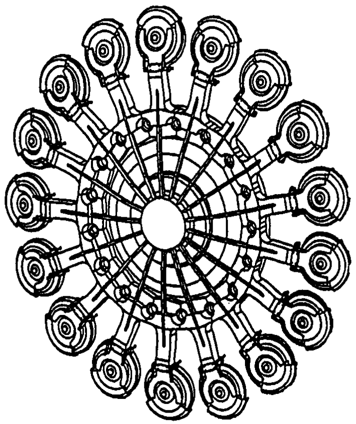
Ion Implantation

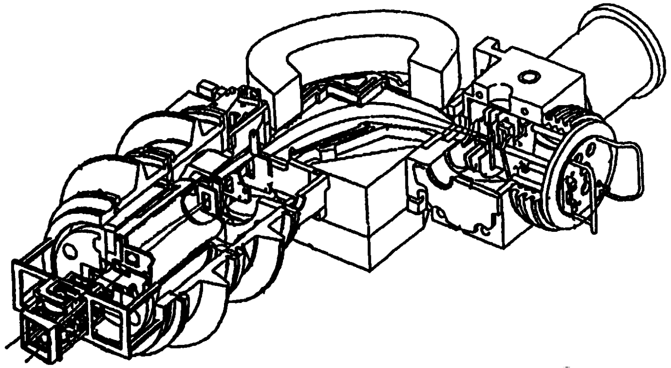
A web-based course from SemiZone:

25 lecture modules & a video “lab tour”

www.semizone.com

Dr. Michael Current





Stanford Center for Professional Development

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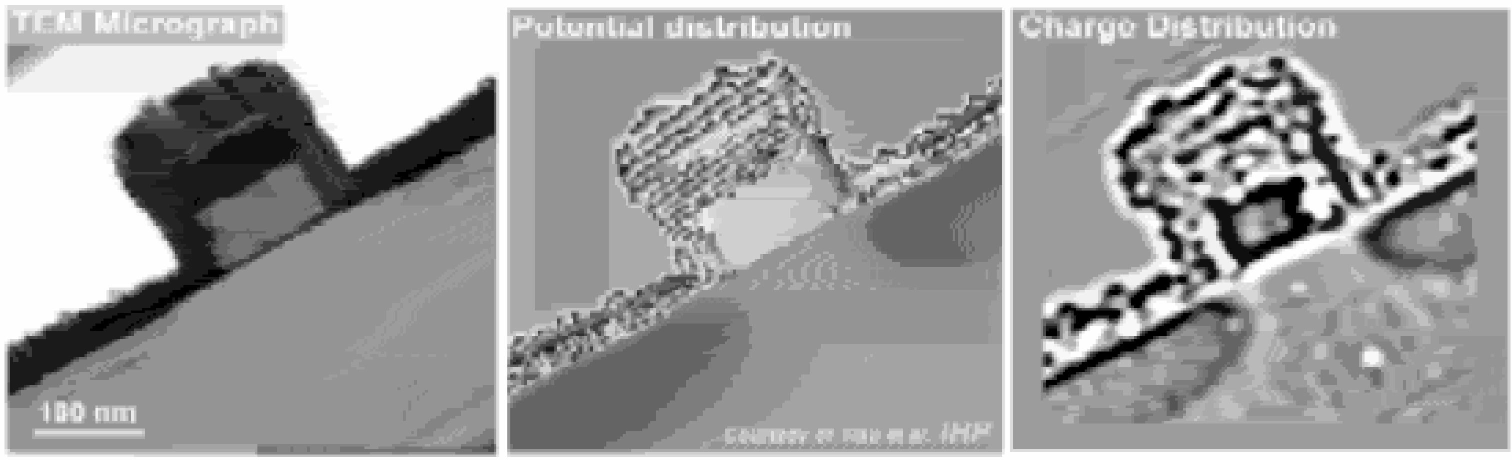
Ion Implantation

Who Should Take This Course?

* Ion implant process & maintenance engineers for devices & materials
* Ion Implant equipment field service engineers
* Process development engineers for advanced devices & materials
* Metrology developers & analytical service providers
* Technical marketing in implant equipment & support
* New product design engineers for ion implant systems & support
* Front-end fab managers, process & equipment technology advisors
* Legal, safety & purchasing support personnel

Ion Implantation: Course Outline

1. Applications: Doping of transistors, SOI wafers
2. Fundamentals: Range, Damage, Annealing
3. Equipment design & operation: Beamlines, PIII
4. Process metrology & controls: Dose, range, damage, charging, contamination
5. Process Integration: Multiple implants, Implants into small spaces
6. Useful resources: Users Groups, Websites, Books & Conferences



TEM Hologram: W.D Rau: IHP Germany; usj-99

Applications & Fundamentals: 1

Applications (3 modules)

Doping of transistors with masks & ion beams
CMOS transistor scaling
Source/drain and channel junction scaling
Limits to low energy implantation & annealing
Shift from bulk-Si to Silicon-on-Insulator (SOI) CMOS
Dopant activation limits
Junction abruptness requirements
Fabrication of SOI materials with implantation

