"Total Junction Metrology"

"… DHE is a powerful method for studying doping and activation processes."
Micron Technology, Inc.

Agenda

- What is Needed?
- Capabilities and Advantages
- Analysis Procedure
- Data:
  - Comparison with SIMS, SRP and 4PP
- Defect Measure
- Strain Enhancement

Active/Junction Layer Parameters : What is Needed?

CURRENT ANALYTICAL TECHNIQUES

- Active Carrier profiles are modeled –
  - Combination of 4PP, SIMS, ThermaWave and Implant/Anneal Schedules
- No mobility data until devices are made
- Incomplete feedback on *Actual* Active Layer Characteristics

WHAT IS NEEDED

- Direct Measurements of the key parameters (ρ, μ and n)
- *High Resolution* Profile Steps
- Decisions about process lot that is based on *Actual* data
- Need for ALP, Inc. Differential Hall Effect Analytical Technique

ALP Differential Hall Effect (DHE) System

ALP Unique Capabilities and Advantages:

- Measurement Resolution ~ 3-5 Angstroms
- Room Temperature Process – No Thermal Steps required
- Clean Procedure – Compatible with Production Sequence
- Fully Automated Measurement Operation – Repeatability
- Direct measurement of μ and ρ profiles along with n profiles

DHE System - Analytical Process

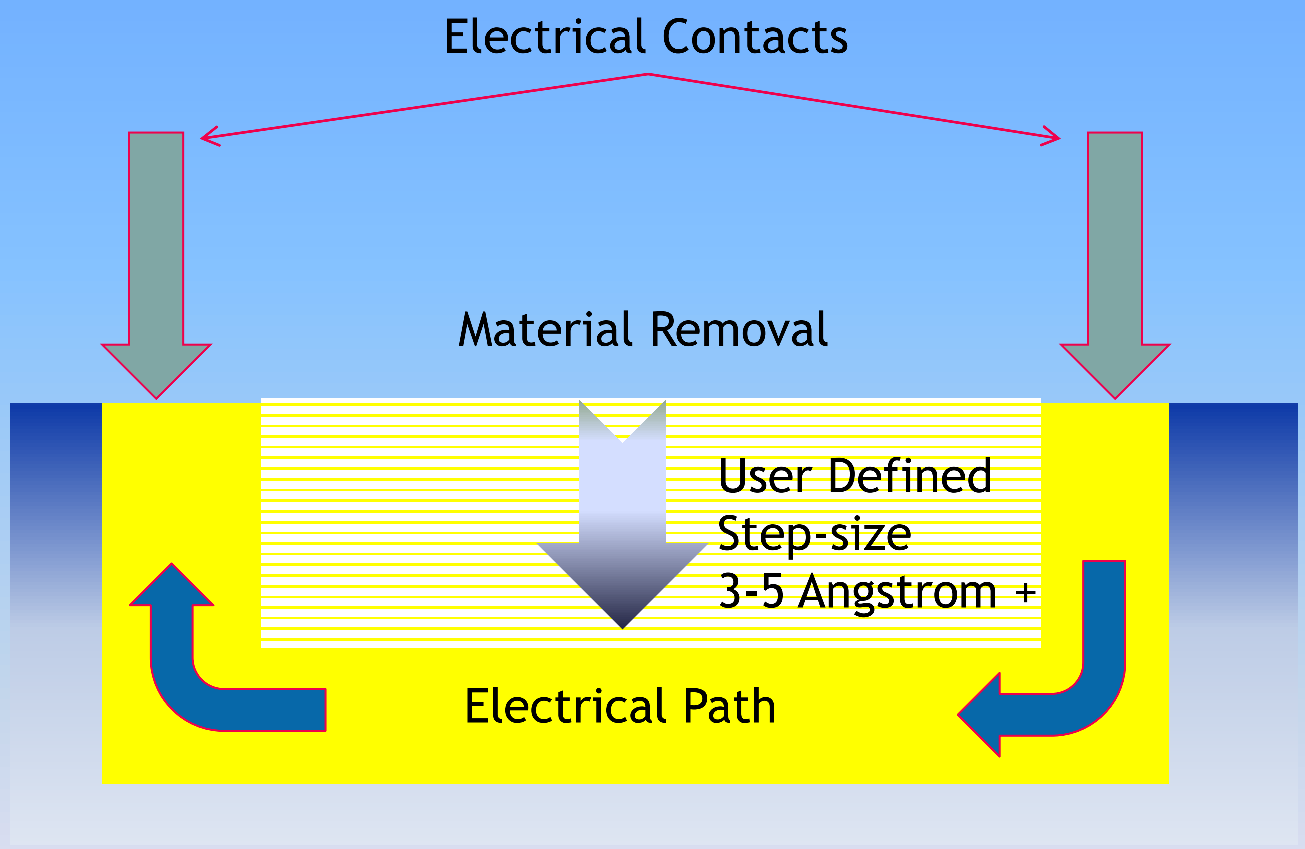
- Process is divided into 2 parts that alternately steps rapidly through the junction:
- Controlled Step-wise Reduction of Active Layer Thickness
- Measurement is done
- Differential Hall Effect represents a unique analytical method

