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Accelerating Yield

TW Metrology For Implant And Annealing At 32 nm Node

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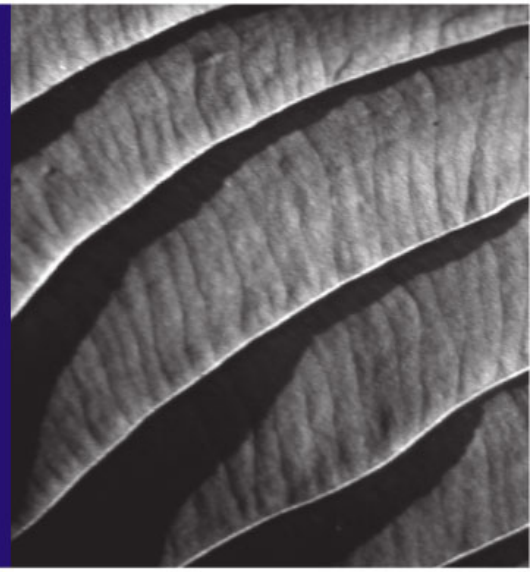
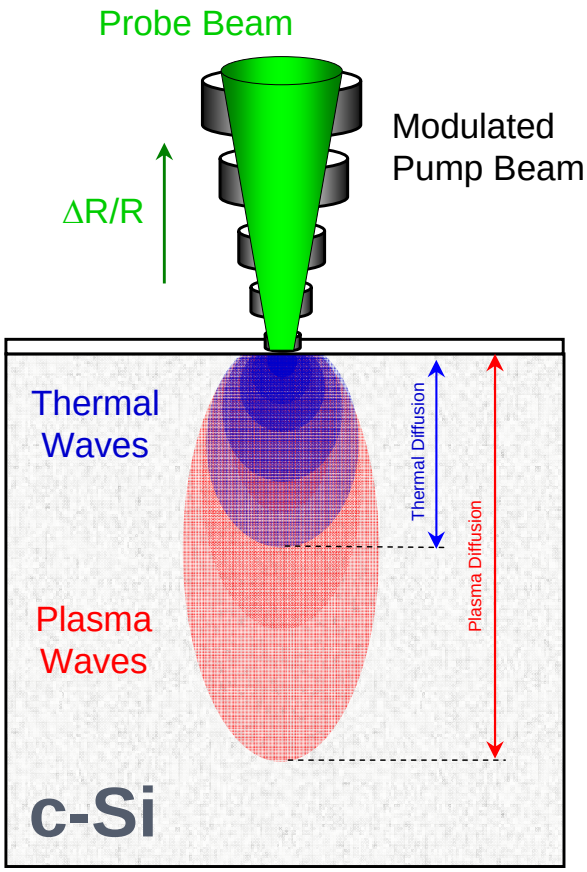
KLA-Tencor Corp.

WCJTG Meeting, July 17, 2008 Semicon West 2008



Therma-Probe® Technology

- First non-contact and non-destructive system for 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
- Small 1 μm beam size
- In-line monitoring capabilities



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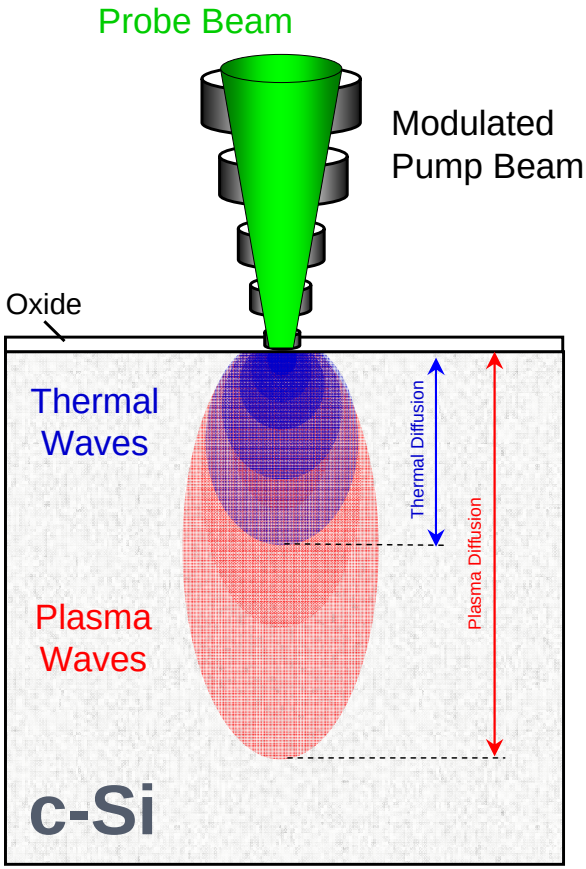
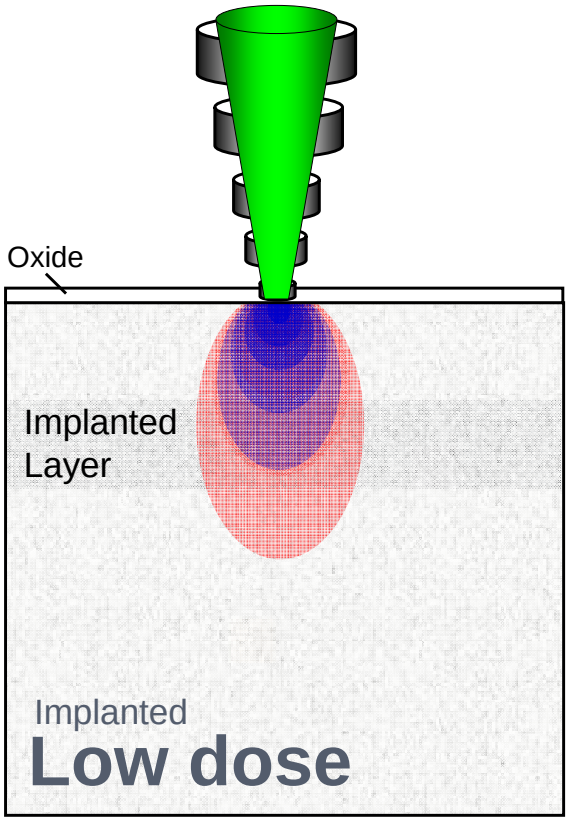
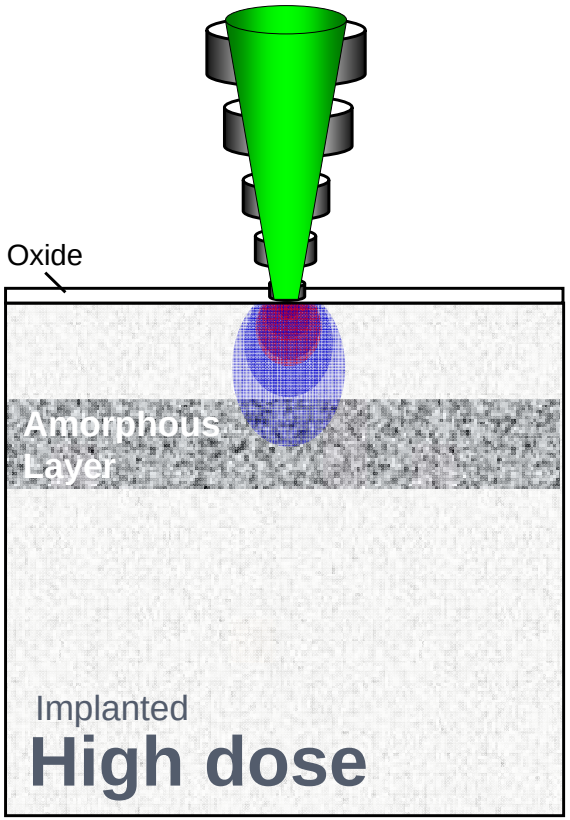
Plasma- and Thermal-Waves in Implanted Si



Plasma Dominated Signal



Plasma - Thermal Transition



Thermal Dominated Signal

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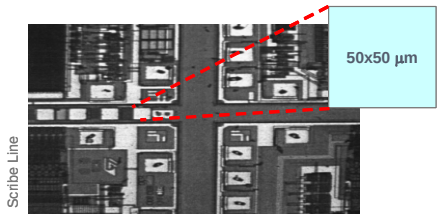
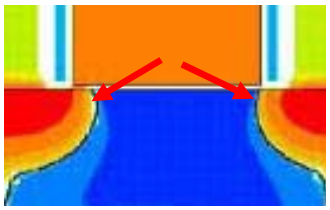
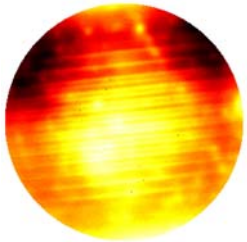
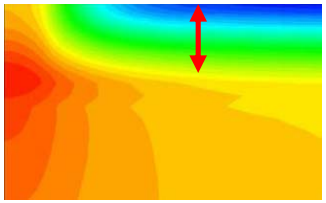
Implant Process Challenges & Solutions

Challenges	Solutions
SPC-level Process Monitoring ▪ Integration issues detected ONLY on product wafers	Inline Monitoring
Implant Asymmetry & Channeling ▪ Implant angle induced process error ▪ Control device variations	AOI Monitoring
Implant & Anneal Uniformity Control ▪ Implant dose & Anneal temperature ▪ Control device variations	Micro Uniformity Mapping
Dopant Activation (USJ) ▪ Diffusionless junction formation ▪ Complete dopant activation	Junction Profile Measurement









