Channeling 2012

Deflection of MeV protons by an unbent half-wavelength silicon crystal

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Sensor and Semiconductor Laboratory

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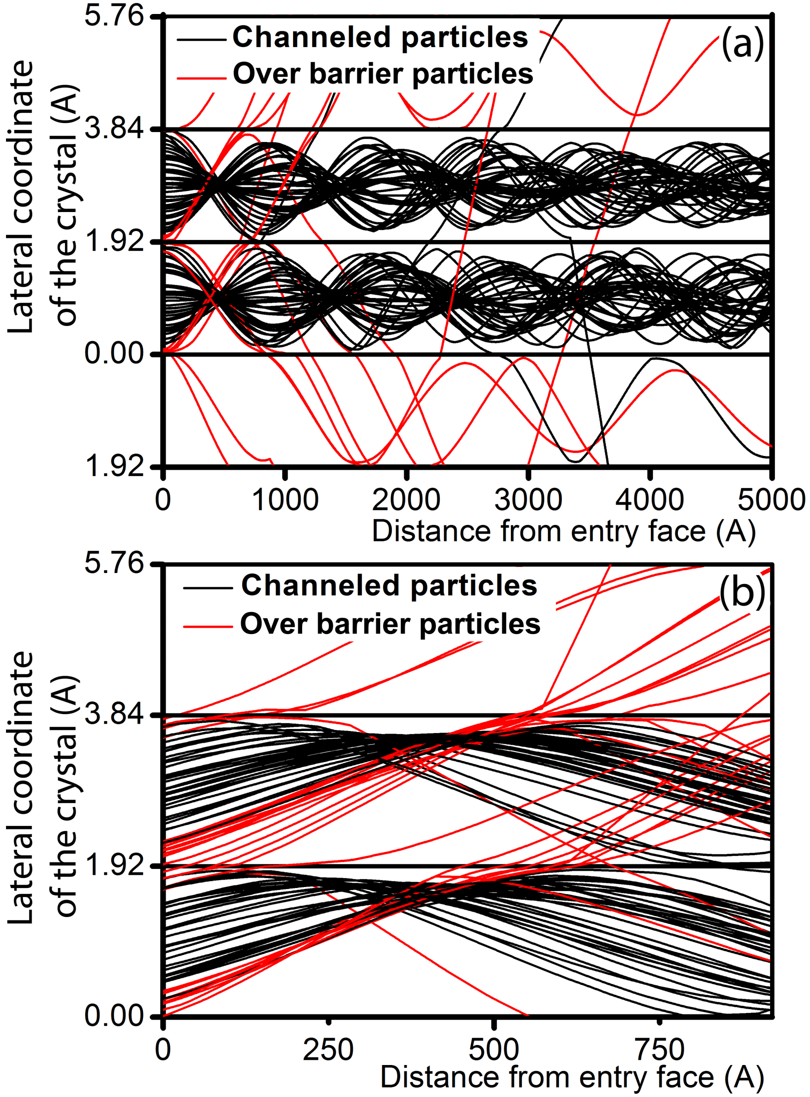
Outlook

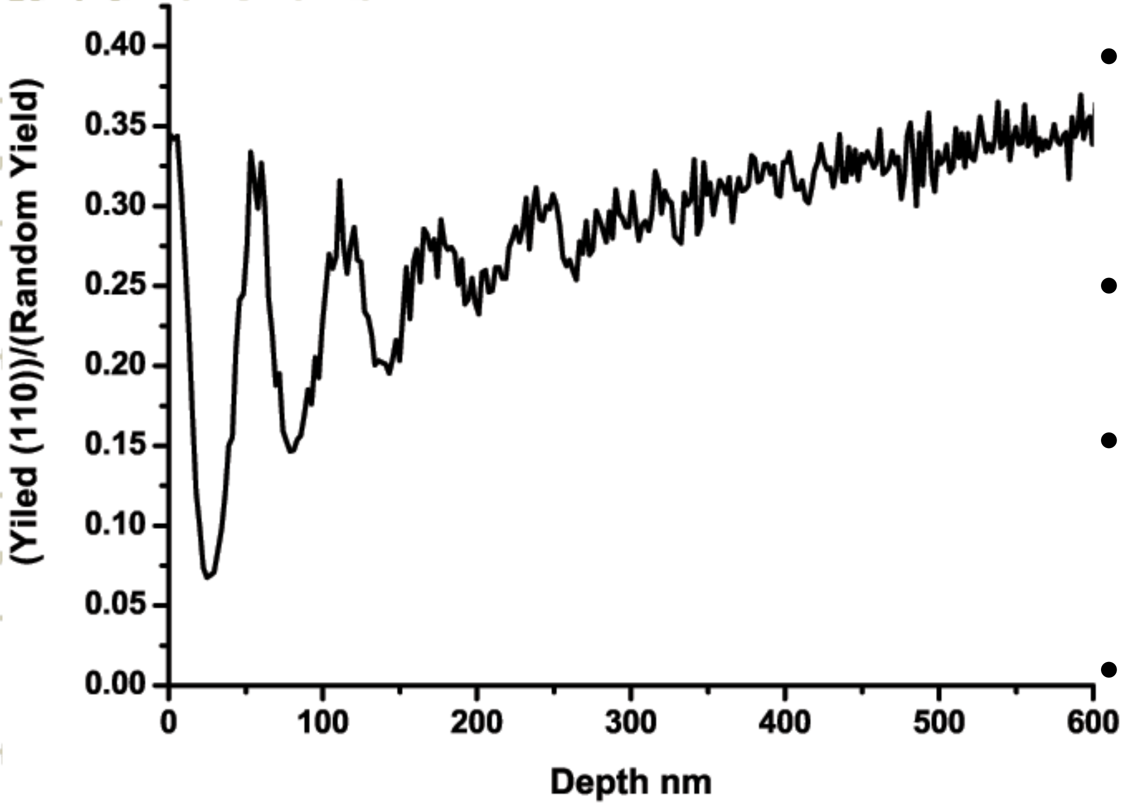
- Particles trajectories
- SIMOX structures
- Fabrication of large area silicon nano-membranes
- The experimental setup
- Experimental results