$$n(x) = \frac{1}{\mu(x)\ \rho(x)\ q_{\ electron}}$$

Direct measurements

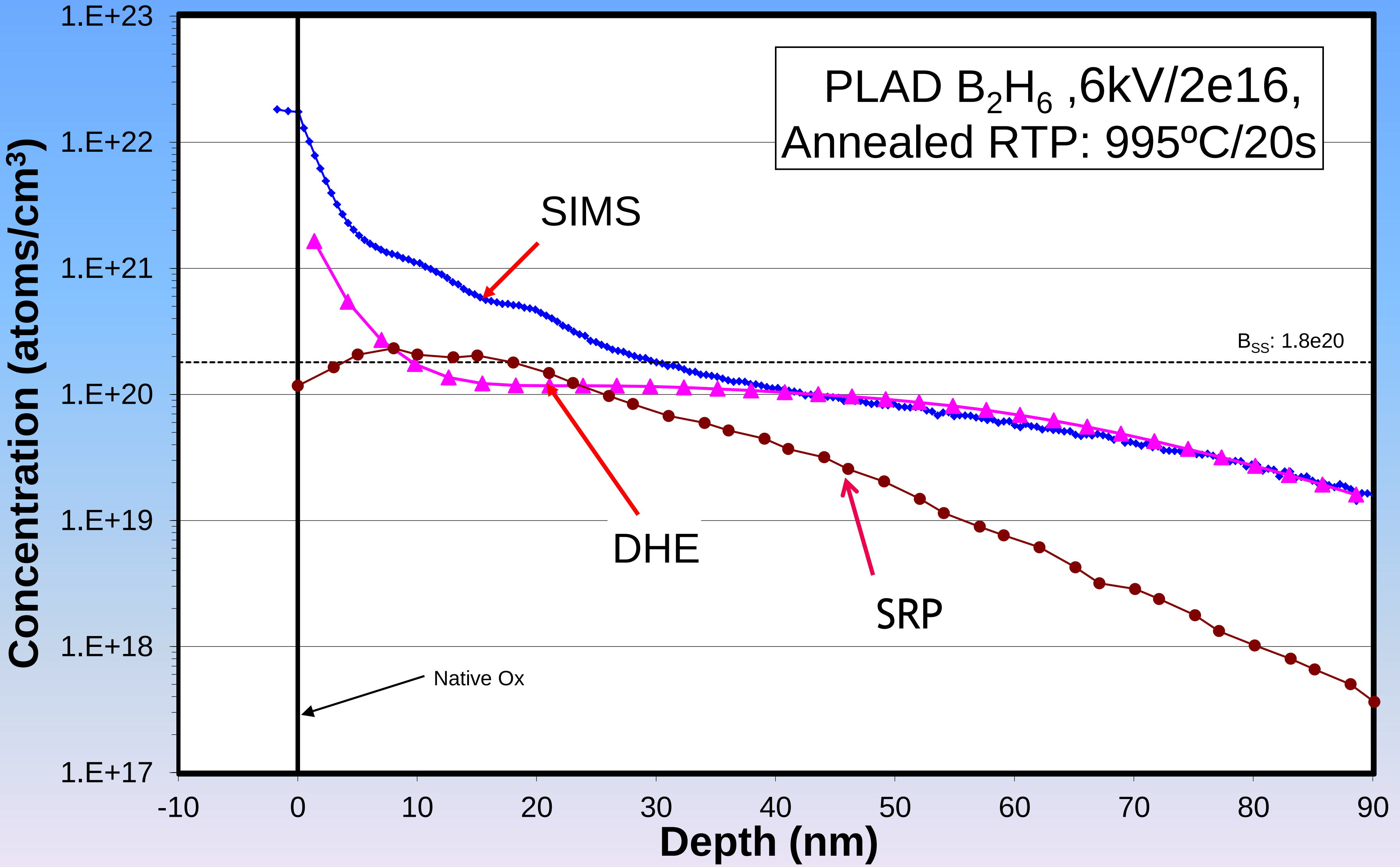
DHE System: Analytical Process

Each Step Yields: R_s and μ. All Measurements are In-Situ



Activated Wafer Sample. Size currently ~15mmx15mm

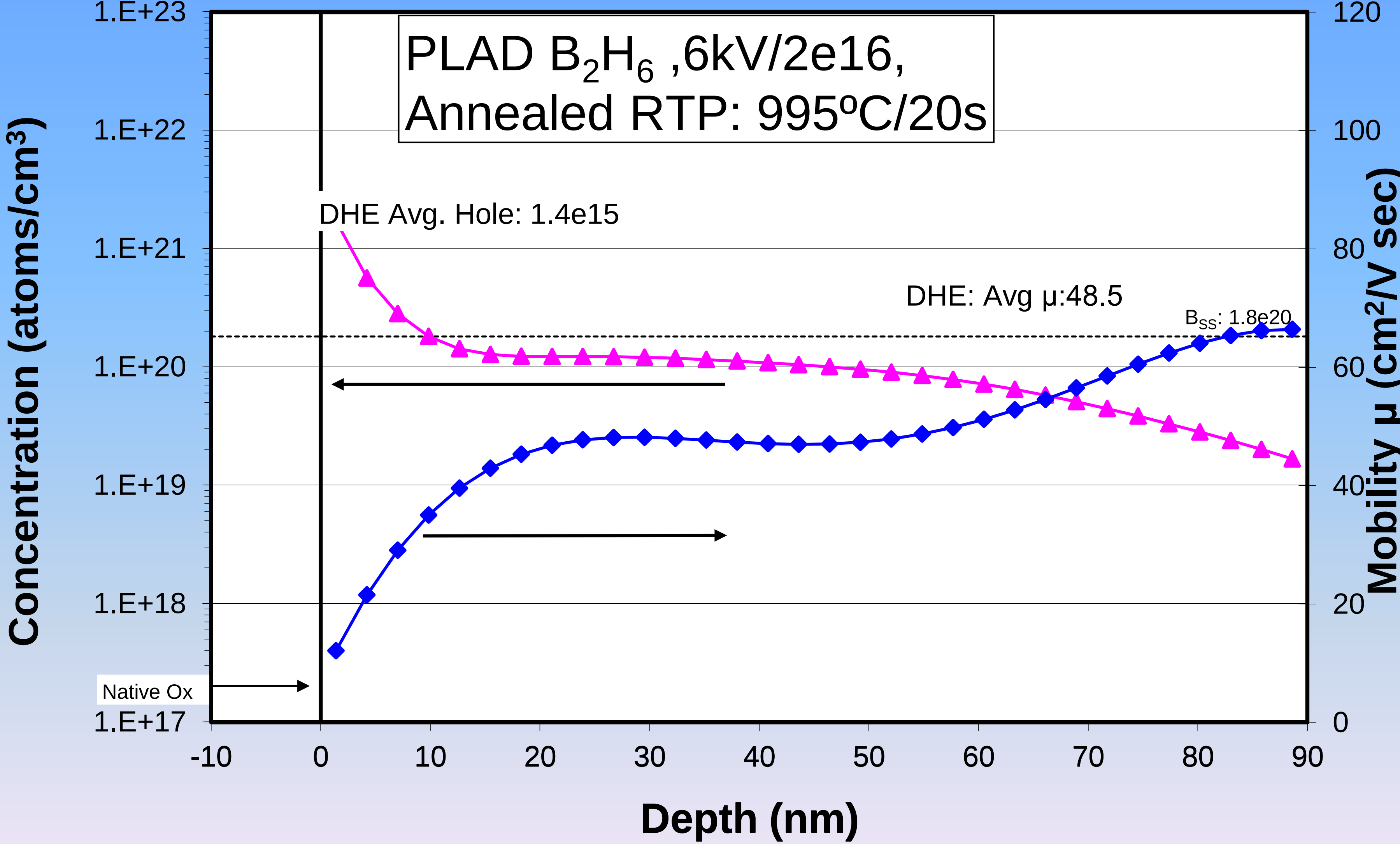
ALP DHE System: PLAD Carrier Concentration



