

CHARACTERIZATION OF INDIUM DOPING PROFILES BY LEXES AND SIMS

○ Dimitry Kouzminov, Brad Bates and Jerry Hunter

ACCUREL SYSTEMS

○ Pierre Staub, Chrystel Hombourger, Michel
Schuhmacher

CAMECA

○ Houda Graoui, Amir Al-Bayati, Majeed Foad

APPLIED MATERIALS Inc

OUTLINE

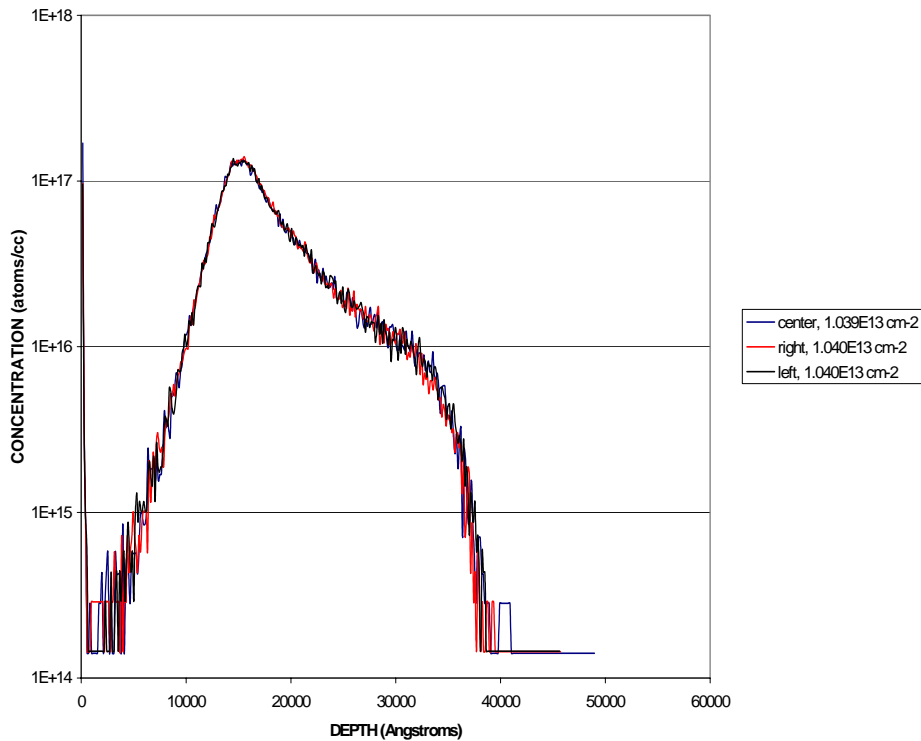
- ❑ INTRODUCTION
- ❑ DETAILS OF EXPERIMENT
- ❑ RELATED HIGHLIGHTS OF LEXES AND SIMS TECHNIQUES
- ❑ EXPERIMENTAL RESULTS OF $1\text{E}14$ at/cm² INDIUM IMPLANT CHARACTERIZATION
- ❑ EXPERIMENTAL RESULTS ON $6\text{E}13$, $3\text{E}13$ AND $1\text{E}13$ at/cm² INDIUM IMPLANTS
- ❑ COMPARISON OF DOSE MEASUREMENT BY LEXES AND SIMS
- ❑ CONCLUSIONS

INTRODUCTION

DETAILS OF EXPERIMENT

- ❑ Indium implantation, 150 keV, 1E14 at/ cm2, 6E13 at/cm2, 3E13 at/cm2 and 1E13 at/cm2 and RTP anneal (*Applied Materials Inc*)
- ❑ Anneal conditions: 700°C, 950°C, 1050°C, 1100°C, 1150°C for 5 sec
- ❑ Measurement by SIMS:
 - **CAMECA 4FE7**, O₂⁺ beam, E_p= 1.5 keV (*ACCUREL*)
 - **CAMECA SC Ultra**, O₂⁺ beam, E_p= 500 eV, 36° (full oxidation) (*CAMECA*)
 - **ATOMIKA**, O₂⁺ beam, E_p= 500eV, 30° (full oxidation) (*ACCUREL*)
- ❑ Measurement by **LEXES** (CAMECA *Shallow Probe*), (*CAMECA*)
 - *In La*, E-beam energy 8 keV, beam size 50 μm, count time 500 sec