particles trajectories



- 2 MeV protons planar channeled between (110) Si planes
- Particles oscillates between atomic planes, λ ≅210 nm
- **Zero tilt between beam and crystal**
- **Tilt equal to half the planar critical angle**
- Expected deflection of channeled and over-barrier particle beam by an unbent crystal
- Idea from E. Tsyganov , A. Taratin, NIMA 363, (1995) 511-519

Channeled particles trajectories

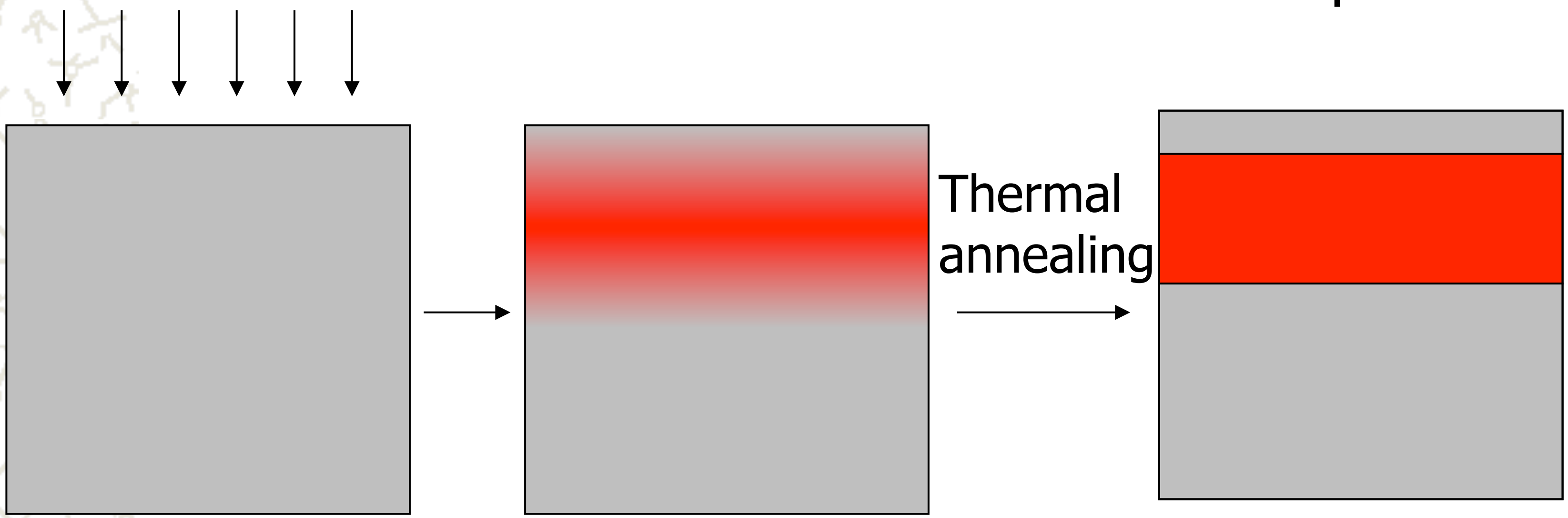


- 2 MeV He^{++} channeled between (110) planes.
- λ ~140 nm.
- planar oscillations clearly observed.
- Measument made at INFN-LNL labs.

