PC 3242 Part II

Topic	Text Book (Zhen Cui '05)	Lectures
Optical lithography	Chapter 2	1, 2 & 3
Electron Beam Lithography	Chapter 3	4 & 5
Focused Ion Beam Technology	Chapter 4	
Low Energetic Ions (keV)		6, 7 & 8
SIMS	Extra material provided	
FIB in Lithography	Chapter 4	
High Energetic Ions (MeV)	Extra material provided	8
RBS	Extra material provided	9
Light ions in lithography	Extra material provided	10, 11
Etching	Chapter 7	10, 11
Nano Imprint Lithography	Chapter 6	12
3DP Three Dimensional Printing	Extra material provided	13

JA van Kan 2024

SIMS

+ve & -ve Ion Yield Processes

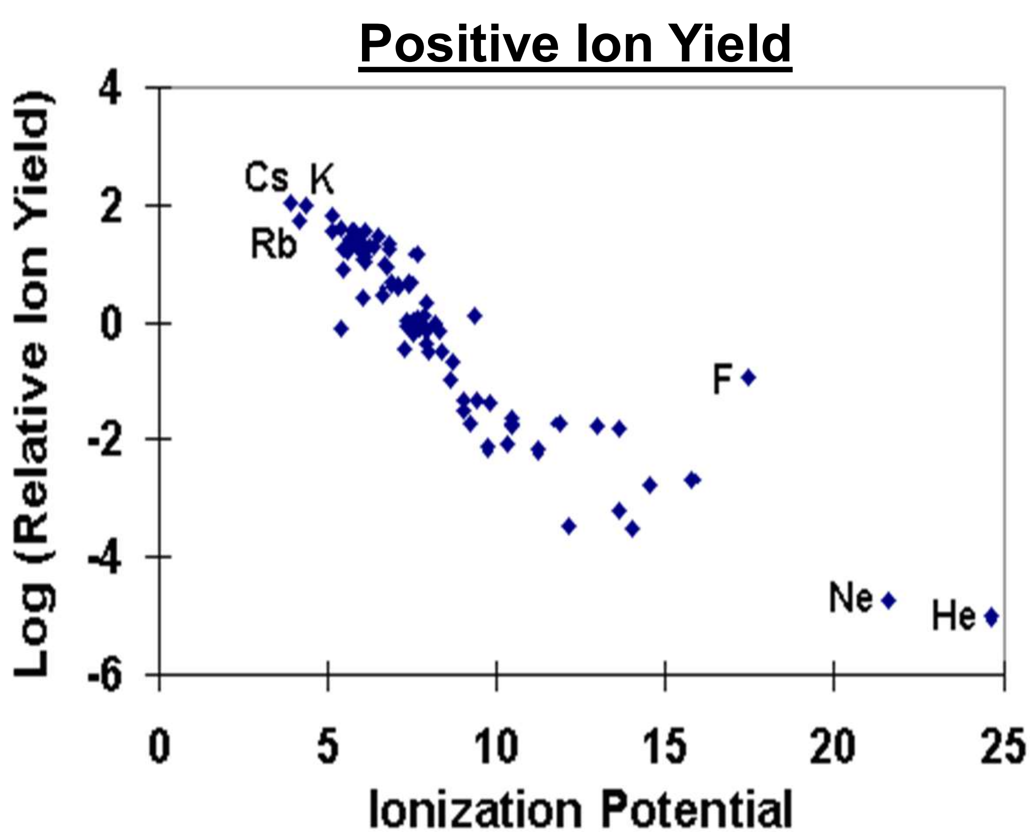
- ***Oxygen enhancement*** occurs as a result of metal-oxygen bonds in an oxygen rich zone. When these bonds break in the ion emission process, the oxygen becomes negatively charged because its high electron affinity favors electron capture and its high ionization potential inhibits positive charging. The metal is left with the positive charge. <u>Oxygen beam sputtering increases the concentration of oxygen in the surface layer</u>.

- The enhanced negative ion yields produced with ***cesium bombardment*** can be explained by work functions that are reduced by implantation of cesium into the sample surface. More secondary electrons are excited over the surface potential barrier. Increased availability of electrons leads to increased negative ion formation.