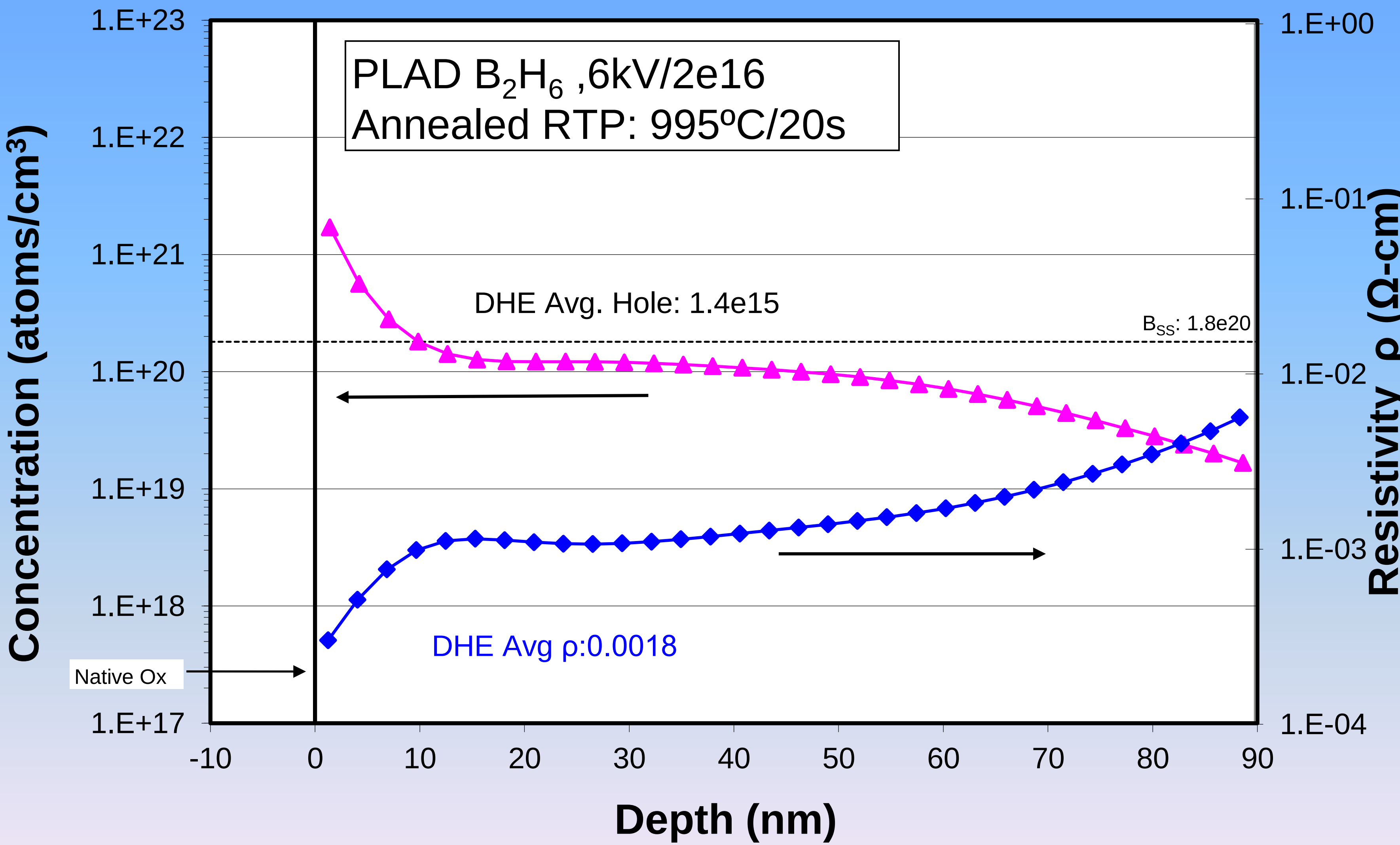
Active Layer Parametrics, Inc.

