Implant Process Characterization With Modern In-line Metrologies

July 16, 2009

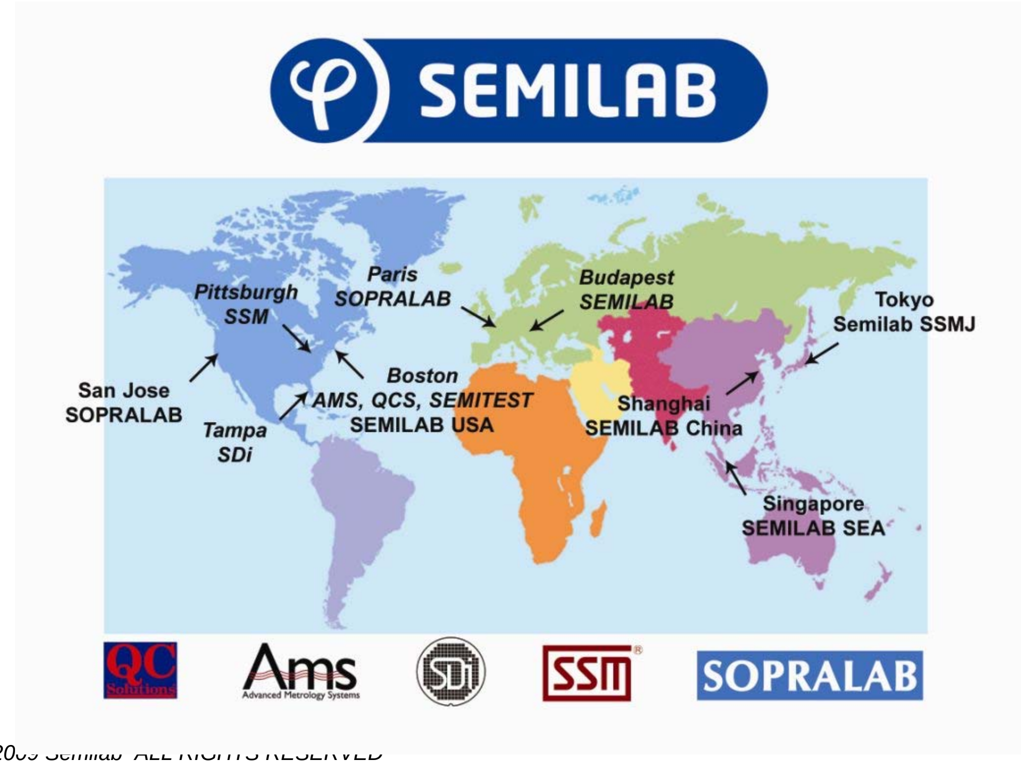
Junction Technology Group, Semicon West 2009 Program

Outline

- Introduction to Semilab
- Implant metrology
  - Dose
  - Implant depth
  - Junction depth
  - Sheet resistance
  - Doping profiles
  - Activated surface dopant density
- Will illustrate techniques that provide above parameters
- Summary

Semilab Background

- We have brought several powerful techniques into the Semilab family
- We offer multiple products for monitoring the implant/anneal processes
- The specific customer needs will determine the best fit.



The Ion Implant Process

- Deposit photo-resist
- Expose / develop
- Perform blanket implant on product wafers and often monitor wafers also
- Measure implant dose, depth
- Anneal, to activate dopant
- Measure sheet resistance, junction depth, activation, profiles

Monitoring Before Anneal

- Provides SPC monitoring of implanters and implantation process
  - Real-time monitoring, immediate feedback
- Measures
  - Dose
  - Implant Depth
- Assumes damage = f(dose)

Monitoring After Anneal

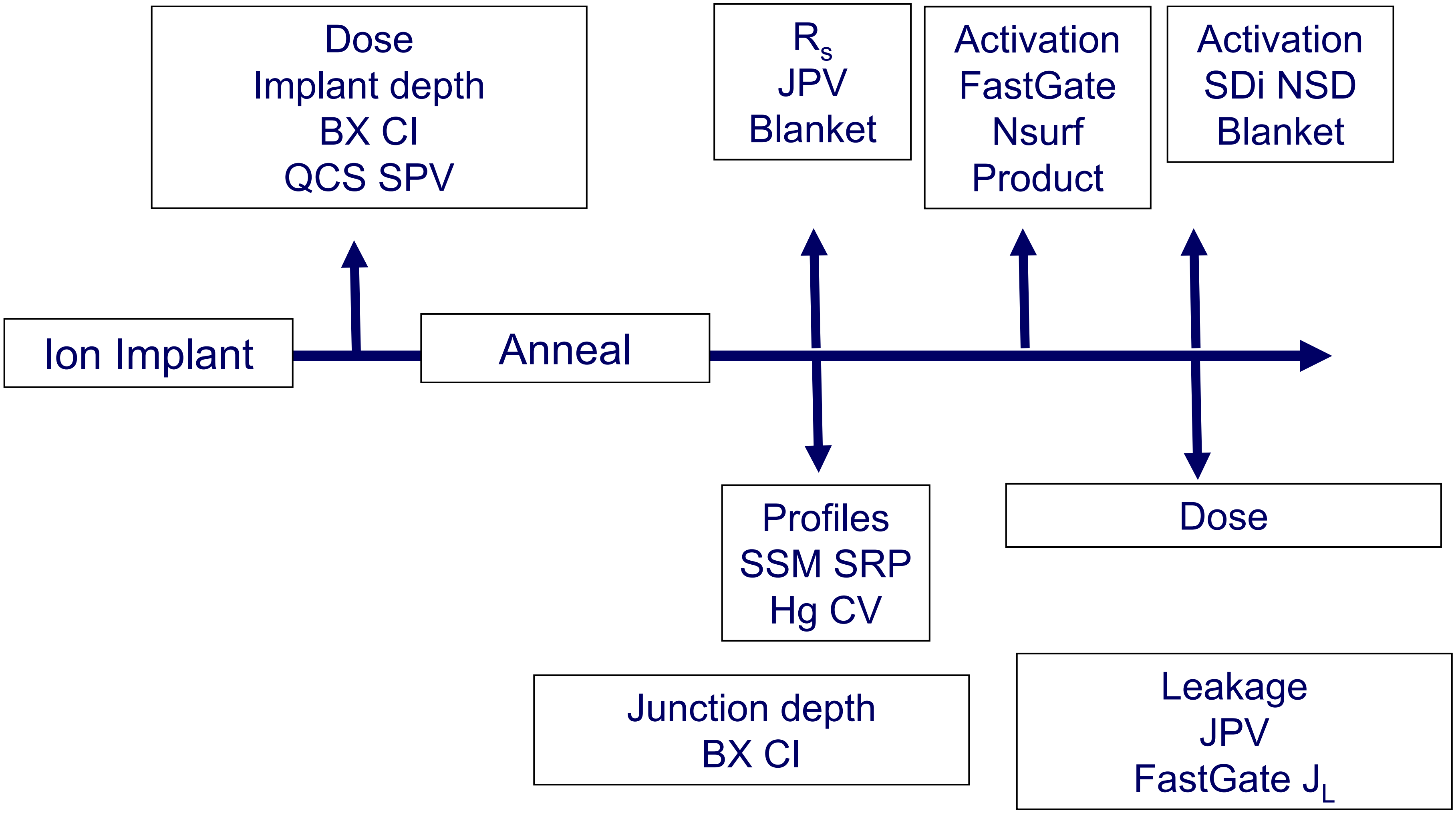
- The dopant species is activated by the anneal
- The *activated dopant* affects device performance
- Measure
  - Sheet resistance
  - Junction depth
  - Profiles

Obsolete or Timeless?