SIMS

Secondary Ion Yields - Elemental Effects

- The SIMS ionization efficiency is called ion yield, defined as the fraction of sputtered atoms that become ionized.
- Ion yields vary over many orders of magnitude for the various elements.
- The most obvious influences on ion yield are ionization potential for positive ions and electron affinity for negative ions



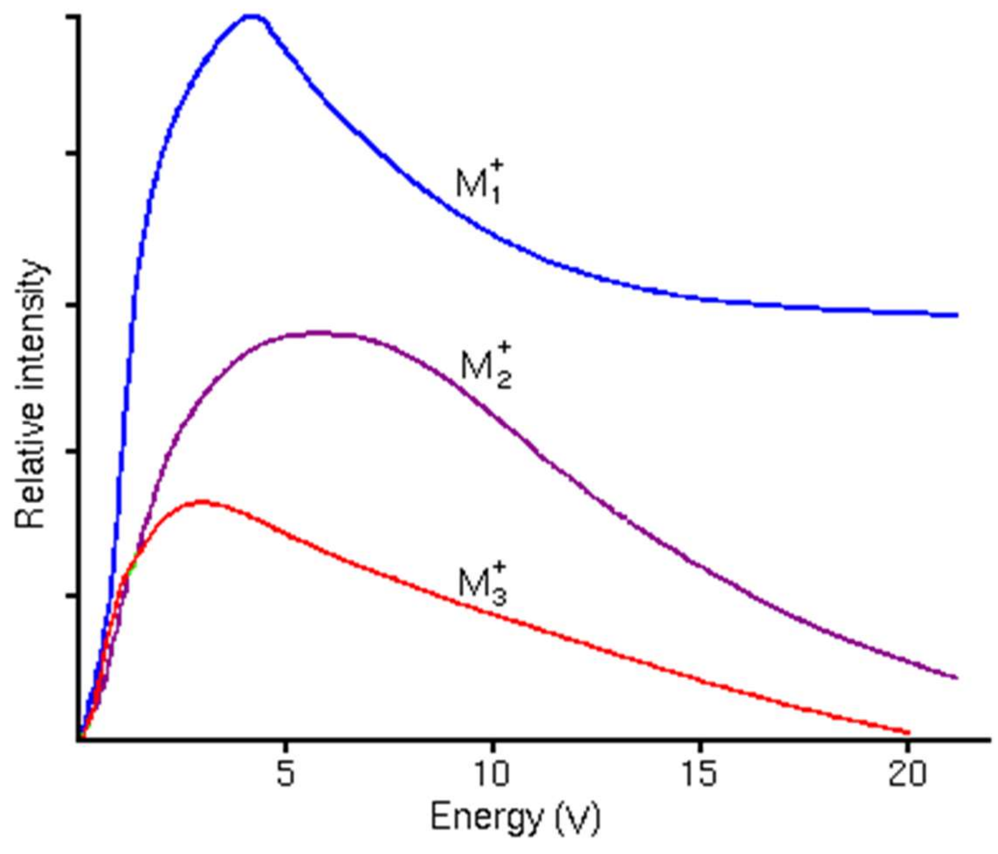
Positive ion yields relative to silicon in a silicon matrix with oxygen sputtering

SIMS

Secondary Ion Energy Distributions

- The sputtering process produces secondary ions with a range of (translational) kinetic energies. The energy distributions are distinctly different for atomic and molecular ions. Molecular ions have relatively narrow translational energy distributions because they have kinetic energy in internal vibrational and rotational modes whereas atomic ions have all kinetic energy in translational modes.

The following figure shows typical energy distributions for mono, di, and triatomic ions.



Low Energy Heavy Ion Beam *Applications*

- *Secondary Ion Mass Spectrometry (SIMS)*
- *IC circuit diagnostic & repair*
  Removing a section of a circuit and preparing it for SEM analysis
  Physically changing a malfunctioning circuit can help trouble suiting
- *Mask repair; Optical masks can be revived through FIB;*
  EUV masks are even more sensitive and require Electron beam repair!
- *TEM sample preparation: Thin cross sections can be prepared ~100nm*
- *Dedicated fabrication of small features: Small area fine feature altertion*
  In several seconds a UV lithography prefabricated head can be reduced in size down to 100 nm. (2001)
- *Lithography*
  Low energy ion projection has been evaluated but has been abandoned

FIB has high sensitivity as the electronic stopping produces a lot of electrons (~100x more sensitive compared with e-beam writing)

➔ *This can lead to shot noise, ie not enough particles to evenly cover an area to be exposed, leading to edge roughness.*

☺ +++ *Practical absence of proximity effects*

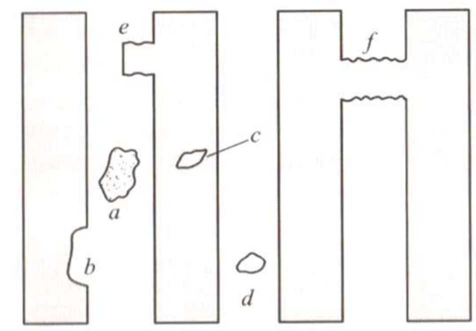
- - - *Limited penetration depth for slow heavy ions*

- - - *Sputtering & damage to substrate/resist*

FIB

Applications (Mask Repair)

Cr mask repair can be done using laser repair this is fast but limited to larger defects.
FIB used to repair optical masks, removal of features.
SIMS is useful to determine when enough material has been removed.



Various types of mask defects (opaque defects: *a*, *e*, *d*, *f*; clear defects: *b*, *c*)

One drawback is the deposition of Ga in the mask during the repair! Especially short wavelength will be blocked more!

