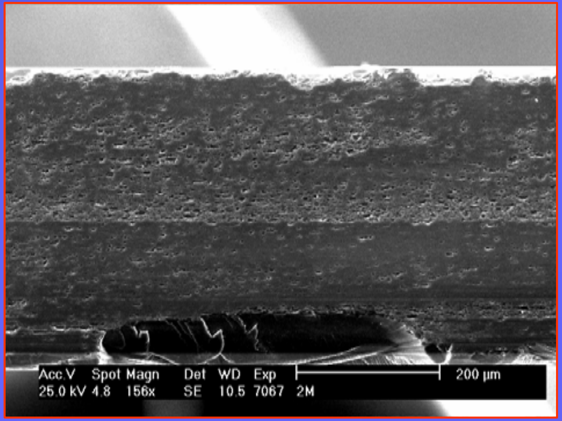
Chemical etching



Chemical polishing enhances standard roughness (R_a)

Structural characterization



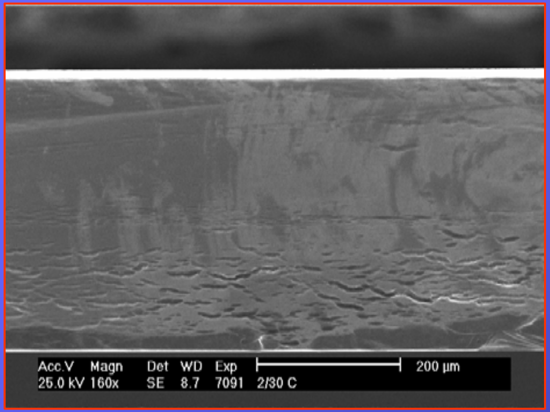


As diced

Rough and highly defected surface

RBS channeling results

- Successful correlation between surface crystalline perfection and post-dicing surface treatments
- Precise tailoring of sample preparation for crystal channeling



Chemical etching

Inhomogeneous surface BUT high crystalline degree

(Baricordi *et al*. APL 2005).

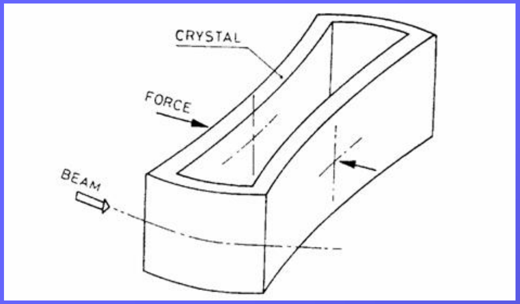
Characterization of samples from other labs

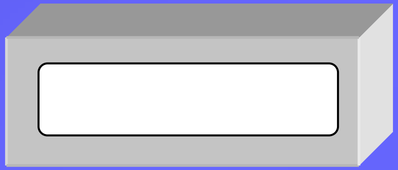
Labs

- IHEP (Russia)
- PNPI (Russia)