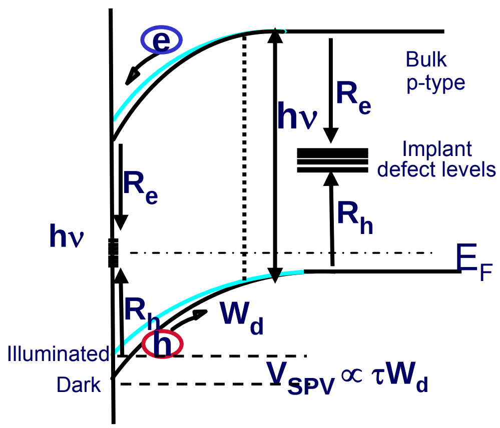
- Before anneal
  - Therma-Wave (traditional approach)
    - Measures in TW units, dependent on energy and dose
    - Actually measures the damage caused by the implant process

- After anneal
  - 4-Point Probe
    - Measures sheet resistance (ohms/square)

Semilab Offerings



QCS ICT-300
Non-Contact Fast Mapping Metrology



Based on ac-SPV Method

- ✓ **Both as-implanted and annealed wafers**
- ✓ **Energy range: 0.5keV to 3.0MeV**
- ✓ **Dose range: 1E10cm^{-2} to 5E15cm^{-2}**
- ✓ **All common species: B, P, As, BF_2,F, He, In, etc.**
- ✓ **Repeatability: < 1% (for low/medium dose < 0.5%)**

What is Measured?

Implanted Silicon

Implant dose, energy, angle

$$V_{SPV} = \frac{I_{eh} kT}{q^2 n_i} \frac{1}{\gamma N_d \Delta R}$$

N_d – implant induced defect density

ΔR -- implant region width

γ -- capture probability

Annealed Silicon

Average doping density

$$V_{SPV} \propto \frac{1}{\omega} I_{eh} \left(\frac{kT \ln(N_{sc}/n_i)}{qN_{sc}} \right)^{1/2}$$

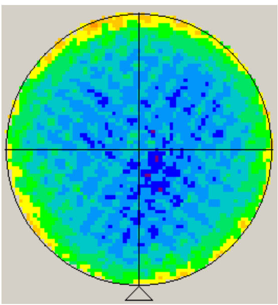
N_{SC} – doping concentration

I_{eh} – light intensity

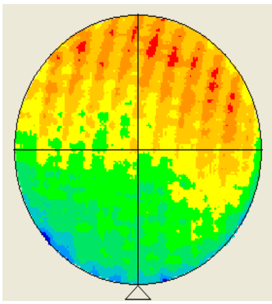
ω -- light modulation frequency

ICT-300 Implant Monitoring Capabilities

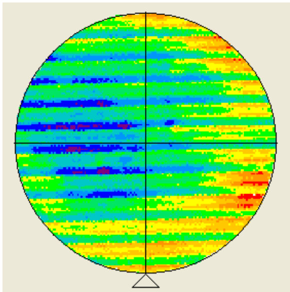
Implanter Micro-Uniformity Detection



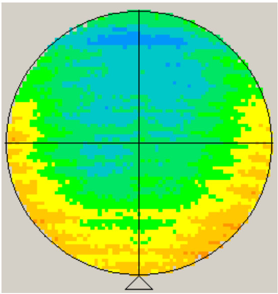
Implant system A
B 5keV 1E15



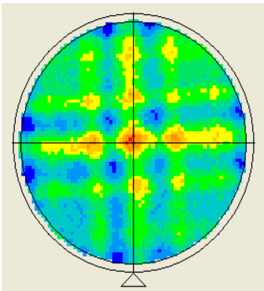
Implant system B
P 45keV 8E14



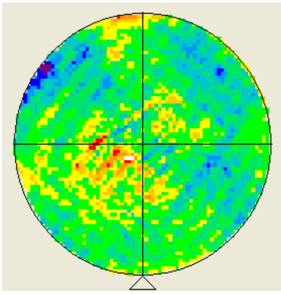
Implant system C
As 3keV 4E15



Implant system D
B 5keV 1E15

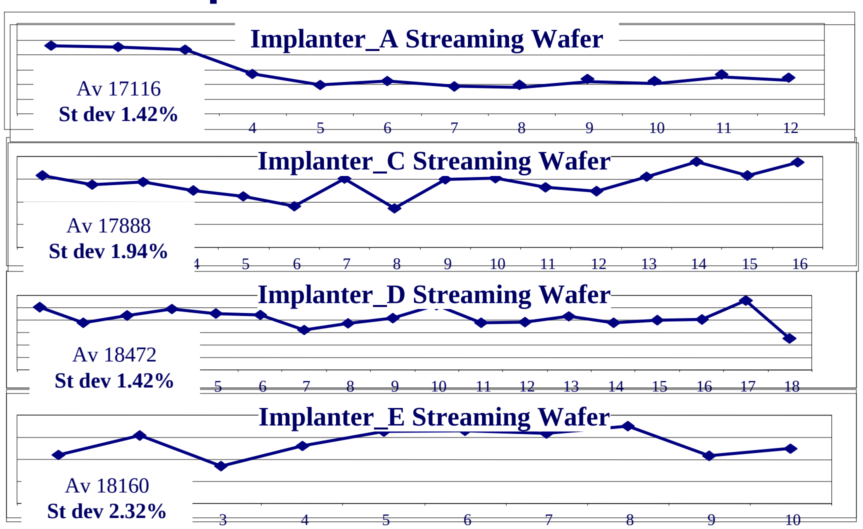


Implant system E
B 2keV 3E15



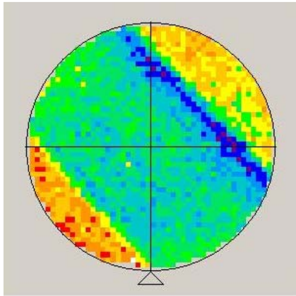
Implant system F
B 0.65keV 1E15

Multi-Implanter SPC: B 31keV 8e12



Correlation to Final Electric Test

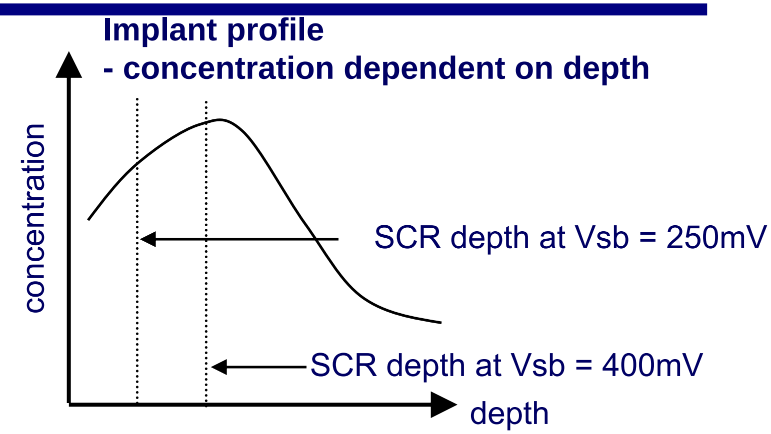
Implant: As^{75} 2e12 cm^{-2} 300keV



QCS
as-implanted

ET

SDI measurement technique and V_{sb} corrections



SDI independently measures 2 parameters: surface barrier (V_{sb}) and ac-SPV signal (V_{SPV})

$$NSD = N_A = \frac{2\cdot(Vsb - \frac{kT}{q})}{q\cdot\varepsilon}\cdot C_D{}^2$$