Applying a Reactive Ion Etching (RIE) step after the repair will improve transmission up to 90%.

Combining RIE with acid wash can improve transmission back to 100%
Micro Elect Eng. ***21*** *(1993) 191*

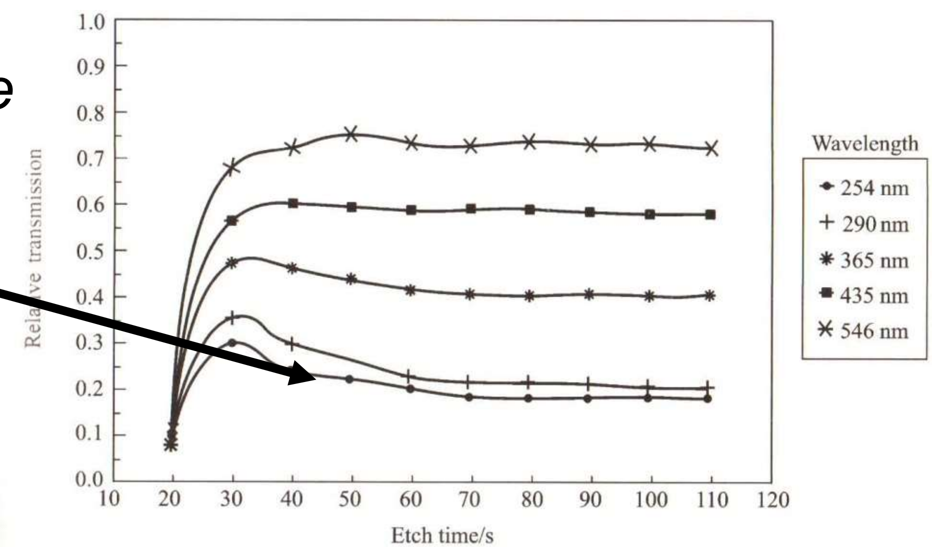


Fig.4.10. Transmission loss due to gallium staining in FIB repair of mask defects

An electron gun is used to prevent charging in the case of SiO_2

➔ EUVL requires 13.4 nm Electron Beam Induced Deposition (EBID) repair!

FIB

Applications (Beam Assisted deposition)

Besides removal ion beams and electron beams can be used to locally deposit material

A gas is administered into the system (close to the interaction point), this can lead to deposition of atoms on the surface. Not pure elements but alloys

*There is a **balance** between sputtering and deposition it **depends** on:*

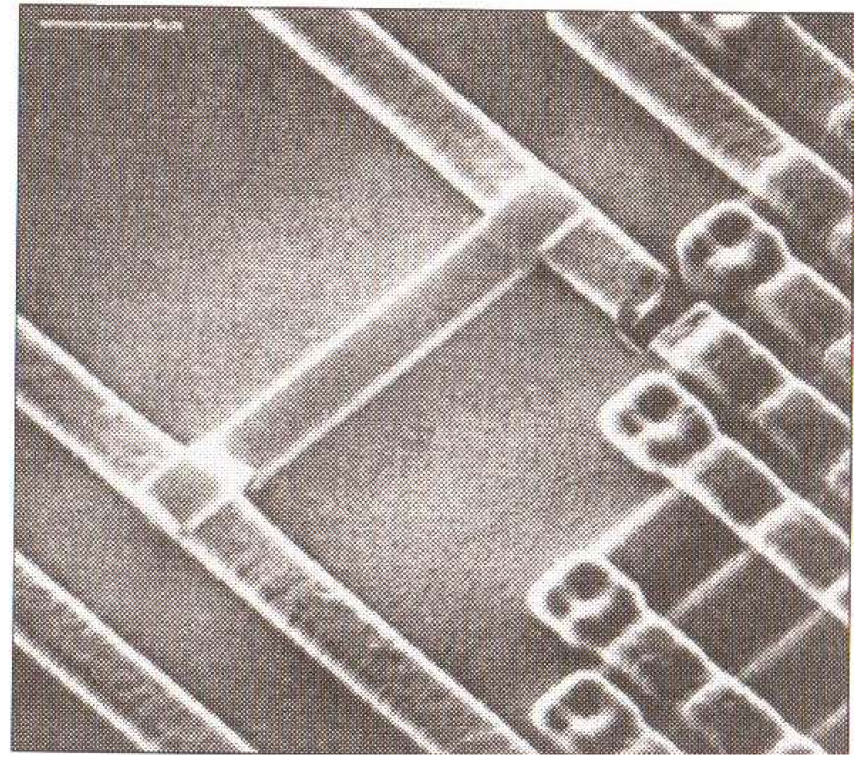
- *Ion/electron energy*
- *Ion/electron dose*
- *Gas flow rate*
- *Chamber pressure*