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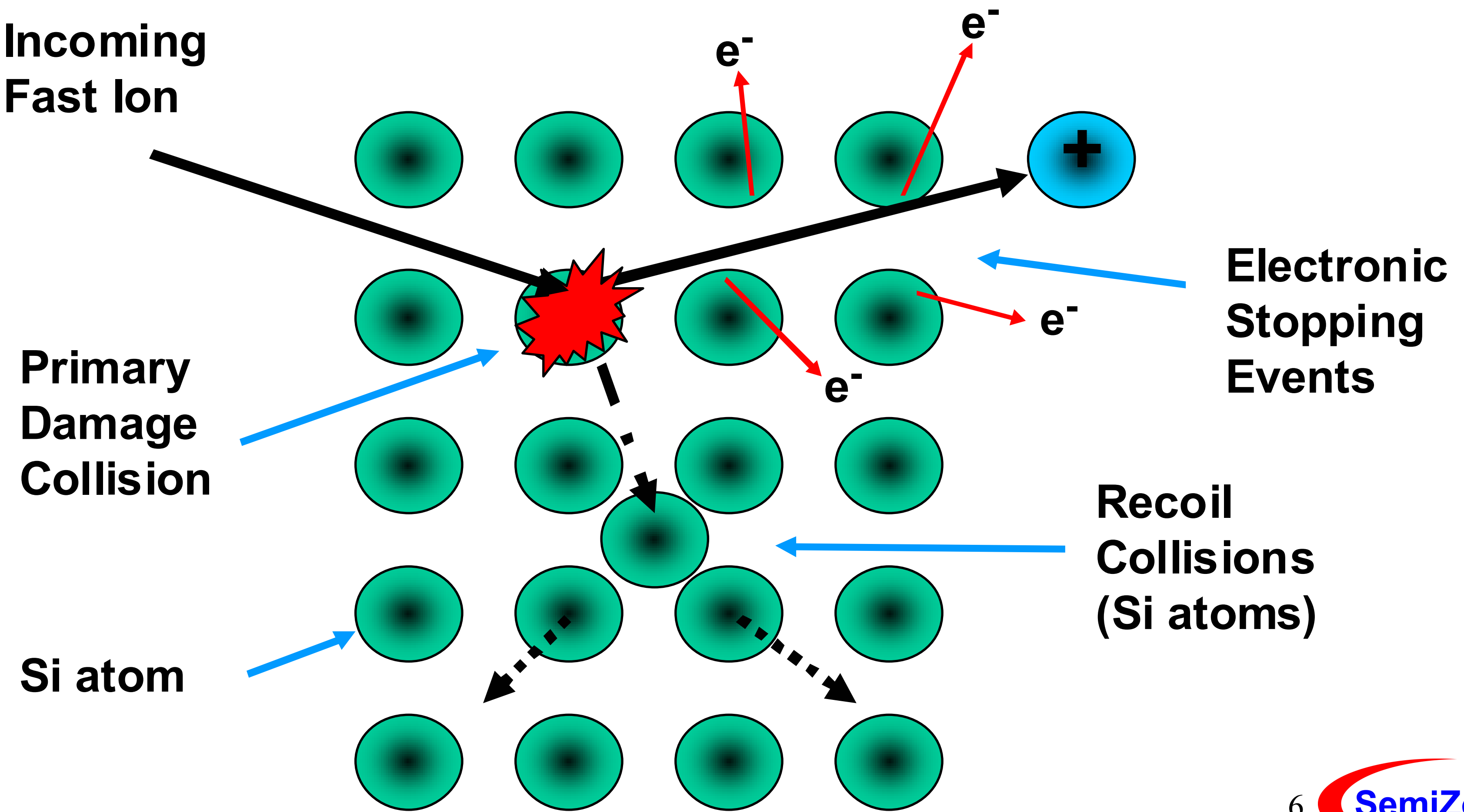
Applications & Fundamentals: 2

Fundamentals (3 modules)

Ion stopping powers & ion range vs. energy
Ion profile shapes, channeling
Ion collisions & lattice damage
Damage accumulation & amorphization
Defect annealing mechanisms
Dopant activation kinetics & resistivity limits
Defect type classifications
Dopant diffusion & sheet resistance trends
Dopant profiles for "ultimate" shallow junctions
Dopant implants, diffusion & carrier mobility in thin-SOI

Stopping Powers: Collision Events

"Electronic" Stopping: ion collisions with single electrons
"Nuclear" Stopping: ion collisions with Si core electrons (and nuclei)



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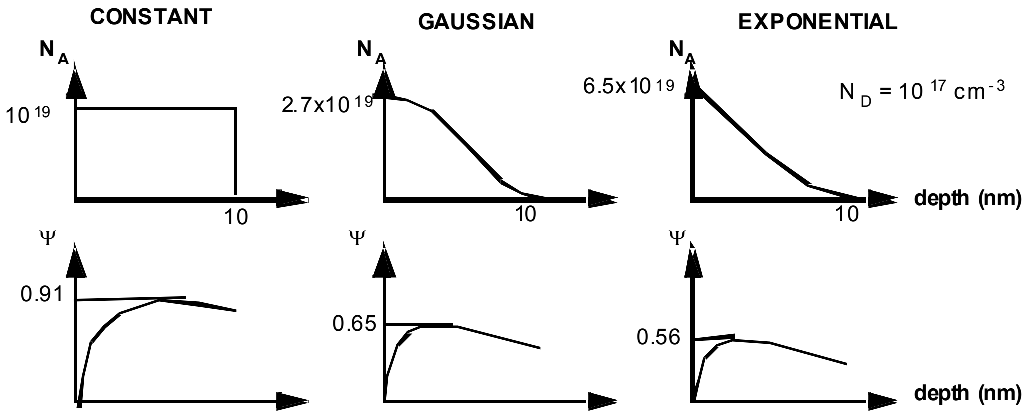
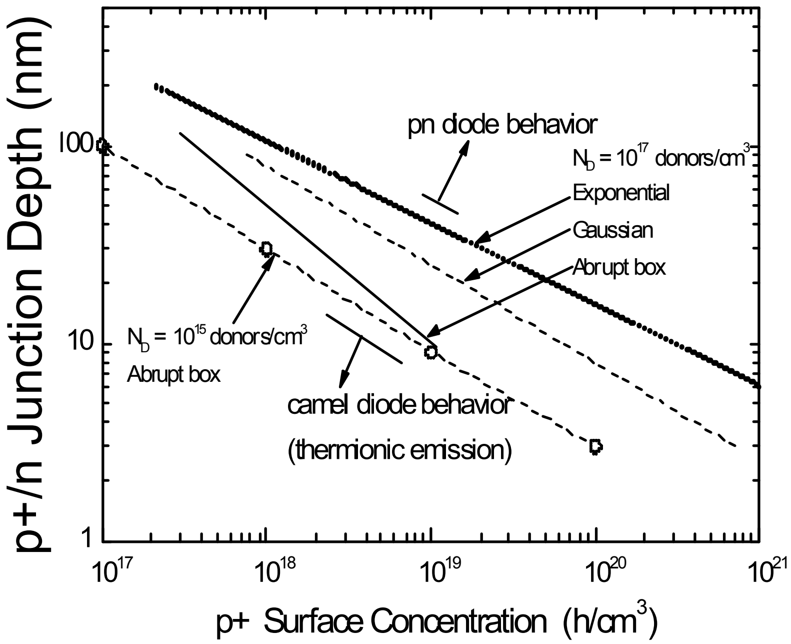
Ultra-shallow Junction Depth Limits:
Thermionic Emission

Abrupt (box-like) vertical dopant profiles have highest barrier to thermionic emisison from contacts (also lowest sheet resistance per doping dose).