Measurement depth = Space Charge Region depth W

Calibration: NSD versus surface barrier, V_{SB}, dependence is measured and implant specific calibration is introduced.

→ Measured data corrected for variations in surface barrier, V_{SB}.

COCOS (ref. Wilson [1])

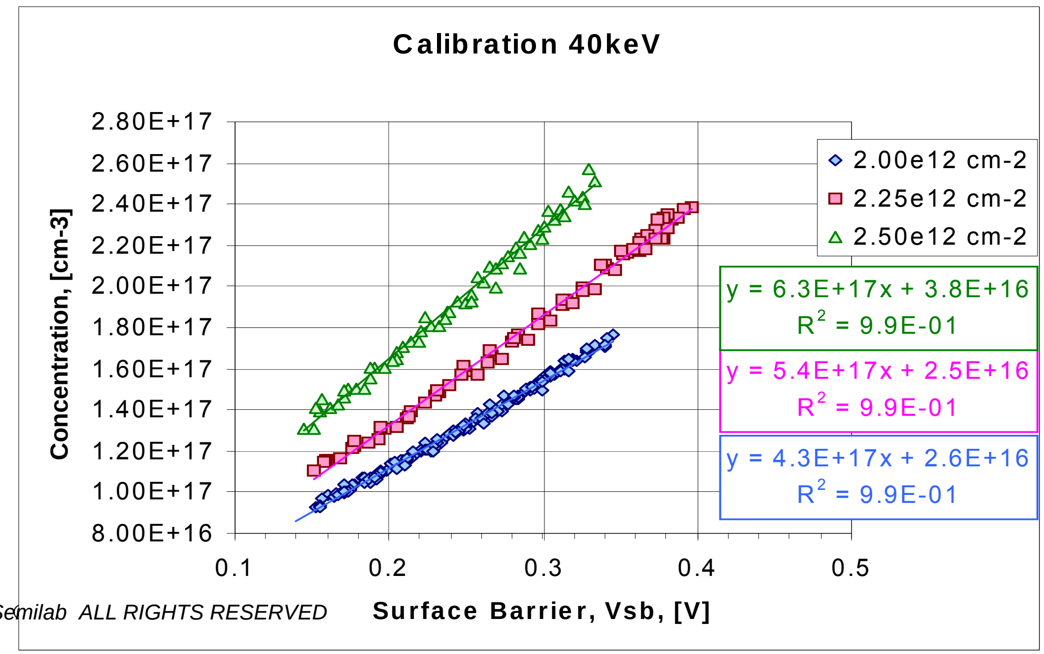
V_{CPD}(dark)=V_{OX}+V_{sb}(+const)

V_{CPD}(light)=V_{OX}(+const)

V_{sb}= V_{CPD}(dark)- V_{CPD}(light)

ac-SPV (ref. Nakhmanson [2])

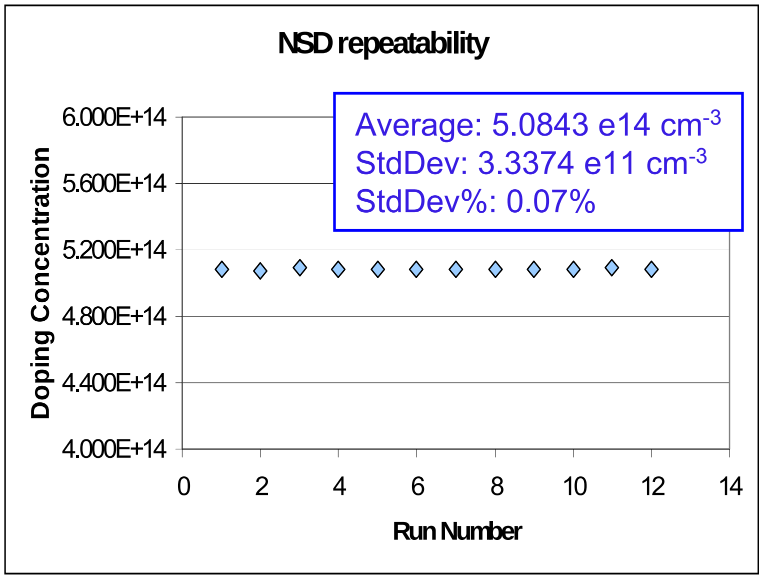
$$C_D = \frac{const\cdot Ieff}{\varpi\cdot V_{SPV}}$$



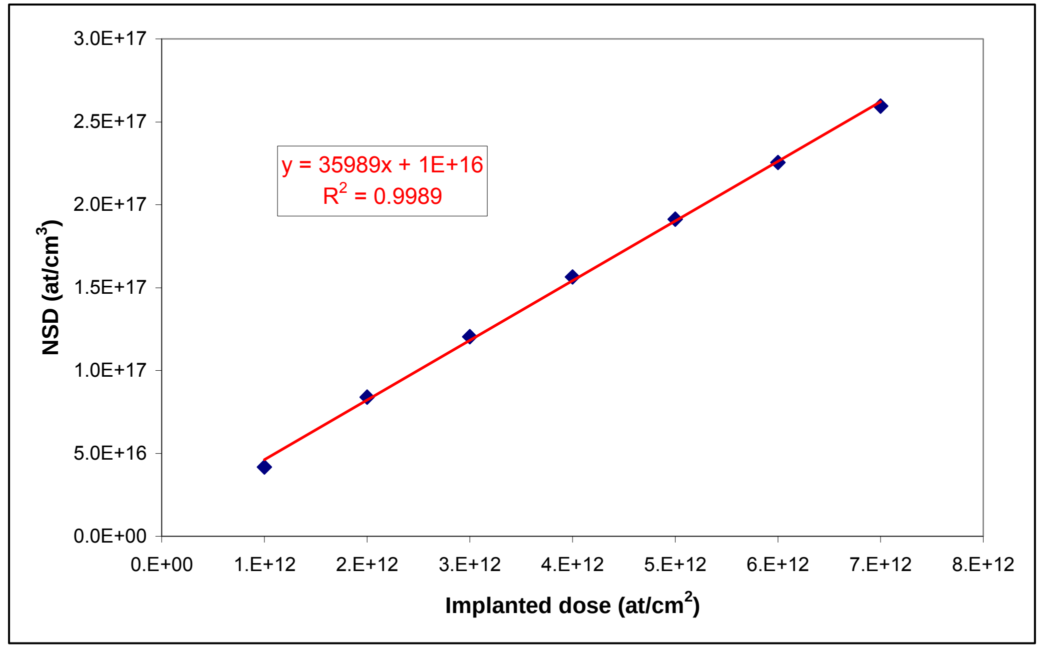
1. M. Wilson et al., ASTM STP 1382, (1999)
2. R. Nakhmanson, Solid State Electron. 18, 617 (1975)

