IMAGING OF SUBSURFACE NANOSTRUCTURES VIA BEAM-EXIT CROSS-SECTIONAL POLISHING (BEXP) AND ULTRASONIC FORCE MICROSCOPY

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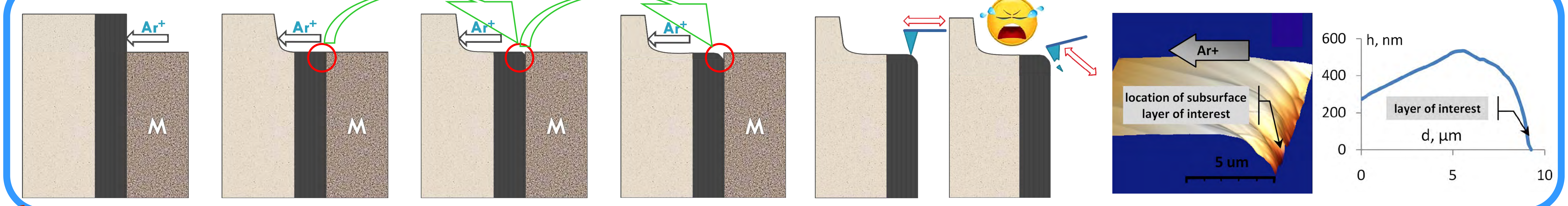
Abstract:

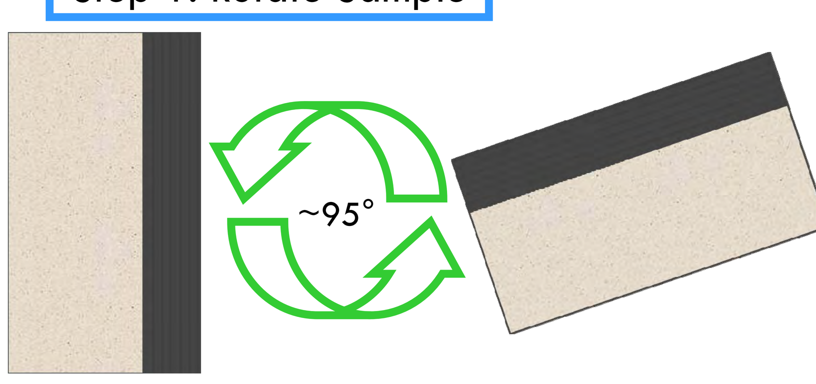
Whereas scanning probe microscopy is well respected for its nanometre scale resolution and sensitivity to surface properties, it generally cannot image solid state nanostructures under the immediate sample surface. Existing methods of X-sectioning (focused ion beam, mechanical and Ar ion polishing) either cannot provide a required surface quality or cannot enable the user to select the area of section freely. In this paper we present a novel method of Ar ion beam cross-section polishing via beam exiting the sample. In this approach the sample is tilted at a small angle with respect to the ion beam that enters from underneath the surface of interest and exits at a glancing angle. This creates an almost perfect nanometre scale flat cross-section with close to open angle prismatic shape of polished and pristine sample surfaces ideal for SPM imaging. Using the new method and material sensitive ultrasonic force microscopy we mapped the internal structure of quantum dot Superlattice structures of 18 and 50 nm layer periodicity with depth resolution on the order of 5 nm, mapped internal density distribution and substrate interface of a fragile Mezoporous Si 0.5um layer and we also report using this method to reveal details of interfaces in VLSI low-k dielectric interconnects, as well as discuss performance of the new approach for SPM/SEM studies of nanostructured materials and devices.