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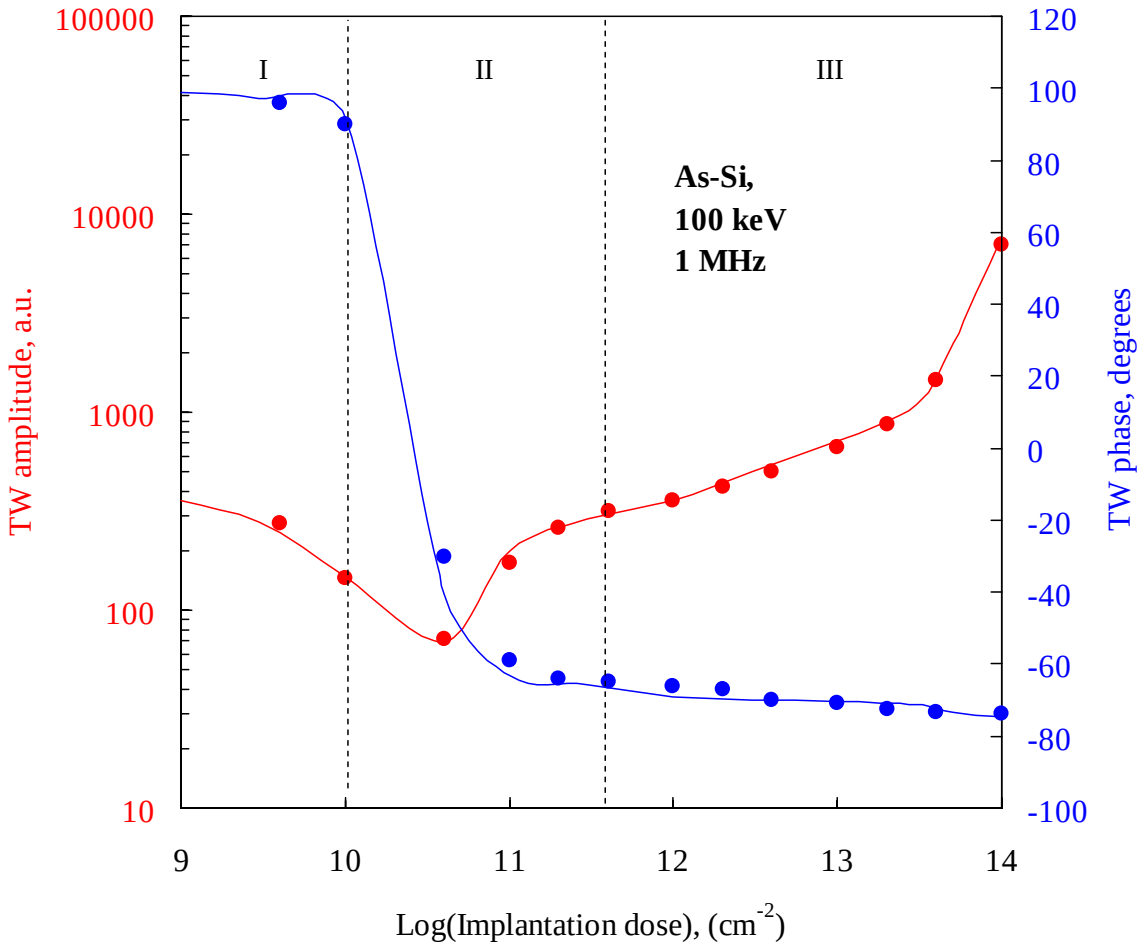
TP Signal Dependence on Dose

- At low doses (Region I), the TW signal is dominated by the plasma-wave component.
- TW amplitude rapidly decreases with increasing implantation dose while the TW phase remains almost unchanged.
- In the Region II, the TW phase exhibits a sharp drop indicating a change in the dominant physical mechanism from plasma to thermal.
- At relatively high doses (Region III), the TW signal is increasing due to the increasing thermal component and changes in optical constants.



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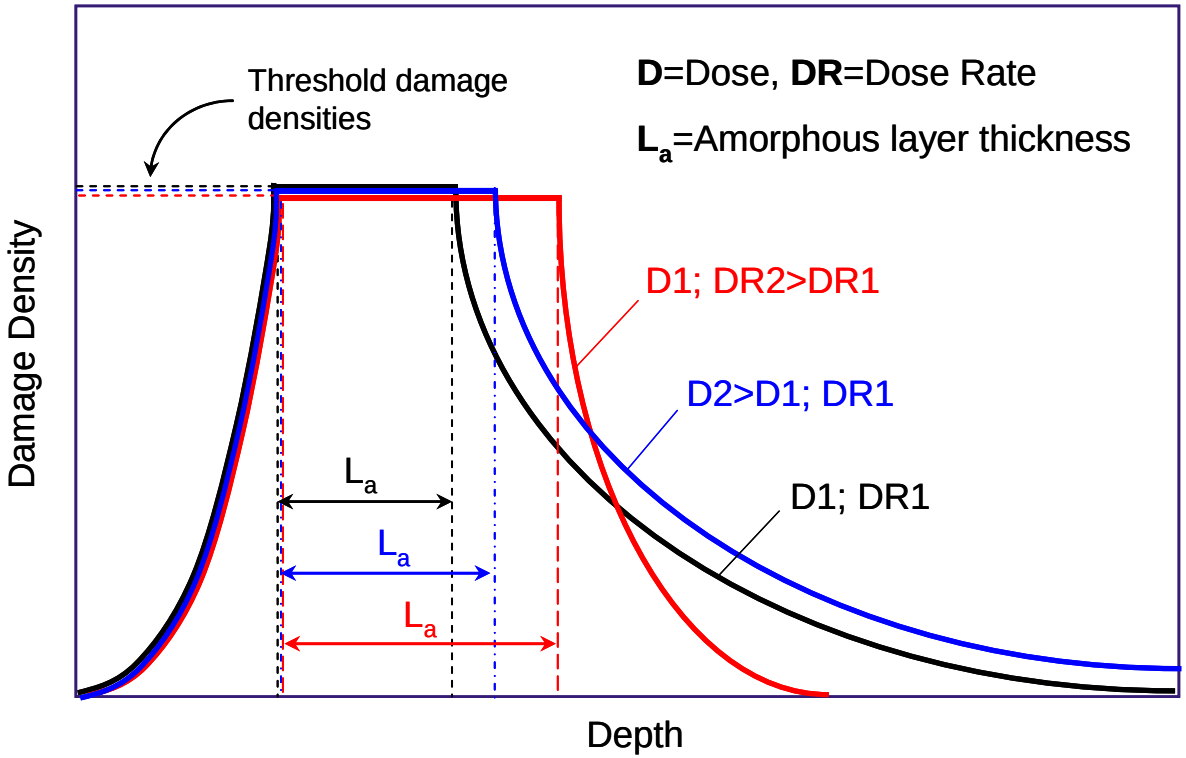
Dose Rate (Beam Current) Effect

- Increase in Dose (D) produces deeper amorphous layer dept (L_a) without affecting the shape of the tail.
- Increase in Dose Rate (DR) produces deeper amorphous layer depth (L_a) and steeper tail.
- More abrupt tail for higher DR results in less EOR damage after anneal (known)
- Higher DR result in more *ABRUPT* tail in a damage depth profile



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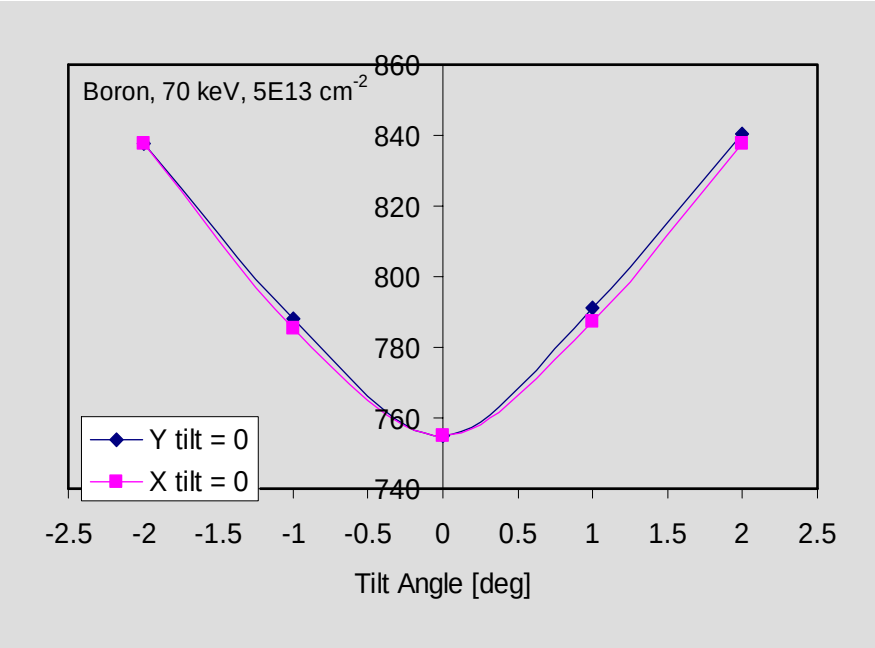
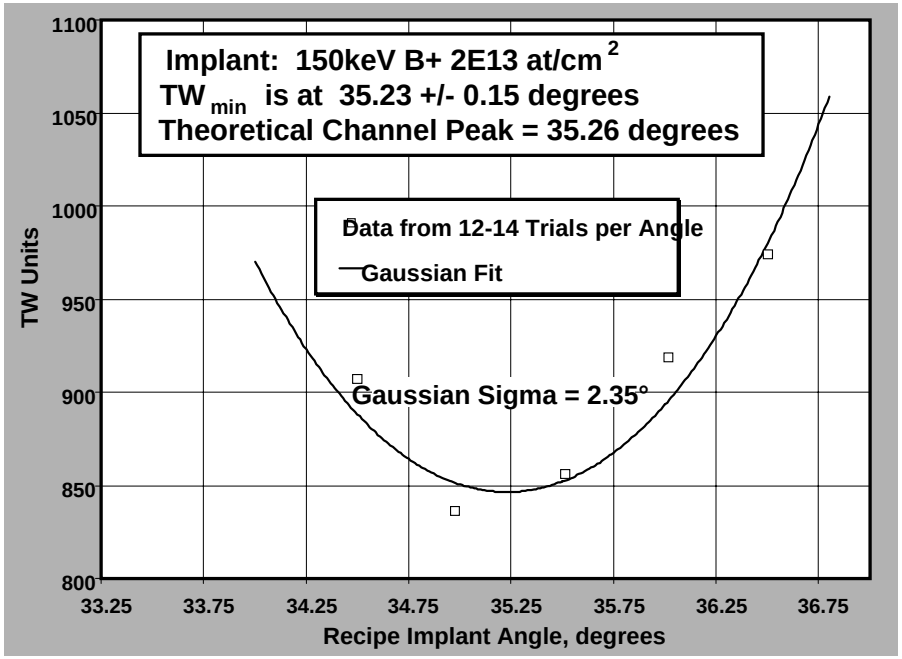
Implant Angle of Incidence Control