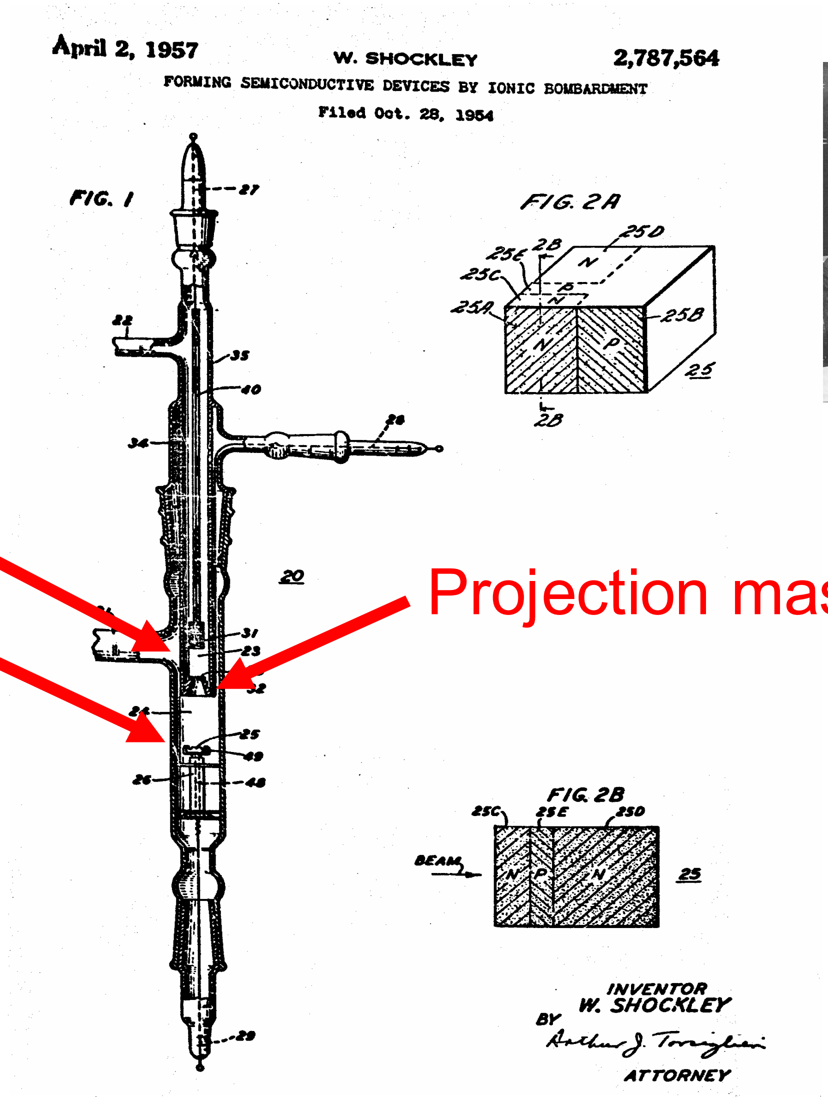
E. Jones, "Ultra-shallow Junction Fabrication using Plasma Immersion Ion Implantation and Epitaxial $CoSi_2$ as a Dopant source", PhD Thesis, UC Berkeley, 1996.
J.H Shannon, "Control of Schottky barrier height using highly doped surface layers", Solid-state Electron. 19 (6) (1976) 537-543.

Equipment Design & Operation

(5 modules)

Ion implantation equipment requirements
Beamline designs (columns & ribbons)
Plasma immersion ion implantation
Beamline components: ion source, magnets, etc.
Vacuum levels
Beam & wafer scanning
Dosimetry
Plasma immersion operation
Productivity: Scanned area,
"Golden rules" for dummies (wafers)

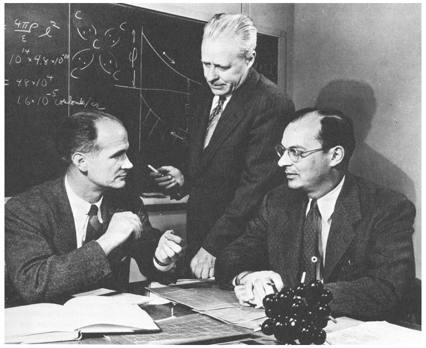
Early Designs: Bell Labs (1954)



Ion Source

Target (a bit of Ge)