NSD Ion implant measurement data

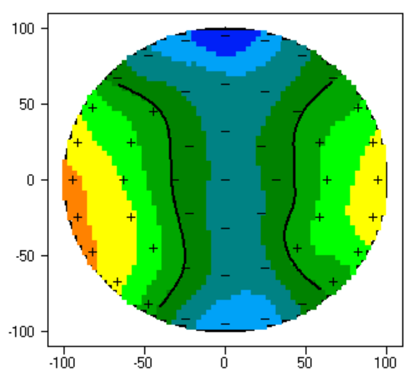
Outstanding measurement Precision (P/T)



25keV P implant – correlation vs dose



Includes full wafer mapping capability



500keV P implant
Dose: 5E12
(0, 0) angle

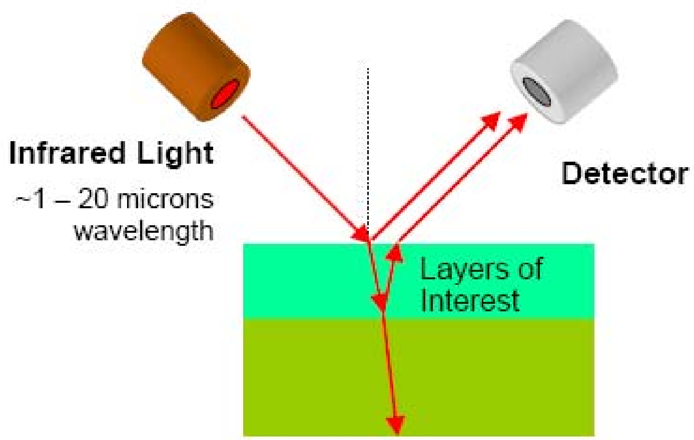
- NSD provides excellent day-to-day stability and P/T capability, accounting for variations of wafer surface state.
- Dose measurement range : $1x10^{10}$ to $1x10^{14}$ cm^{-2}; plus higher doses with junction
- Software automatically corrects for light reflectivity due to oxide films.

MBIR USJ Data Analysis

- Refractive index of the doped layer was calculated using Drude model, and rectangular profile of the concentration.

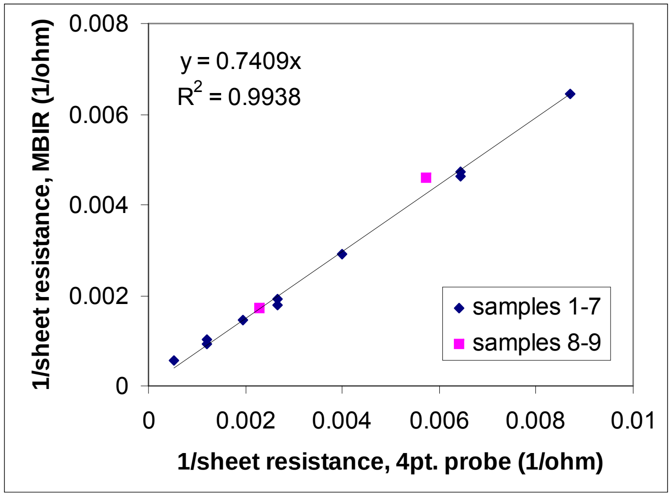
- Model fit was performed with three varied parameters: doped layer thickness, activated carrier concentration and carrier mobility.

- Wavenumber range used : 600-7000 cm^{-1}.

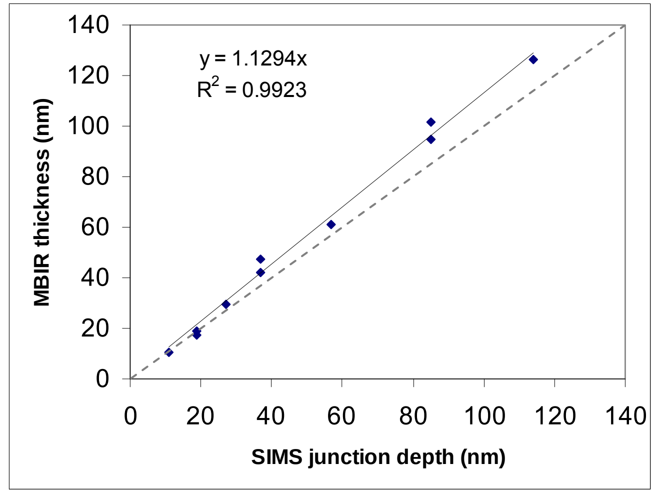


MBIR Correlation With Reference Methods

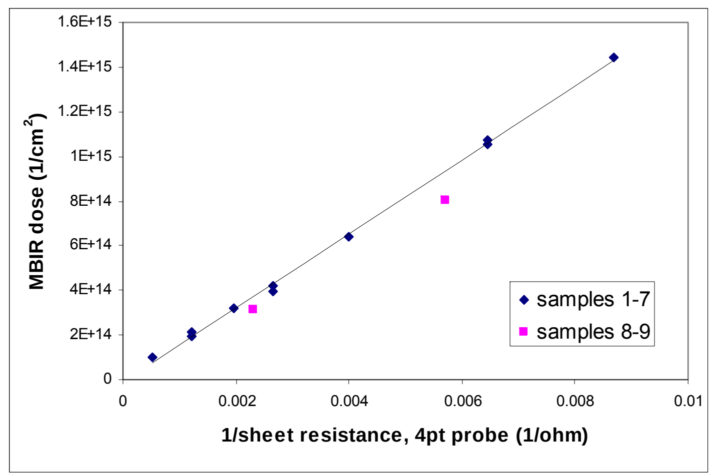
Sheet Resistance



Doped Layer Thickness



Activated Dopant Dose



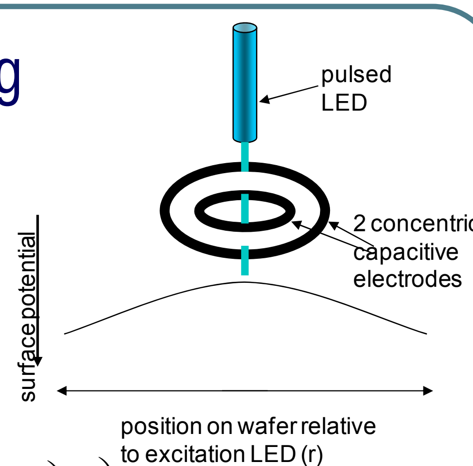
- MBIR $1/R_s$ is calculated as the product of the mobility μ and activated dopant dose (times the electron charge):
- $1/R_s = e\mu Dose$