- TP resolution enabled implant tilt alignment calibration to 0.03º
- Provides true implant effects not masked by anneal step





High implant tilt angle verification is shown using a <112> channeling test

TP offers quick accurate AOI measurements for post PM qualification tests

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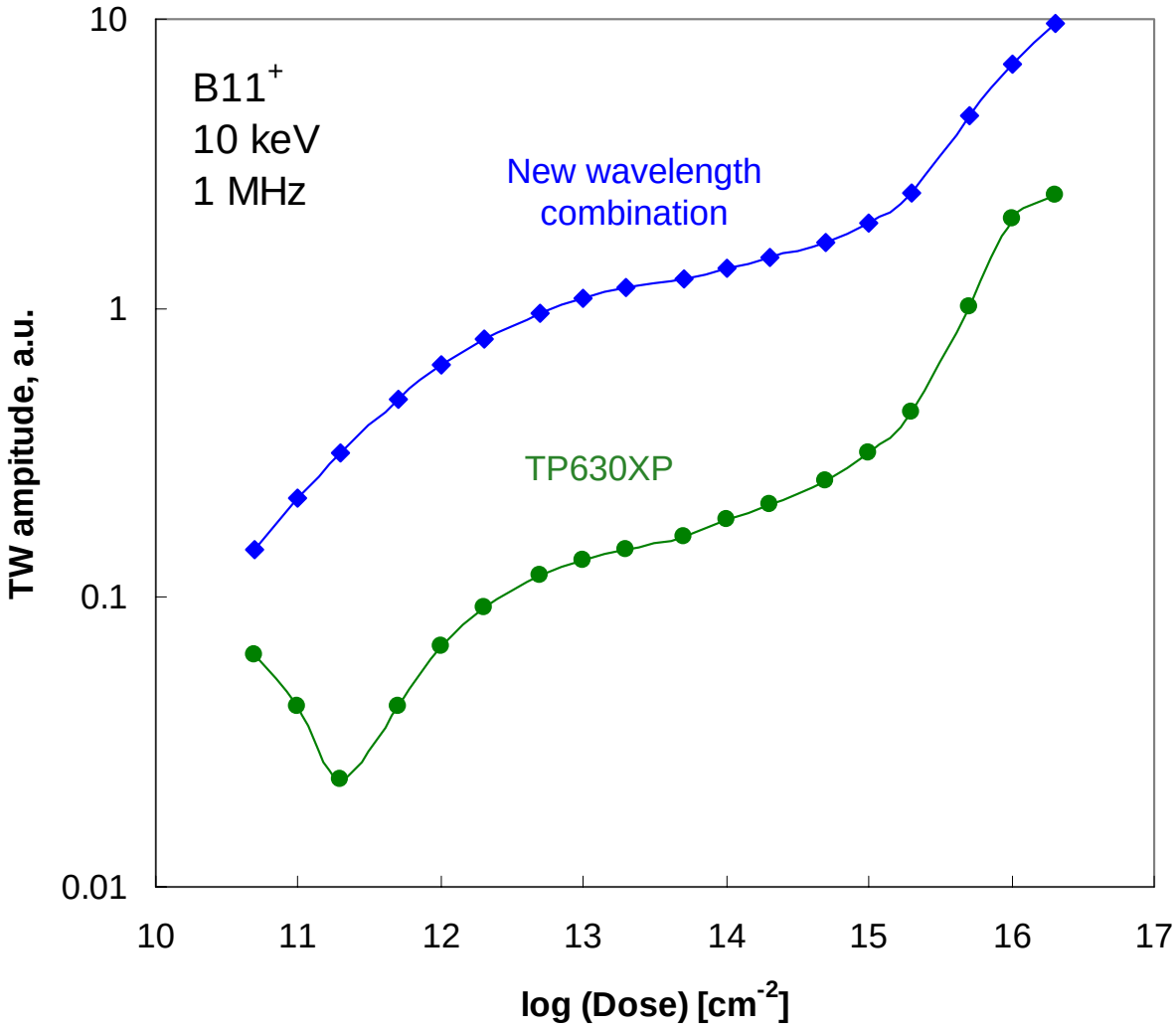
Controlled Plasma-Thermal Interference

- By selecting the optimal wavelength combinations, the MOR signal behavior, sensitivity and strength can be adjusted for each particular application



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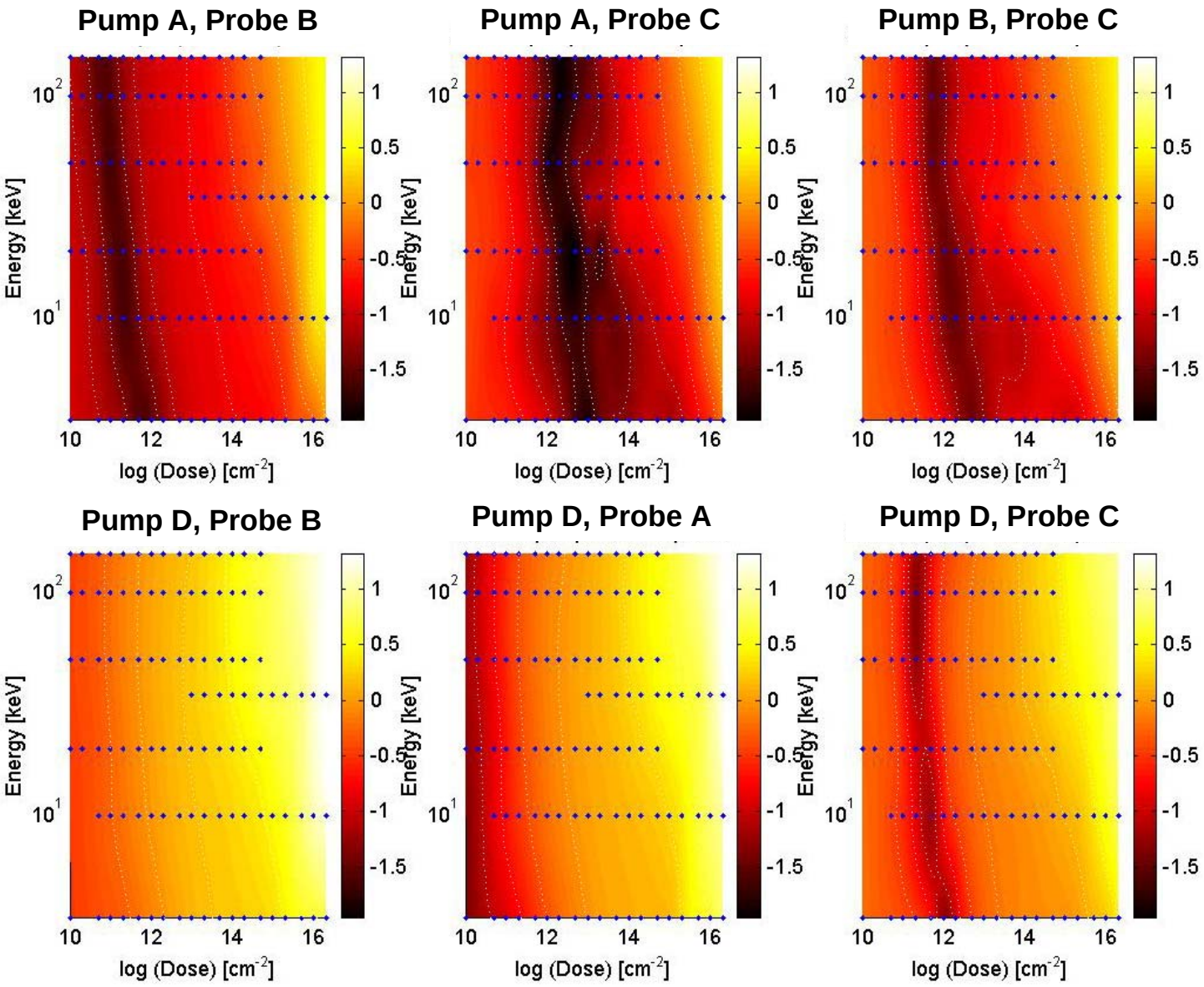
MOR Signal Maps



- Color scale (z axis) is normalized log (signal)
- Blue symbols represent experimental data points on wafers