TYPICAL HIGH-PRECISION MEASUREMENT OF ACROSS-WAFER IMPLANT VARIATION

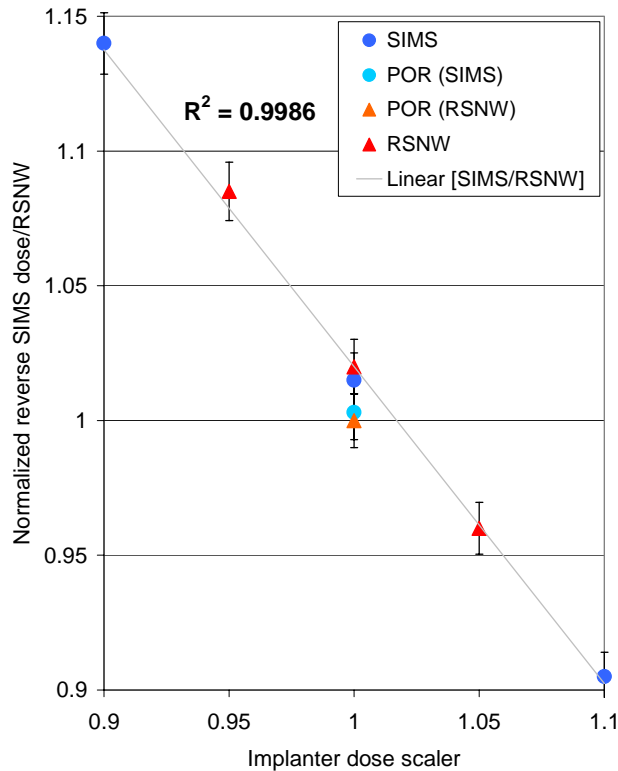


- ❑ Example of N-Well implant x-wafer variation measurement
- ❑ Highest detected difference is $<0.1\%$

 **Achievable SIMS measurement precision $<0.1\%$**

CORRELATION BETWEEN SIMS AND DEVICE PARAMETRICS

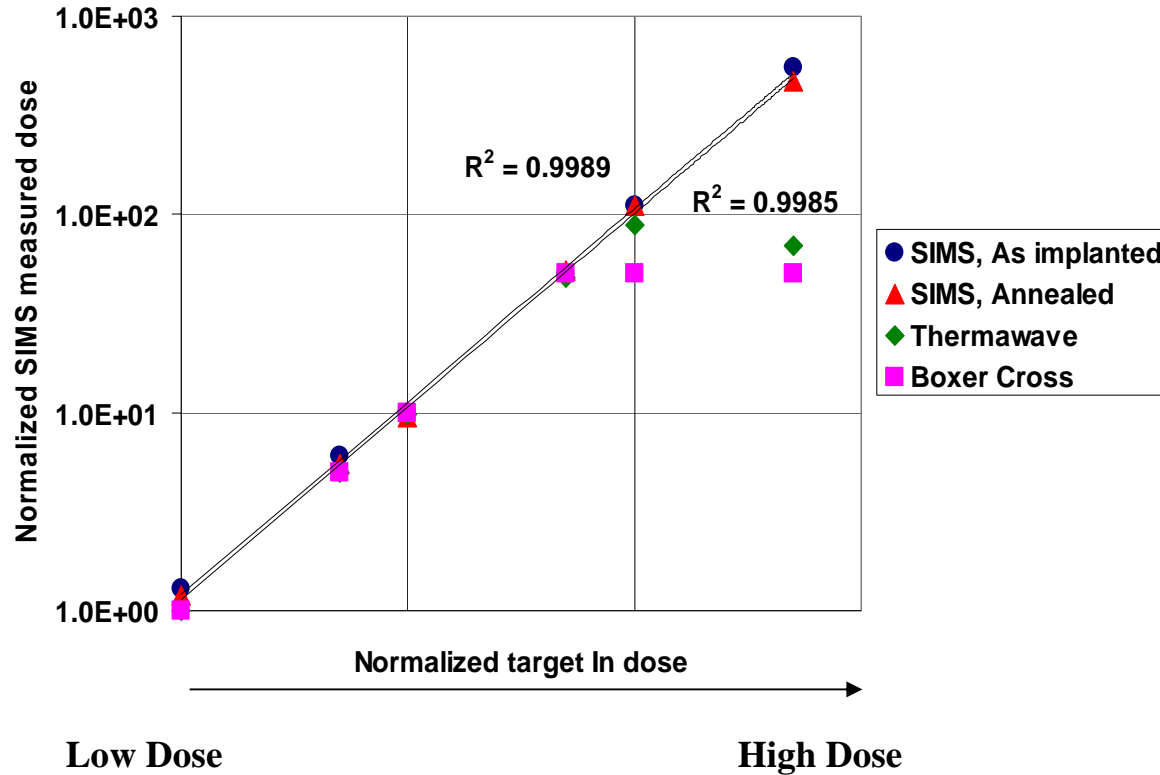
RSNW-SIMS correlation



- ❑ SIMS data on POR and new implanter target correlate within 0.5% with result of split-lot experiment on RSNW parameter