Accurate control enables us to fabricate 3D structures

Microstructure made by both ion beam sputtering and ion beam assisted deposition

FIB

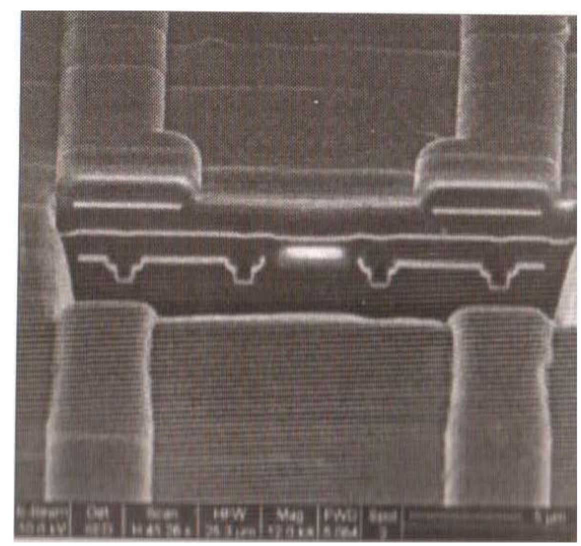
IC circuit diagnostic & repair



In IC manufacturing FIB is used as a tool to do fault finding in IC circuits. This can be done in several ways.

1) One can do fault finding through alteration of an IC circuit.

2) Or you can produce a 3D cross section of an IC circuit and investigate this with an SEM. This can tell you where the fabrication went wrong.

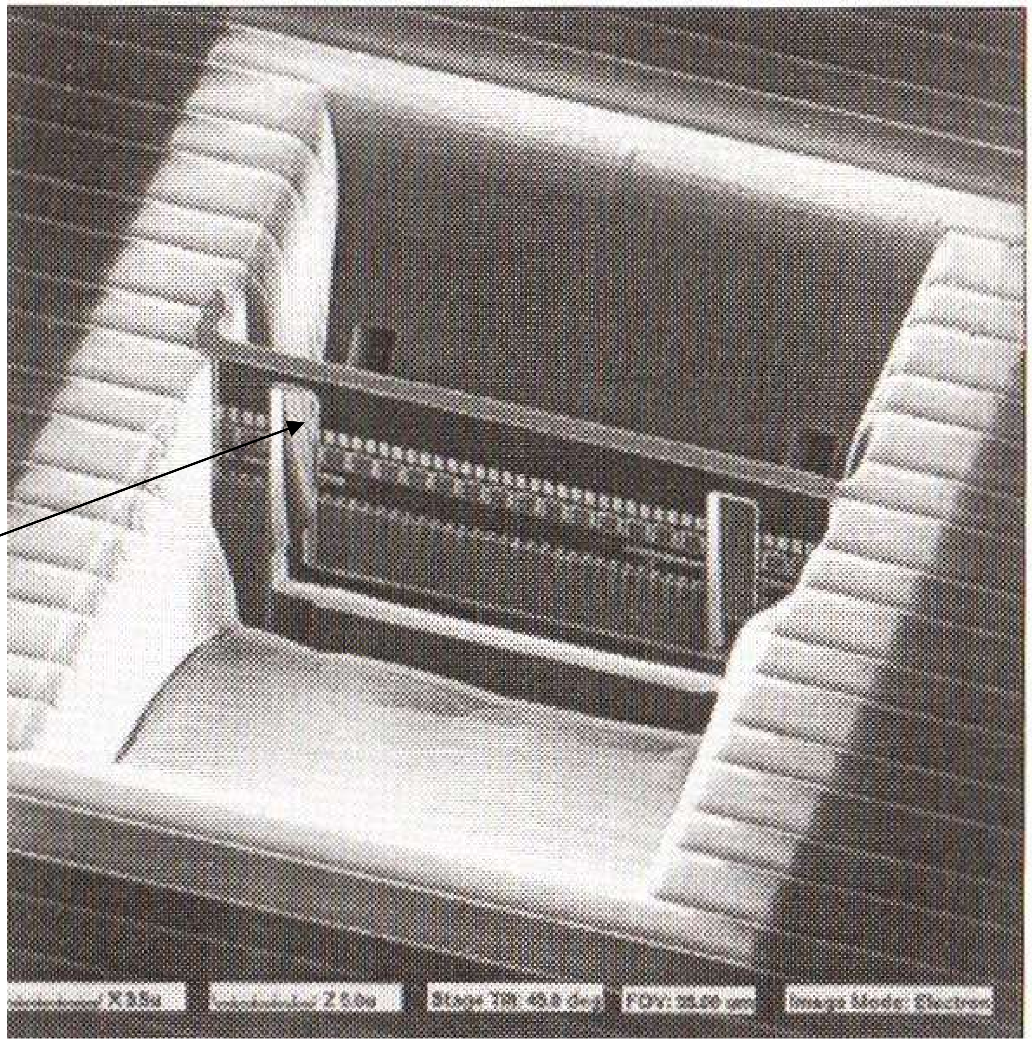


3) An alternative way can be done using a MeV ion beam as we will see later

FIB

TEM sample preparation

TEM analysis requires thin cross sections so that the electrons can pass through the sample and form a diffraction pattern. Typical thickness of these samples is 100 nm.