Samples

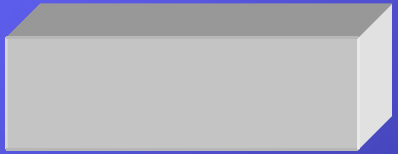
- O-shaped



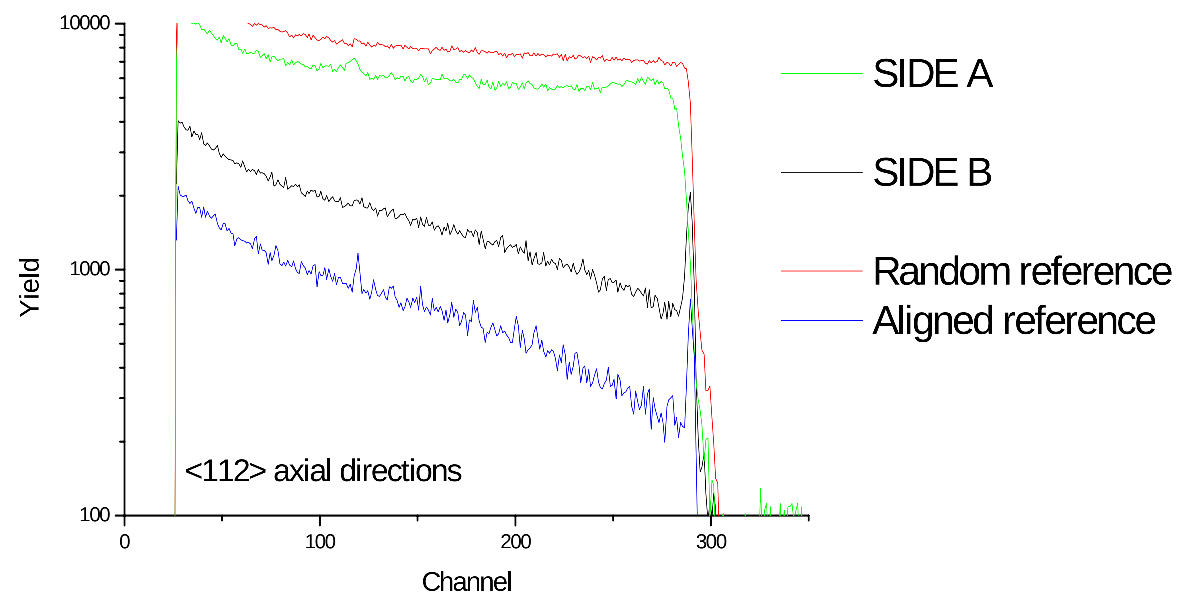


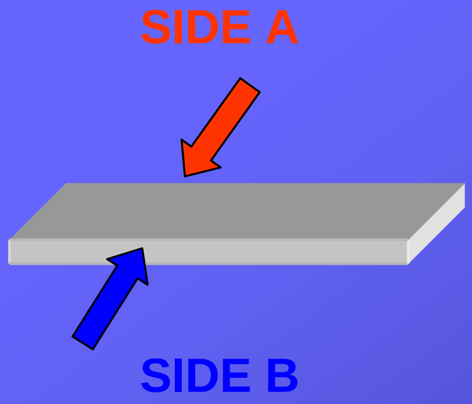
- Simple thin rod

- Thick rod



Example of RBS-channeling analysis

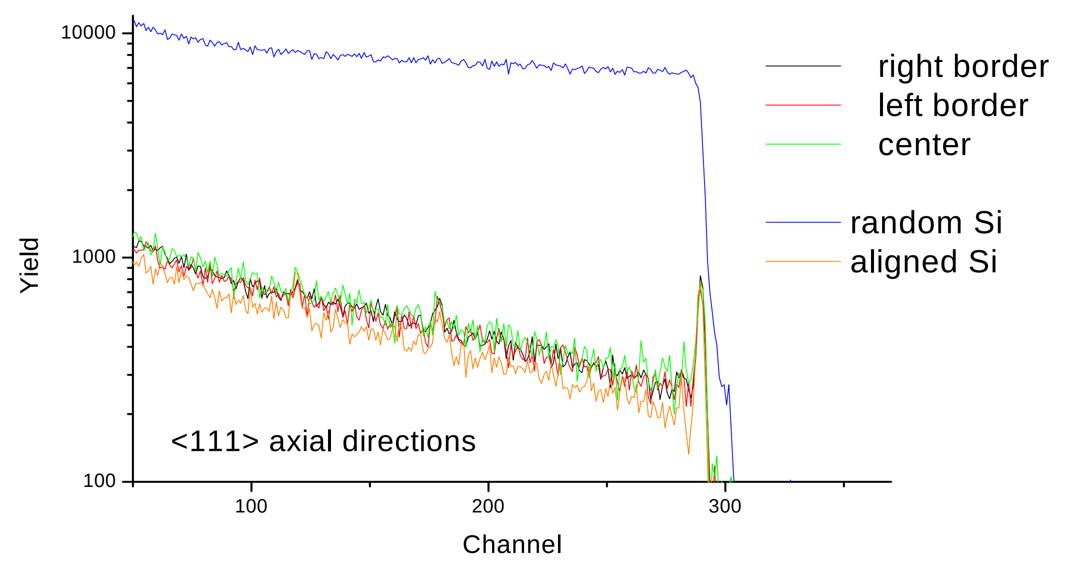


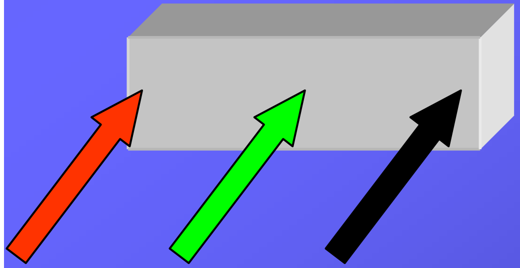


- Different degree of crystalline perfection between SIDE A (nearly amorphous) and SIDE B

- SIDE B presents a highly defected surface with respect to perfect reference crystal

Example of RBS-channeling analysis





- Investigation on 2D spatial defect distribution: nearly perfect overlap of the spectra indicates homogeneous spatial distribution of defects

