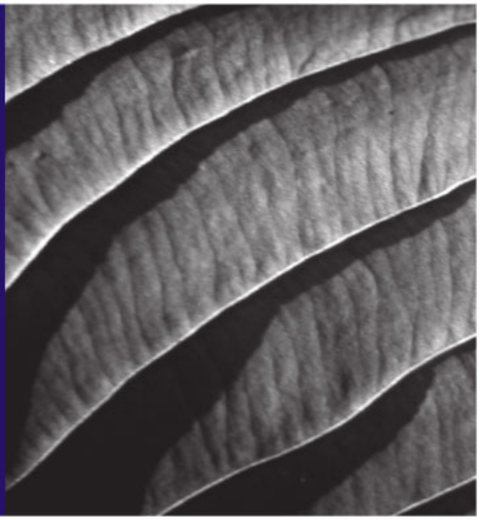
Accelerating Yield

Advanced Implant and Junction Metrology for 45 nm and Beyond



Alex Salnik

Junction Technology Group Meeting, Semicon West 2007, July 19, 2007

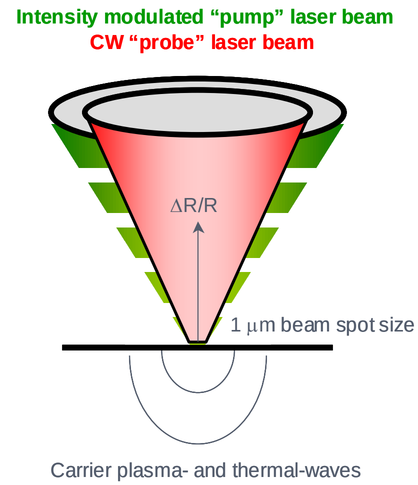
Agenda

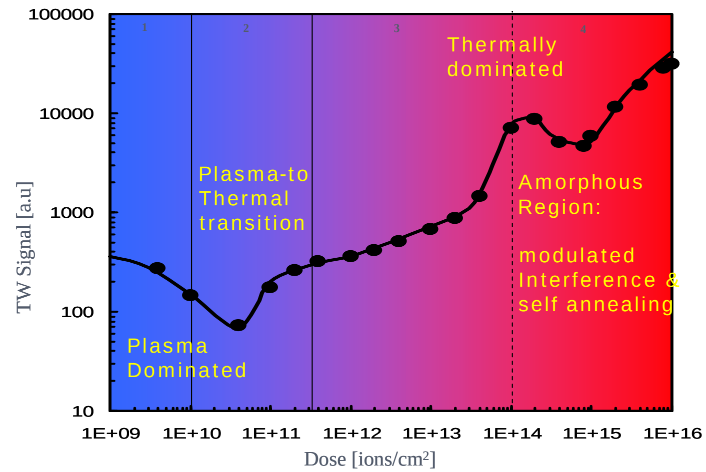
- Therma-Probe®
- Advanced Ion Implant Dose Monitoring
- USJ Parameter Monitoring
- USJ Carrier Depth Profiling
- Ion Implant Damage Depth Profiling (concept)
- Microscale Imaging
- Summary

KLA-Tencor Accelerating Yield

Therma-Probe®

- The first non-contact and non-destructive system for ion implant characterization
- Thermal Wave unit (TW unit) industry standard for over 20 years
- Based on Modulated Optical Reflectance (MOR) technology
- Mainstream application is implant dose monitoring
- Signal is driven by carrier plasma- and thermal- wave mechanisms