Projection mask



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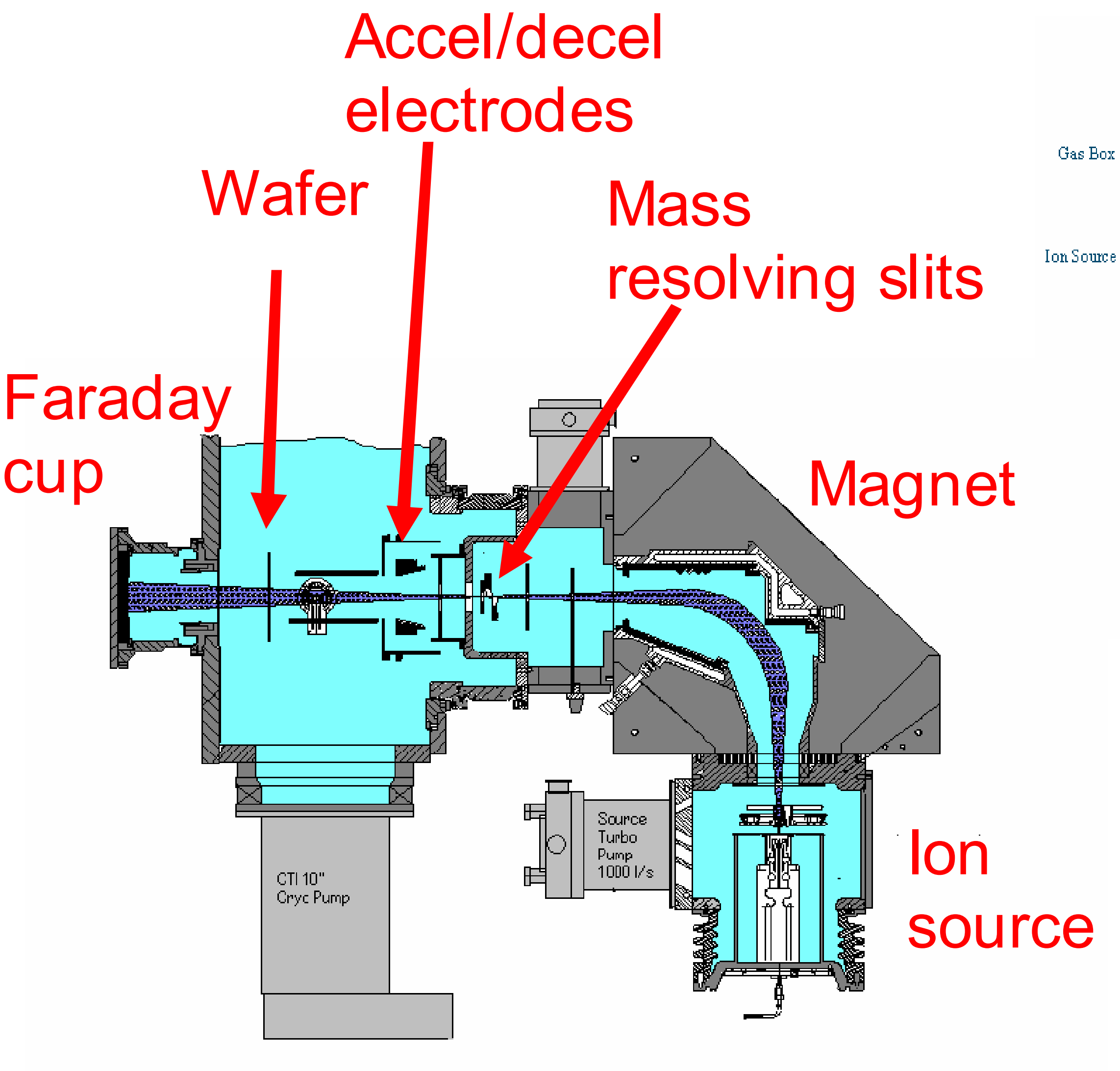
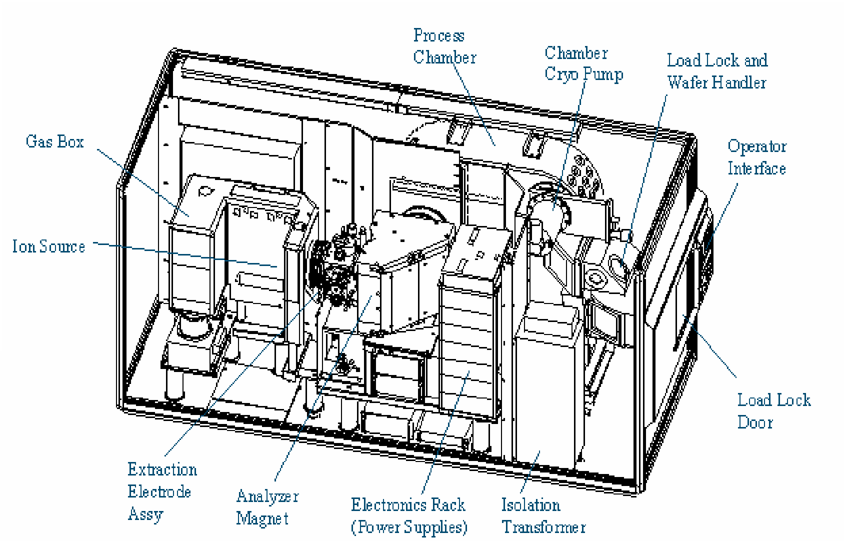
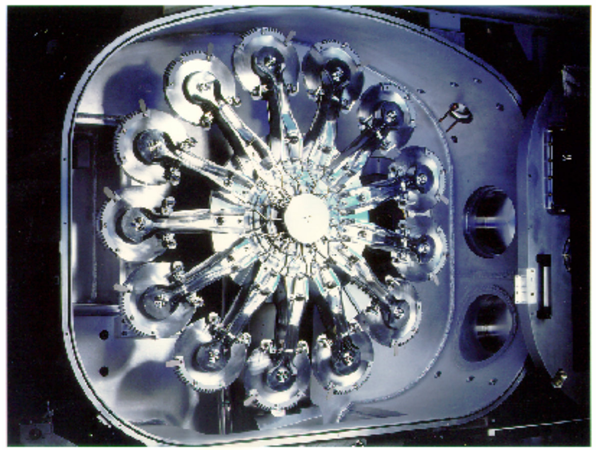
High Current Beamline







AMAT xR80

Resonant Dose Errors

Resonant Dose Error Examples

* X-Y and X-theta scan “lock-up”
* 60-cycle beam noise for 1200 rpm wheel spin

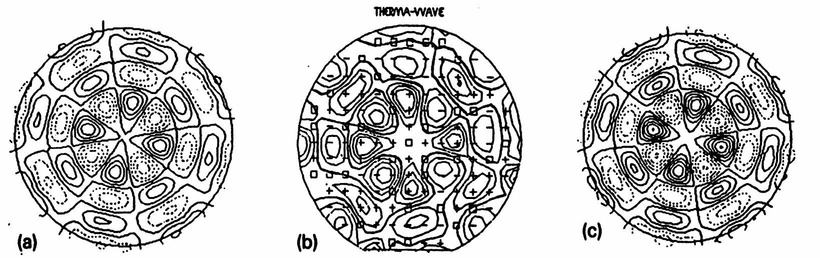
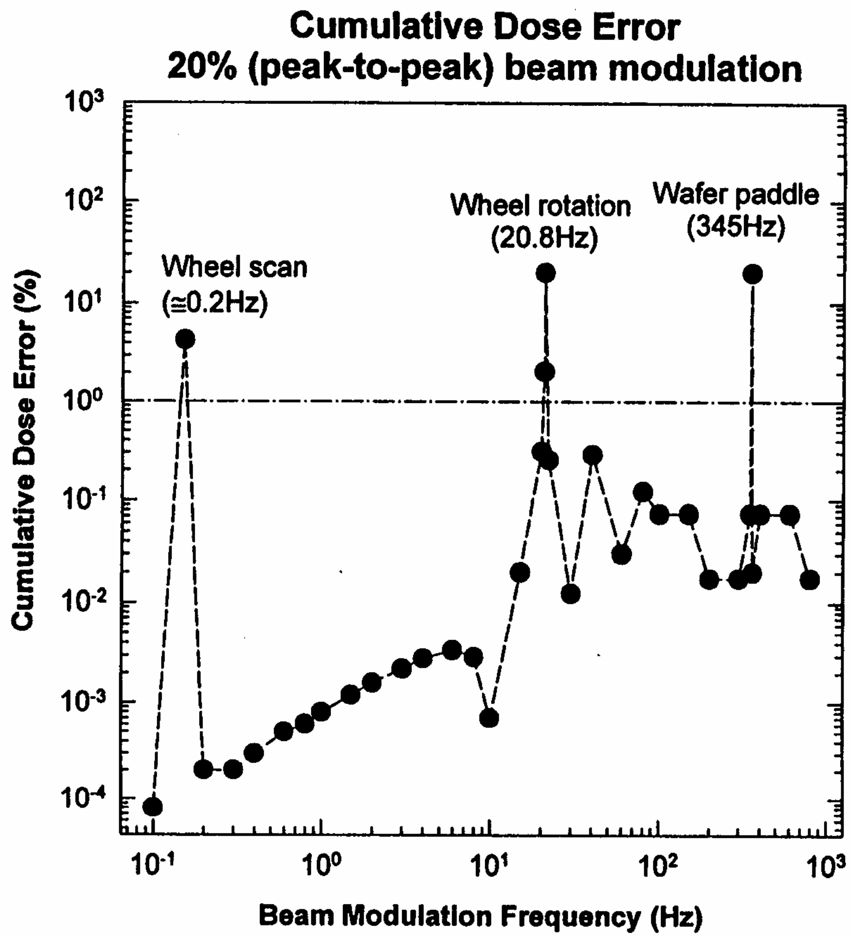


Fig. 5. Simulation of beam scan and wafer rotation resonance pattern. Implant time: 5 s; wafer rotation speed: 1.0 rps; beam scan frequency: H: 88.85 Hz, V: 502.13 Hz. (a) Simulation. Dose uniformity: 6.53%; contour interval: 5%. (b) An experimental result. Therma-wave (TW) map. TW uniformity: 0.80%; contour interval: 0.5%; TW signal: 609.6 TW units. (c) Simulation. The dose is converted to Therma-wave units. Empirical Therma-wave sensitivity used is as follows: $TW = -1580.61 + 168.063 \log_{10}(dose)$. TW uniformity: 0.79%; contour interval: 0.5%; TW signal: 604.05 TW units.