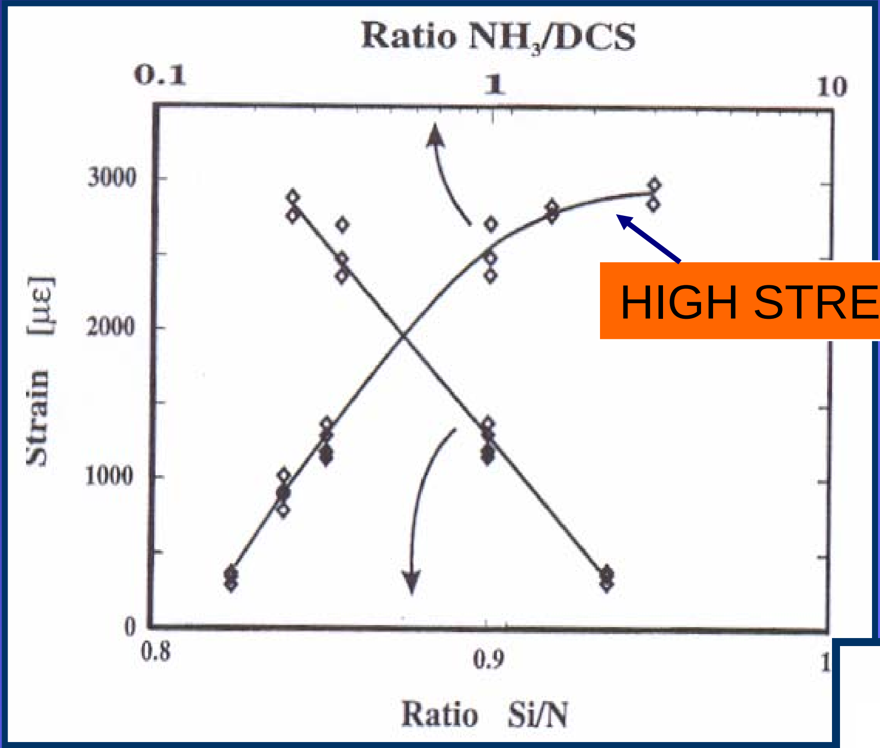
- The minimum yield is slightly higher than reference silicon, indicating low defects concentration and high crystalline order

Samples with internal stress: deposition of tensile thin films

A method for control of bending is obtained by a thin layer (or strips) of high stress intrinsic coating Si_3N_4.

Our goal was to identify the optimal parameters of Si_3N_4 film deposition via low-pressure chemical vapour deposition (LPCVD).

$$\boxed{3\,SiCl_2H_2 + 4\,NH_3 \xrightarrow{\sim 750^\circ C} Si_3N_4 + 6\,HCl + 6\,H_2}$$

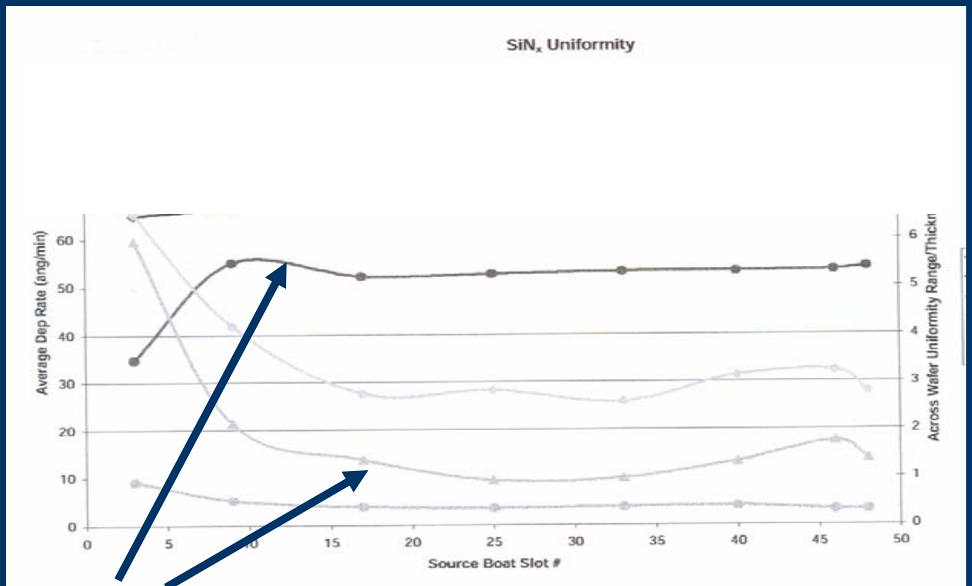


HIGH STRESS

To obtain a high residual stress the NH_3/DCS ratio must be higher than the unity, but...

a good film thickness uniformity requires a NH_3/DCS ratio lower than the unity.