S.Qin, et al. IEEE Trans. On Plasma Science 2011

ALP DHE System: PLAD Mobility



ALP DHE System: PLAD Resistivity



ALP DHE System: 4PP Comparison

Sample	4PP (Ω/sq)	DHE Rs (Ω/sq)	% Difference
M1C	128.98	129.33	+0.27 %
M2C	148.13	145.02	-2.1 %
M3C	161.52	157.89	-2.24 %
M5C	143.49	145.60	-1.47 %

- Difference is minimal from accepted 4PP standard
- Minor deviations result from contact variation

Defect Measure

- Measure of deviation of the measure (DHE Drift Mobility) from the ideal (ASTM derived mobility). Presence of lattice damage.
- Matthiessen's Rule:

=0, for Ideal

$$\frac{1}{\mu} = \frac{1}{\mu_{impurities}} + \frac{1}{\mu_{lattice}} + \frac{1}{\mu_{defects}} \ldots$$

Subtracting the ideal (ASTM, defect-free, strain-free),

$$\frac{1}{\mu_{Measured}} - \frac{1}{\mu_{Ideal}} = \boxed{\frac{1}{\mu_{defects}}}$$

Defect Measure

- Defect Analysis:

$$\frac{1}{\mu_{Measured}} - \frac{1}{\mu_{Ideal}} = 0$$ ➡ IDEAL

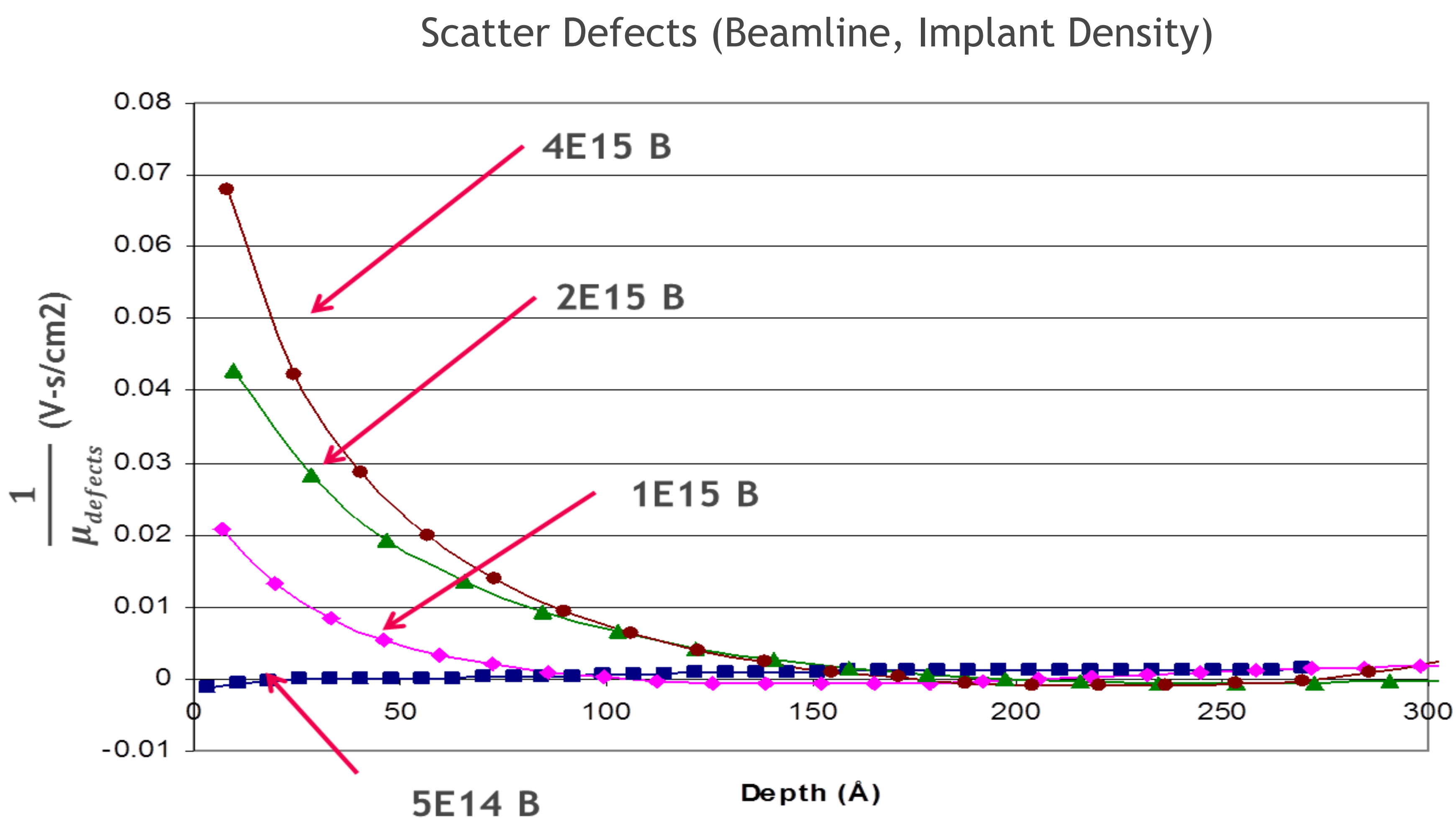
$$\frac{1}{\mu_{Measured}} - \frac{1}{\mu_{Ideal}} > 0$$ ➡ DEFECT DOMINATED