Principle of JPV Sheet Resistance Measurements

- Junction Photovoltage-based sheet resistance measurement: a method for non-contact implant monitoring with high-resolution mapping capability.
- Basic principle:
  - e^- and hole generation by chopped LED light
  - This causes change in junction voltage
  - Change spreads laterally, and the attenuation depends on sheet resistance
  - Change of the potential is picked up by capacitive sensors
  - Signal depends strongly on LED chopping frequency (f)
  - R_s, C_d and R_d (J_{leak}) are calculated by fitting the theoretical JPV signal

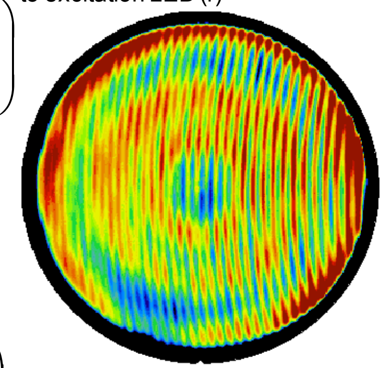
- Potential spreading

$$\frac{\partial U}{\partial r} = -IdR_s = -I\frac{R_s}{2\pi r}$$



- Current spreading

$$\frac{\partial I}{\partial r} = 2r\pi\left(J\Theta(r_0 - r) - \left(\frac{1}{R_d} + i\omega C_d\right)U\right)$$



- Equation to solve to obtain R_s

$$r^2\frac{\partial^2 U}{\partial r^2} + r\frac{\partial U}{\partial r} - r^2\left(\frac{R_s}{R_d} + i\omega R_s C_d\right)U + J\Theta(r_0 - r) = 0$$

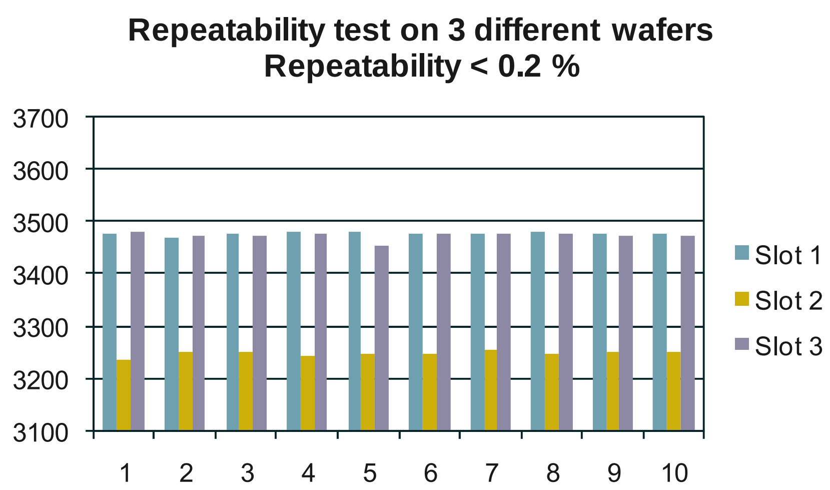
JPV Sheet Resistance Measurements

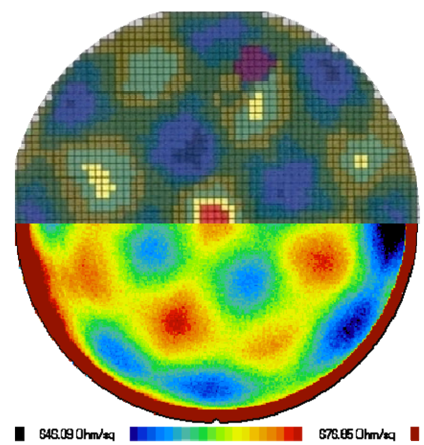
Applications and specifications

- Implant process control (R_s depends on dose and energy) on various implant types: USJ, deep implant, pocket implant, plasma immersion implant, etc.
- Dose range: >5E11cm^{-2}
- Species: B, P, As, BF_2, etc.

Sheet Resistance and Leakage Current Mapping

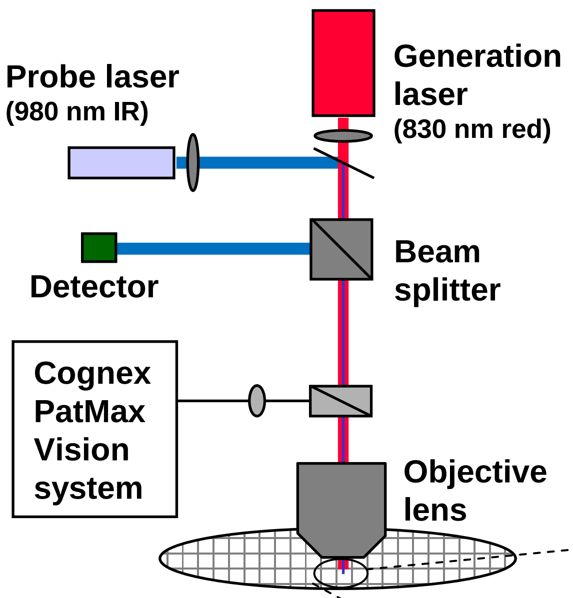
- Visualization of non-uniformities, implanter errors (striping, etc.) which are not detectable by low resolution methods
- Detects variations and inhomogeneities smaller than 1 % of the wafer average
- Works on oxidized and non-oxidized wafers



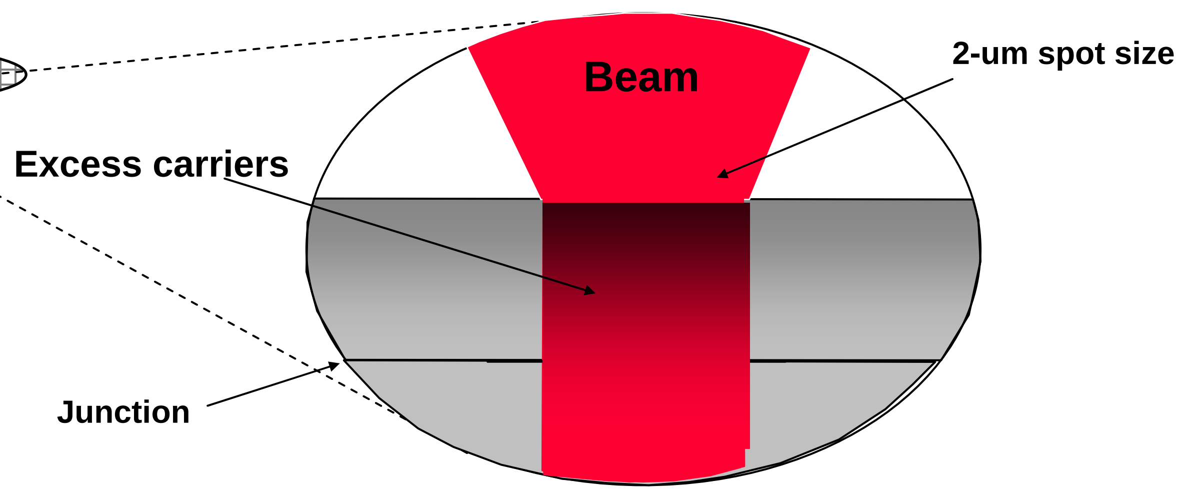


JPV – 4PP correlation:
•Same wafer.
•Top half is 4PP map (625 points)
•Bottom half is JPV map (17,000 points)
•Both maps take the same time to make.