A trade-off is needed



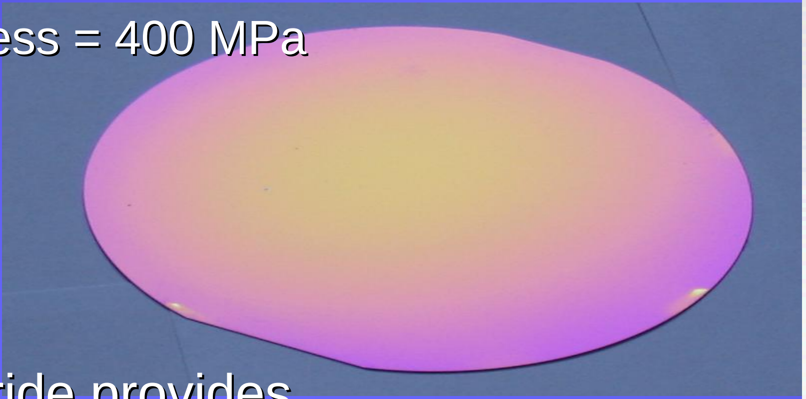
Slots 1 to 10 on the source end of the boat showed the highest degree of non-uniformity. e so This n eff

$NH_3/SiCl_2H_2 = 1:5$

Uniformity

Our LPCVD Parameters

- Pressure: 300 mTorr
- Temperature: 825°C
- $NH_3/SiCl_2H_2$: 0.2
- Film thickness: 187 nm
- Residual stress = 400 MPa

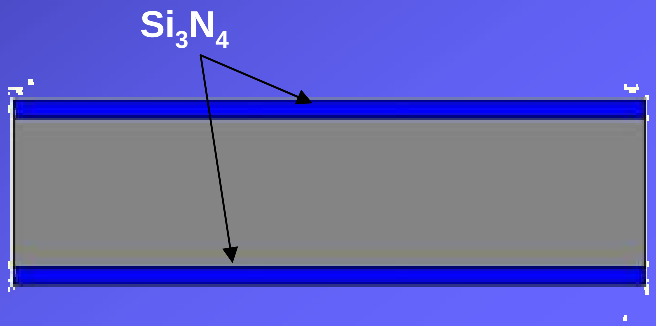


- Silicon nitride provides a tensile film with adjustable stess
- It does not alter crystal quality like with microindentations

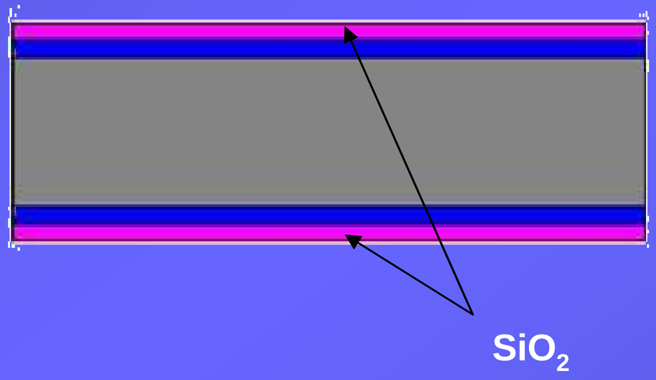
LPCVD reactor (LP-Thermtech) at Sensors and Semiconductor Laboratory

Deposition of Si_3N_4 layers

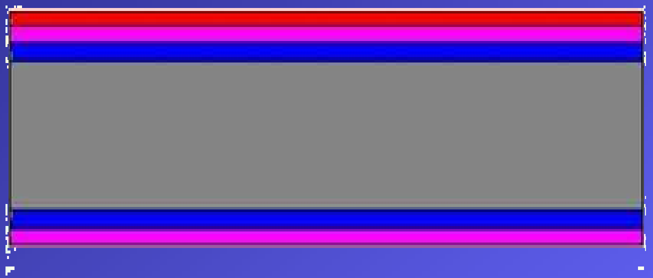
4” (111) oriented silicon wafer with thickness h=200μm is started



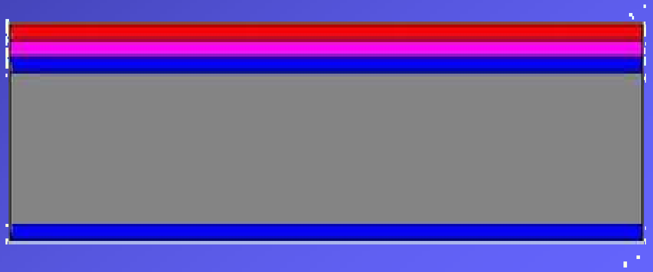
200-nm-thick Si_3N_4 coating is deposited by LPCVD on both sides of the wafer