Defect Measure: Dependencies

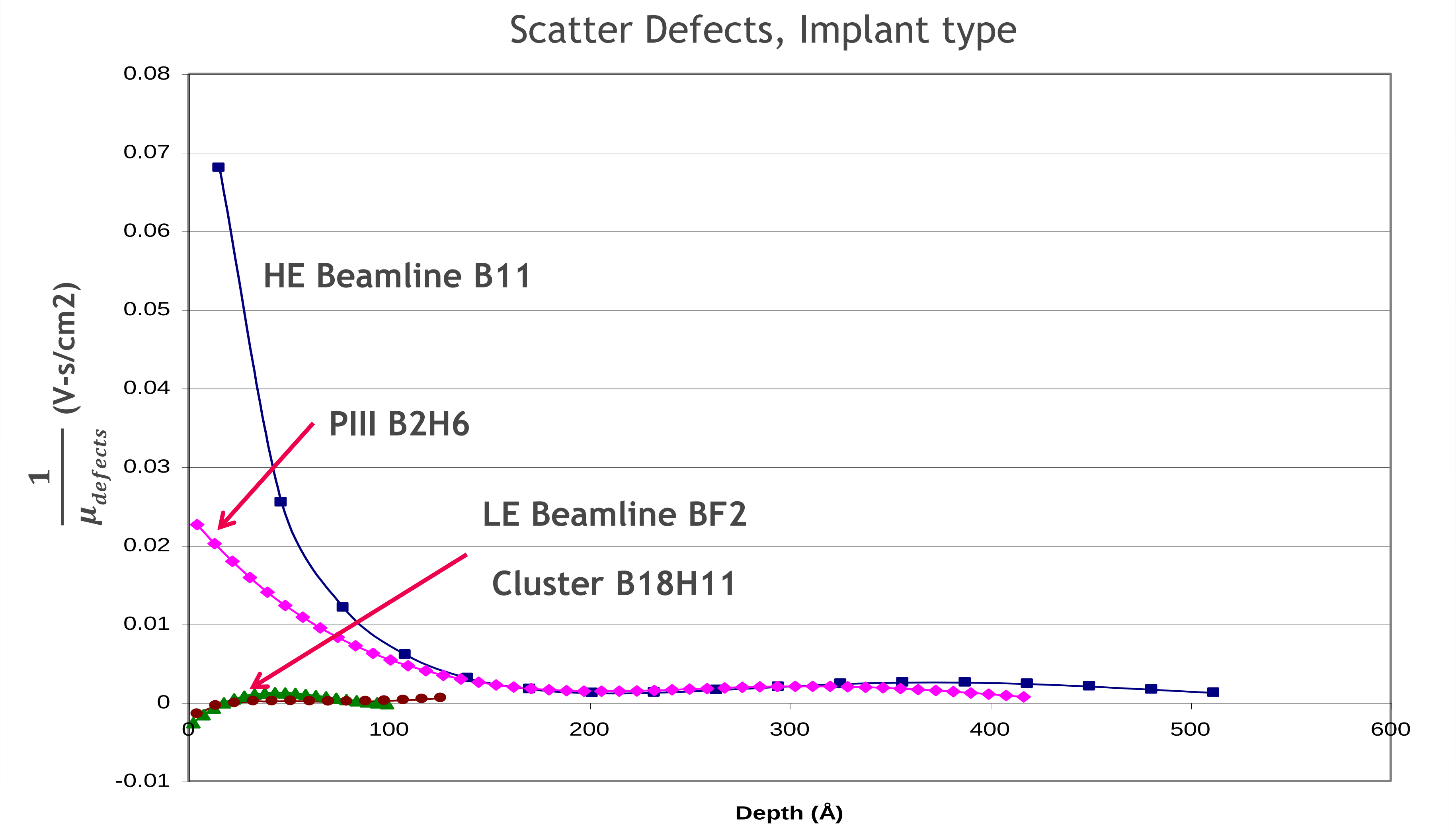
- Most specimens indicated significant scatter defect contributions
- Occasionally specimens were found with zero scatter defects
- Factors which affected scatter defect contributions:

1. Type of Implant (e.g. BL, PLAD, Cluster)
2. Implant Energy and Dose
3. Type of Anneal
4. Anneal Temperature and Time

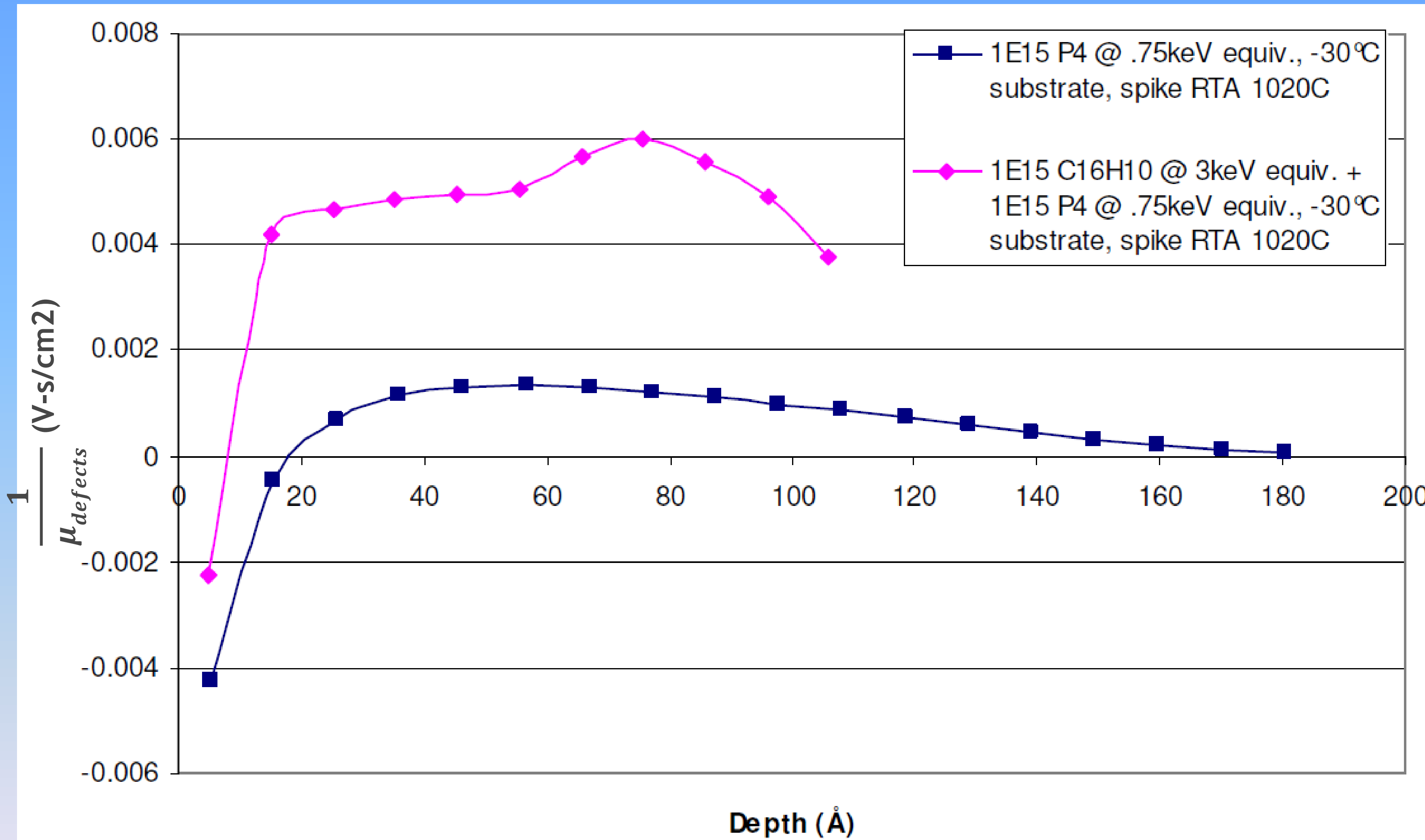
Defect Measure: Concentration Dependence