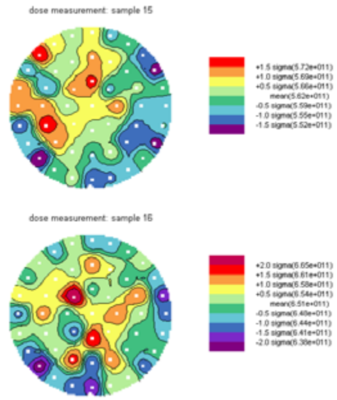
Principle of Carrier Illumination Technology



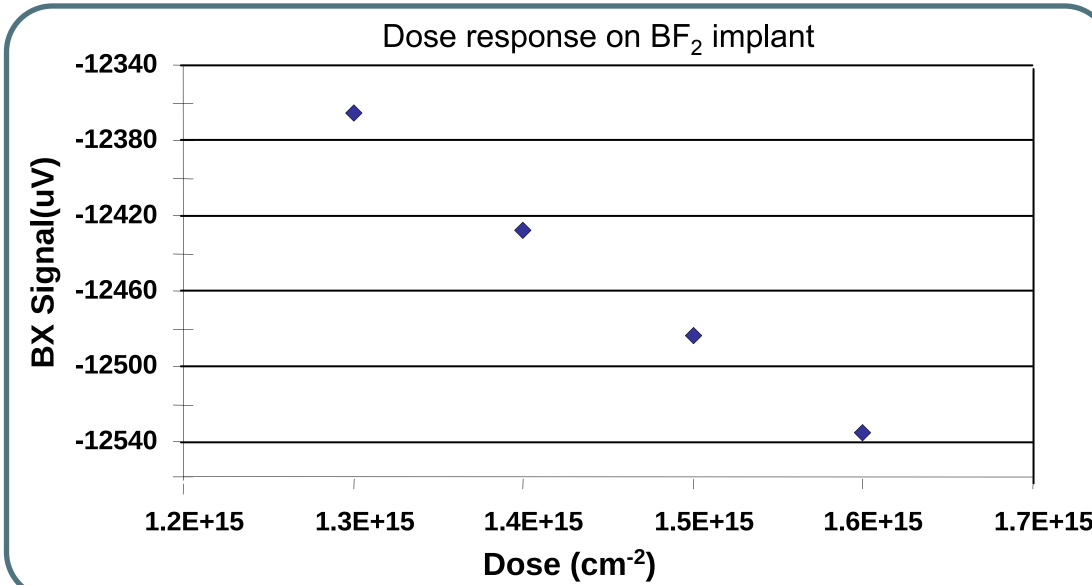
- Generation laser creates excess carriers and, where significant damage is present, heat.
- Excess carrier gradient forms index of refraction gradient
- Probe laser uses index of refraction gradient or surface heat to determine junction depth, dose level or PAI depth.
- Generation laser is modulated (2kHz) to enable high signal/noise ratio.



Carrier Illumination Technology



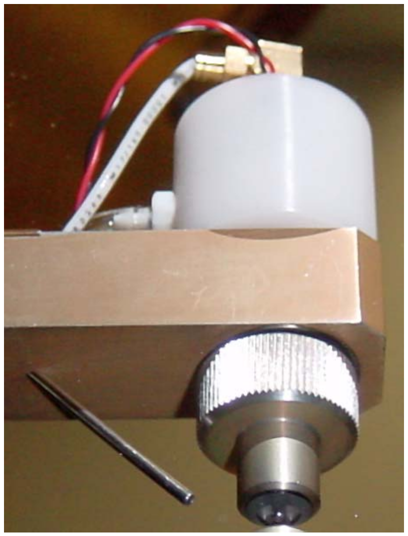
Measurements on Boron implanted wafers



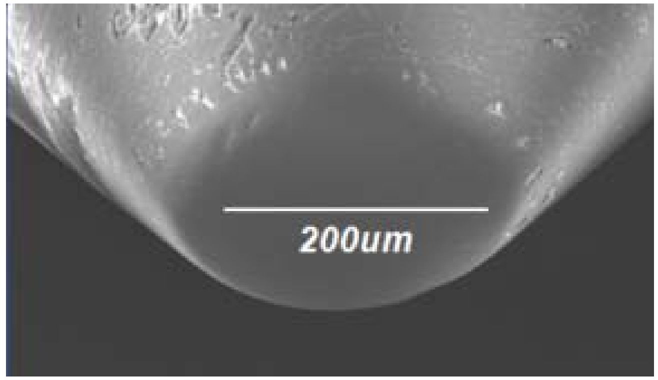
- Implant monitoring
  - Dose range: $1x10^{10}$ cm^{-2} to $1x10^{16}$ cm^{-2}
  - Energy range: 100 eV to 3 MeV
  - Species: As, B, P, BF2, In, Sb
- PAI depth
  - Depth range10 nm to 100 nm
- Junction depth measurement
  - Depth range:10 to 70 nm
- Scope applications for development:
  - Measurement on SOI substrates
  - Cu (metal) via structures measurement
  - Integration with Semilab JPV method