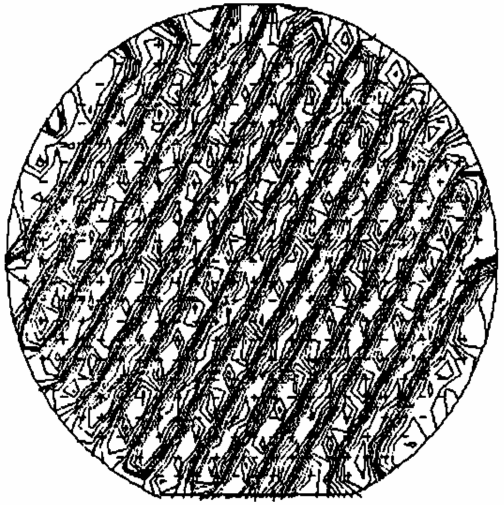


Process Metrology & Controls: 1

Dose (2 modules)

Ion beam "noise" time regimes
Measurements: Sheet resistance, SIMS,
X-ray emission, Optical reflection
Round Robin dose samples, correlated machines
Micro-uniformity: beam shape & scan speed
Beam blow-up: wafer surface potentials
Scan offset: beam location & scan speed profile
Dose saturation: dose and profiles at low energies
Mask shadowing
Gate stack scattering: Gate-edge "hot spots"

Dose Micro-uniformity



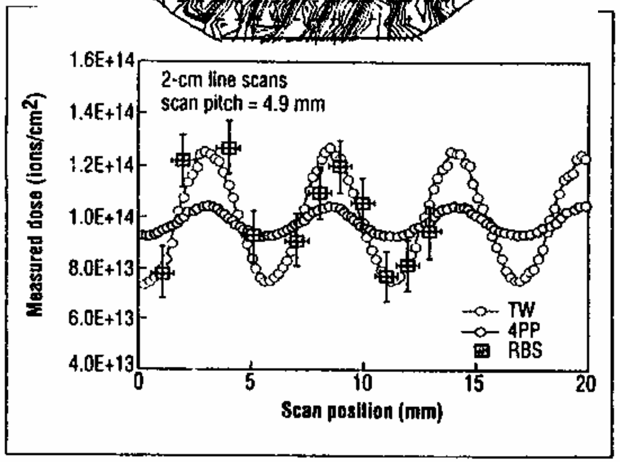
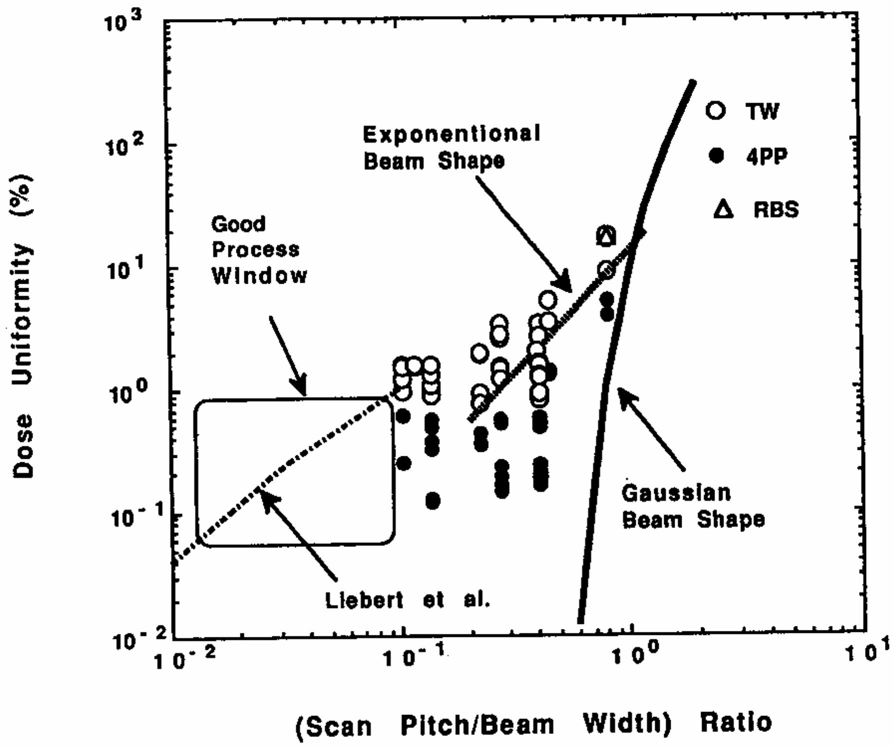


Figure 7. Observed dose variations for optical (Therma-Wave), electrical (four-point probe), and physical (RBS) measurements on a wafer implanted with a scan pitch of ≈ 5 mm.

Factors:
Beam width, scan & rotation speed
Probe spatial resolution



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Process Metrology & Controls: 2