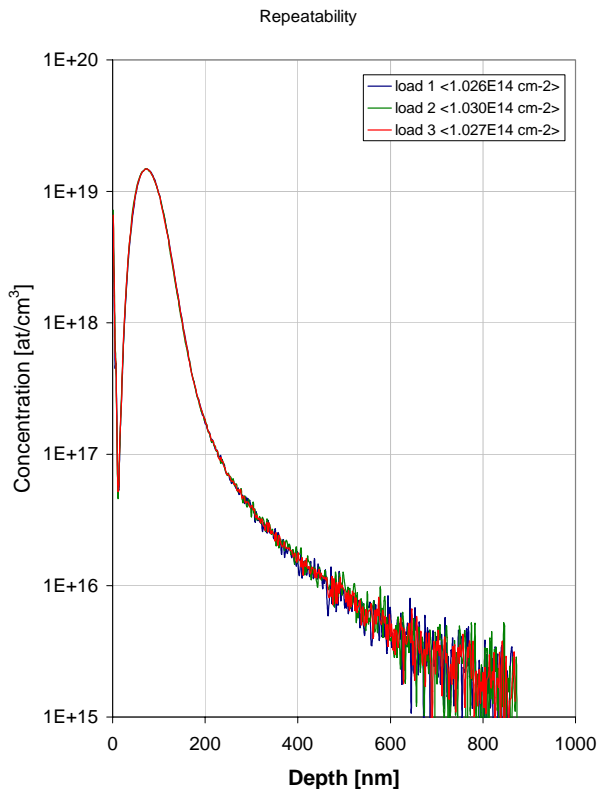
 **SIMS meets metrology requirement**

INDIUM MEASUREMENT LINEARITY



➤ SIMS provides excellent measurement linearity within 1E11 – mid E13 at/cm² dose range on Indium

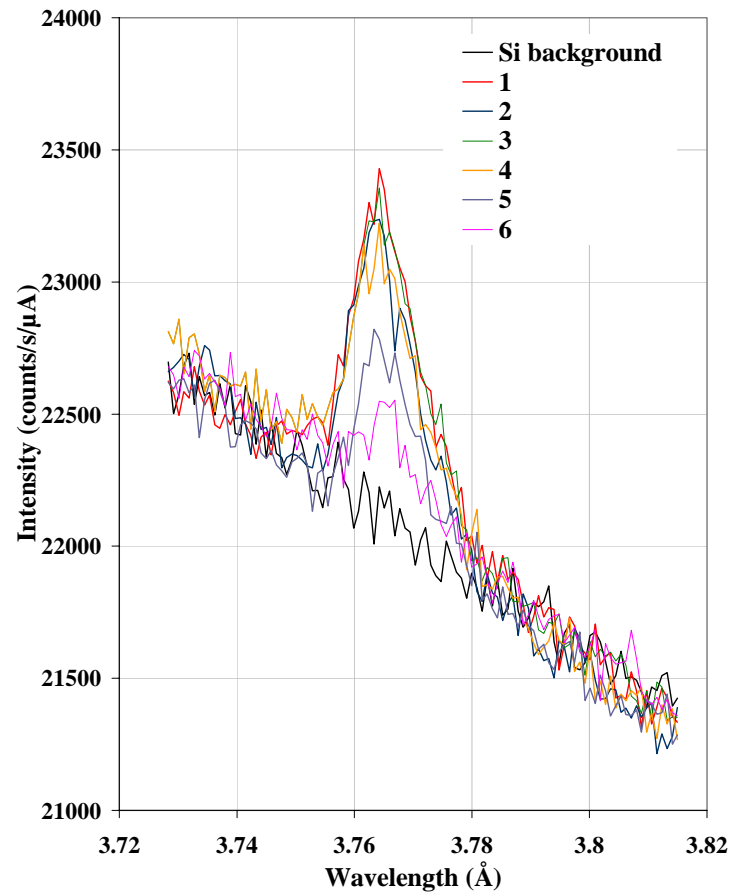
ASSESSMENT OF SIMS MEASUREMENT REPEATABILITY



- ❑ 3 measurements per sample/load – average dose calculation
- ❑ Load-to-load variation analysis

➤ **Measurement variation was <1% in the current study**

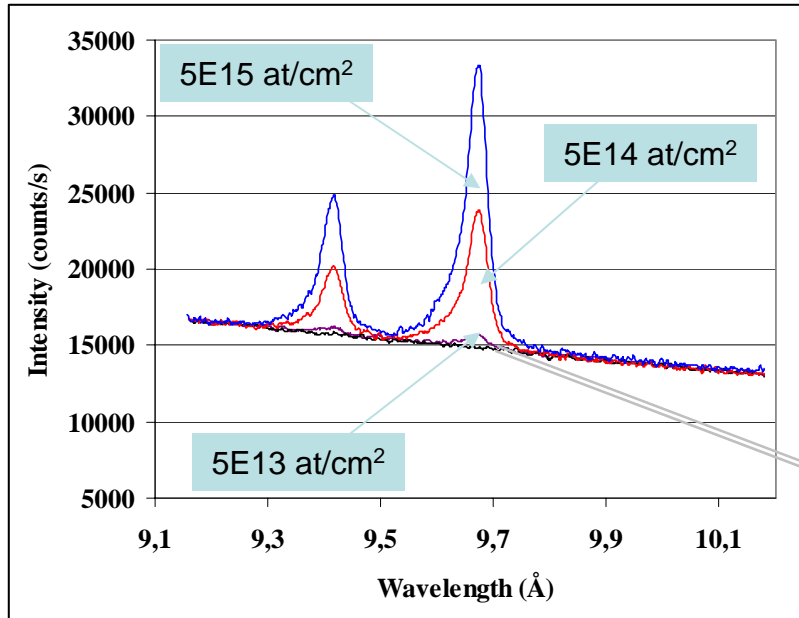
EXPERIMENTAL SPECTRA FROM LEXES



1. 1E14 at/cm² as-implanted
2. 1E14 700°C anneal
3. 1E14 950°C anneal
4. 1E14 1050°C anneal
5. 1E14 1150°C anneal
6. 3E13 at/cm² as-implanted