SiO_2 masking layer is subsequently deposited onto the Si_3N_4 by LPCVD



Deposition of a photoresist on the top

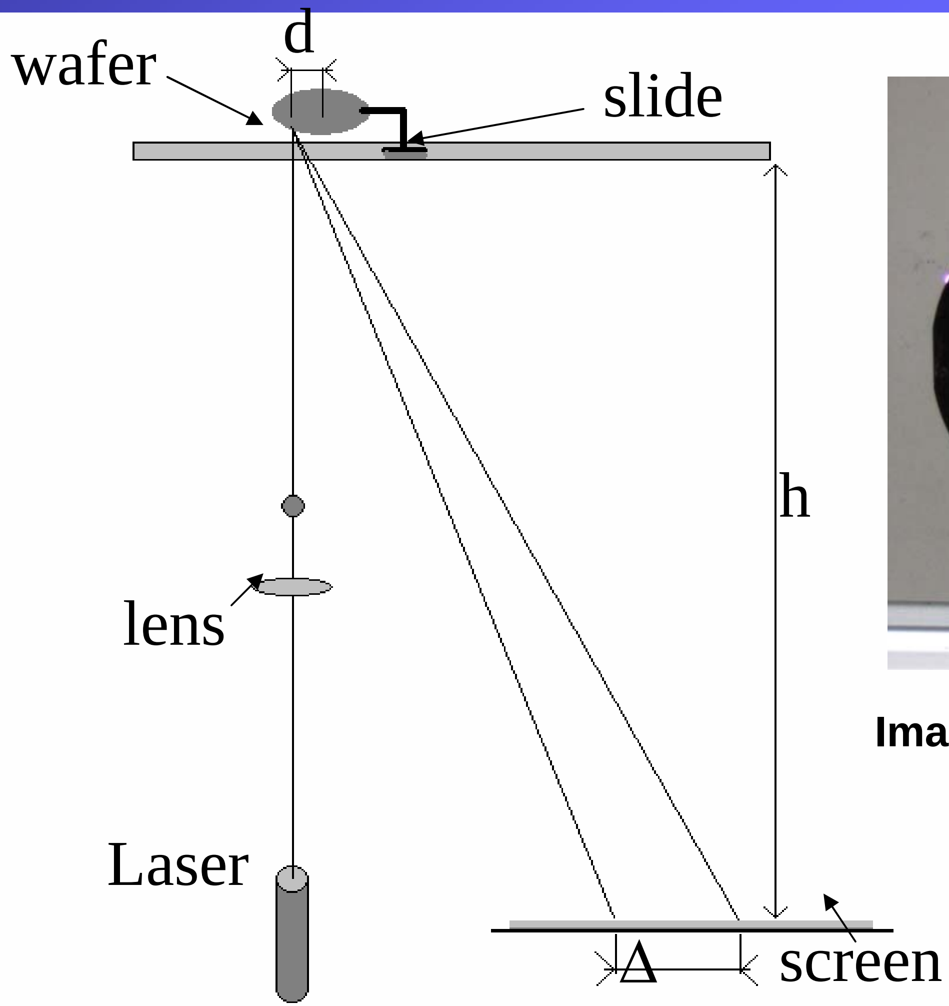


Selective etching of SiO_2 on the bottom by HF using the polymer as a selective mask

removal of the photoresist in acetone and removal of the Si_3N_4 in H_3PO_4

removal of SiO_2 on the top by HF. The tensile residual stress in silicon nitride (Si_3N_4) film induce a bending to the Si substrate

Optical characterization



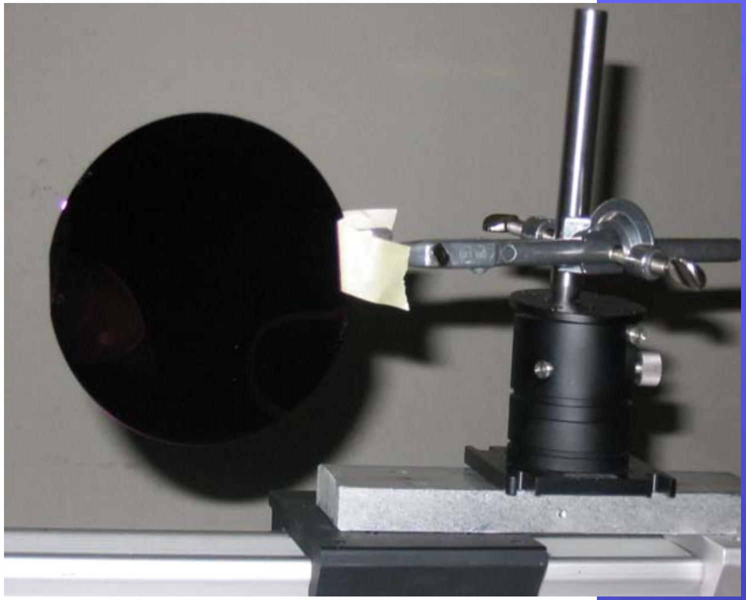
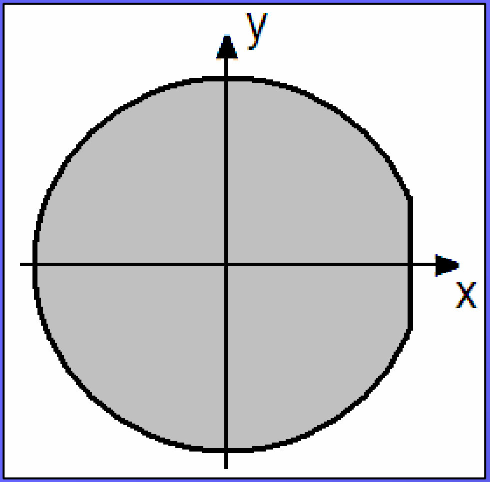