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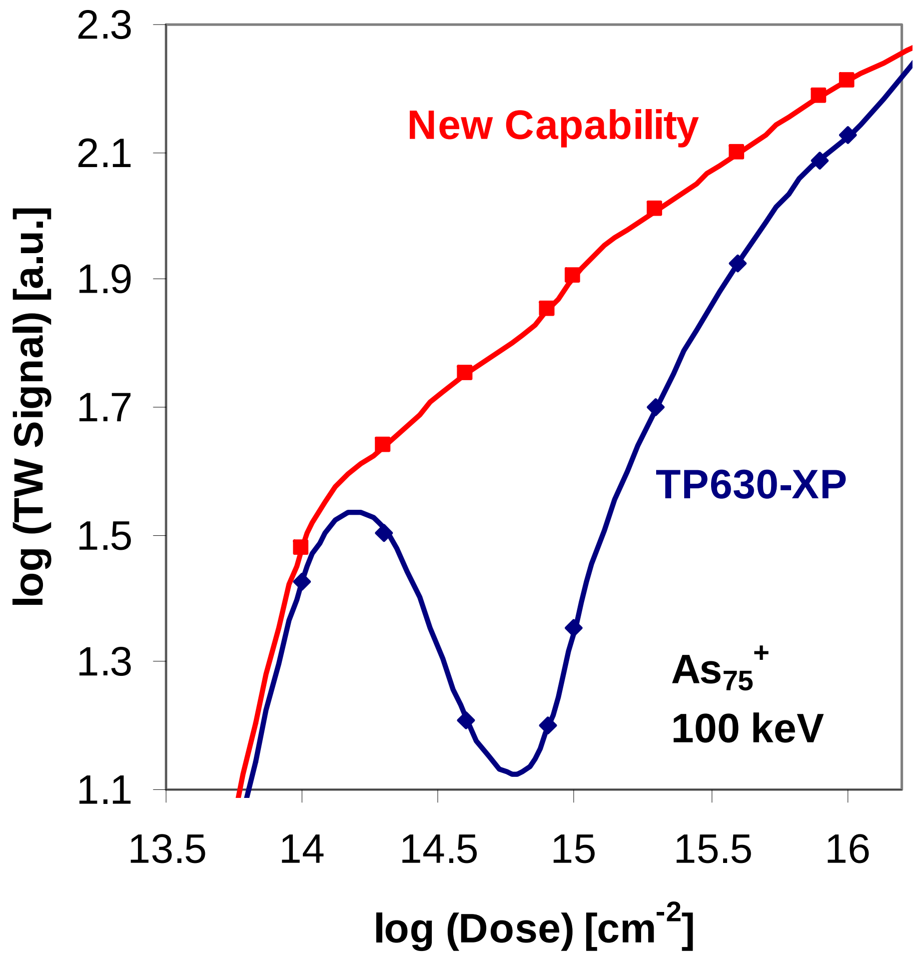
New Performance Capabilities

- Monotonic high dose response
  - Good sensitivity across entire dose range
  - Unique TW value removes ambiguity



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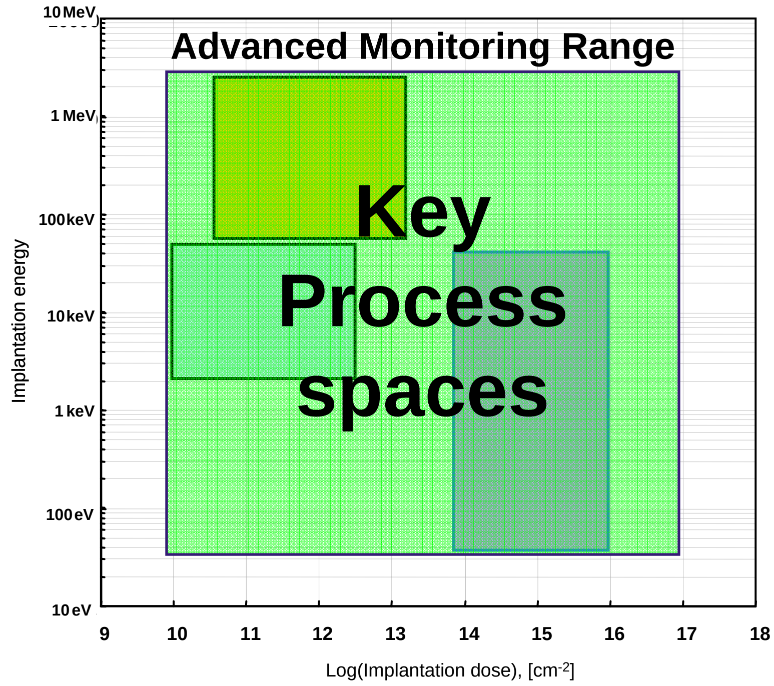
Advanced Ion Implant Dose Monitoring