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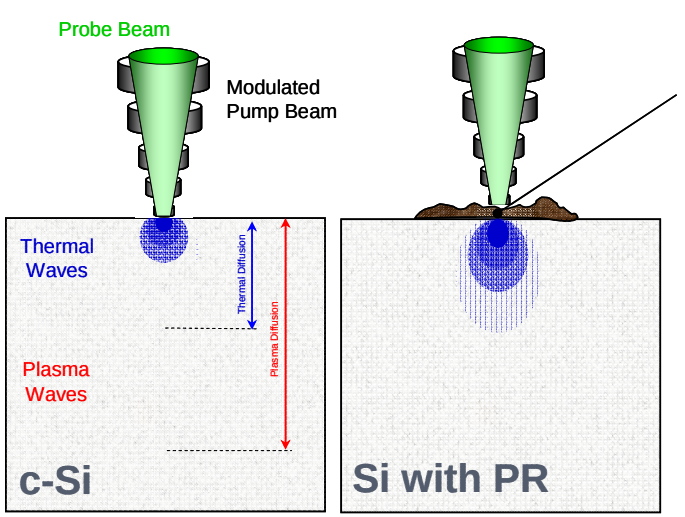
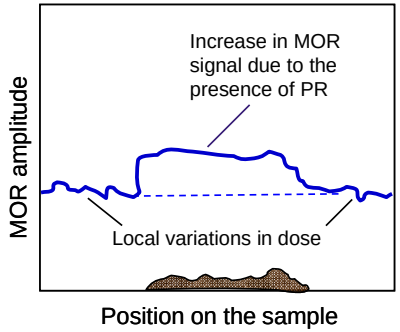
Other Implant Related Applications

- Energy Contamination
- Channeling Detection
- Implant SOI
- Chain Implants
- Sequential Implants
- Detection of PR Residuals



Increased temperature rise due to higher optical absorption and lower thermal conductivity of PR



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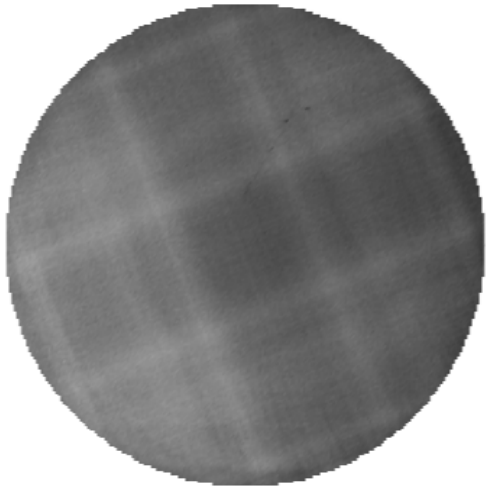
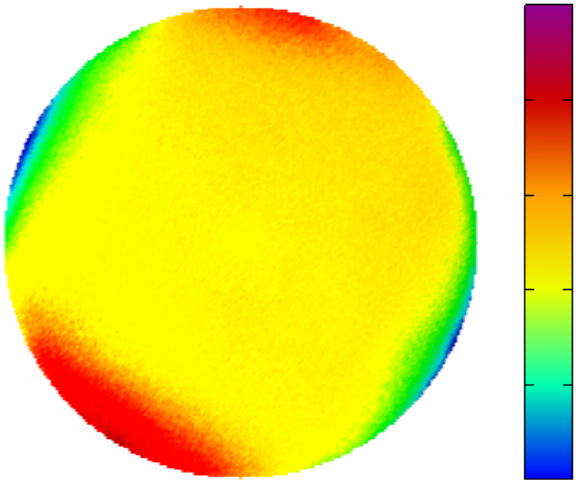
Implant Signatures