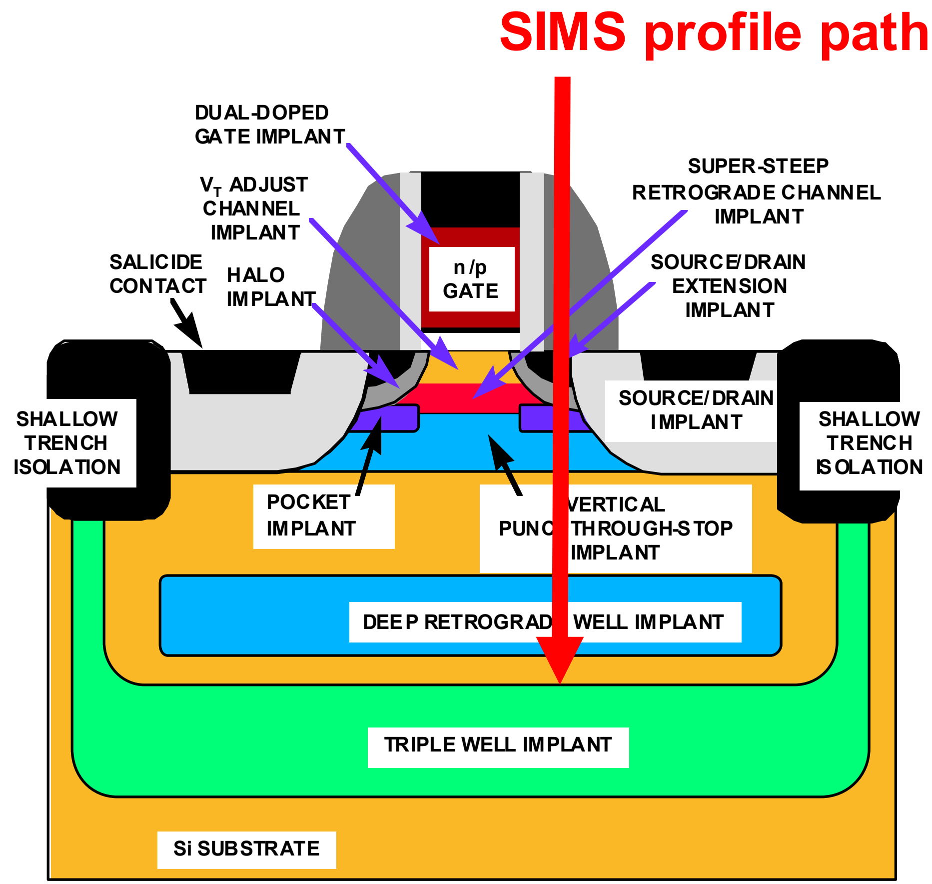
Ion Range (1 module)

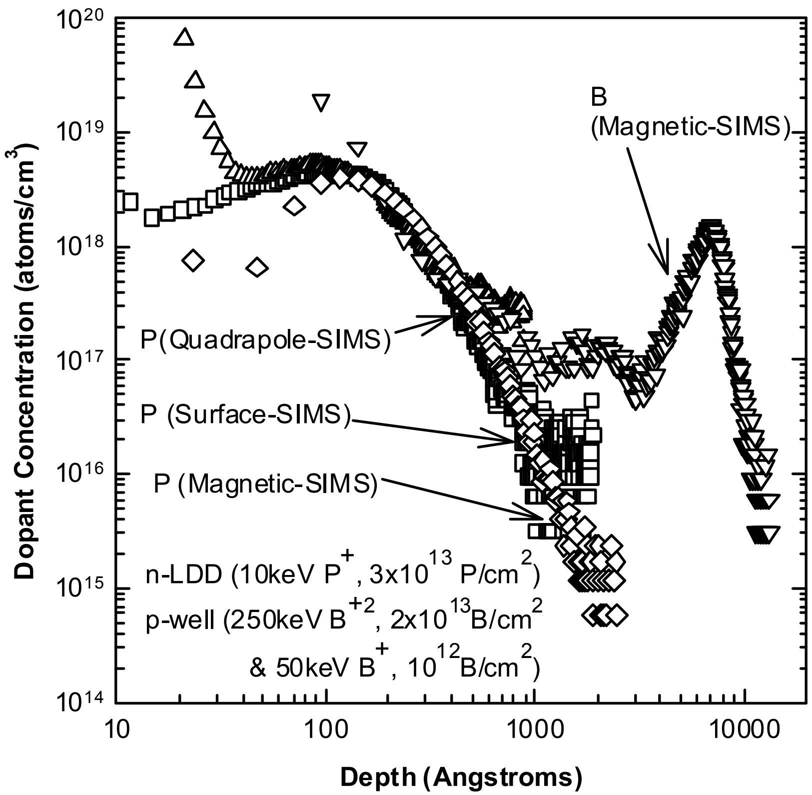
Measurements: SIMS, RBS, electrical & optical
Full-process profile composites
Channeling: wafer scan effects
New methods: Nuclear Reaction Analysis (H in Si),
“Carrier Illumination”, Phase-image TEM,
Scanning Spreading Resistance

Damage (1 module)

Measurements: RBS, TEM, TW, BX, PAD
Annealing kinetics: [311] & loop dislocations
Damage accumulation: Ion mass, flux rate, temperature
Damage profiling

Full-Process Profiles





M.I. Current, M.D. Scotney-Castle, V. Chia, S. Prussin, L.A. Larson, "Profile Analysis of a 0.25µm CMOS Process" in Ion Implantation Technology-96, eds. E. Ishida et al. IEEE #96TH8182 (1997) 194-197.