Image of the wafer holder

From Stoney equation:

$$\sigma_f = \left(\frac{E_s}{1-\nu}\right) \cdot \frac{d_s^2}{6R_f d_f}$$



Values of radius and residual stress:

Axes	wafer thickness (μm)	h (mm)	Δ (mm)	d (mm)	Radius R (m)	Young modulus Es (GPa)	Poisson	Film thickness (nm)	Residual stress (GPa)
x	200	5455	141	94	7,27	130	0,276	200	0,82
y	200	5455	133	80	6,56	130	0,276	200	0,91
								mean value	0,87
x	300	5450	52	72	15,09	180	0,276	200	1,24
y	300	5450	54	69	13,93	180	0,276	200	1,34
								mean value	1,29

Crystal bending through screen printing technique: preliminary samples

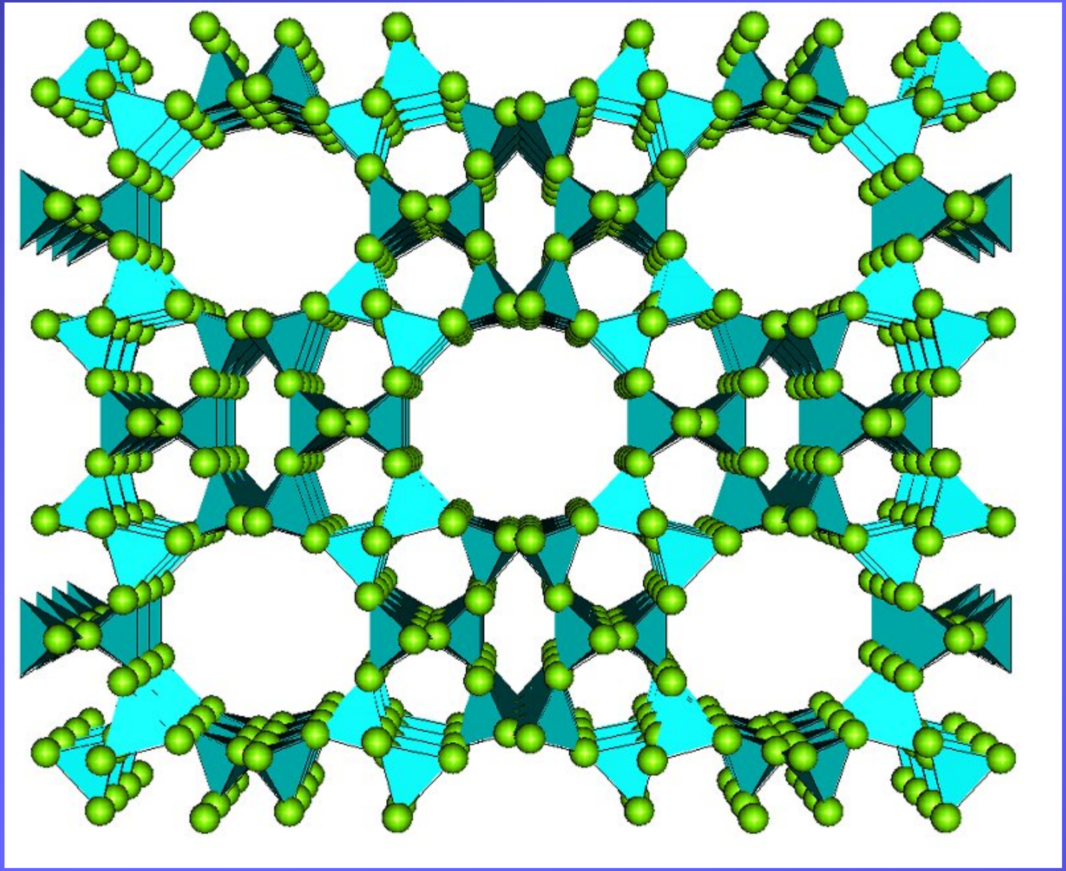
Screen printing technique: preliminary results