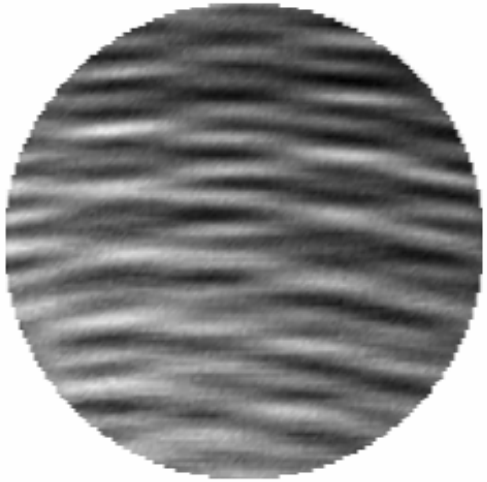
Signal Variation: **0.1 %σ**

Type A Implant



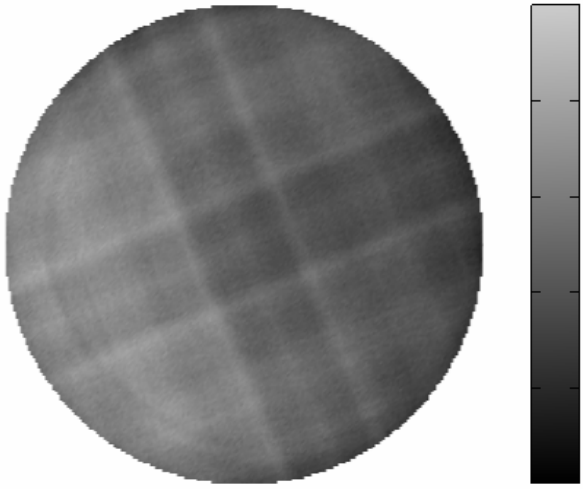
0.8 %σ

Type B Implant



0.2 %σ

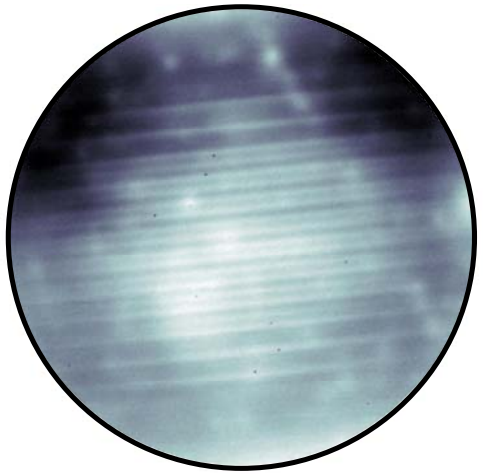
Type C Implant



0.1 %σ

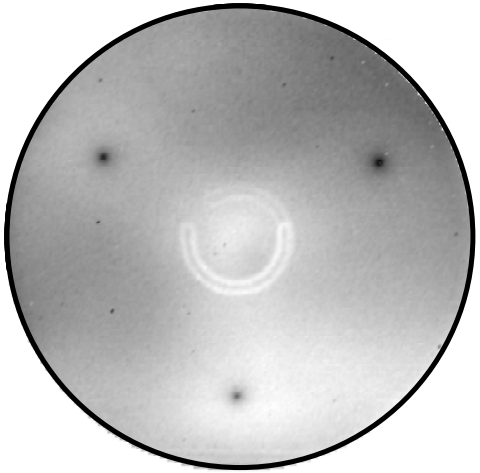
Type D Implant

Anneal Signatures



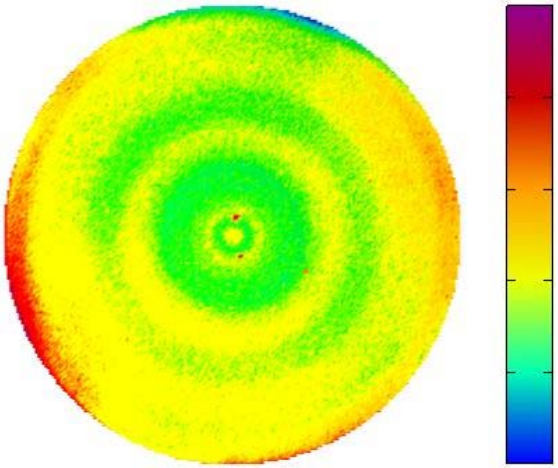
2 ‰σ

Flash Anneal



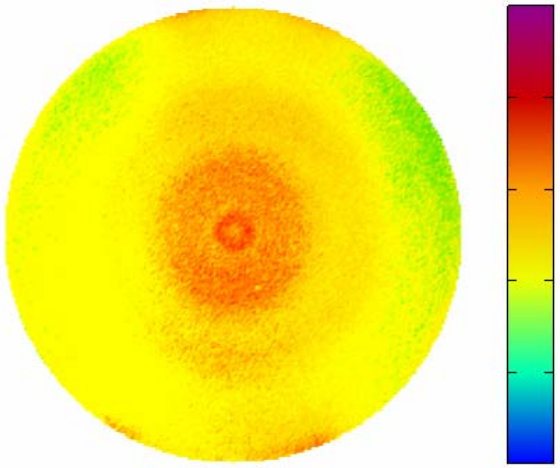
0.6 ‰σ

Spike + Flash Anneal



0.7 ‰σ

RTA Anneal



6.8 ‰σ

RTA Anneal

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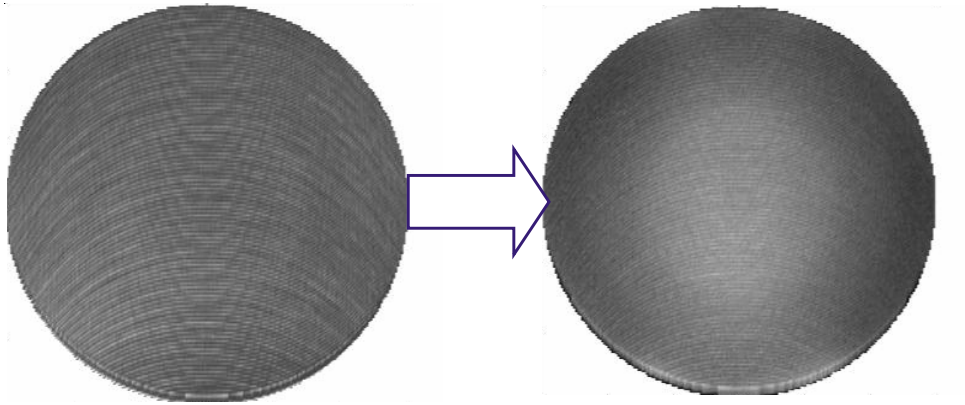
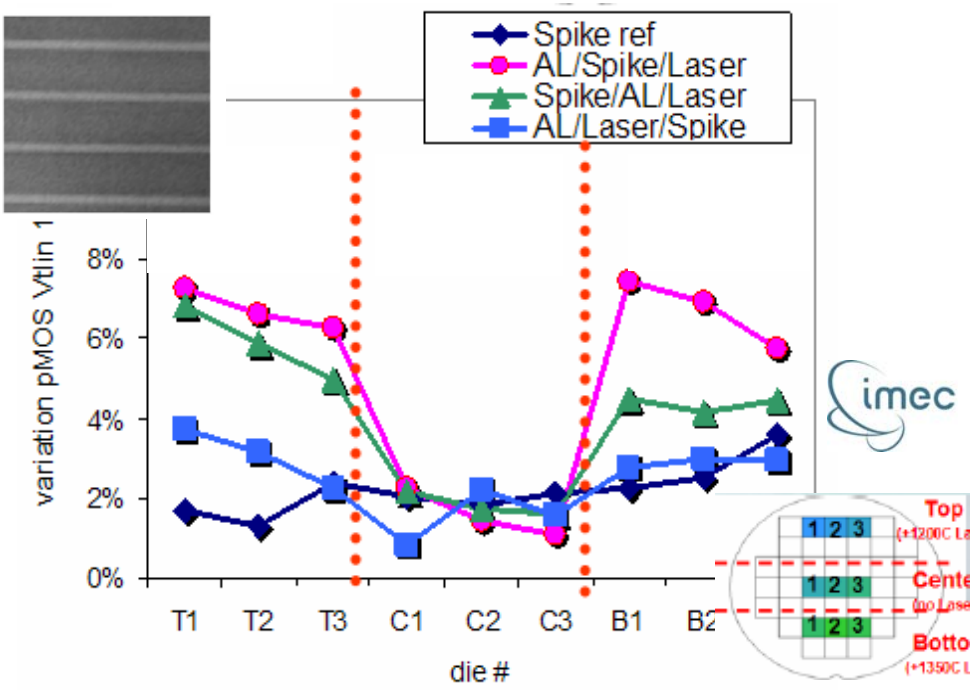
Correlation of Micro Uniformity to Device

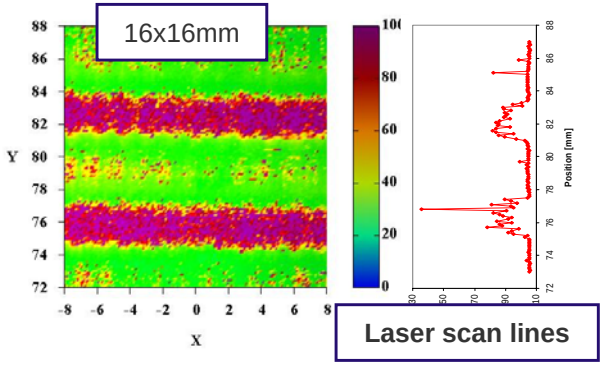
Anneal Optimization



Anneal Conditions to Vt



Anneal Control



Monitoring within scan uniformity and scan-to-scan stitching

Localized variations due to implant, anneal, pattern density will significantly affect device performance

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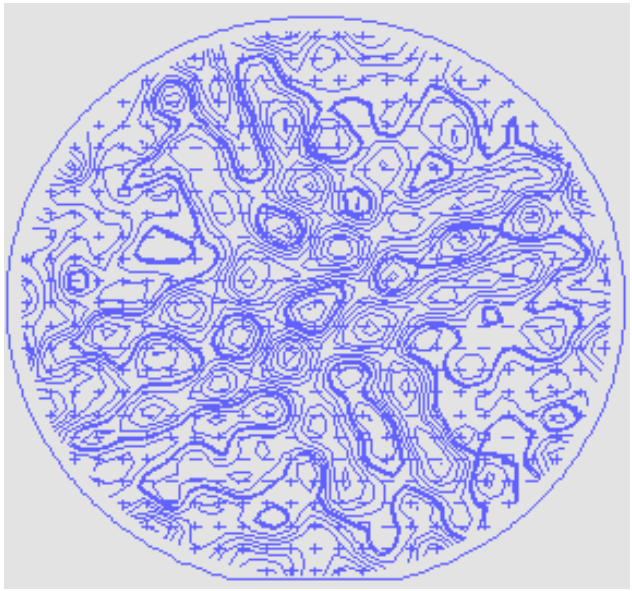
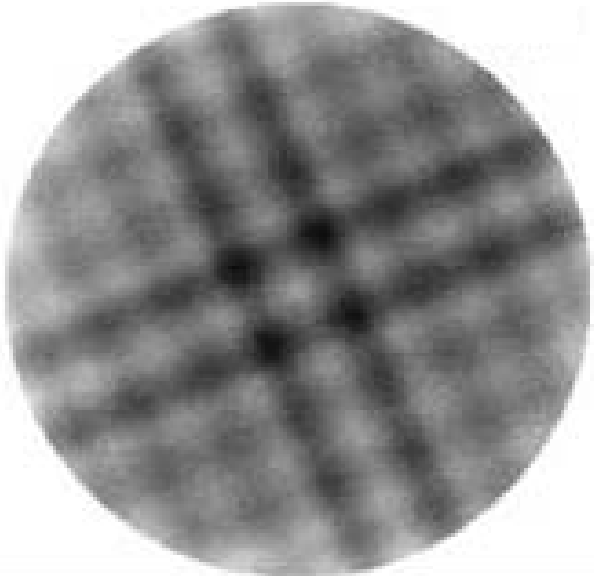
Implant and Anneal Signatures

0.69 %σ



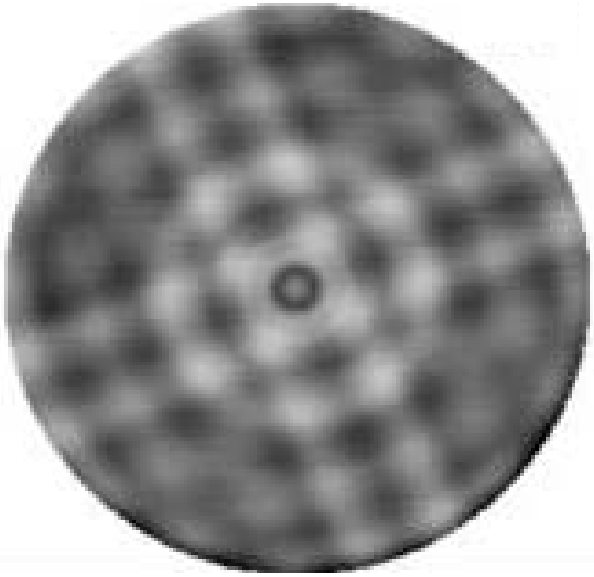
Implant
(Contour map)

0.73 %σ



Implant
(High resolution)

0.37 %σ



Anneal
(High resolution)

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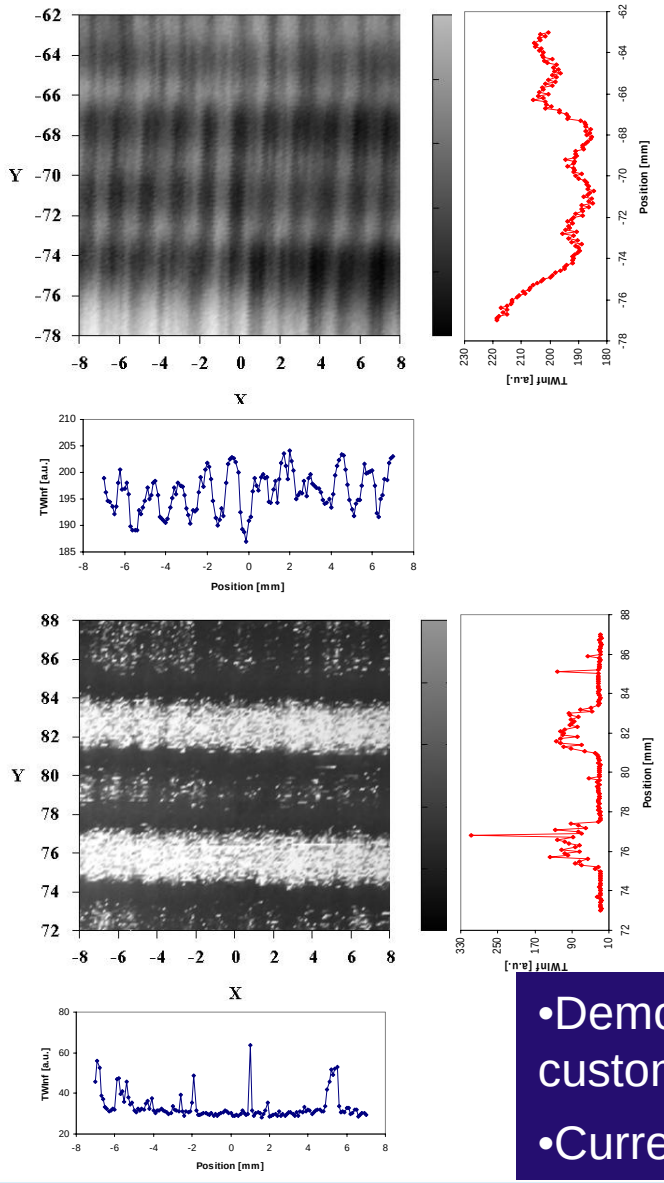
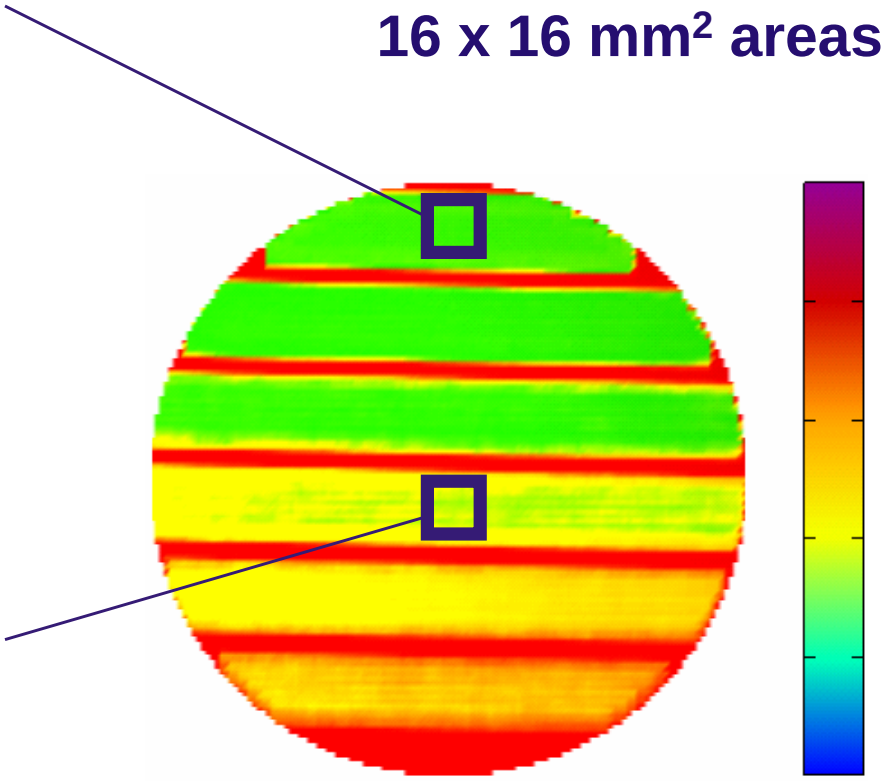
Anneal Signatures: Fine Structure