Prior Art Ion Beam Polishing

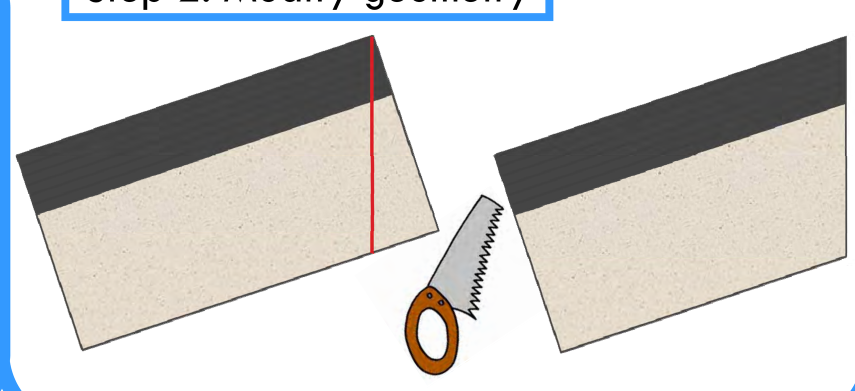


Beam Exit X-section Polishing (BEXP)

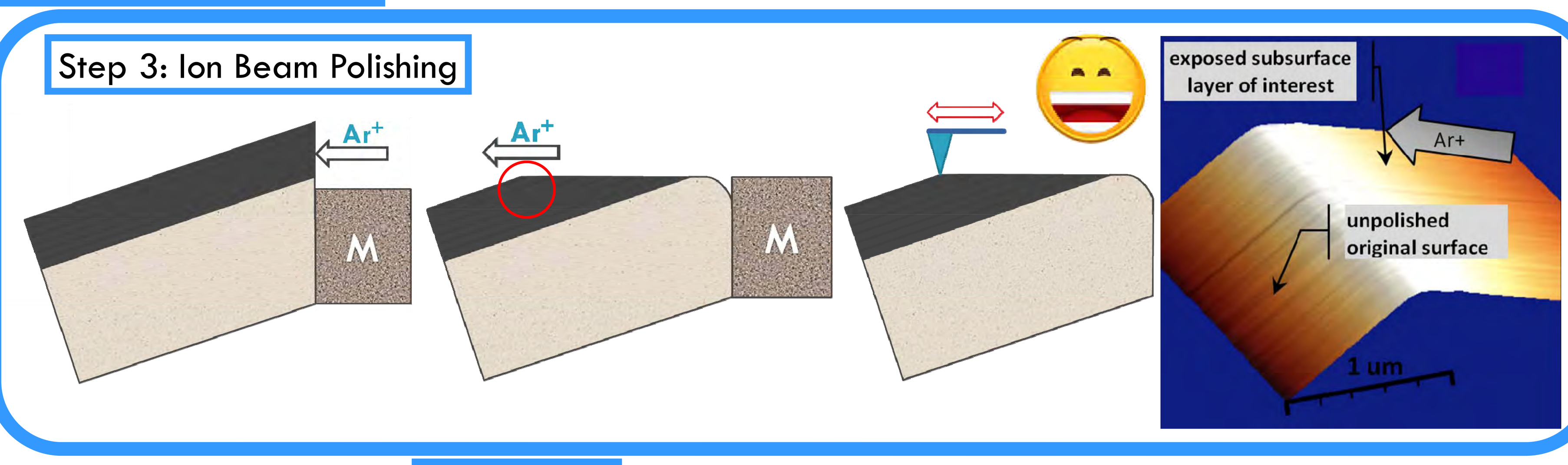
Step 1: Rotate Sample



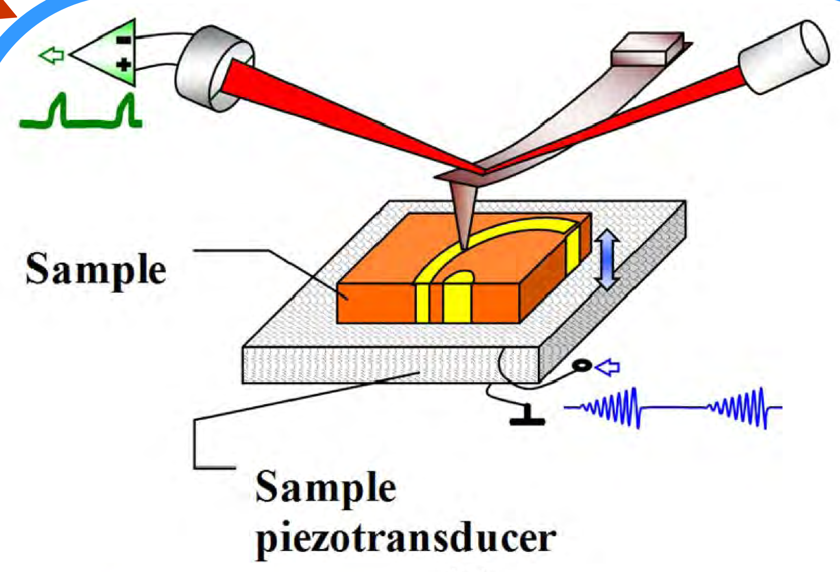
Step 2: Modify geometry

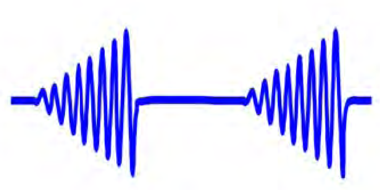