- Summary of advanced system performance
  - Full-dose, full-energy spectrum capability
  - Wavelength combinations cover dose/energy regions of interest
  - Radically improved dose detectability (DD)
  - Flexibility allows for a variety of advanced applications



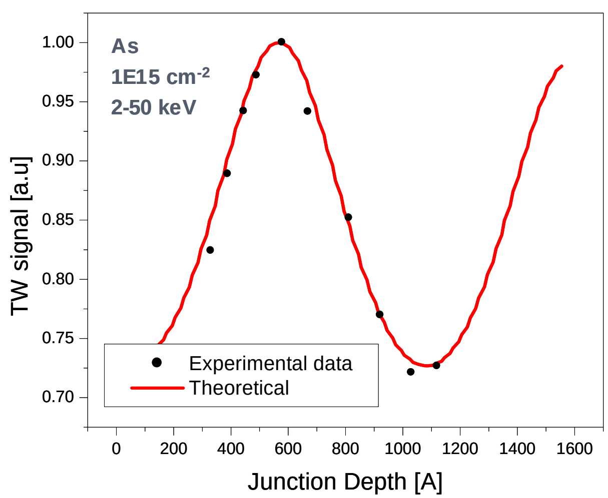
USJ Parameter Monitoring

- **What is the ideal metrology solution for USJ ?**
  - Non-destructive, Non-contact
  - In-line Product Monitoring (small measurement area)
  - Fast (high throughput)
  - Reproducible
  - Sensitive to Active Dopant
  - Enables Carrier Depth Profiling

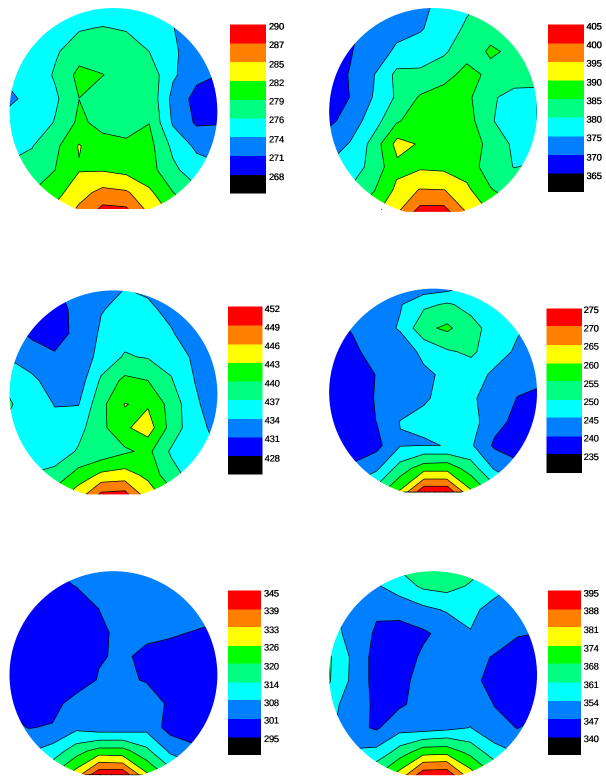
USJ Parameter Monitoring

Junction Depth

- TW signal has cosine dependence on junction depth
- Ambiguity is removed by applying an advanced signal processing algorithm



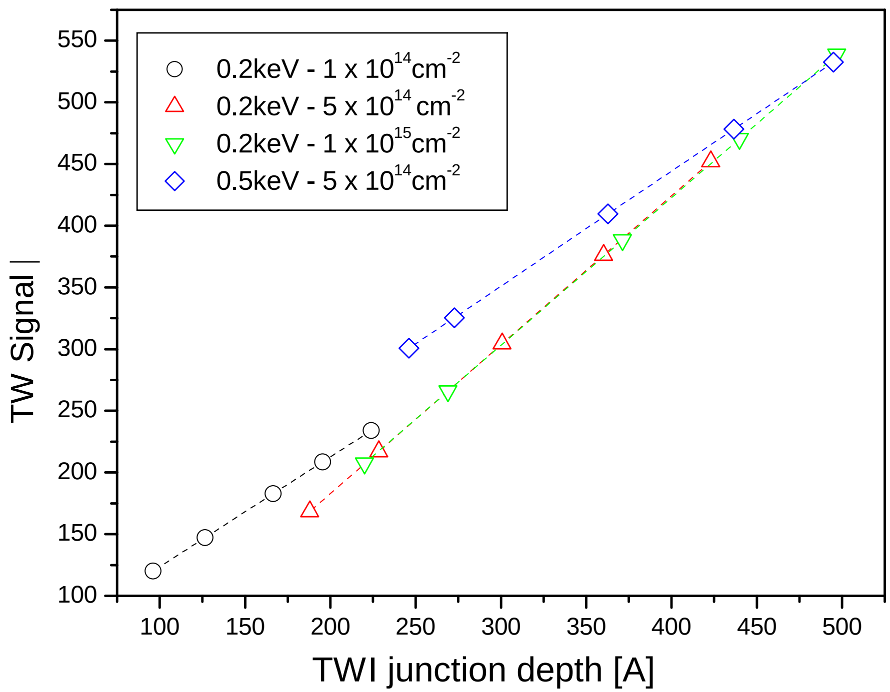
USJ Depth Maps (Å)