Contact Probing Metrology

SSM-Hg CV

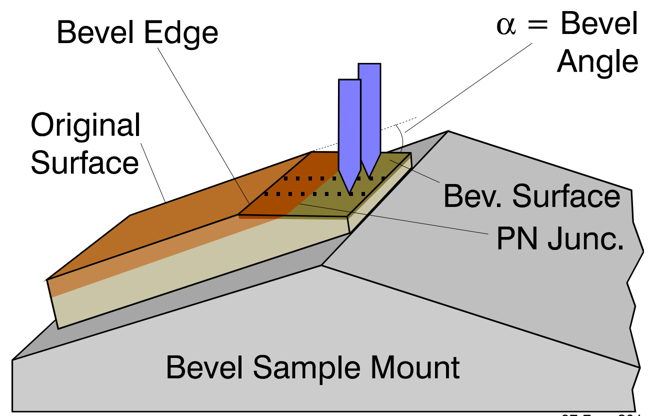


SSM FastGate® CV

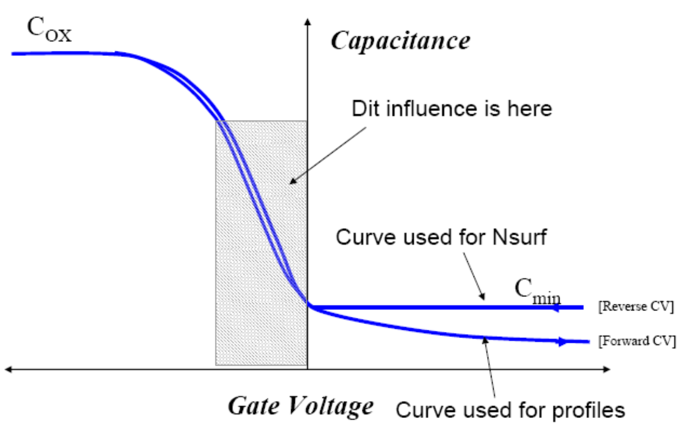


SRP

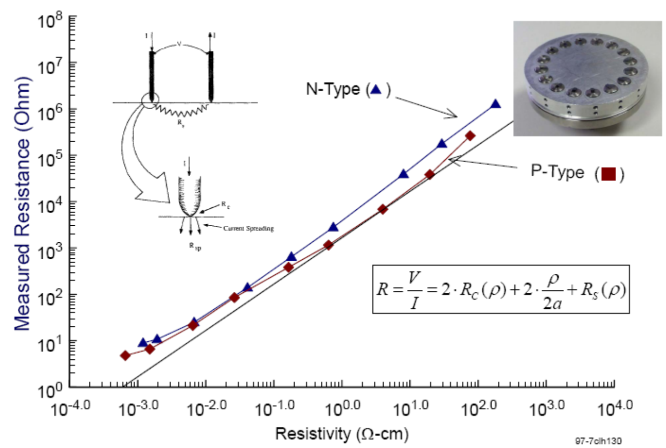
SSM 2000



High Frequency MOS CV Curve

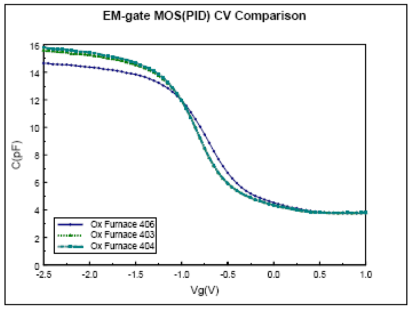


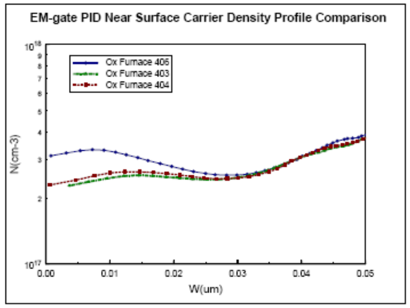
Typical Conventional Calibration



Contact Probing Metrology

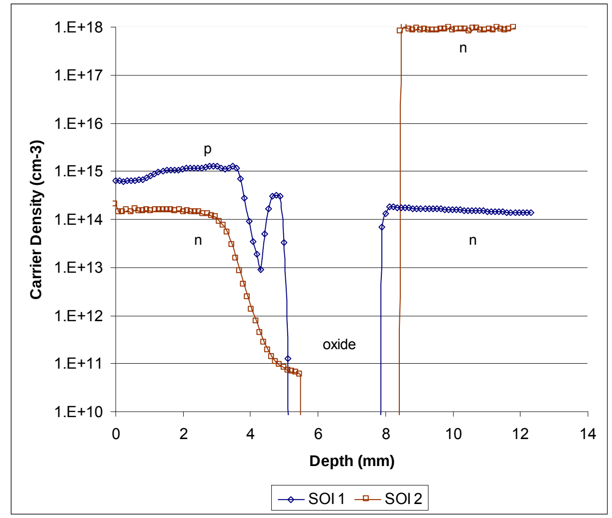
Case Study-furnace issue



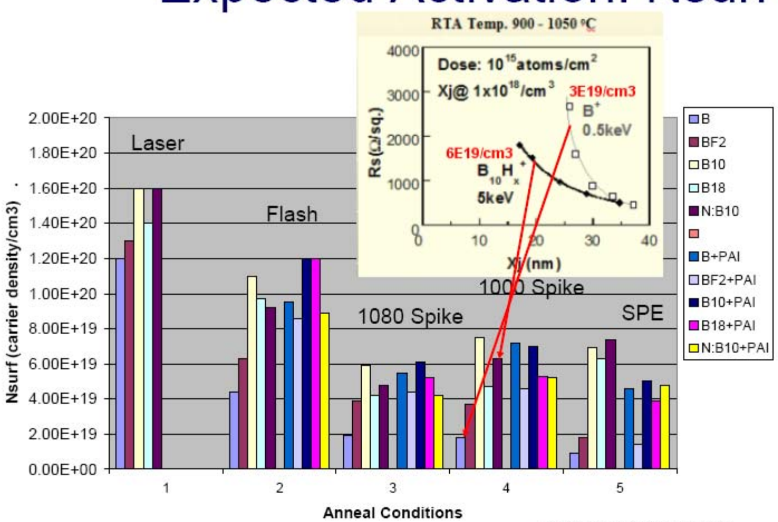


PID CV curve comparison of three oxidation furnaces.
A clear distinction between
furnace 403,404 and 406 can be seen.
Furnace 406 shows a clear increase in carrier density
by about 50% close to the surface.