Step 3: Ion Beam Polishing

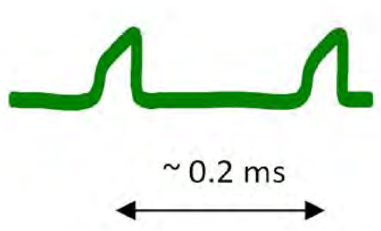


Ultrasonic Force Microscopy

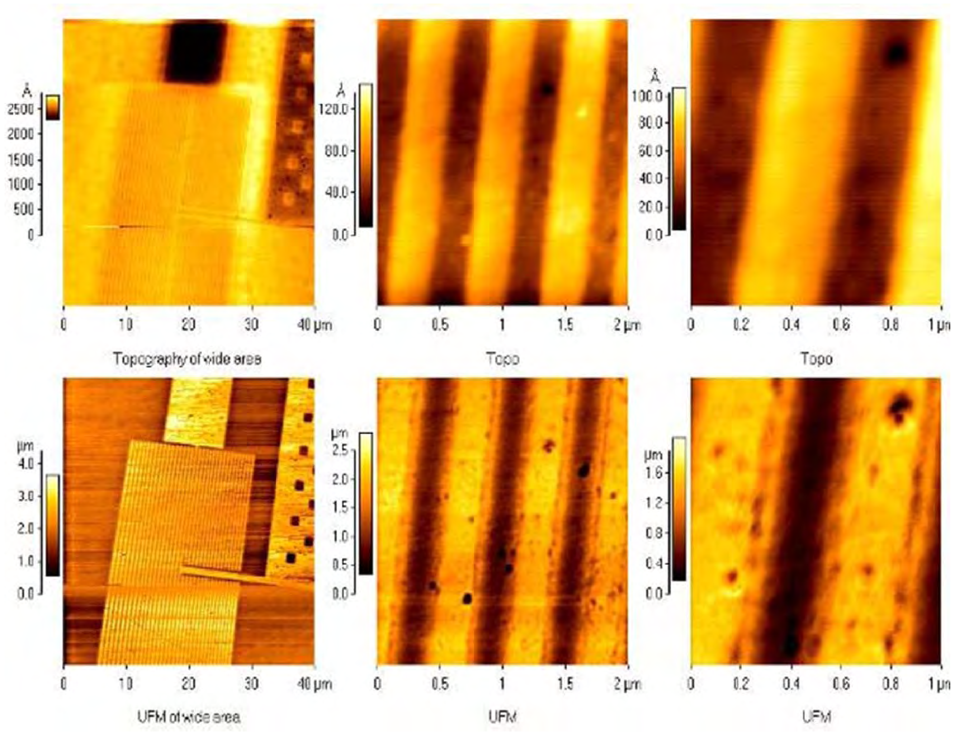




(b) Typical frequency of the piezocrystal is within 2-10 MHz



(c) The superimposed amplitude modulation is within 1-3 KHz and usually of a saw tooth profile