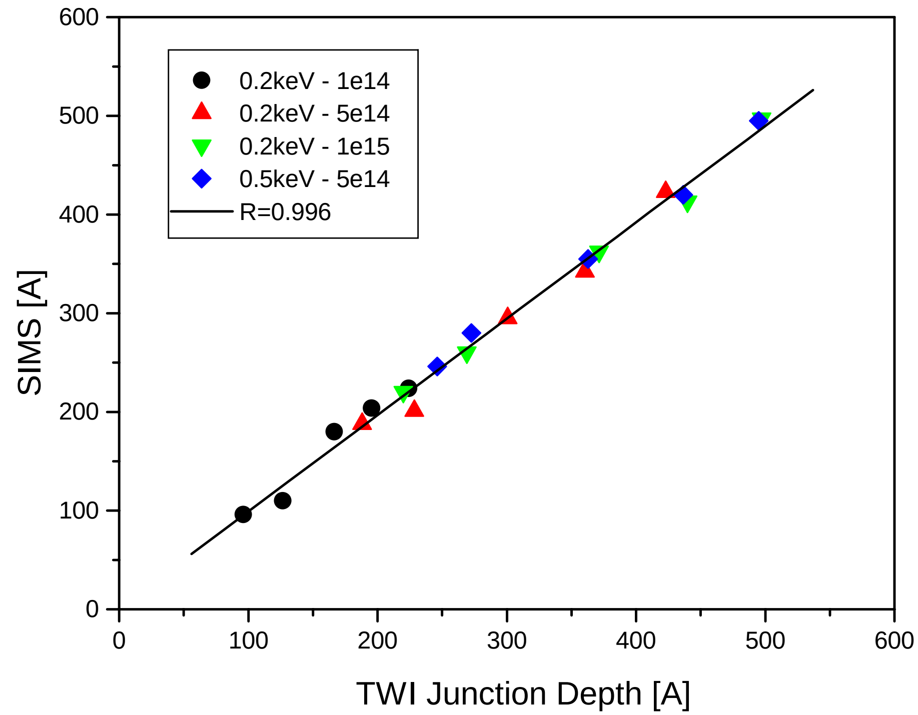


USJ Parameter Monitoring

Junction Depth Correlation

- TW signal is correlated to SIMS to obtain USJ depth values
- Good correlation is obtained for all doses and energies.

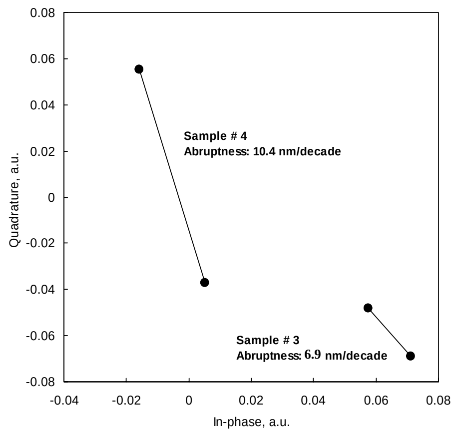




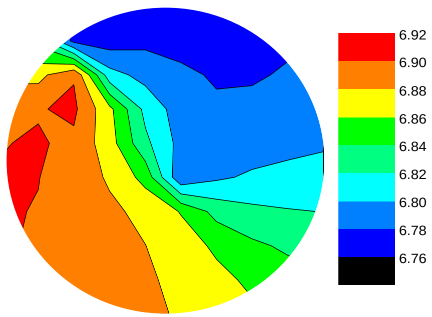
USJ Parameter Monitoring

Junction Abruptness

- Measurements are performed at two pump-probe beam separations
- MOR signal is analyzed in Q-I coordinates
- The slope between the two points is calculated
- Slope uniquely defines the abruptness