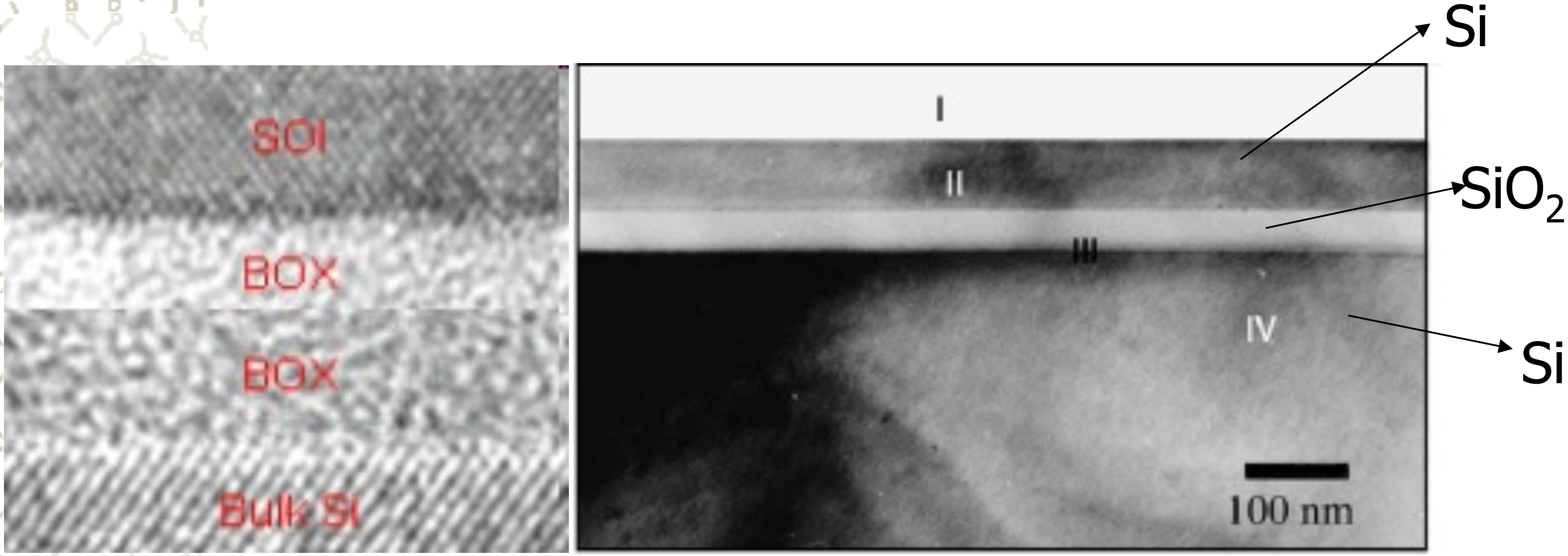
SIMOX structure I

Substrate heated at 650 °C and oxygen ions implantation

Thermal anneling at 1320 °C in O_2/Ar atmosphere



SIMOX structure II



- Thermal annealing restores silicon cristalline quality and creates a buried SiO_2 layer.
- Interfaces between Si and SiO_2 are well terminated.

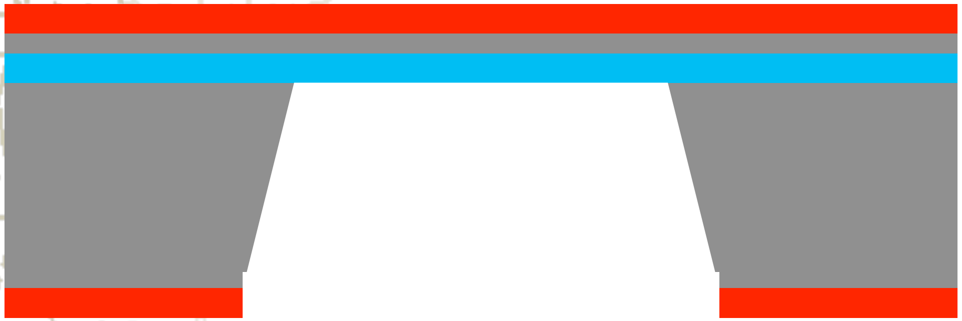
Fabrication of large area silicon nano thickness membranes

- SIMOX starting structure
  100 nm device layer
  400 nm box layer
  675 µm bulk layer

- LPCVD coating with silicon nitride

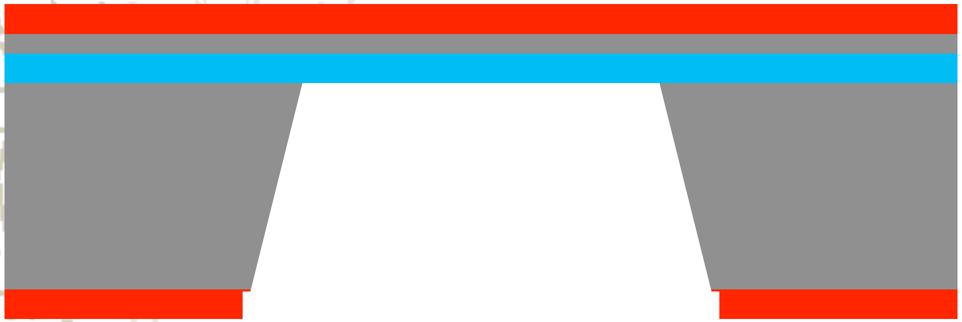
Fabrication of large area silicon nano thickness membranes