Defect Measure: Implant-Type Dependence



Defect Measure: Pre-Implant Dependence



- Effect of a Carbon pre-implant [Excess Scatter Defects] JTG 2011

ALP DHE System: PLAD Vs BeamLine

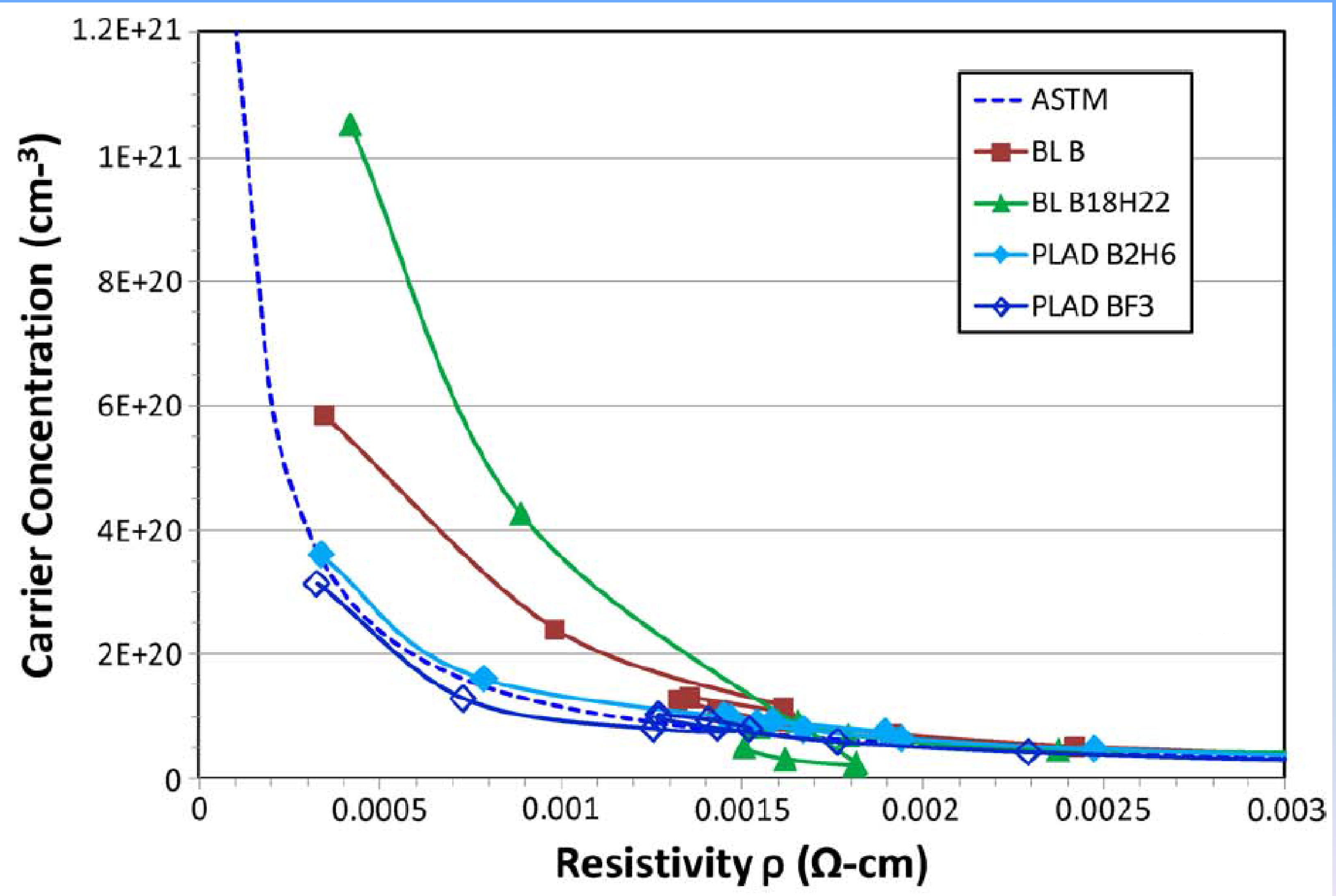
- "Scatter Defects strongly correlate to the implant ion specie atomic mass unit and energy"