USJ Abruptness Map (nm/dec)

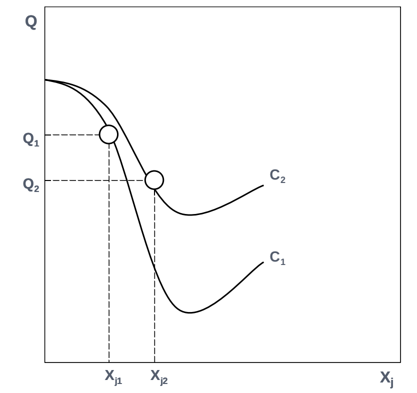


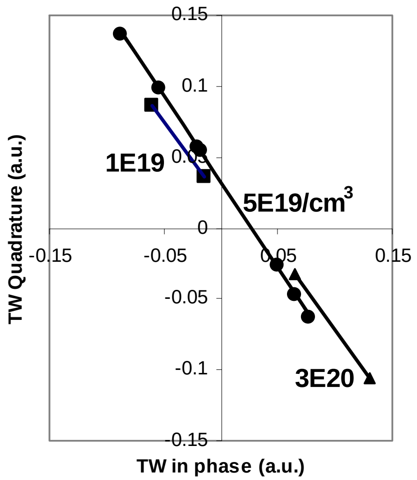
USJ Parameter Monitoring*

Peak Carrier Concentration

Peak carrier concentration and junction depth are measured *simultaneously*

- MOR signal is analyzed in Q-I coordinates
- Each (Q-I) pair uniquely corresponds to junction depth and a peak carrier concentration (for box-like profiles)
- Junction depth and peak carrier concentration values are obtained simultaneously





* In collaboration with IMEC: T. Clarysse, et al. J. Vac. Sci.Techn. B, 24,1139 (2006)

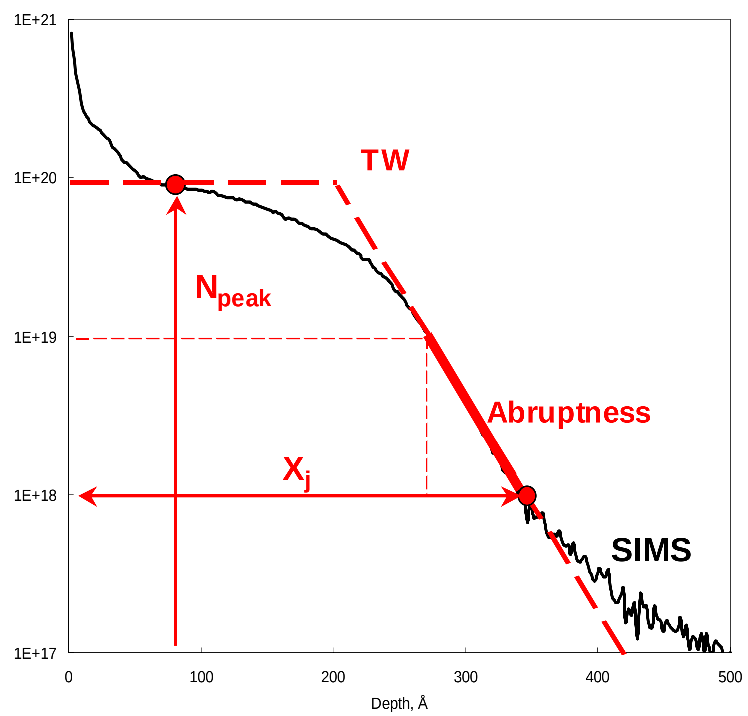
USJ Carrier Depth Profiling

- Parametric Profile Approximation:
  - USJ Depth (Therma-Probe Measurements)
  - USJ Abruptness (TP)
  - Peak Carrier Concentration (TP)
- Solving the Forward and Inverse Problems:
  (in collaboration with T. Clarysse's group at IMEC)
  - Experimental Pump-Probe Beam Offset Scans (TP)
  - Solution to Forward Problem (IMEC)
  - Inversion of Offset Scans (IMEC, K-T)