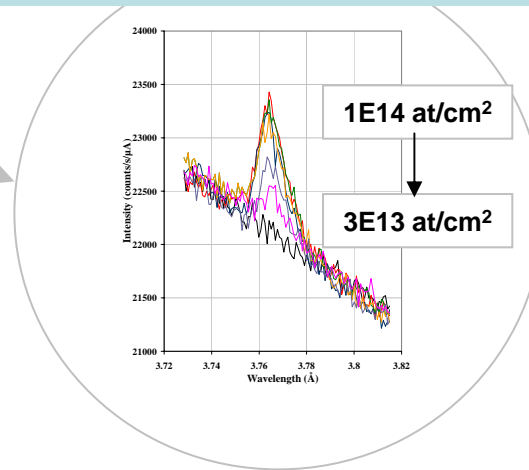
□ *Count time per spectral position (plot on the left) is 5 sec; quantification performed with 60 sec count time on the peak and background to improve counting statistics*

CHALLENGING NATURE OF CURRENT STUDY FOR LEXES



Typical working range

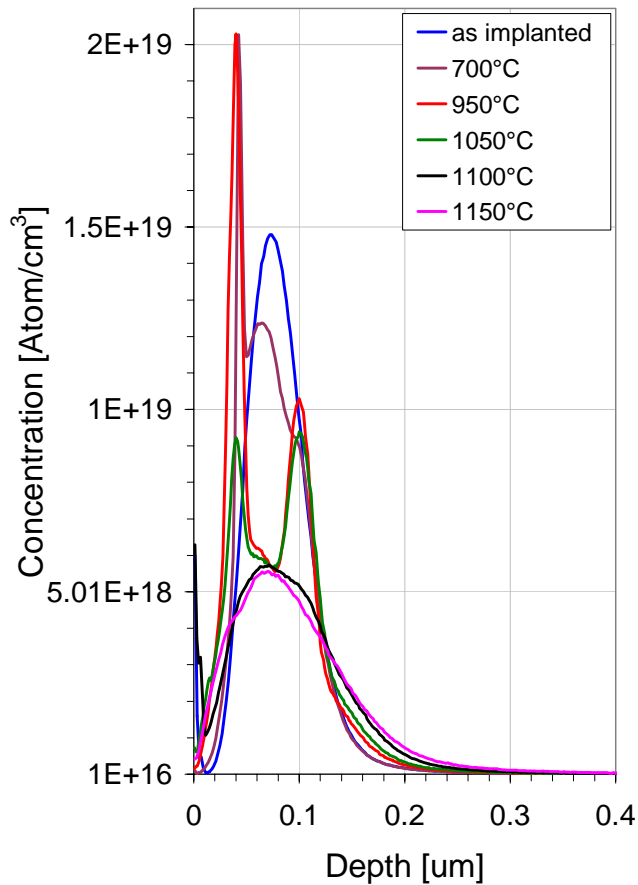
Working range in this study



 **Current study extends working range of LEXES to medium/ low doses**

**EXPERIMENTAL RESULTS ON $1E14$
at/cm² INDIUM IMPLANT**

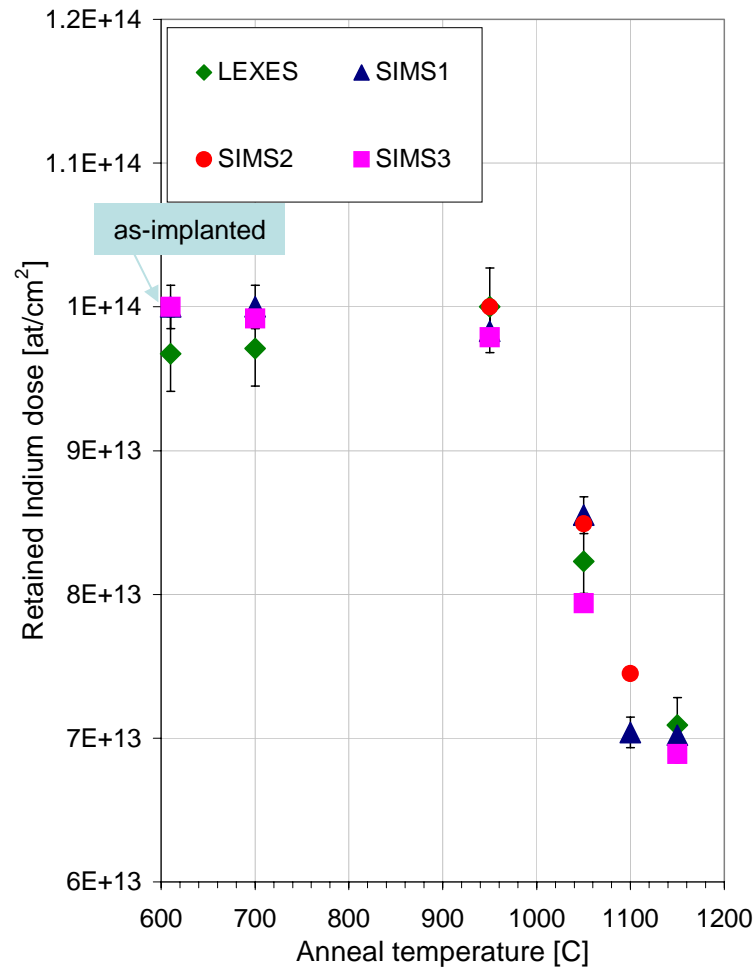
EVOLUTION OF INDIUM IMPLANT WITH ANNEAL TEMPERATURE