Implant Type	Energy/ Dose [eV/cm^2]	RTP/spike	DHE Surface Defect $1/\mu_{DEF}$
BL B	500/1E15	1000°C	0.013
PLAD B2H6	1.2k/5E15	1000°C	0.000
BL B18H22	10k/5.56E13	1000°C	0.050
PLAD BF3	1.7k/4E15	1000°C	0.000

X_j Approx. 25nm for all samples

IEEE Transactions On Plasma Science March 2012, Qin, McTeer, *etal.* *[Micron Tech.]*

ALP DHE System: Defect Analysis



ALP DHE System: Defect Analysis

- Higher Activation for PLAD Vs Beamline ~17%
- R_s /ρ is ~14% lower for PLAD Vs than Beamline
- PLAD Mobilities are higher near the surface

ALP DHE System: Beamline Vs PLAD Device Data

- Devices were fabricated and tested by Micron Technology,Inc. (W/L=100)

- Higher Transconductance ($\Rightarrow$ higher I_{DS}) ⬆ 16% -30% — Lower Scattering Defects + Better Activation

- Lower V_T ⬇ ~3% -16% — Better Activation, Lower ρ

- Lower R_s ⬇ ~14% Lower R_{cs} ⬇ ~50% — Better Surface Film Activation

- Quantitative DHE Analysis *CAN* be used to get device performance

[S. Qin, et al., Solid State Tech 2012. Micron Tech.]

Defect Measure: Strain-Enhancement

Element	Radius (A)	Element	Radius(A)
C	0.77	As	1.21
B	0.84	Ge	1.22
P	1.1	Sn	1.4
Si	**1.17**	Sb	1.41

- Strain may be biaxially compressive or tensile
- Generally beneficial
- Modifying Defect Measure,

$$\frac{1}{\mu_{Measured}} - \frac{1}{\mu_{Ideal}} = \frac{1}{\mu_{defects}} - \frac{1}{\mu_{strain}}$$

Defect Measure

- Defect *and Strain-Effect* Analysis:

$$\frac{1}{\mu_{Measured}} - \frac{1}{\mu_{Ideal}} = 0$$ ➡ IDEAL

$$\frac{1}{\mu_{Measured}} - \frac{1}{\mu_{Ideal}} > 0$$ ➡ DEFECT DOMINATED

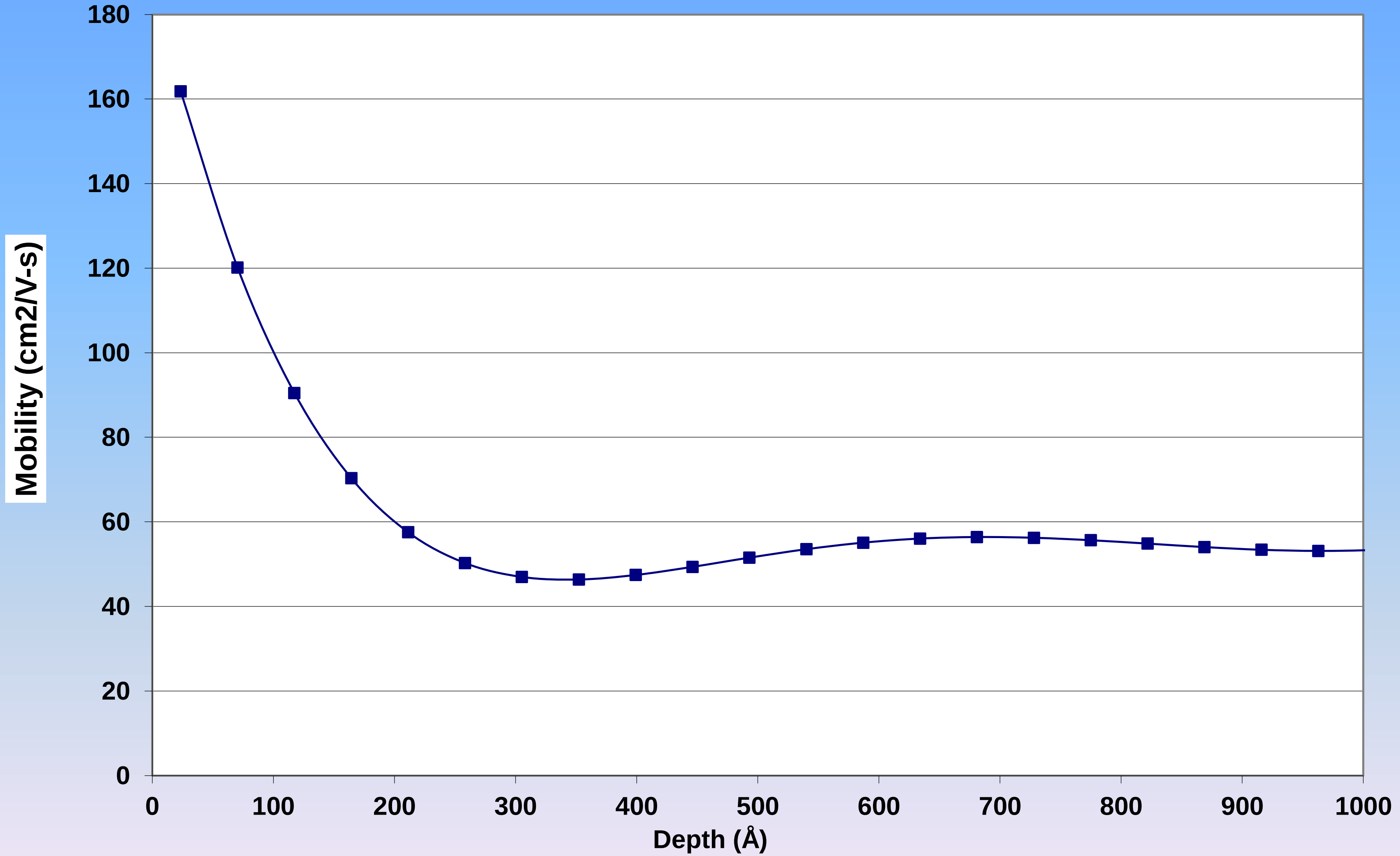
$$\frac{1}{\mu_{Measured}} - \frac{1}{\mu_{Ideal}} < 0$$ ➡ MOBILITY ENHANCEMENT