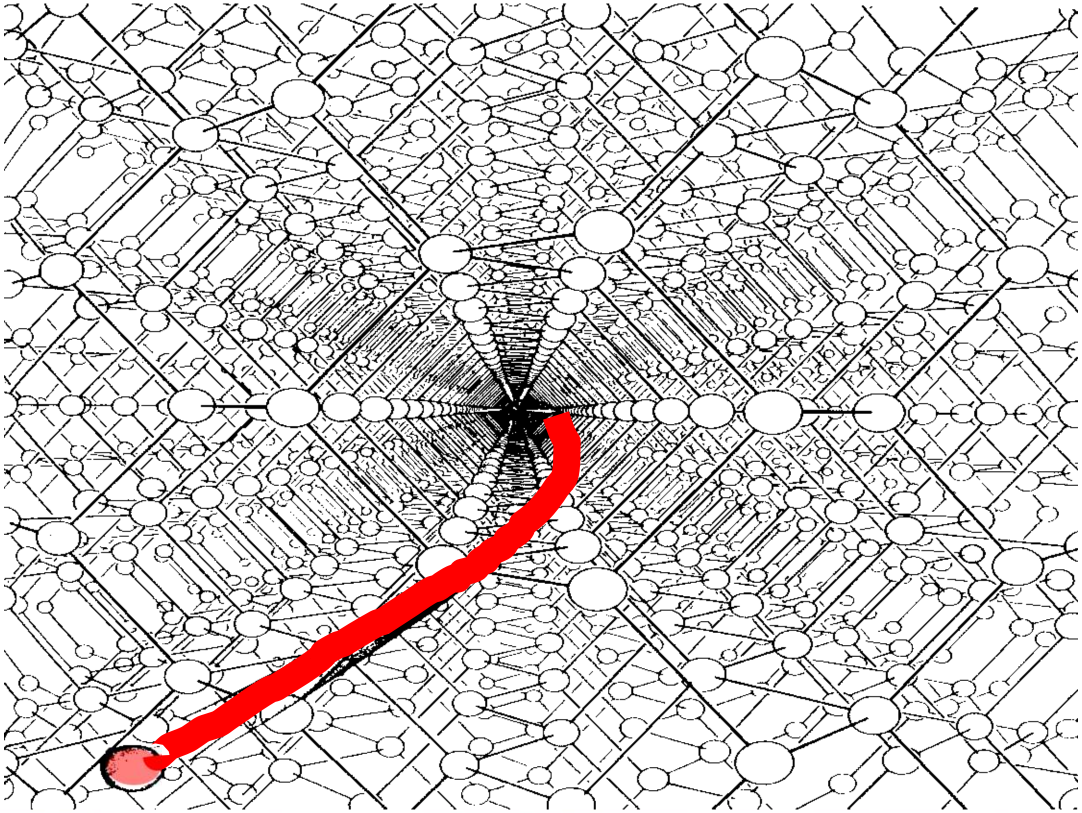


FIB tends to have ripple formation at the sidewall of etched structures. This will cause interference in the TEM analysis.

Therefore the final etching is done using a very fine focus to produce a smooth sidewall finish.