H (mm)	D (mm)	d (mm)	Radius of curvature (m)	Young modulus Es (GPa)	Poisson Sub	film thickness df (nm)	Residual Stress (GPa)		
5950	262	18	0.82	180	0.276	20000	0.10		
5950	272	15	0.66	180	0.276	20000	0.13		
5950	279	17	0.73	180	0.276	20000	0.11		
5950	240	14	0.69	180	0.276	20000	0.12		
5950	221	15	0.81	180	0.276	20000	0.10		
5950	183	14	0.91	180	0.276	20000	0.09		
							mean residual stress(GPa)		
							0.109160445		

Film thickness permits to obtain a radius

of curvature even smaller than 1 m

Novel crystals for channeling: zeolites



High acceptance for channeling in natural and artificial zeolites

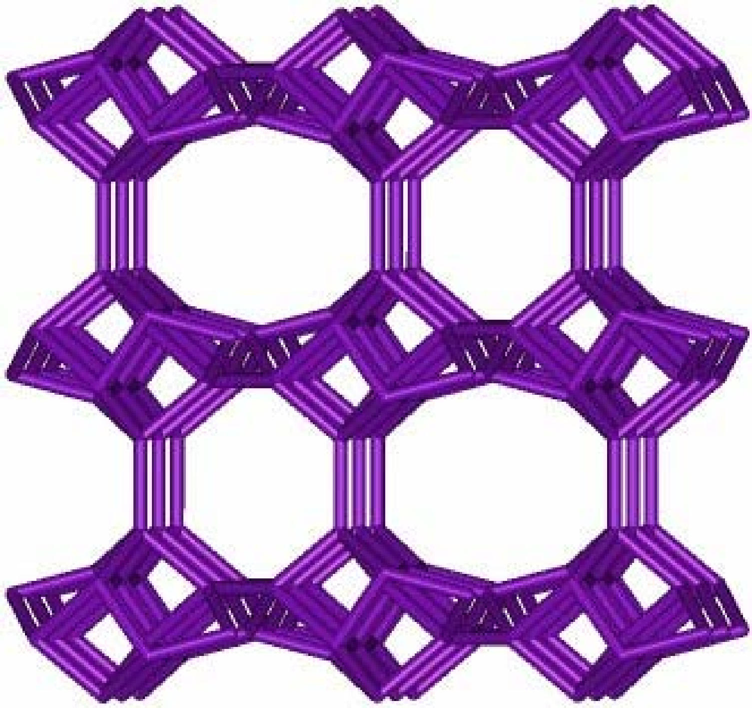
Simulation of potential candidates and characterization of samples

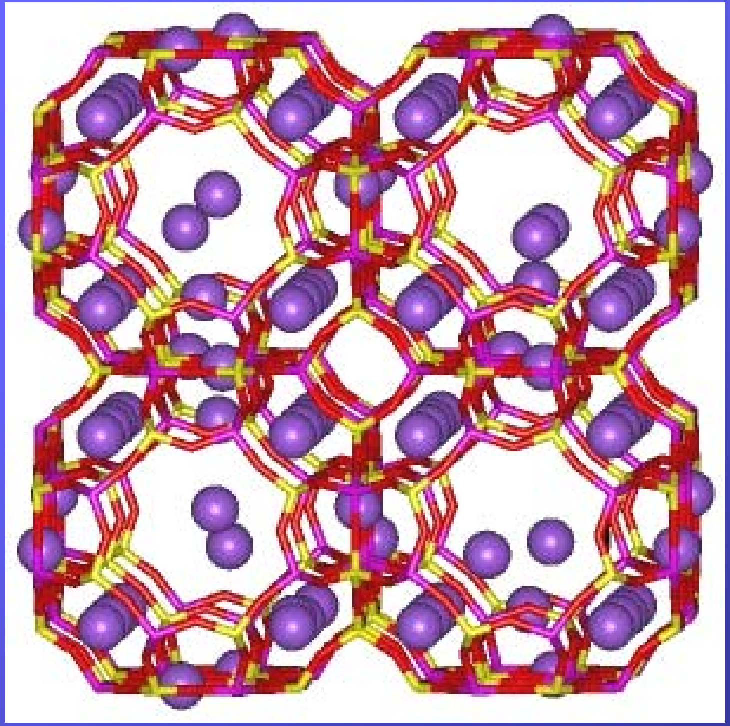
What a zeolite is?