16 x 16 mm² areas



- Demonstrated correlation to device performance at customer sites
- Currently working with IMEC to further quantify

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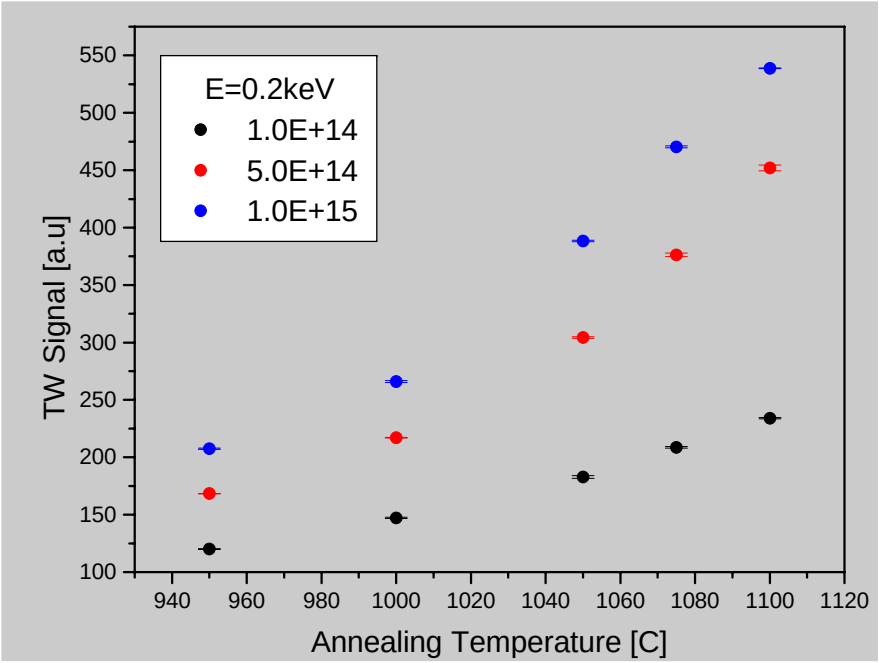
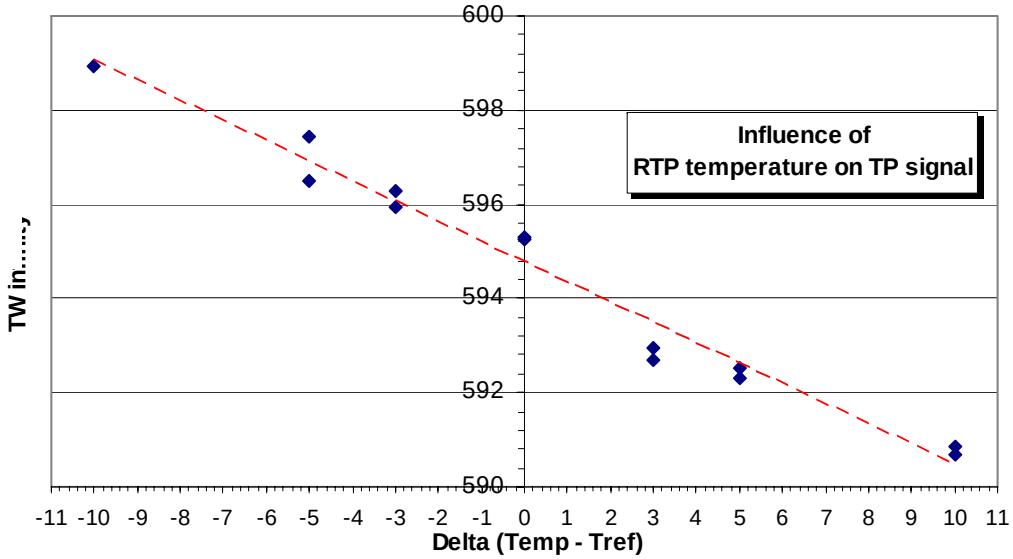
Ultra Shallow Junction Capability
Anneal temperature

Anneal temperature monitoring



Production Results



- Anneal temperature resolution <2 deg
- Enables RTP and spike anneal process monitoring

- Currently anneal temperature resolution better than **2 deg** in production

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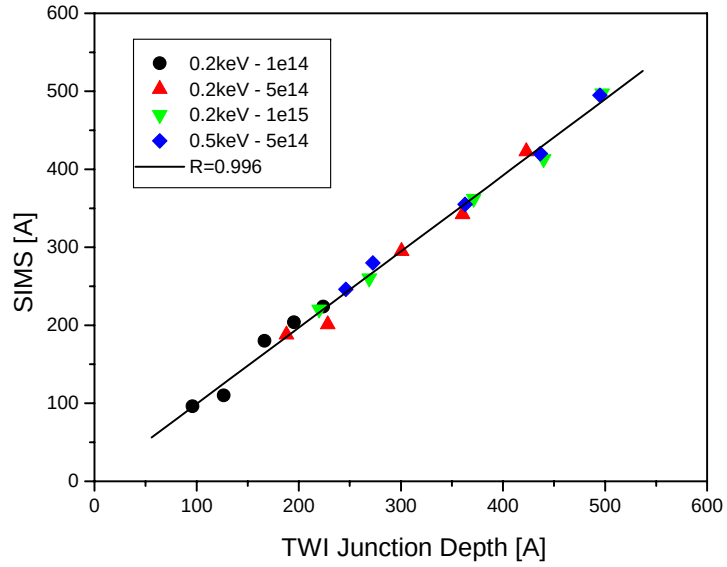
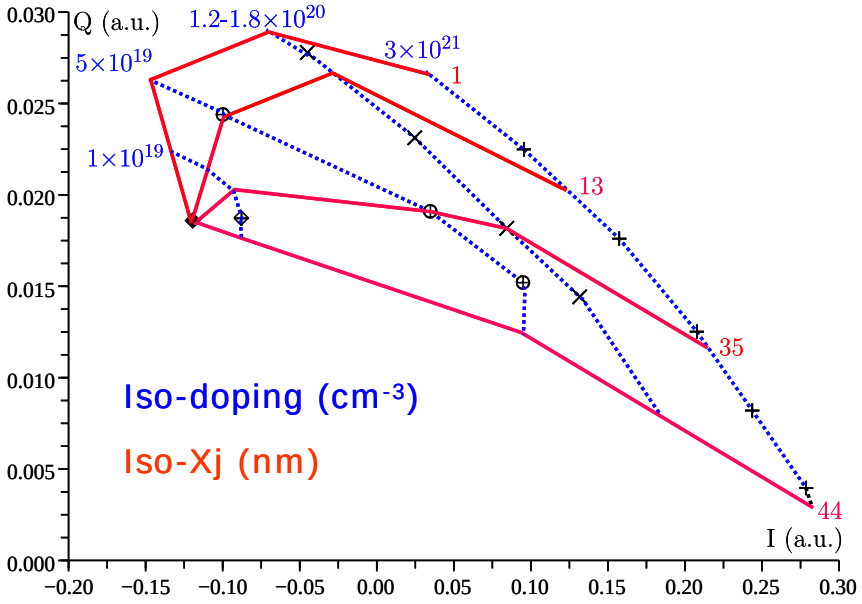
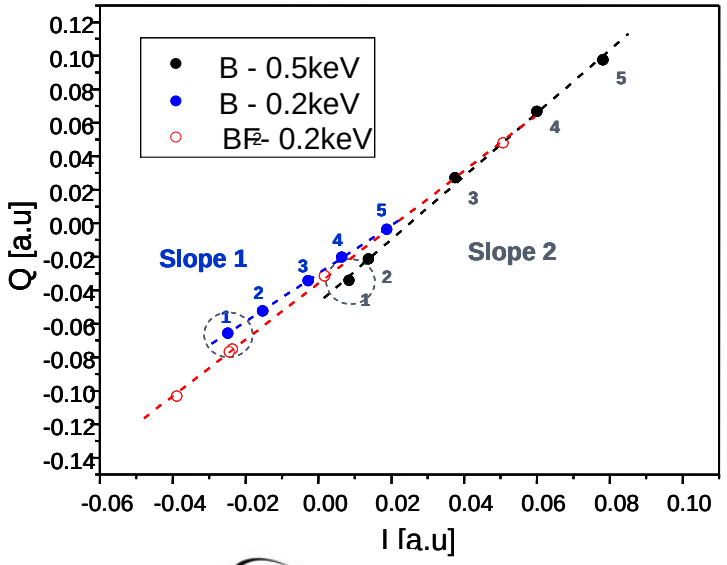
USJ Dose, Depth & Carrier Concentration