FIB

Difficulties in Quantification

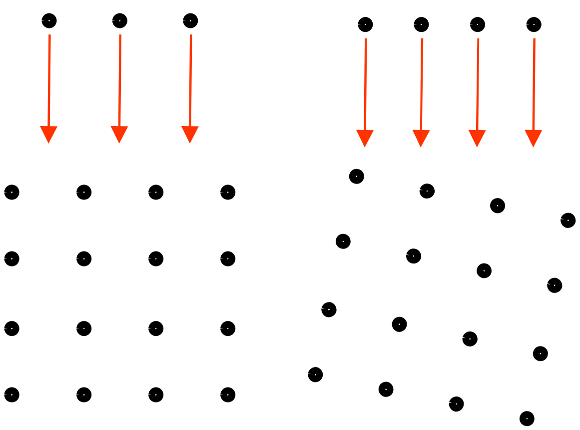


Channeling of ions in matter

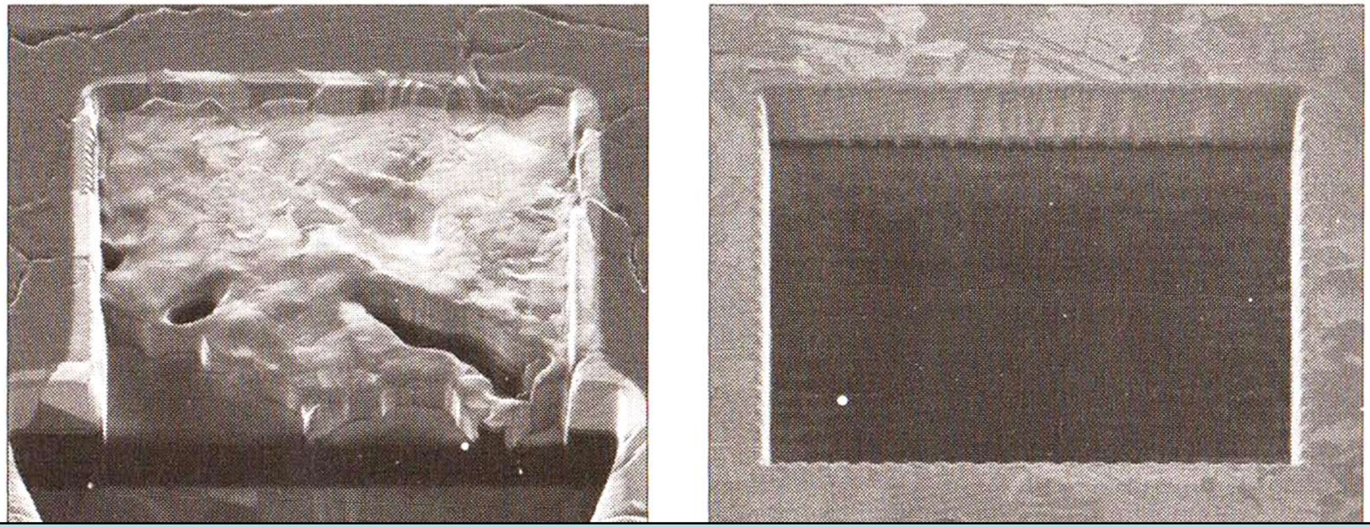
Orientating the ion beam along a crystal axis: Why has nuclear interaction decreased?

In channelling orientation there is increased electronic stopping, the ion bounce in between atom rows ie decrease in nuclear stopping which leads to much less damage and sputter