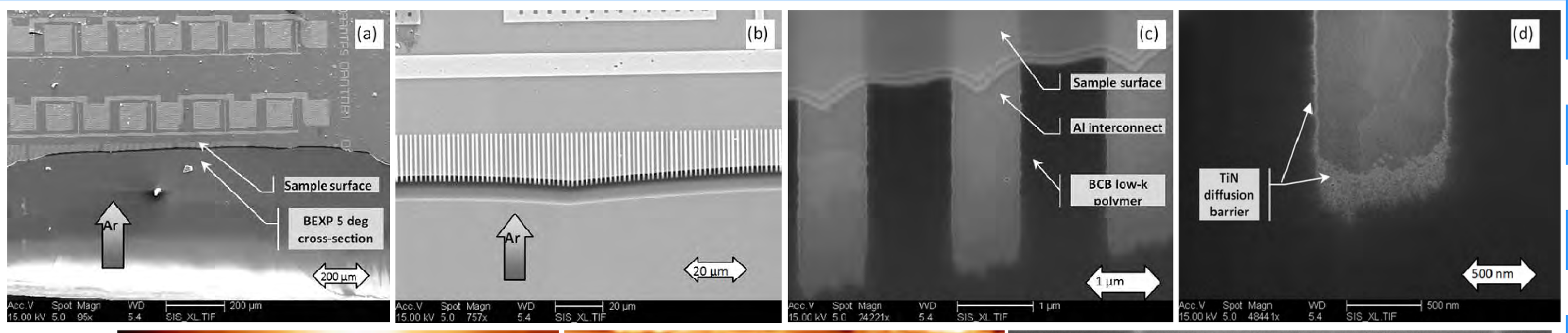
Upper three images—contact AFM, increasing magnification going from left to right;
Lower three—UFM images, same sample area and magnification with clearly increased resolution and structural detail

(Geer, Shekhavat, Briggs and Kolosov, JAP 2002)