USJ Carrier Depth Profiling

Approximated Carrier Depth Profile

- Three independent USJ parameters define the approximated carrier depth profile
  - USJ Depth (X_j)
  - USJ Abruptness
  - Peak Carrier Concentration (N_{peak})



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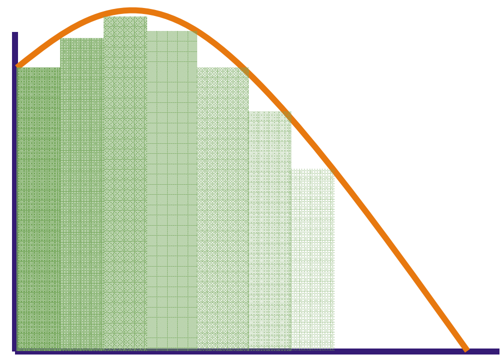
USJ Carrier Depth Profiling*

- Relevant dopant depth profile characteristics
  - peak carrier concentration, junction depth and abruptness
- Extension of TP application to completely independent dopant profile measurement (no calibration to SIMS)
- Begin with simple box-like profiles (CVD layers) to validate approach
- Proceed with more complicated profiles

As junction depth decreases and abruptness increases, profile approaches that of a single layer



* In collaboration with IMEC: J. Bogdanowicz, INSIGHT 2007 Workshop (Napa, CA)

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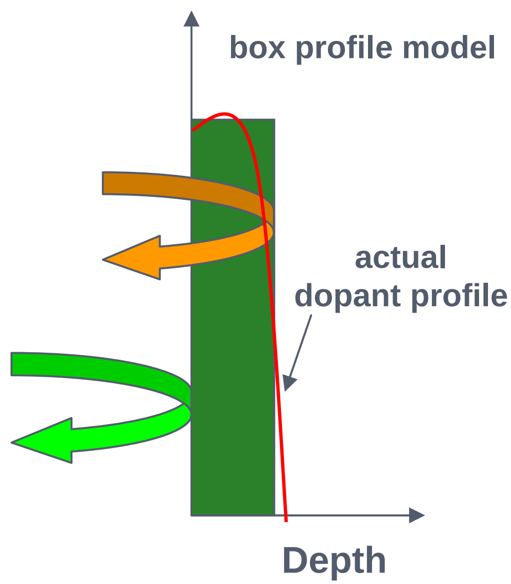
USJ Carrier Depth Profiling*

- For box like profiles the signal results from the optical interference of a surface and an interface reflection
- The amplitude of the quadrature signal varies cosinusoidally with the junction depth and the cosine amplitude varies with doping

Simplified Model

$$Signal = C\,(\underline{N_{surf}} + \underline{\cos(2knz_{\text{int}})(N_{sub} - N_{surf})})$$