FIB sputtering of Cu



Aligned Random

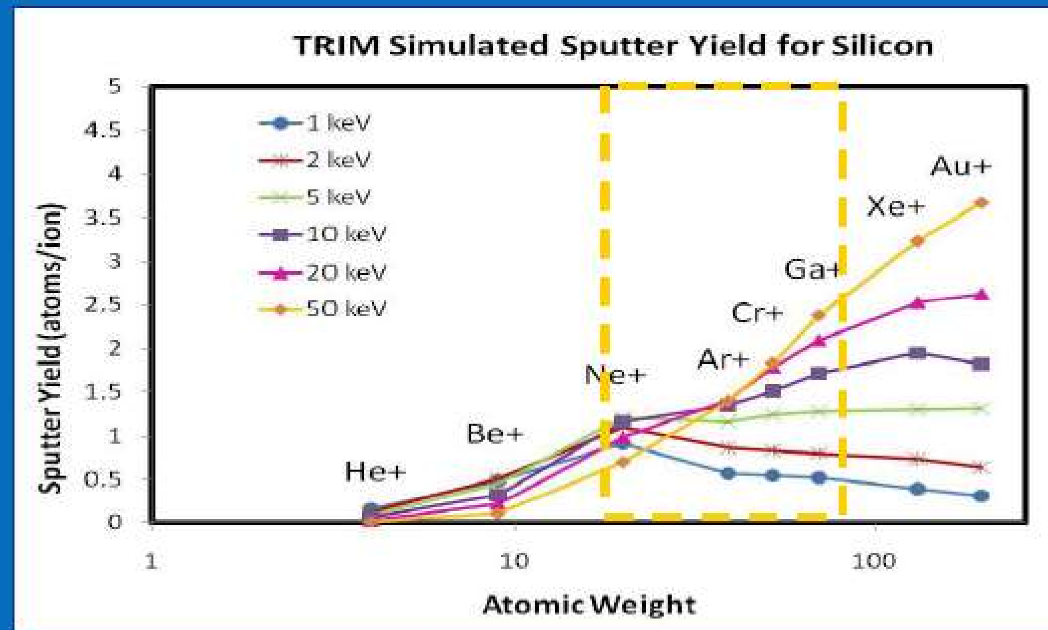


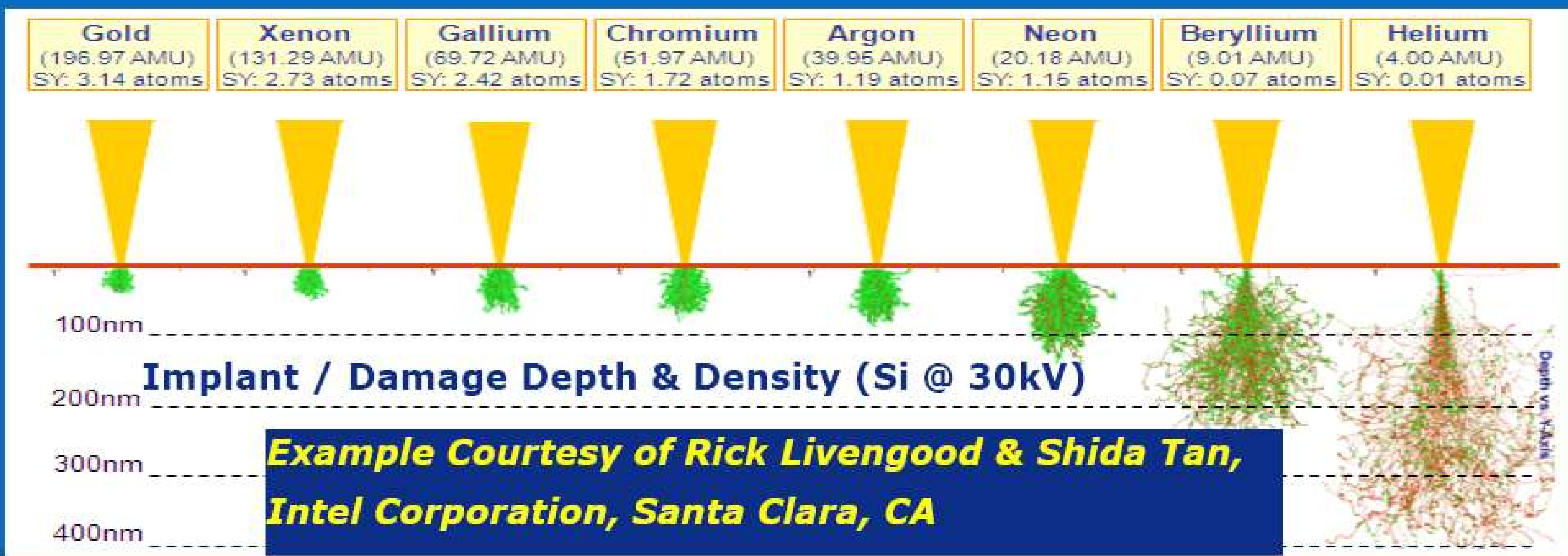
Which of these sputtering experiments was obtained aligning the ion beam along a crystal axis?

Ion Species Under Investigation (TRIM™ simulation results)

CE Nanomachining Requirements

- Small probe size
- High Brightness
- Low beam energy spread
- Shallow implant depth
- Low displacement per incident ion
- Reasonable sputter yield
- Minimal circuit invasiveness
- Beam induced chemical selectivity
- Beam induced CVD (metal & diel.)





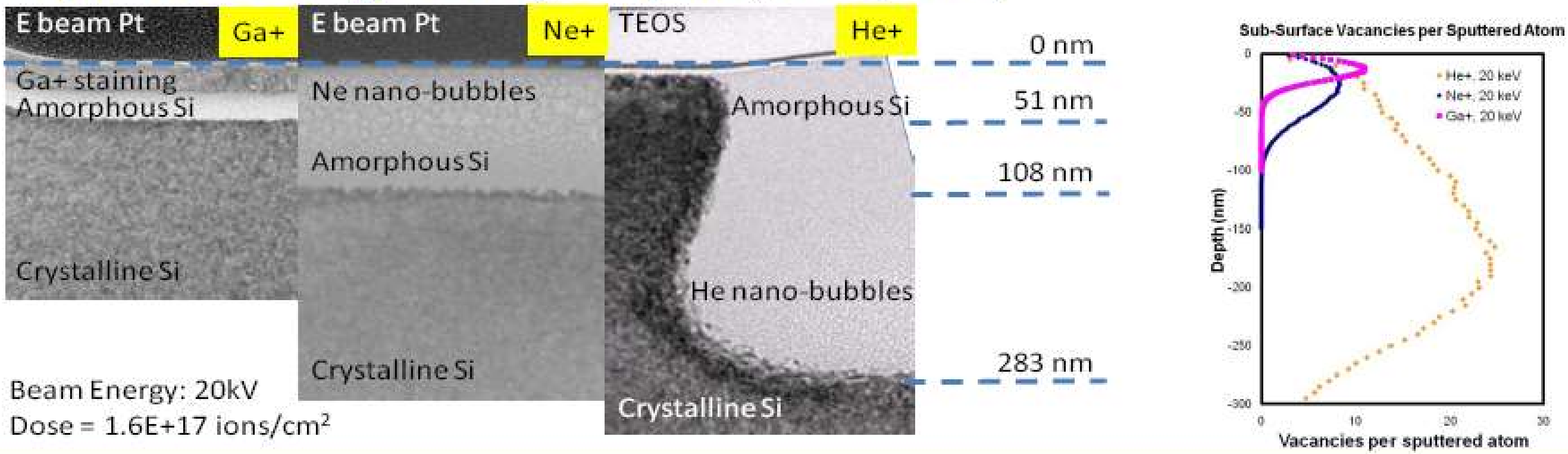
Example Courtesy of Rick Livengood & Shida Tan, Intel Corporation, Santa Clara, CA

FIB

Experimental Results: Implant/Sputter Analysis

(TEM Analysis Courtesy of D. Shima, M. Baca, K. Yu, and S. Hield, Intel Corp.)