- TW signal has harmonic dependence on junction depth
- The Q-I slope in Q-I space can be used to decouple energy and dose effects
- USJ depth and carrier concentration can be monitored simultaneously

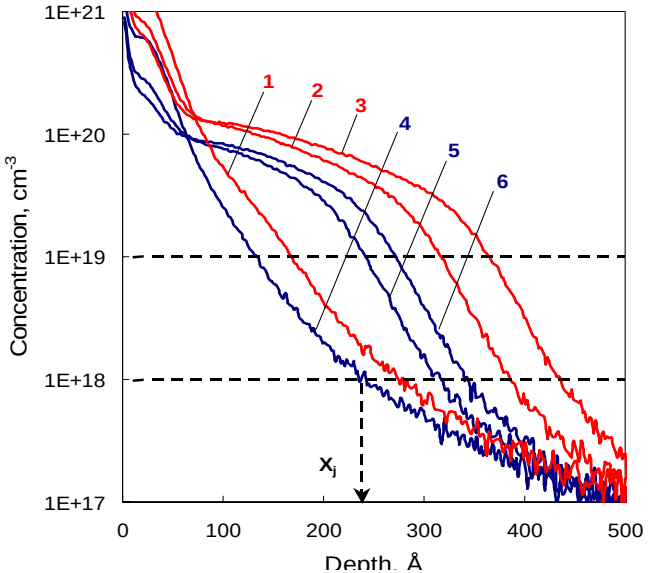


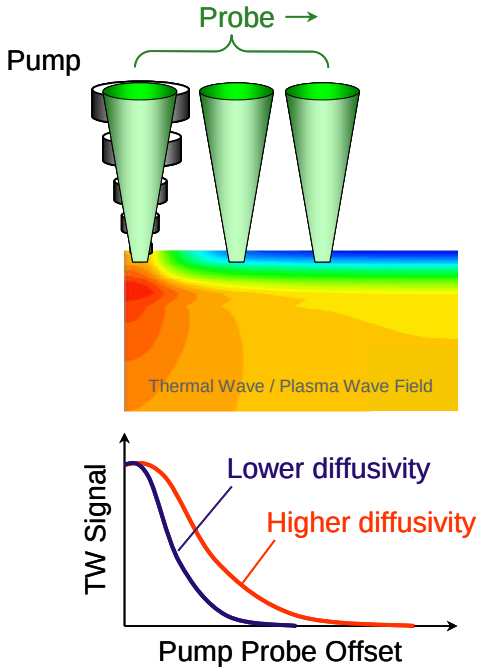


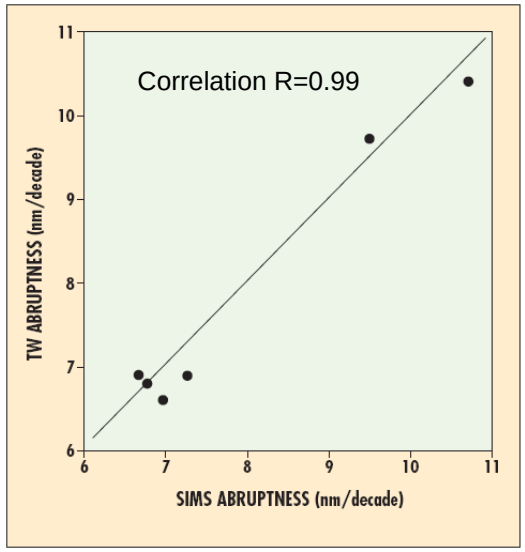


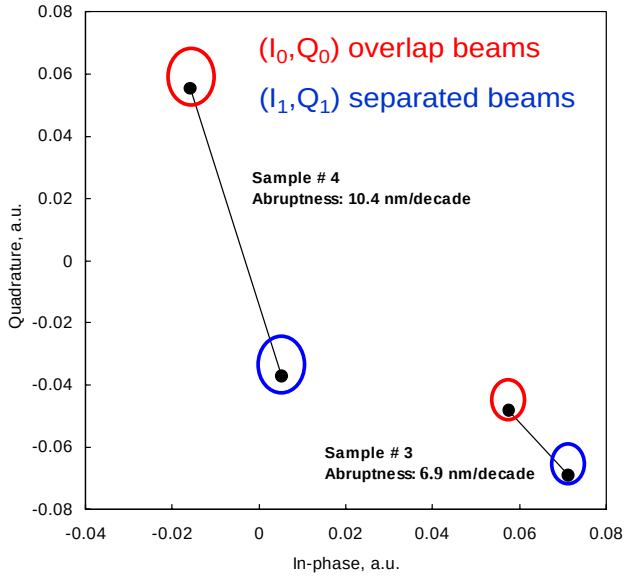
USJ Abruptness

- 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









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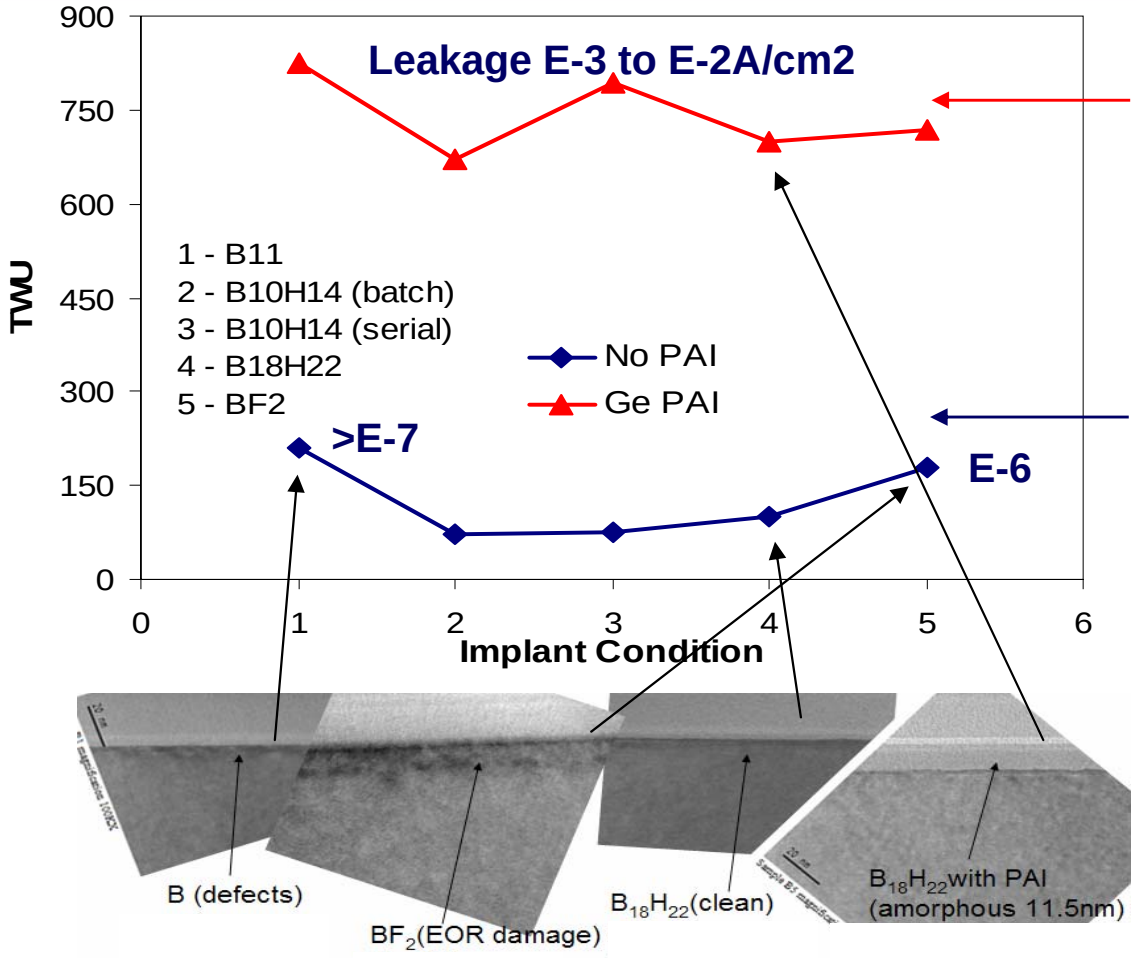
EOR Damage Monitoring



*alternate signals can give additional information in decoupling EOR damage

Various B_{11} 1E15 cm^{-2} 500 eV equivalent implants with subsequent laser anneal:

- With Ge PAI - all wafers have remaining amorphous layer
- No PAI - higher signals for B_{11} (residual damage) and BF_2 (EOR damage)