- Silicon nitride patterning with standard photolitographic techniques

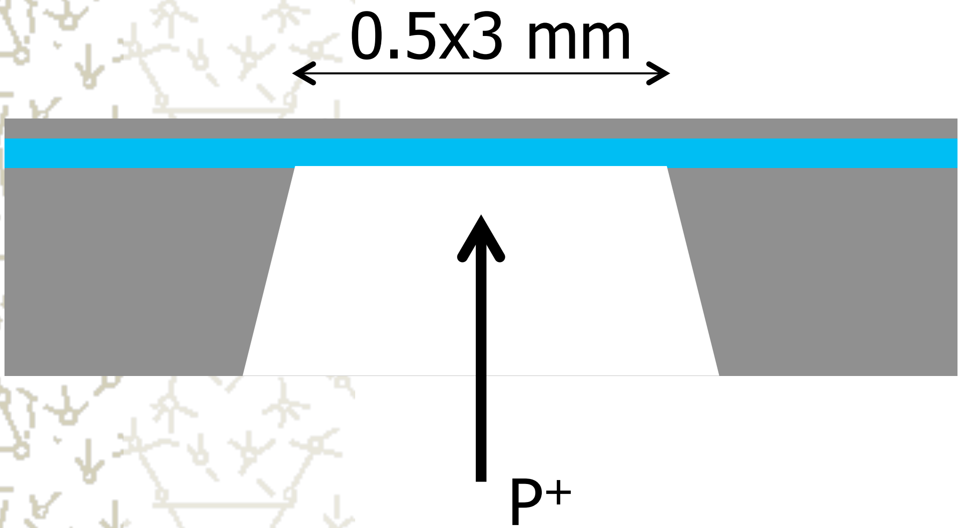


- Silicon anisotropic etch does not etch silicon nitride nor the SiO_2 layer

Fabrication of large area silicon nano thickness membranes

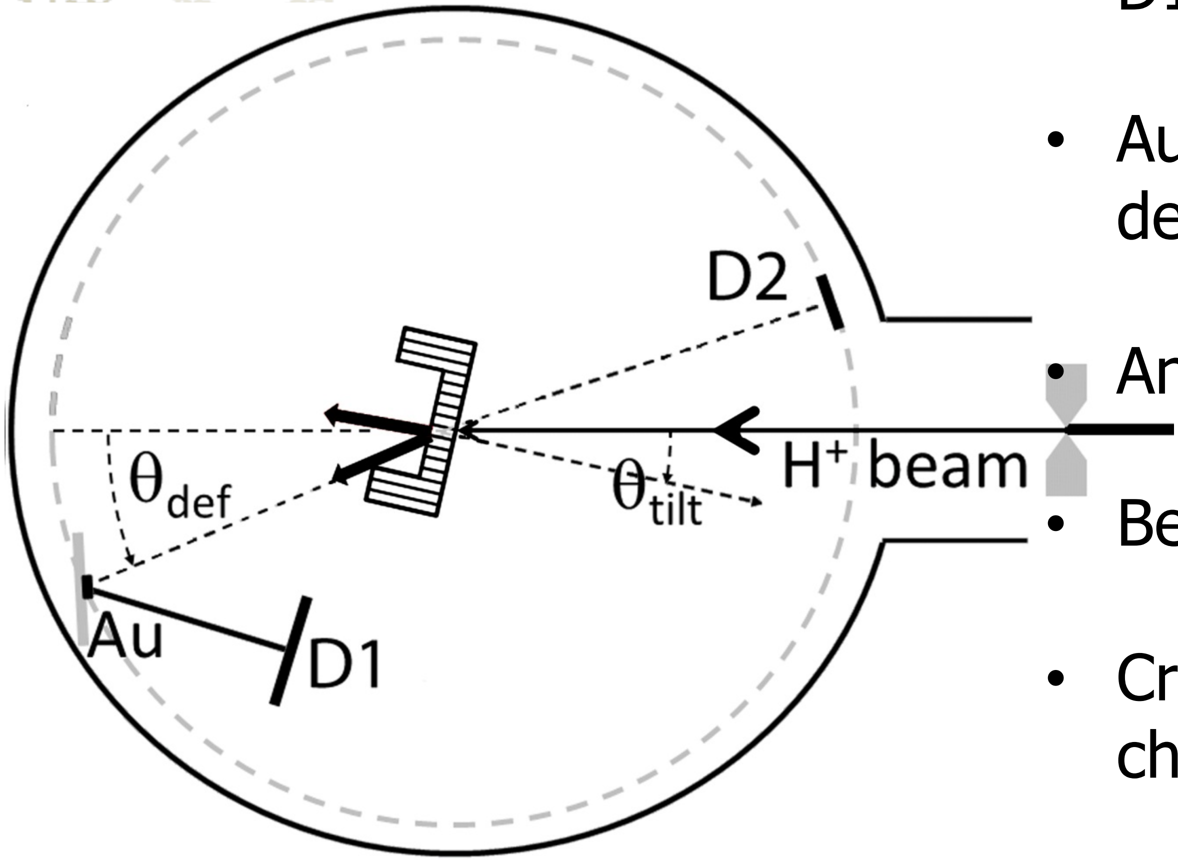


- Removal of the silicon nitride and silicon oxide layers