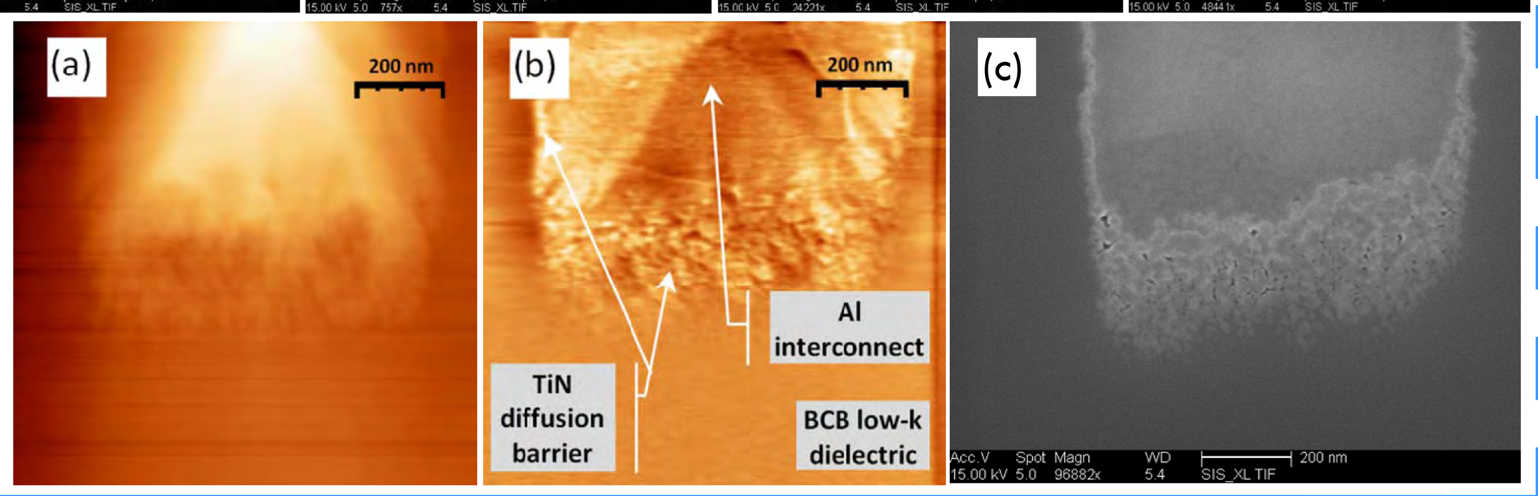
RESULTS

Ultra Large Integration Circuits

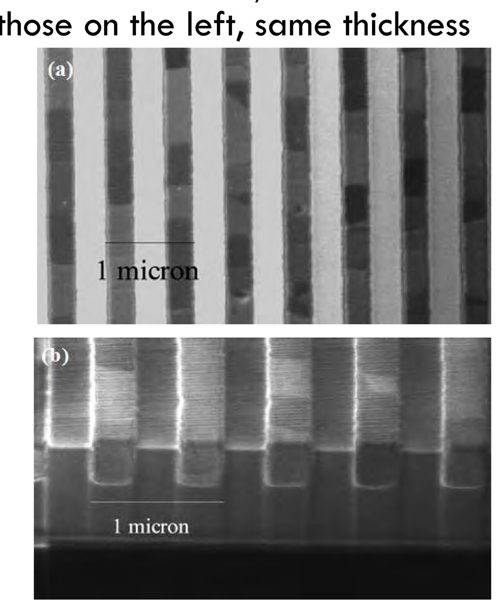
Upper row SEM images show the BEXP section and sample top surface with increasing mag. (a->d)



a) contact AFM image showing bottom of Al trench in BCB polymer some 400 nm from the surface
b) UFM image of same area as (a) giving much more detail as well as qualitative elasticity contrast
c) SEM image of similar to (a), (b) magnification, same Al trench



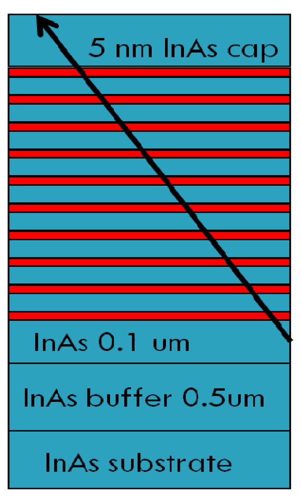
SEM images of same VLSI sample top view and FIB X-section, Al trenches are 1/2 width of those on the left, same thickness