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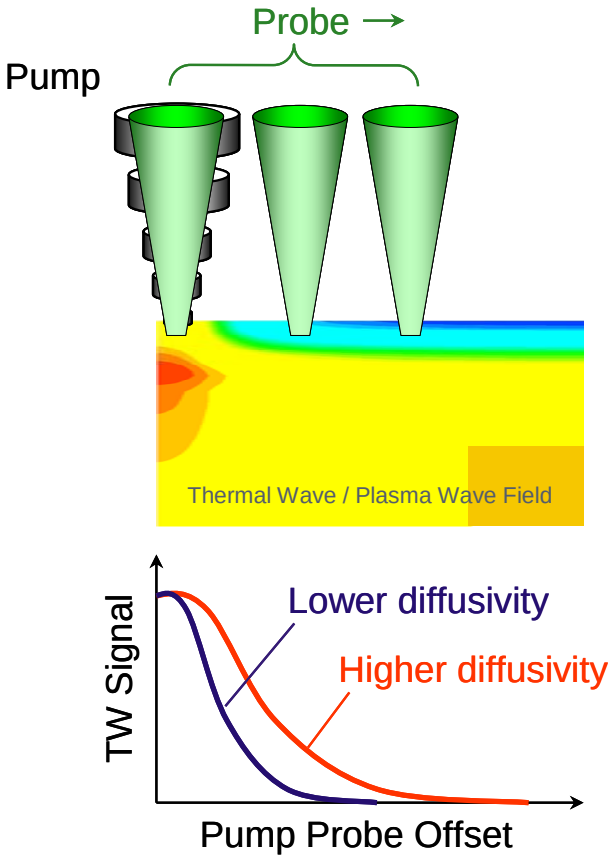
Full Carrier Depth Profiling

- 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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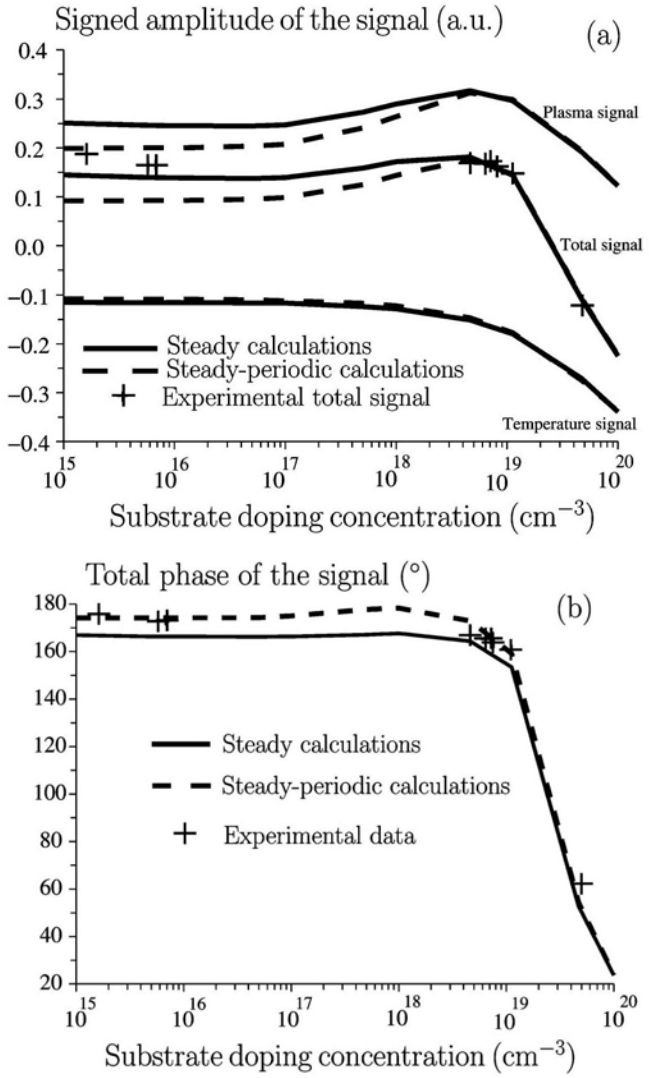
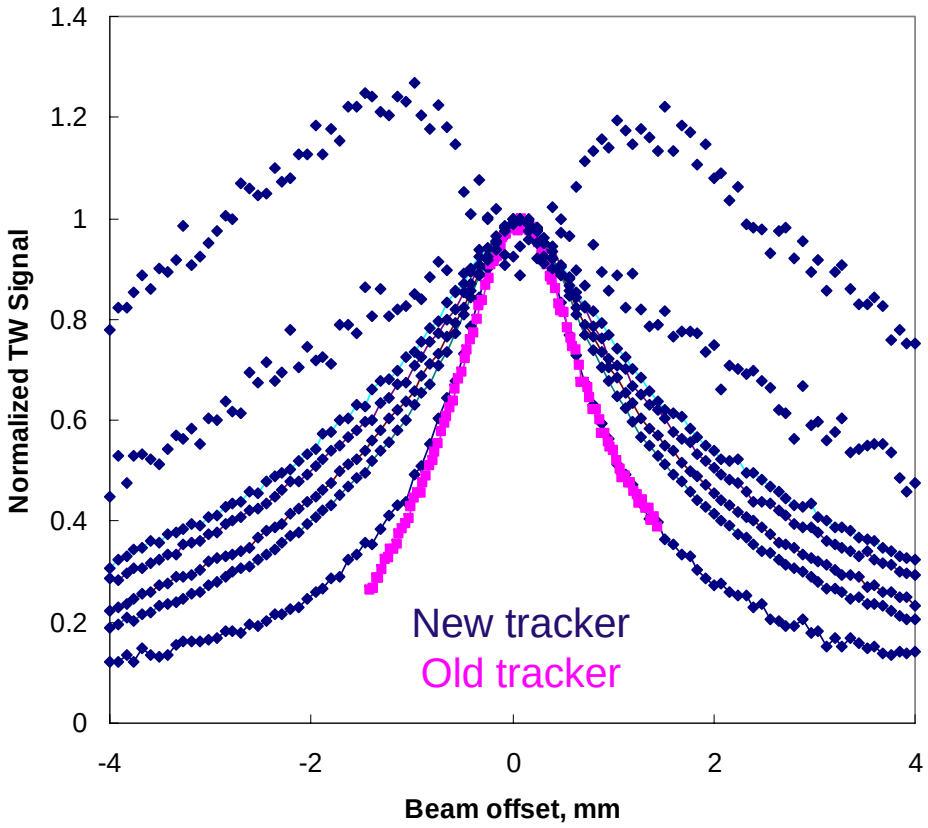
Progress in Carrier Depth Profiling
Homogeneous Samples

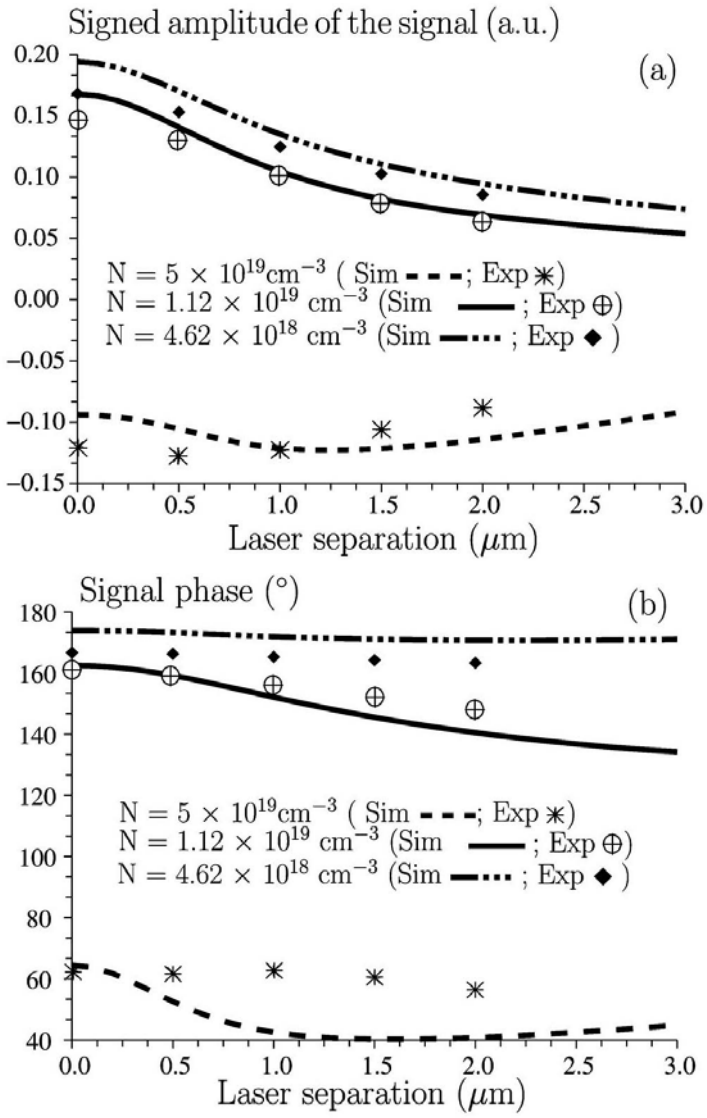
- Theoretical models have been developed to describe the MOR signal generation in the homogeneous Si samples
- The theoretical results are in good agreement with the experiments performed on TP630XP system



Progress in Carrier Depth Profiling
Box-Like Carrier Profiles

- Theoretical model for the box-like profiles shows a good agreement with experimentally obtained pump-probe beam offset scans





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Summary

- **32 nm advanced implant and anneal applications include**:
  - Optimized implant dose monitoring
  - Beam current (dose rate), Energy contamination
  - Microuniformity mapping and correlation to device performance
  - USJ parameter monitoring
  - EOR defects
  - Carrier depth profiling (IMEC)