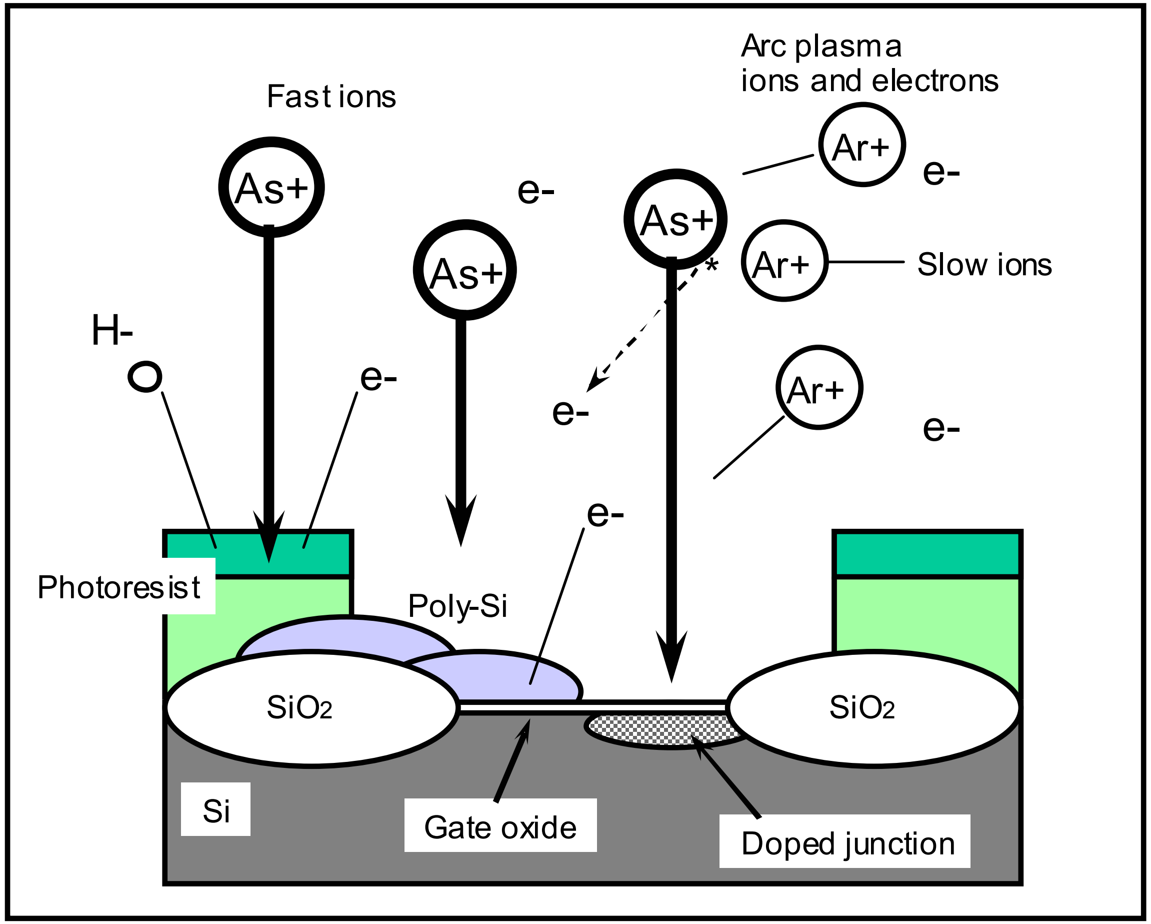
Process Metrology & Controls: 3

Charging (4 modules)

Beam-blow up, “zapping”, dielectric wearout
Beam-plasma Parameters: plasma density, Debye length
Charging Measurements: Capacitors, transistors, EEPROMs (CHARM sensors)
Beam-wafer Interactions: J-V characteristics
“Flood-guns” and all that: Electrons & plasma “floods”
Pulsed-current Effects: Plasma-immersion implanters
Photoresist Effects: Outgassing, PR pattern effects
Beam divergence control: Plasma screening

Ion Beam-Wafer Environment

- **Main components of the beam plasma at the wafer:**
- **Fast ions (As, B; 2-700 keV)**
- **Slow ions (H, Ar; 5-50 eV)**
- **Plasma ions (Ar; 5-50 eV)**
- **Electrons (2-50 eV)**



$$J_{net} = j_{ib}(1+\gamma) + j_{ip}*[1- (1+n_{ib}/n_{ip})*34.2*A_p^{1/2} *e^{([Vsurf- \Phi_p]/Te)}]$$

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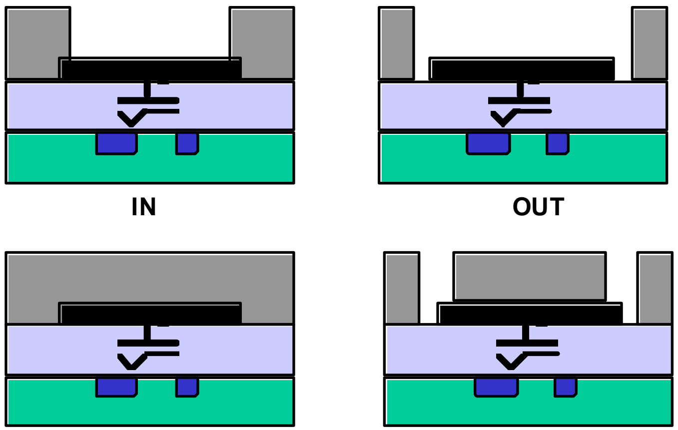
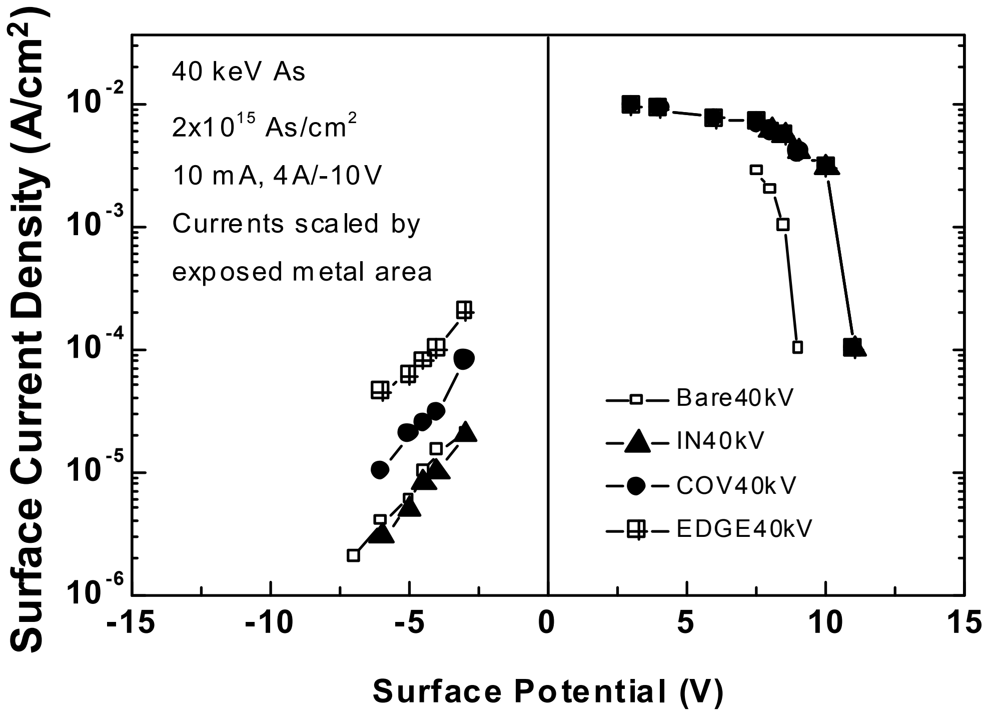
Photoresist Pattern Effects

- j-V characteristics depend on resist cover structure.
- PR usually increases net current flow to local devices.
- Largest effects for PR *covering* the charge collection electrodes!!