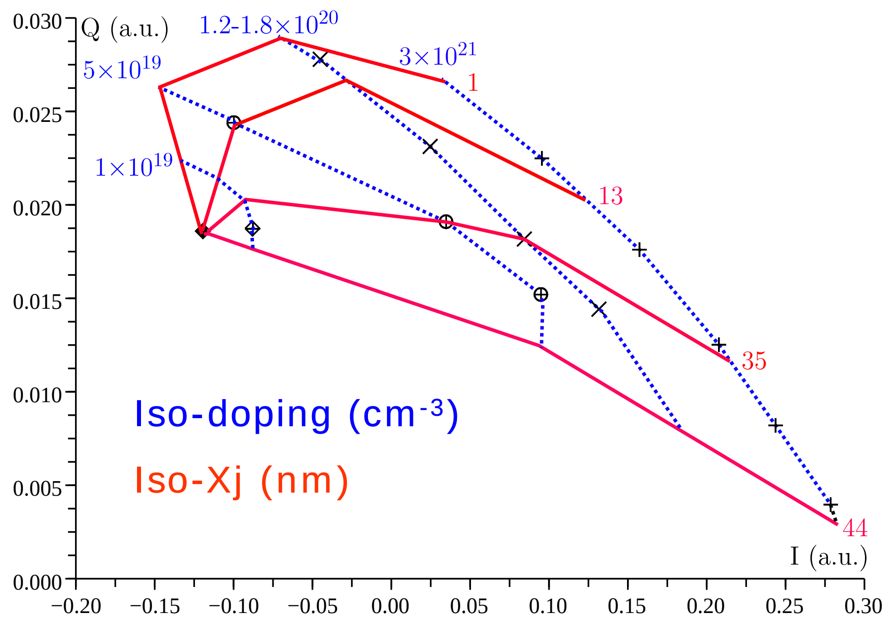


* In collaboration with IMEC: J. Bogdanowicz, INSIGHT 2007 Workshop (Napa, CA)

USJ Carrier Depth Profiling*

USJ Depth and Peak Concentration

- Plotting Q vs. I demonstrates the ability to directly extract the junction depth and the peak carrier concentration from a single measurement
- Unique reconstruction for X_j < 44 nm and N > 5×10^{18} cm^{-3}.



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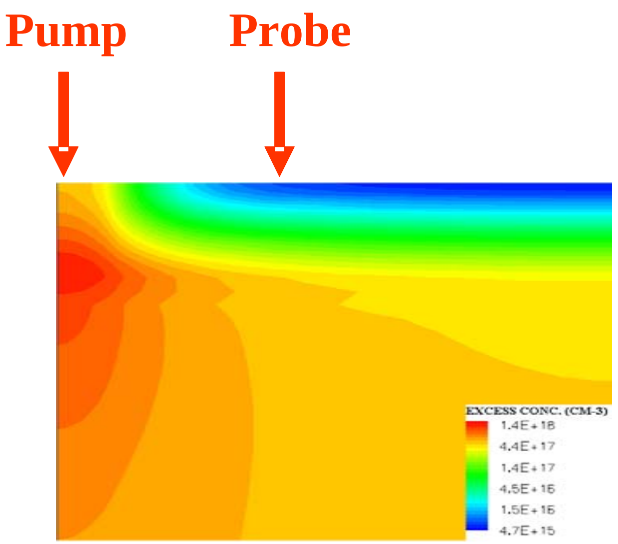
USJ Carrier Depth Profiling*

- Measuring signal while separating the pump and probe beams (offset curve) introduces lateral variation of the carrier density
  - carrier diffusion length increases with decreasing dopant concentration
- Extracting arbitrary dopant profile from offset curves using modeling
  - finite element simulator (FSEM) approach is currently being developed

Simulation of the Excess Carrier Concentration



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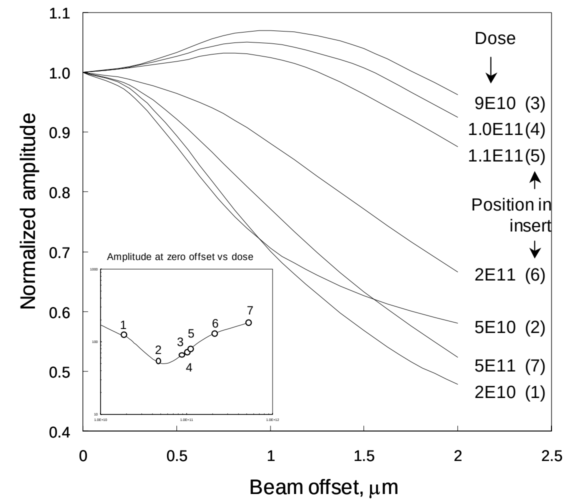
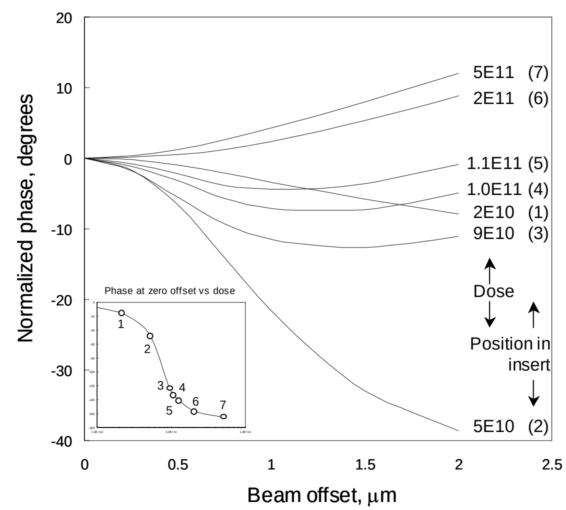
Ion Implant Damage Depth Profiling (concept)