- Evolution of retained dose:
 - As implanted: 1.005E14 at/cm²
 - 700°C – 1.01E14 at/cm²
 - 950°C – 9.80E13 at/cm²
 - 1050°C – 8.55E13 at/cm²
 - 1100°C – 7.04E13 at/cm²
 - 1150°C – 7.02E13 at/cm²

↪ Anneal dynamics is apparent in SIMS profiles

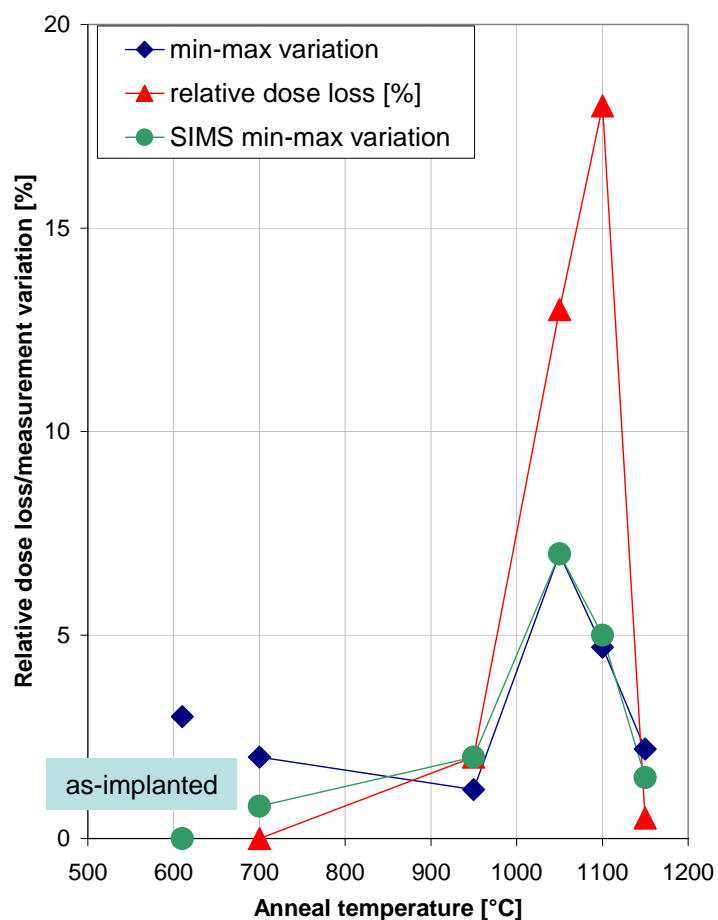
DOSE LOSS WITH ANNEAL TEMPERATURE



- ❑ No dose loss is observed up to 950°C
- ❑ ~30% dose loss occurs within temperature range 950°C > T > 1100°C
- ❑ Little variation of retained Indium dose is seen within 1100°C – 1150°C range
- ❑ Good measurement correlation up to 950°C and at 1100°C

MEASUREMENT VARIATION AND ANNEAL TEMPERATURE

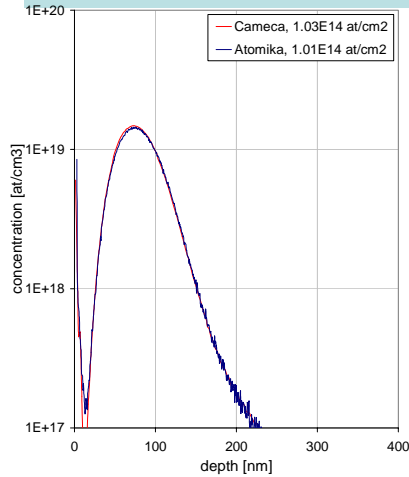
1E14 at/cm² Indium implant



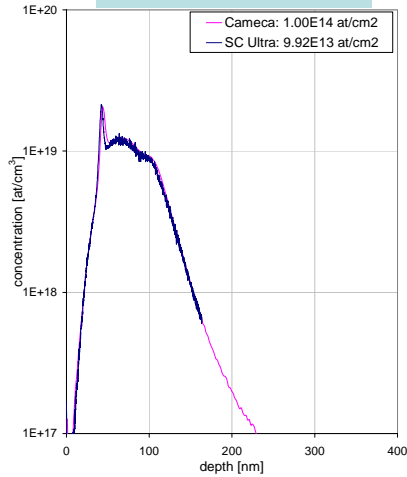
- ❑ Measurement variation is high in the high dose loss range
- ❑ Seen both LEXES-SIMS and between SIMS measurements
- ❑ May not only be related to metrology but also to defect dynamics