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Process Metrology & Controls: 4

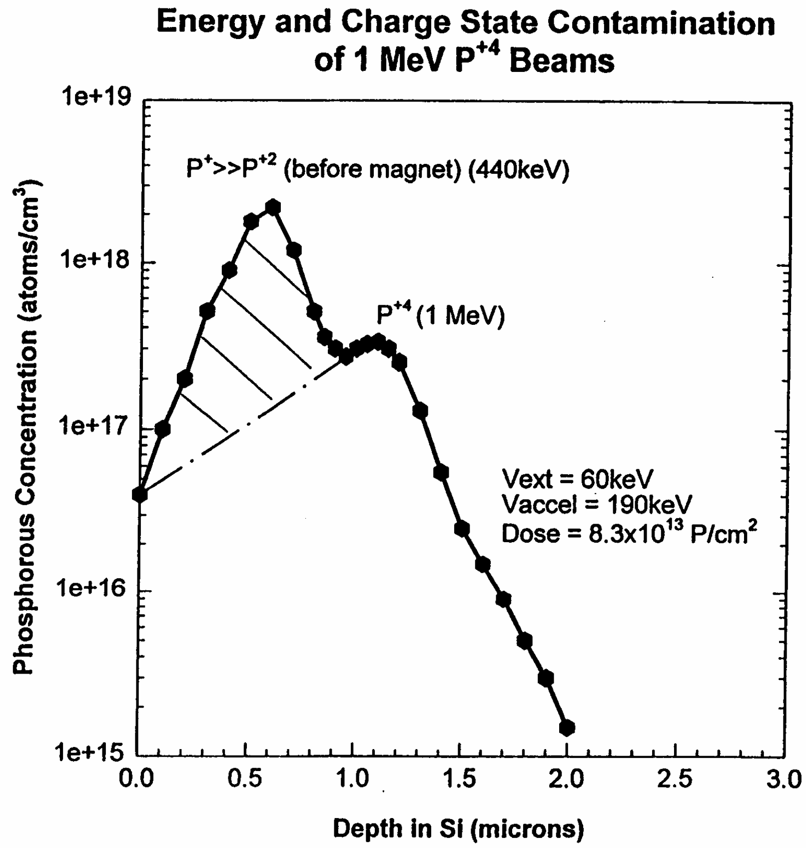
Contamination (3 modules)

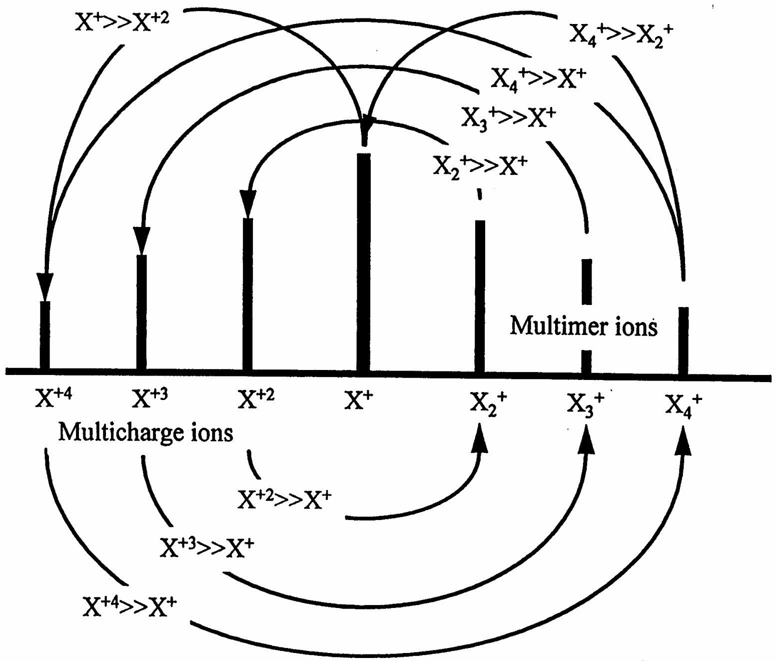
Ions:
Mass resolution: [$^{75}As/Ge$, $^{11}B/^{31}P^{+3}$, $^{11}B/^{12}C$, BF_2^+/Mo^{+2}, hydrides/fluorides]
Collisions: [B^+/BF_2^+, “accel/decel” beams, $^{40}Ar/^{10}B$, P^{+2}/P_2^+, P^{+4}/P^+]

Atoms:
Electrode sputtering: [B/As, metals]
Vapors: [P or As/Sb, surface B, or In or Sb]
Recoil atoms: [Sputtered Al, O from SiO_2 layers]

Particles:
“Rain” in load locks
Electrode arcing
Particle transport in ion beams
Killer particle size: electrical effects on junctions

Molecular and Multi-charged Ions
"Fearful Symmetries"





Aston Bands

Process Integration Examples

Multiple & Molecular Implants

Pre-amorphization, solid-phase epitaxy, dopant activation
F & B effects: B diffusion, F trapping
Cluster ions: surface smoothing
Decaborane ions

Implants into Small Spaces

Small mask openings:
Ion range shortening, damage at mask-edges
Focused ion beam damage profiles

Thin device layers (SOI):
Ion energy limits, dopant diffusion effects
Does implant have a role for ultra-thin SOI CMOS?

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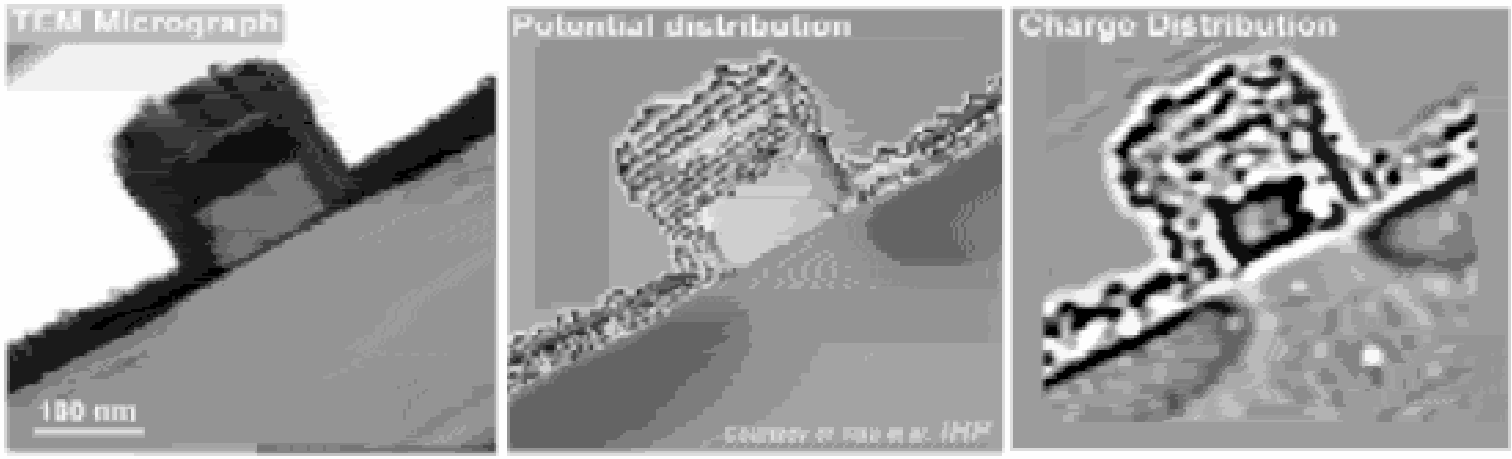

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