- Theoretical model based on the pump-probe offset scans (forward problem)
  - Plasma- and thermal-wave components
- Experimental offset scans performed at different modulation frequencies
  - Experimental conditions correspond to the maximum of plasma-thermal interference, i.e. highest sensitivity to depth profile variations
- Fitting of experimental data and extracting depth profiles

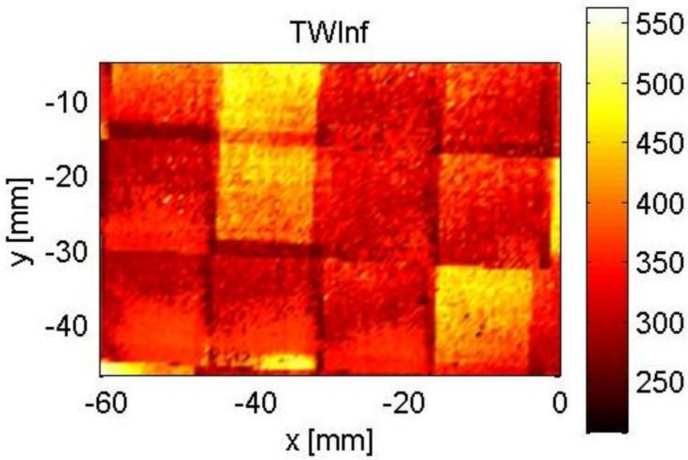




Microscale Imaging

USJ Anneal Uniformity

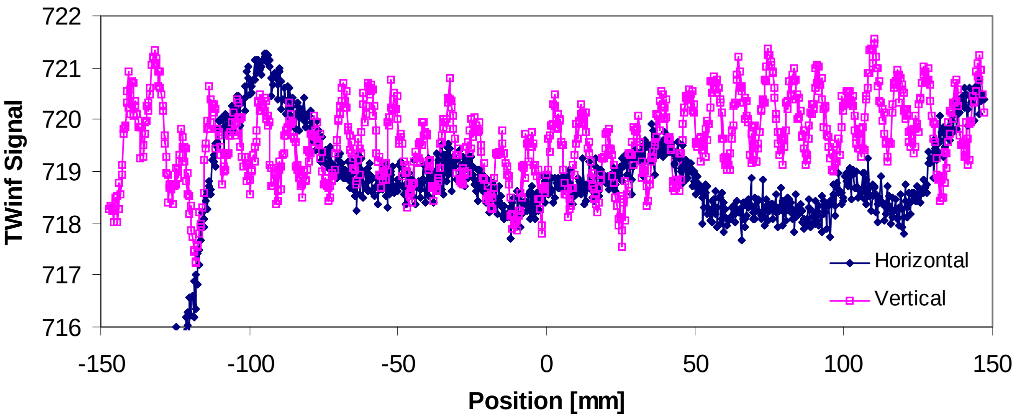
$B_{10}H_{14}$, 1E15 cm^{-2}, 500 eV



- step and repeat checkerboard signature of laser anneal

Implant Uniformity

B_{11}, 1E15 cm^{-2}, 500 eV



- signature of spot beam implanter
  - ~ 5 mm features correspond to pitch of raster scanned beam

Summary

What to Expect From $<$ 45 nm Implant and Junction Metrology ?

- Advanced Ion Implant Dose Monitoring
  - Full-dose, full spectrum capability, dose detectability better than 0.1 % (3σ) across the board
- USJ Parameters Monitoring
  - Simultaneous measurement of all USJ parameters of interest
- Carrier Depth Profiling
  - Reconstruction of active dopant depth profiles, potentially replacing SIMS
- Ion Implant Damage Depth Profiling
  - Simultaneous dose/energy and damage depth profiles for implant characterization, microscale imaging