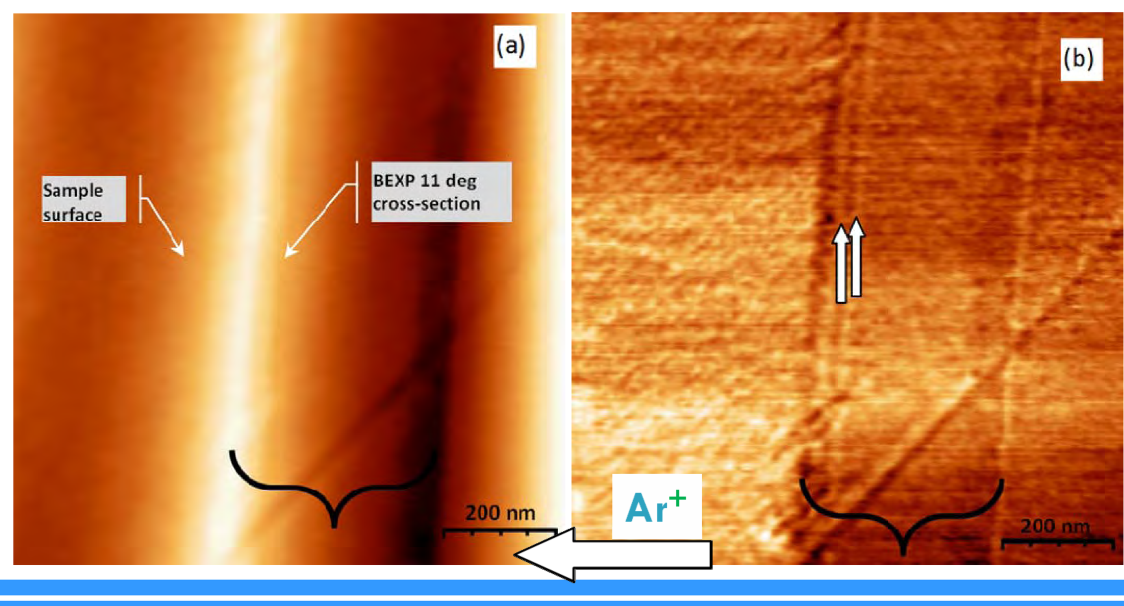


(Geer, Shekhavat, Briggs and Kolosov, JAP 2002)

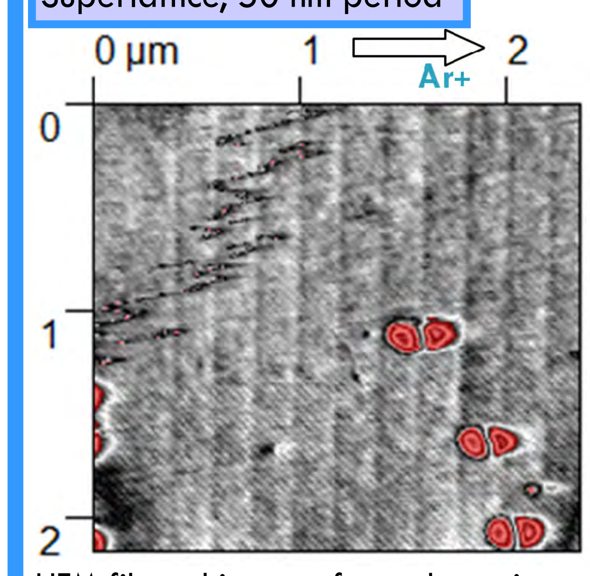
InSb/InAs Quantum Dot Superlattice, 19 nm period

a) contact AFM image of Superlattice sectioned with BEXP
b) UFM image of same area as in (a) with much better resolution, revealing first two QD layers, first one being just 5 nm from top