SOI

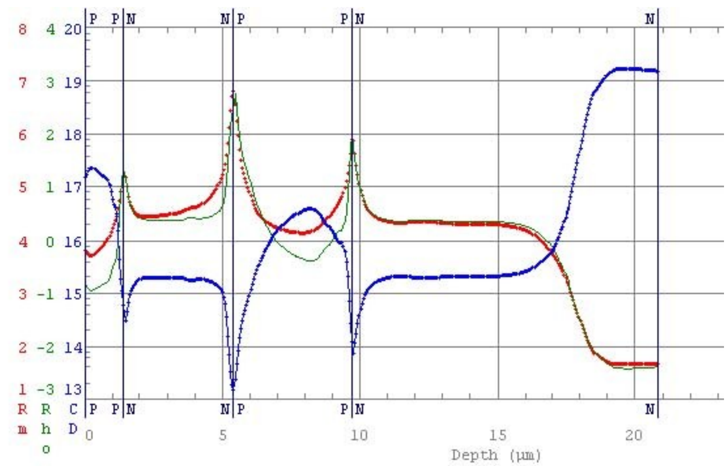


Expected Activation: Nsurf

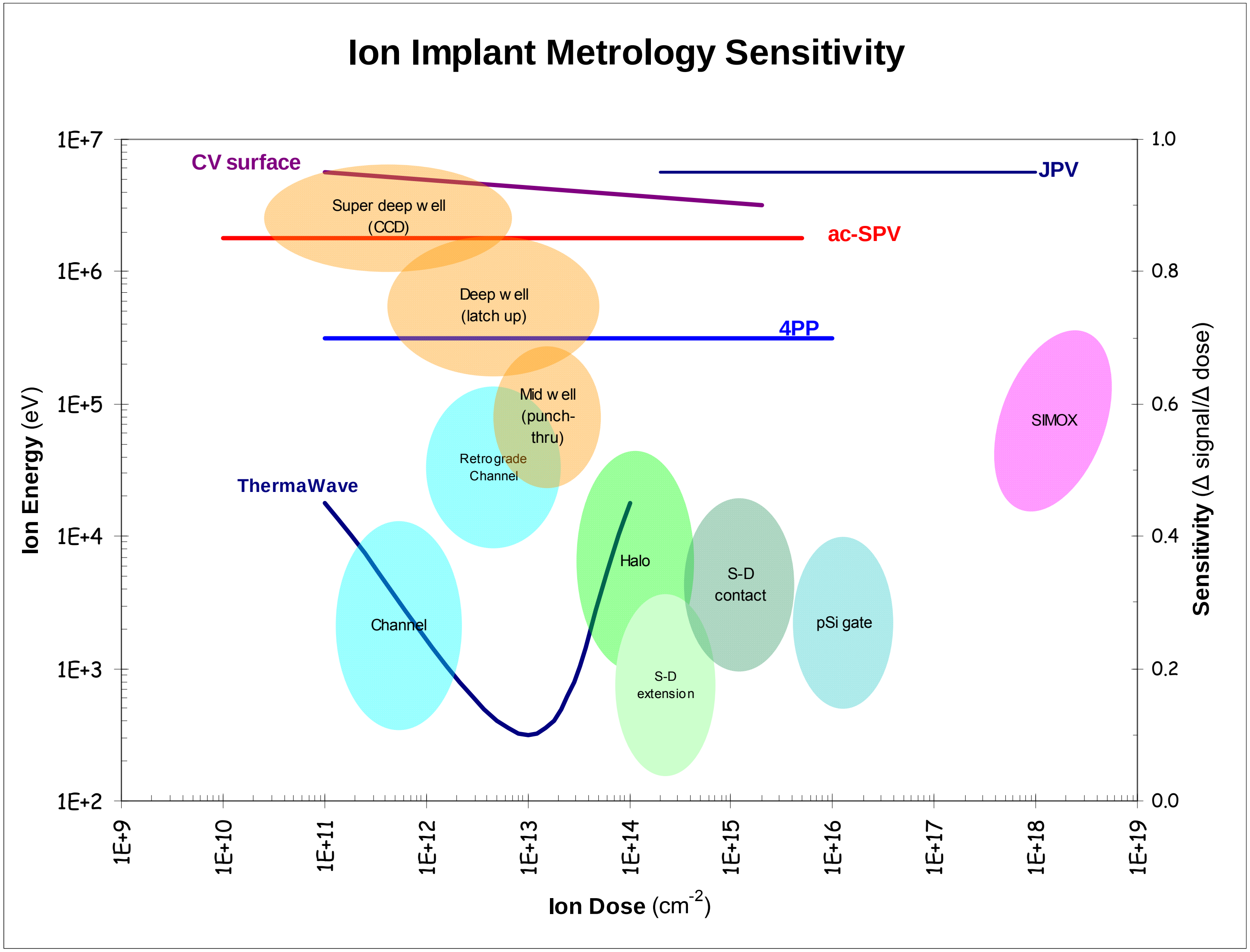


•Ref: John Borland, 2006

Freescale ISPSD06

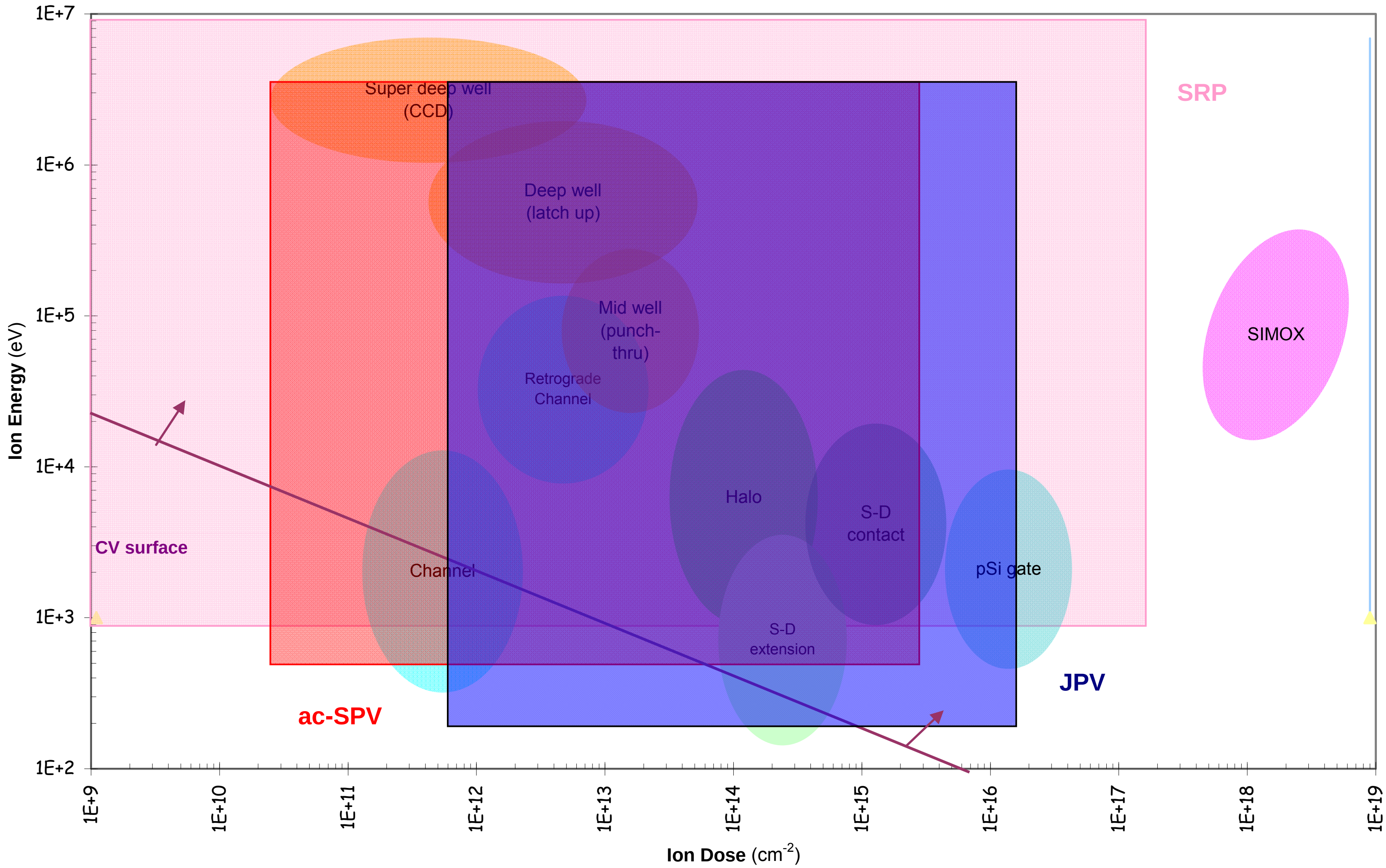


Ion Implant Matrix-Sensitivity



Ion Implant Matrix-Range

Ion Implant Metrology Range



Case Study-AVS Insight '09

Summary

- We have brought several powerful techniques into the Semilab family
- We offer multiple products for monitoring the implant/anneal processes
- We look forward to discussion of your needs to find the best fit.