Zeolite was the name given by the svedish mineralogist Cronstedt in 1756 to identify a class of natural minerals. On heating, desorption was so strong as it appeared as it were boiling (*zein* = to boil, *lithos* = rock).

Zeolite is…

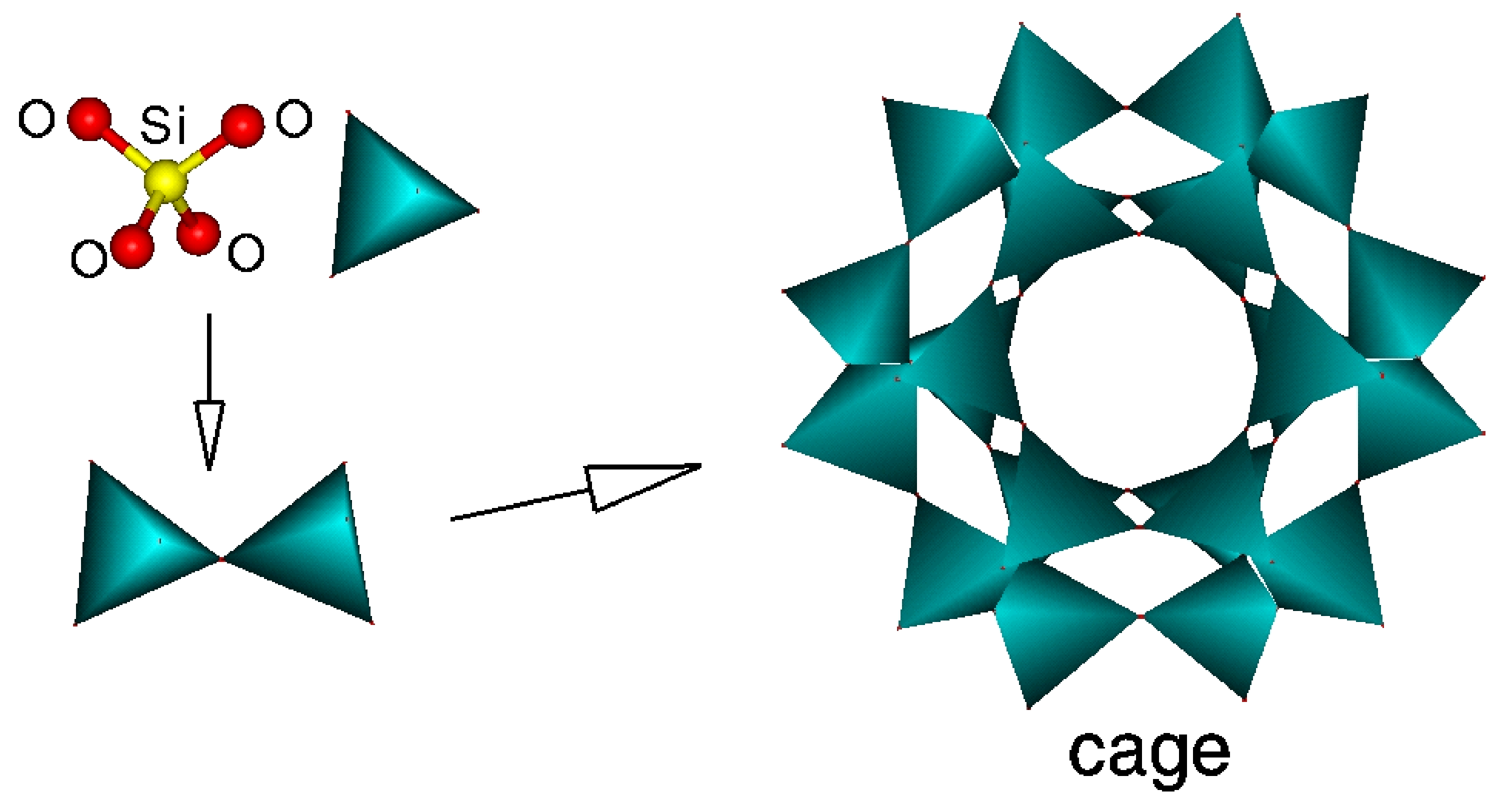
Smith (1963): aluminosilicate with open three-dimensional tetraedric framework, containg cavities partly occupied by ions and water molecules





More technically speaking…

The primary building unit is a coordination tetraedron



Zeolites for channeling?

- Selection of candidates with rectilinear channels, availability of natural or artificial relatively wide crystals
- Simulation of efficiency for channeling with existing codes (iNTAS)
- Tests for channeling with MeV protons

Conclusions

- Fabrication of silicon samples
- Morphological, structural and optical characterizations
- Search for novel materials