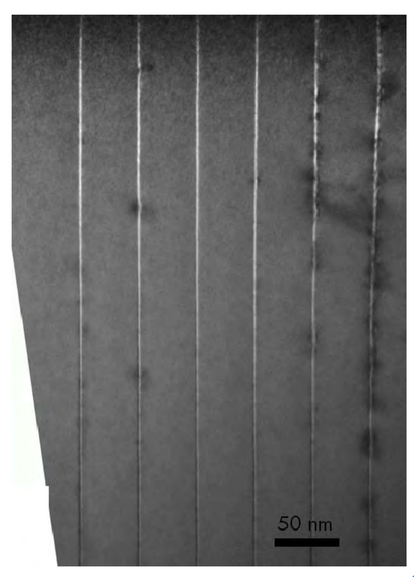


GaSb/GaAs Exchange Dot Superlattice, 50 nm period

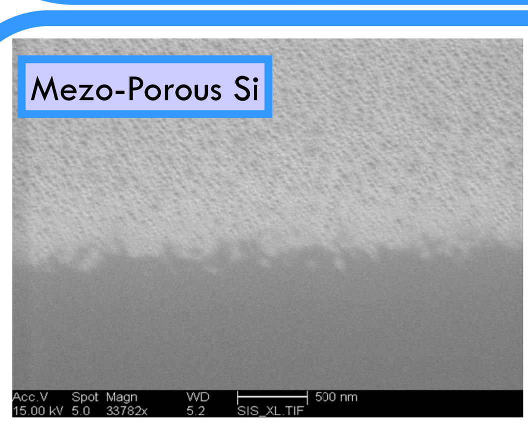


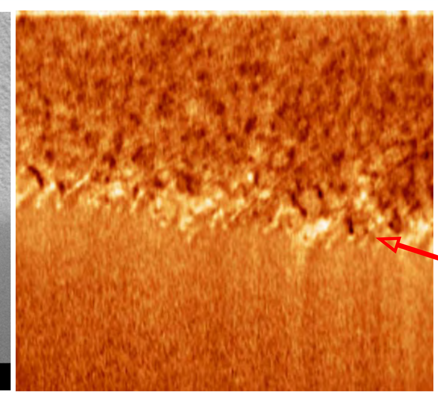
UFM filtered image of sample section with all layers visible done with BEXP

X-TEM image of same GaSb/GaAs Superlattice, different sample

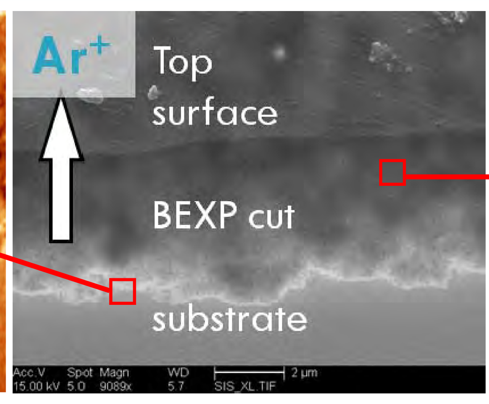


Mezo-Porous Si

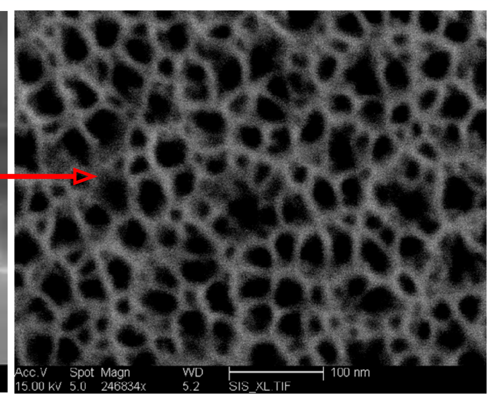




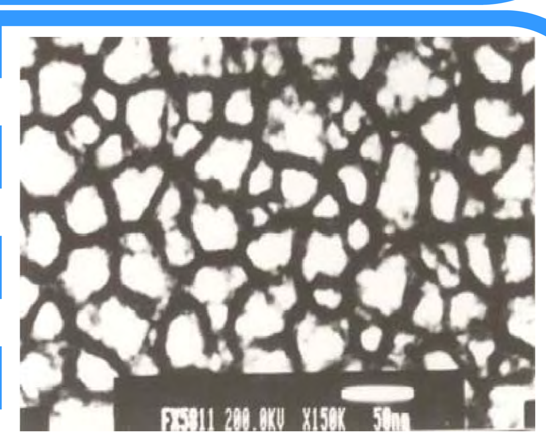
left) SEM image of por-Si/Si interface profile;
right) UFM image of same profile but different area, reveals details of crystallographic orientations in interface attributed to the selective etching of Si



SEM general view of the sectioned by BEXP Mezo-porous Si layer, actual thickness is 700 nm, expanded to 3.5 um



UHR SEM image of por-Si structure, showing pour distribution and diameter some 200 nm from the top (in actual thickness)



TEM image of a Mezo-Porous Si sample of similar porosity and pour size

A Loni, AJ Simons, *Electronics Letters, Vol. 31 No 15, pp 1288-1289, (1995)*

CONCLUSIONS

The BEXP technique:

- Produces high quality sections similar to those done by FIB but easily compatible with SPM technology, UFM resolution competing with SEM/TEM
- Is Material friendly (applicable to materials that are: layered/fragile/high-low stiffness/crystalline-amorphous)
- Gives high control over section area location
- Reasonably fast and easy to do

ACKNOWLEDGMENTS

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