SIMS DATA CORRELATION AND ANNEAL TEMPERATURE

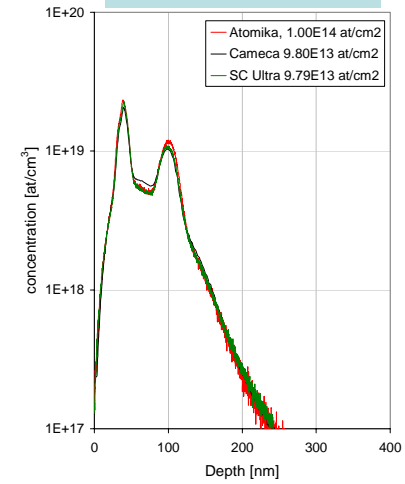
As implanted: good



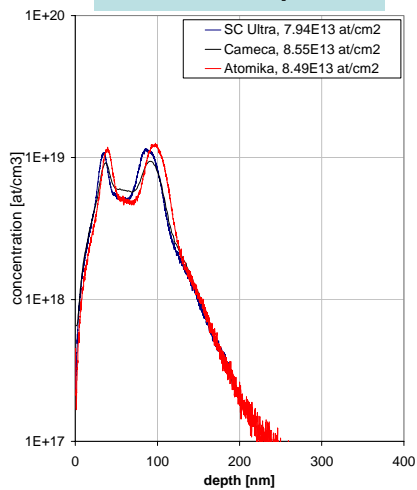
700°C: good



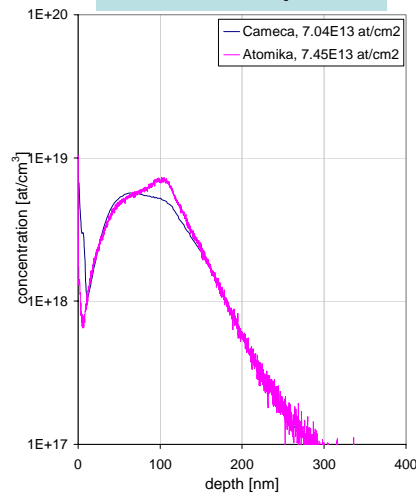
950°C: good



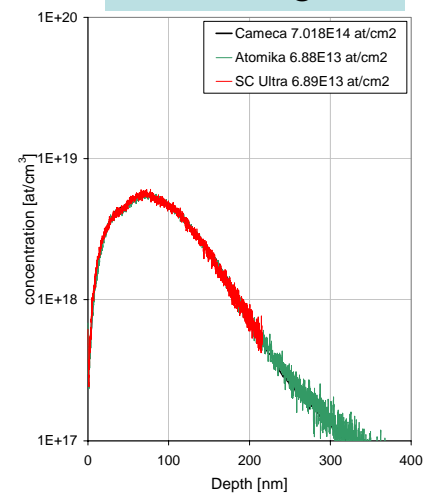
1050°C: poor



1100°C: poor



1150°C: good



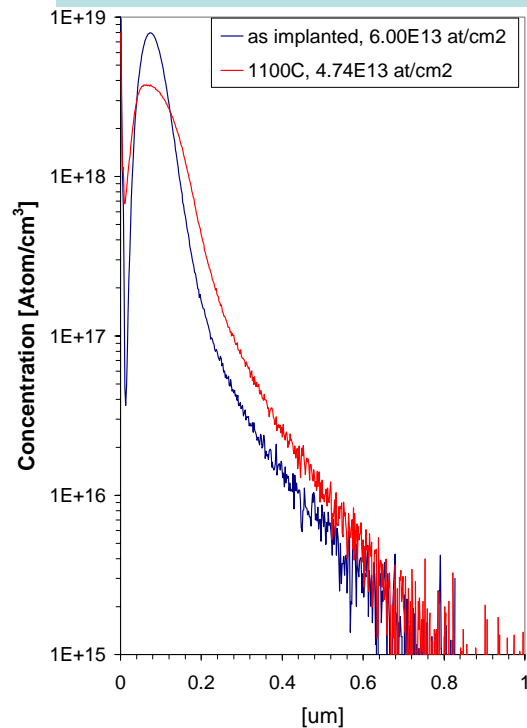
CONCLUSIONS ON 1E14 at/cm² INDIUM IMPLANT STUDY

- ❑ *Significant redistribution of indium occurs within anneal temperature range 700°C to 1100°C*
- ❑ *Minimal dose loss (<2%) occurs up to 950°C anneal temperature*
- ❑ *Evolution of indium distribution is accompanied by 30% dose loss, likely through evaporation, within 950°C – 1100°C range*
- ❑ *Minimal dose loss (<2%) and redistribution occur within temperature range 1100°C- 1150°C*
- ❑ *Indium dosimetry is in good agreement between LEXES and SIMS for anneal temperature up to 950°C and >1100°C*
- ❑ *High measurement disagreement is seen in temperature range 1050°C to 1100°C*
- ❑ *Origin of this disagreement is not confirmed but may be related to complex defect dynamics*