Strain-Dominated Systems: SiGe

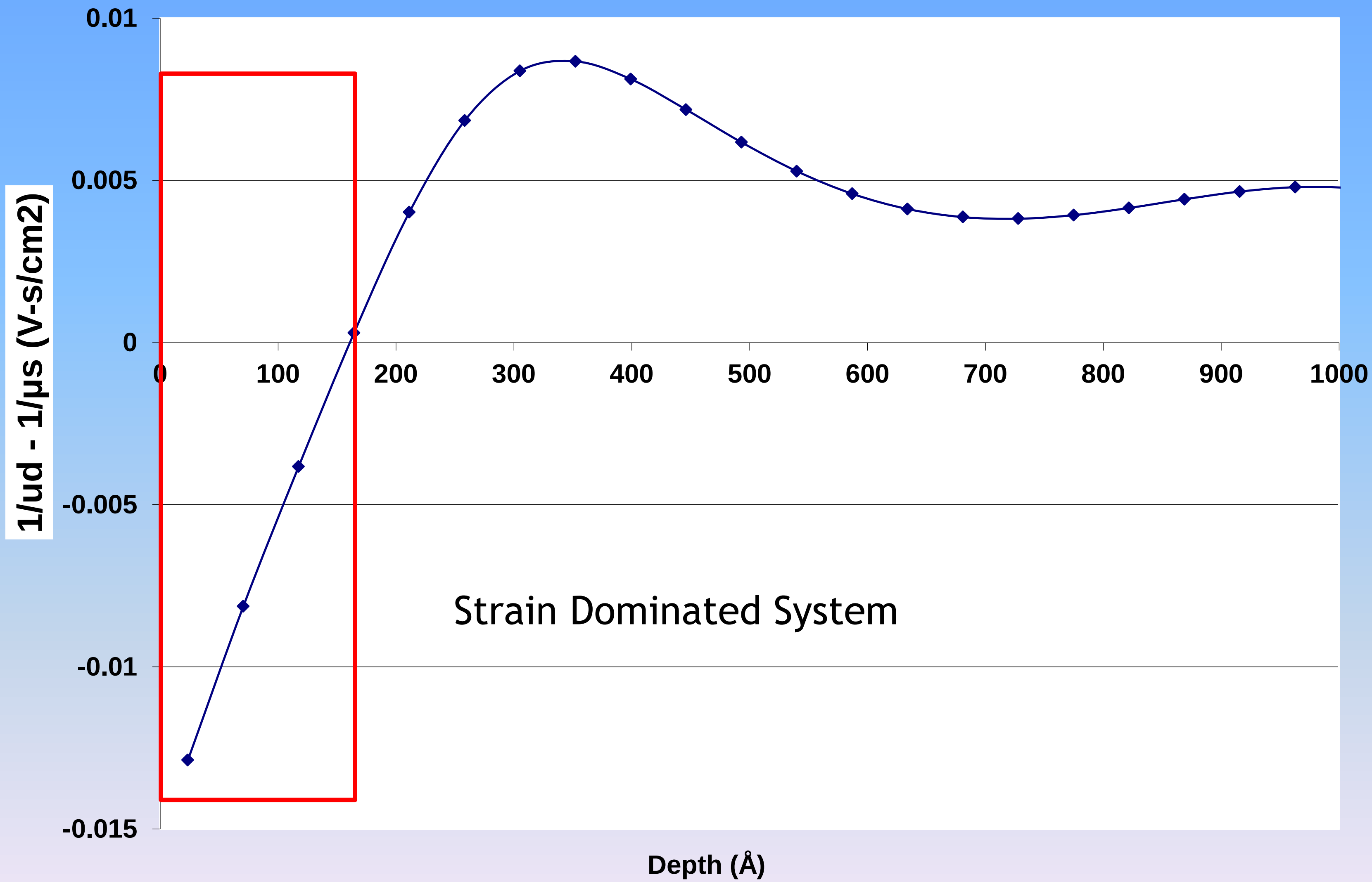
- Combined very-high dose Ge+B plasma implantation + laser anneal
- Structural Data by XRD and XTEM
  - 20% Ge and 55% Ge
- DHE showed 70% increase in mobility for 20% and 4.3x increase for 55%
- Data for sample 55% Ge (1E17/cm2) + B (4E16/cm2)
- 55% concentration peak at ~20 A

* *High Mobility Ge-Channel Formation By Localized/Selective Liquid Phase Epitaxy (LPE) Using Ge+B Plasma Ion Implantation And Laser Melt Annealing* IWJT 2013: Borland, et al.

Mobility Data: SiGe Strain



Defect Measure: SiGe



Summary

- DHE System *directly* measures key Parameters
- DHE Provides Junction profiles for *n*, *μ* and *ρ*
- Selectable step resolution [from 3-5 Angstroms and up]

- Fully Activated Carriers in agreement with SIMS and 4PP
- DHE results published since 2007 in Professional and Technical Journals
- Valuable aid in mobility enhancement studies and defect analysis

- Rapid, Affordable Evaluation of Active Layers
- DHE provides essential data that should be included with every process lot

Active Layer Parametrics, Inc.

TOTAL JUNCTION METROLOGY

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