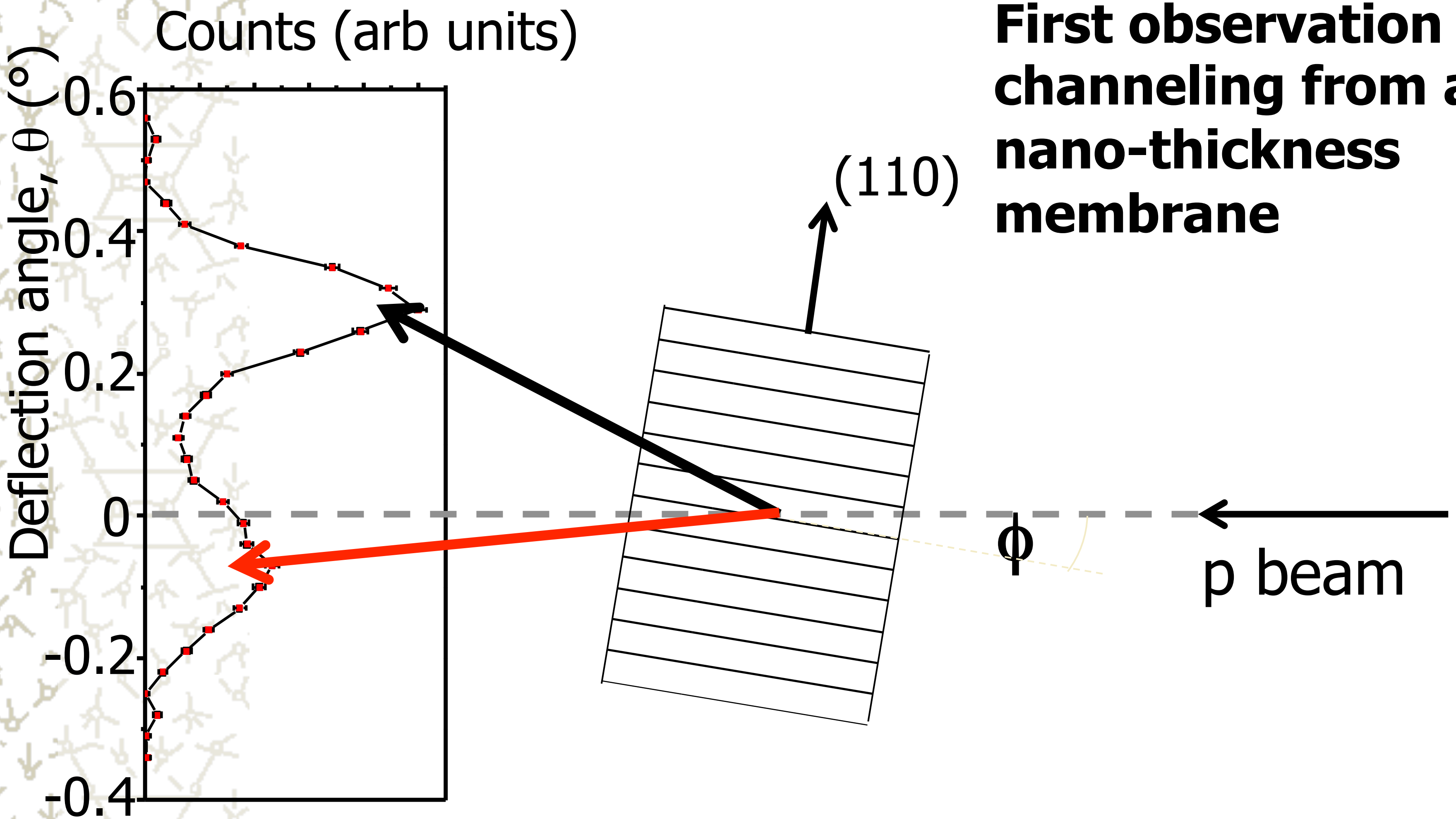
- Final membrane

The experimental setup



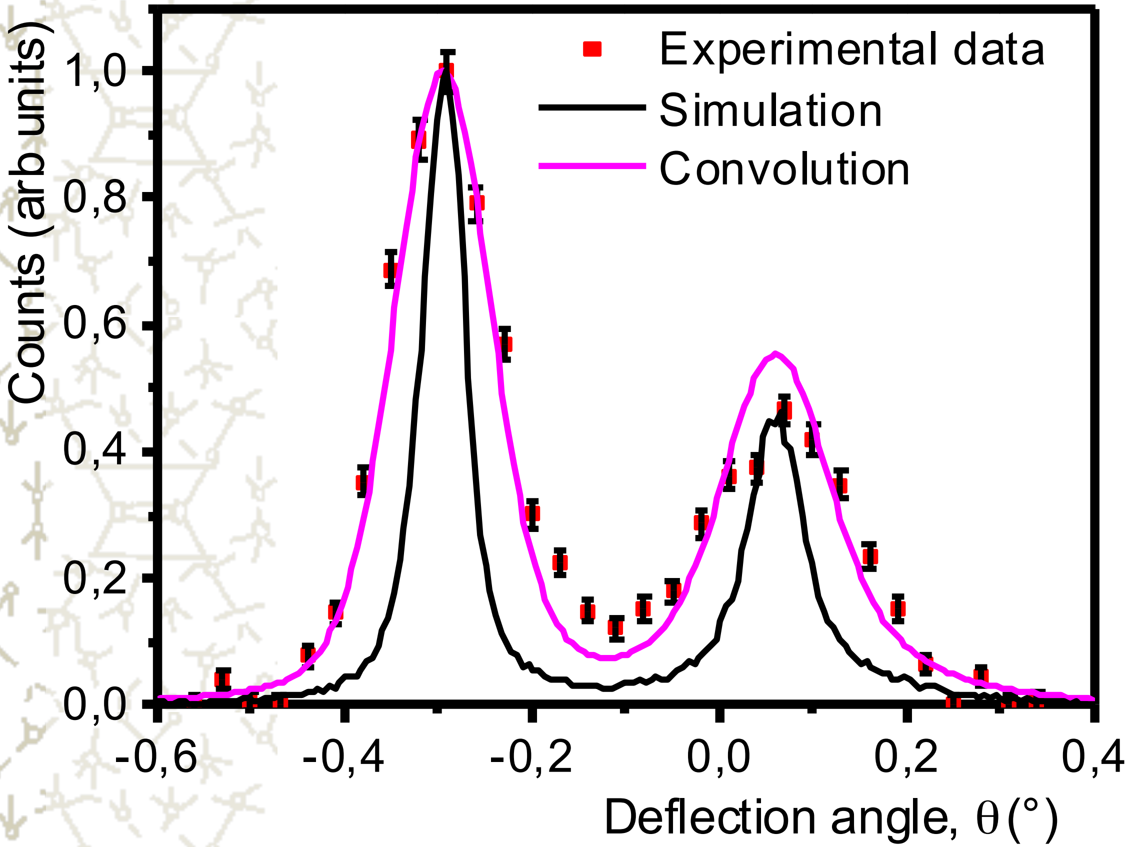
- D1-D2 pion-diode detectors
- Au gold target to probe the deflected beam
- Angular resolution 0.0042°
- Beam divergence 0.01°
- Critical angle for planar channeling ~0.3°
- Setup installed at INFN-LNL