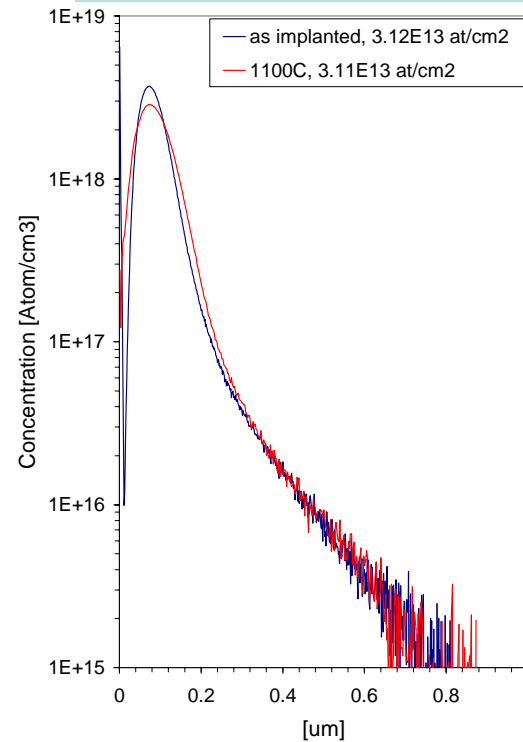
**EXPERIMENTAL RESULTS ON 6E13,
3E13 AND 1E13 at/cm² INDIUM
IMPLANTS**