Si Implant / Damage Analysis (Ga+, Ne+, He+)



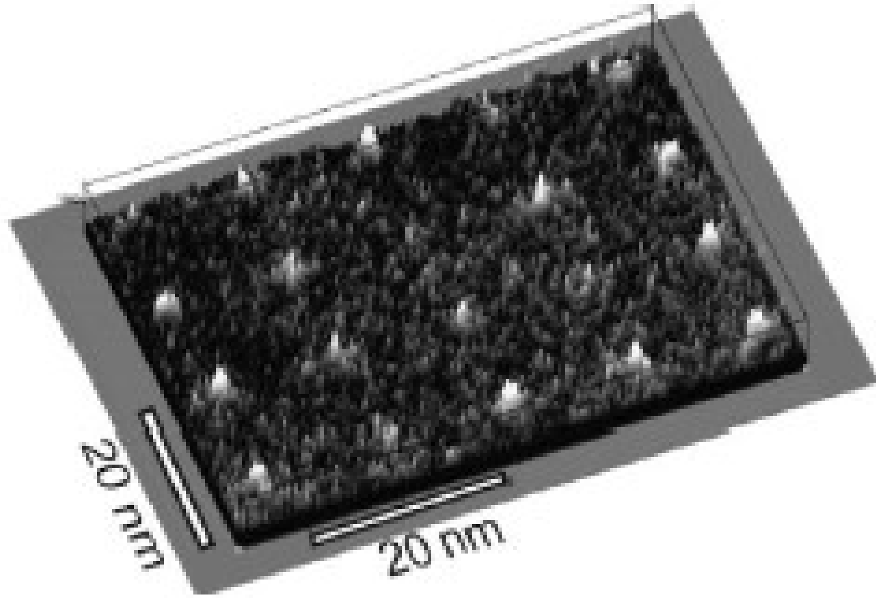
Beam Energy: 20kV

Dose = 1.6E+17 ions/cm^2

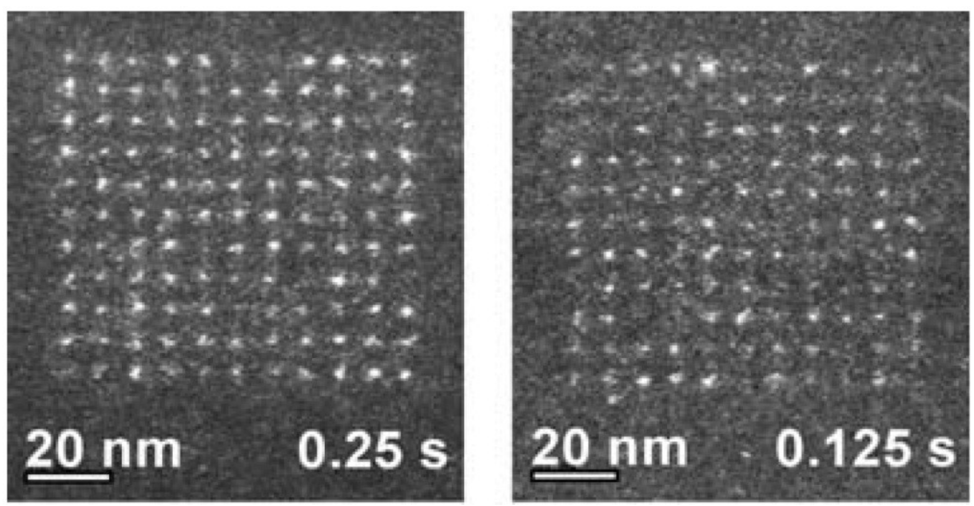
- Neon implant damage depth ~ 100nm at 20 kV (2X deeper then gallium-ions)
- Neon sputter yields = 1 Si atom/ion; 4 Cu atoms/ion (~0.4X less then gallium)

Example Courtesy of Rick Livengood & Shida Tan, Intel Corporation, Santa Clara, CA

Electron Beam Assisted deposition



Electron beam induced deposition (EBID) of W dots on a 30 nm thick Si3N4 membrane. The average dot size is 1 nm FWHM.



Electron beam deposited W dots as a function of electron beam dwell time

P kruit et al Microelec. Eng 83 (2006) 1468

Ion Beam Assisted deposition

Making 3-D structures

Pt pillar growth under 1 nm beam of 25 keV He^+ in Orion He Ion Microscope with precursor gas injection unit.

Pillar diameter~50 nm

*P. Alkemade et al., JVST B**28**, C6F22 (2010)*