Experimental results



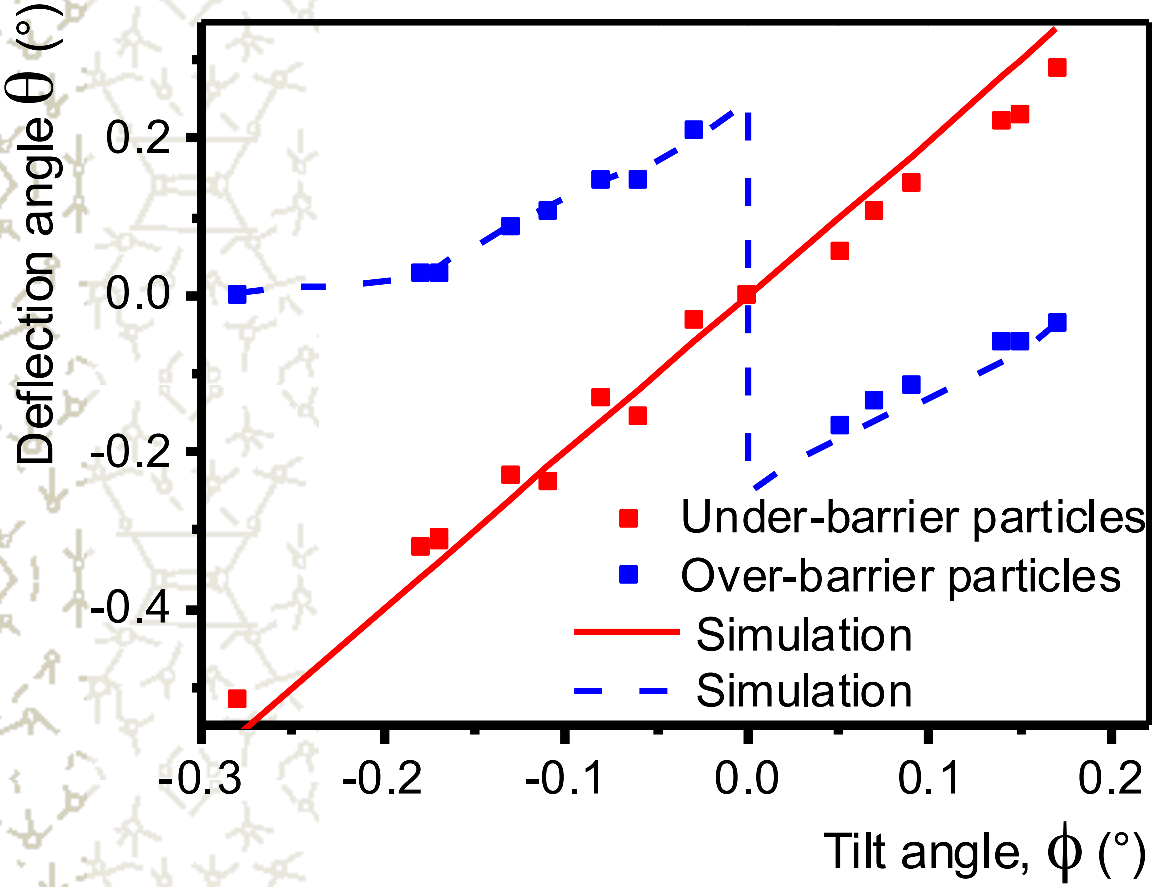
First observation of channeling from a nano-thickness membrane

Experimental results



- Tilt angle 0.15° (half of the critical angle)
- Deflection of channeled particles equal to two times the incidence angle (mirror effect)
- Deflection of over-barrier particles

Experimental results



- «Mirroring» of channeled particle particles clearly observed (red points)
- Deflection of over-barrier particles (blue points)

Conclusions

- We demonstrated that also flat crystals can deflect particles opening the route for a simpler steering strategy
- Deflection by crystals can be realized also at low energies (never demonstrated before), in this regime there is interest for analytical and medical applications.
- Possible applications for high energy beam steering and for studies of radiation emission in ultra-thin crystals.