6E13, 3E13 AND 1E13 at/cm² IMPLANTS: EVOLUTION OF INDIUM DEPTH DISTRIBUTION WITH ANNEAL TEMPERATURE

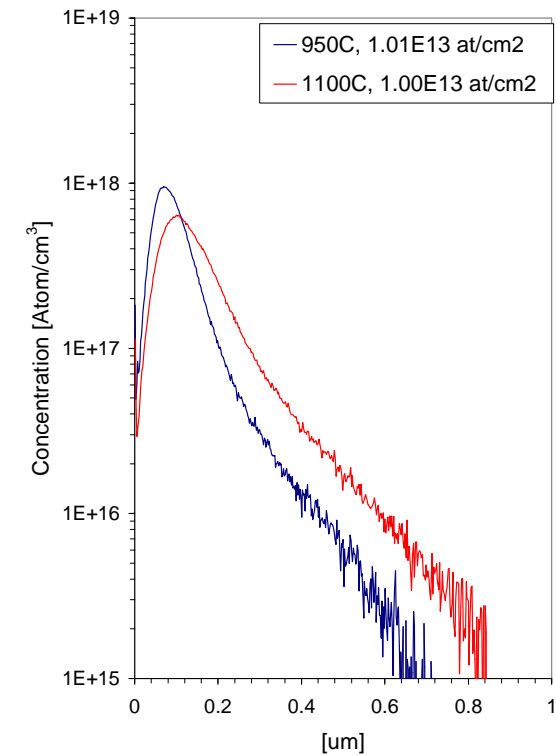
6E13, as implanted
and 1100°C



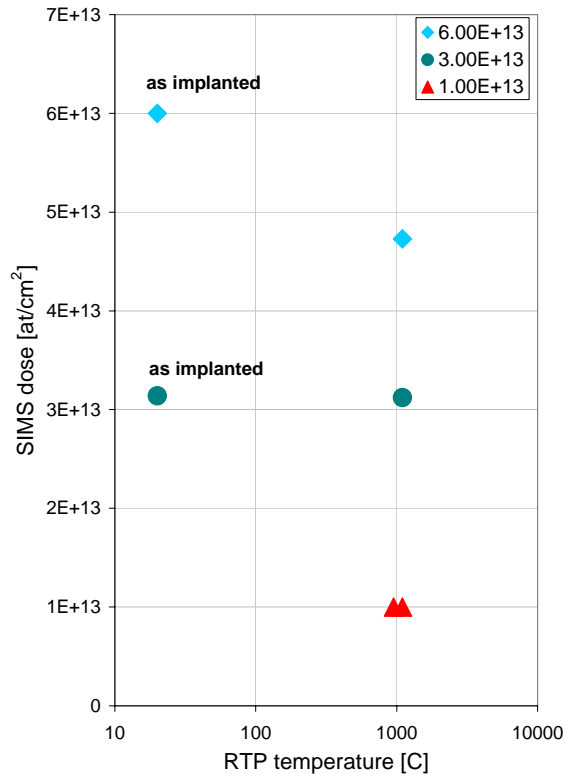
3E13, as implanted
and 1100°C



1E13, 950C and
1100°C



INDIUM DOSE LOSS WITH ANNEAL FOR IMPLANT DOSES 6E13, 3E13 AND 1E13 at/cm²

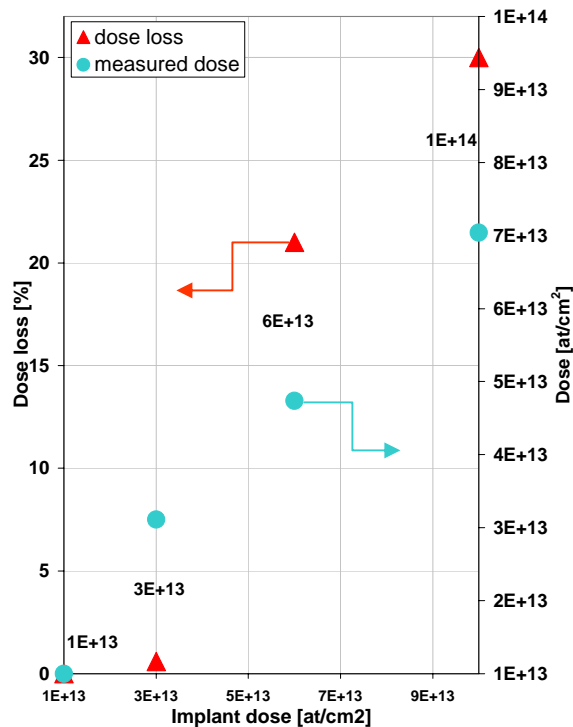


- ~20% dose loss observed at 1100°C for implant dose 6E13 at/cm²
- No measurable dose loss seen at 950°C and 1100°C for implant doses 3E13 and 1E13 at/cm²

Measured Indium dose vs. anneal temperature, 6E13, 3E13, 1E13 at/cm²

INDIUM DOSE LOSS AT 1100°C ANNEAL

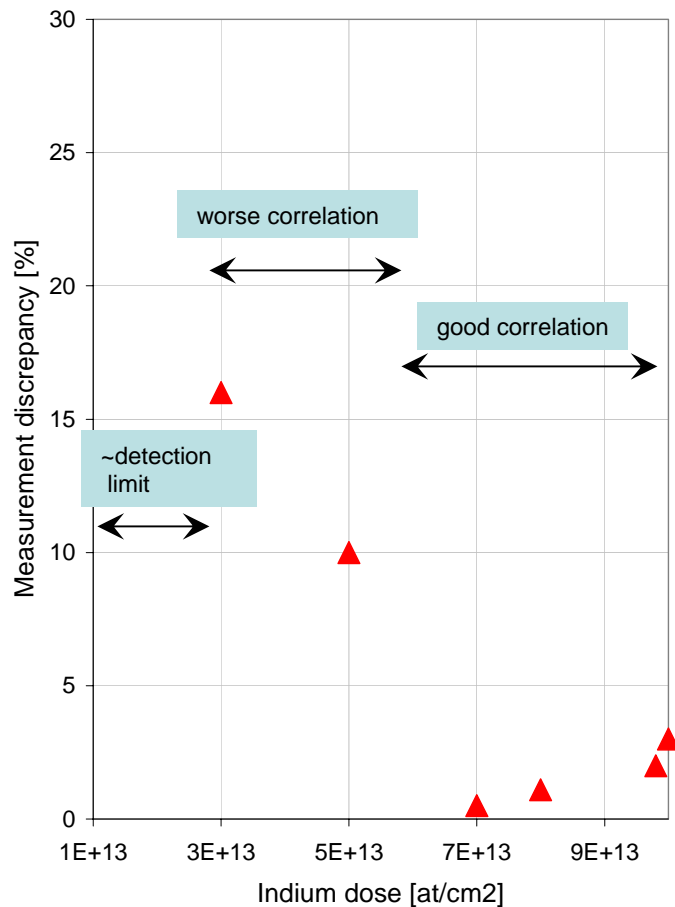
Indium dose loss at 1100°C
vs. nominal implantation dose



- ❑ No measurable dose loss observed for implant doses $3E13$ at/cm² and below
- ❑ Dose loss reaches 20% for $6E13$ at/cm² and 30% for $1E14$ at/cm² implants

➤ Significant dose loss at anneal observed for implant dose $>3E13$ at/cm²

SIMS/LEXES MEASUREMENT CORRELATION



- ❑ Very good correlation (2% and better) is observed for Indium dose $6E13$ at/cm² and higher
- ❑ Disagreement increases with lower dose in the vicinity of detection limit
- ❑ LEXES reaches detection limit between $1E13$ and $3E13$ at/cm²

LEXES – SIMS measurement discrepancy

CONCLUSIONS

- ✓ Both LEXES and SIMS have demonstrated reproducibility and accuracy adequate for Indium implant metrology
- ✓ Excellent correlation between LEXES and SIMS is observed within dose range of high 10^{13} - 10^{14} at/cm², which extends typical range of LEXES application; future focus on low 10^{13} at/cm² range application
- ✓ Depth distribution of 10^{14} at/cm² Indium implant changes dramatically with anneal temperature, as identified by SIMS. This is attributed to defect dynamics
- ✓ Data correlation issue in 1050-1100°C range is under further investigation
- ✓ Indium implants done in the range of 6×10^{13} - 10^{14} at/cm² undergo significant dose loss during RTP anneal
- ✓ Current study identifies direction of future experiments into 3×10^{13} - 6×10^{13} at/cm² Indium implant doses and finer anneal steps to better understand defect dynamics