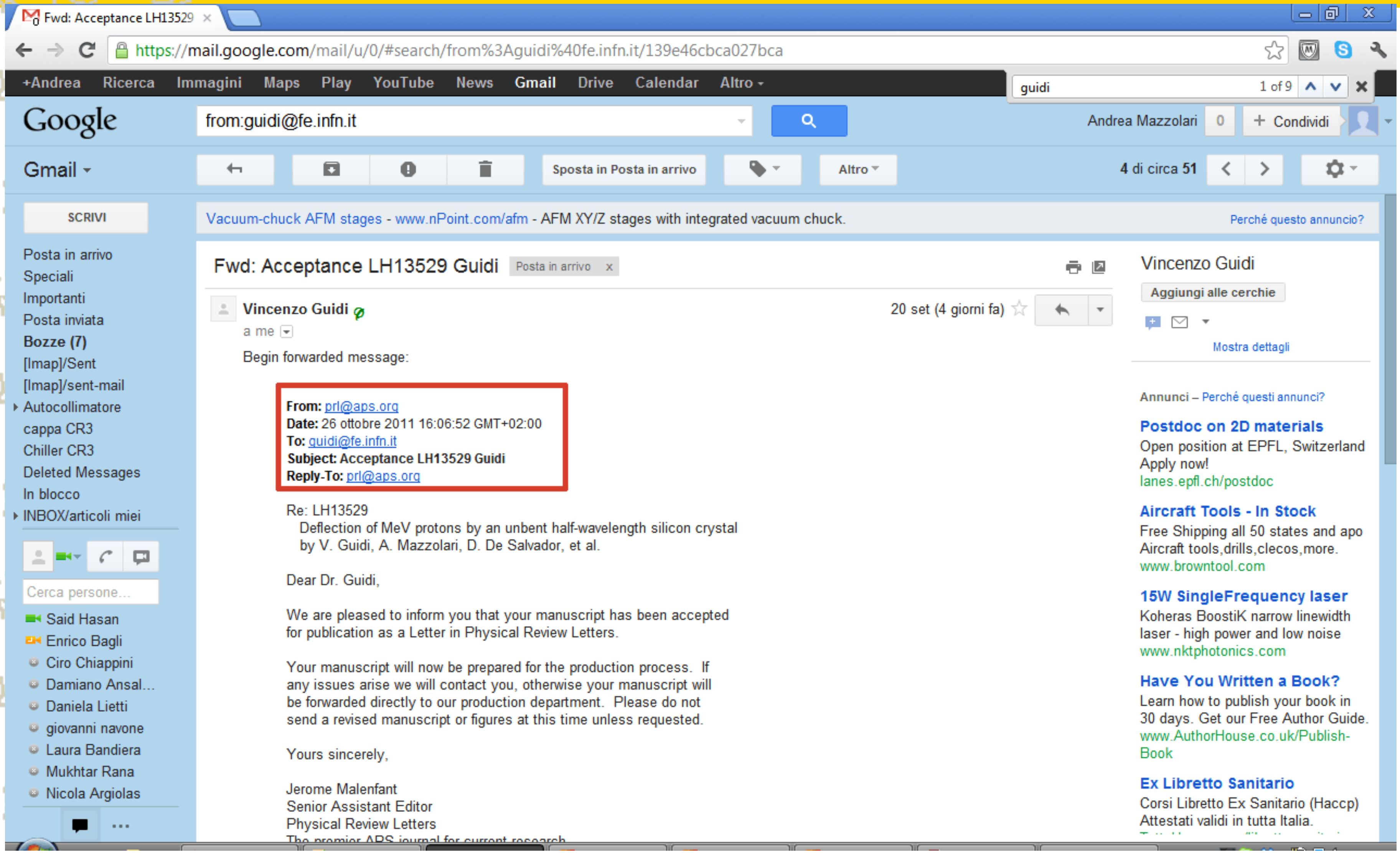
Thank you

Thank you for you attention

Recent papers

	V. Guidi et al. PRL 108, 014801 (2012)	Z. Y. Dang et al, APL 99, 223105 (2011)
Submission date	27 August 2011	3 November 2011
Acceptance date	26 October 2011	14 November 2011
Publishing date	3 January 2012	1 December 2011

Recent papers



Recent papers

34-Deflection of MeV Protons by an Unbent Half-Wavelength Silicon Crystal.pdf - Adobe Reader

PRL 108, 014801 (2012) PHYSICAL REVIEW LETTERS week ending 6 JANUARY 2012

Deflection of MeV Protons by an Unbent Half-Wavelength Silicon Crystal

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(Received 27 August 2011; published 3 January 2012)

The interaction of a 2 MeV proton beam with an ultrathin unbent Si crystal was studied through simulation and experiment. Crystal thickness along the beam was set at 92 nm, i.e., at half the oscillation wavelength of the protons in the crystal under planar channeling condition. As the nominal beam direction is inclined by less than the critical angle for planar channeling with respect to the crystal planes, under-barrier particles undergo half an oscillation and exit the crystal with the reversal of the transverse momenta; i.e., the protons are "mirrored" by the crystal planes. Over-barrier particles suffer deflection, too, to a direction opposite that of mirroring with a dynamics similar to that of volume reflection in a bent crystal. On the strength of such coherent interactions, charged particle beams can be efficiently steered through an ultrathin unbent crystal by the same physical processes as for thicker bent crystals.

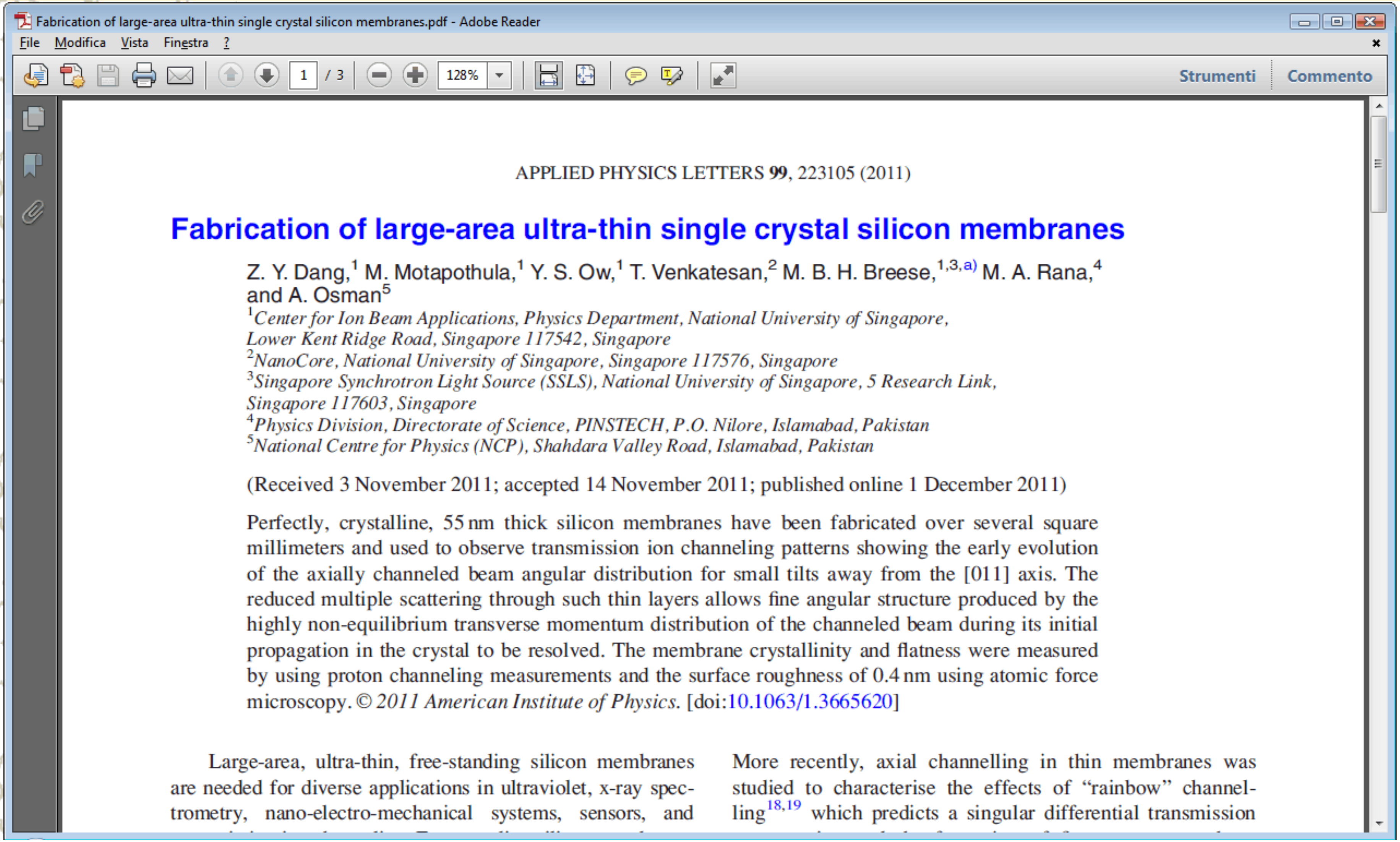
DOI: 10.1103/PhysRevLett.108.014801 PACS numbers: 29.27.−a, 42.79.Ag, 61.85.+p

As a charged particle impinges onto a crystal within the "critical angle" θ_c, with respect to a major atomic plane or axis, coherent interactions with the atoms of the crystal take place, resulting in particle capture with high proba-

wavelengths in the crystal. Such crystals also led to the experimental demonstration of VR [10,16], which was predicted about 25 years earlier by Taratin and Vorobiev [21].

On the strength of their high efficiency for planar chan-

Recent papers



APPLIED PHYSICS LETTERS **99**, 223105 (2011)

Fabrication of large-area ultra-thin single crystal silicon membranes

Z. Y. Dang,[1] M. Motapothula,[1] Y. S. Ow,[1] T. Venkatesan,[2] M. B. H. Breese,[1,3,a)] M. A. Rana,[4] and A. Osman[5]
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Perfectly, crystalline, 55 nm thick silicon membranes have been fabricated over several square millimeters and used to observe transmission ion channeling patterns showing the early evolution of the axially channeled beam angular distribution for small tilts away from the [011] axis. The reduced multiple scattering through such thin layers allows fine angular structure produced by the highly non-equilibrium transverse momentum distribution of the channeled beam during its initial propagation in the crystal to be resolved. The membrane crystallinity and flatness were measured by using proton channeling measurements and the surface roughness of 0.4 nm using atomic force microscopy. © *2011 American Institute of Physics*. [doi:10.1063/1.3665620]

Large-area, ultra-thin, free-standing silicon membranes are needed for diverse applications in ultraviolet, x-ray spectrometry, nano-electro-mechanical systems, sensors, and

More recently, axial channelling in thin membranes was studied to characterise the effects of "rainbow" channelling[18,19] which predicts a singular differential transmission