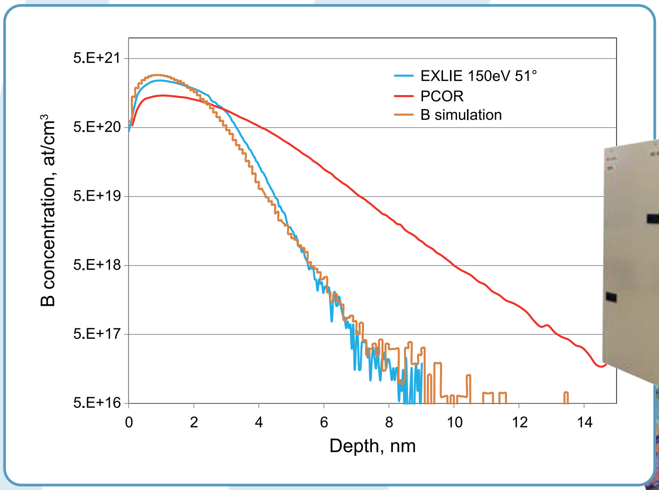
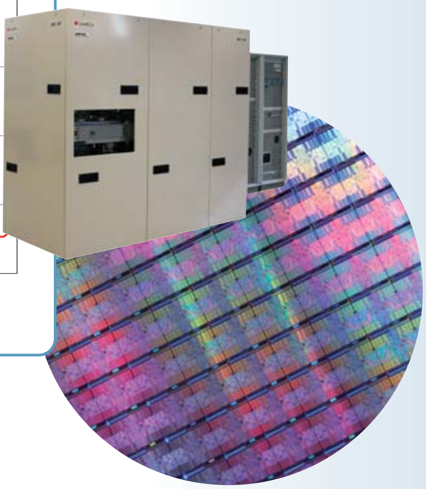
CAMECA®
SCIENCE & METROLOGY SOLUTIONS

Application note

Ultra Shallow Boron Implant Characterization:
EXLIE* SIMS** or **PCOR™ ?
****EXtreme Low Impact Energy***





EXLIE SIMS surpasses all existing methods including PCOR™ for an accurate characterization of ULE B implants with very steep profiles, down to 0.5nm/decade.

AMETEK®
MATERIALS ANALYSIS DIVISION

SIMS depth profiling of low energy boron implants in silicon is usually accomplished using low energy O_2 primary beam (500-1000eV). Sputtering with O_2 ions is accompanied by surface oxidation, responsible for chemical bounding modification of surface atoms and ionization yield enhancement of sputtered surface atoms. In general, these processes (oxidation and sputtering) are depending on each other, and their relative variation contributes to the so-called near surface transient effect. To record the most accurate in-depth distribution of shallow B implant, SIMS analysts must carefully adjust the analysis recipe (sputtering conditions) in order to **minimize the near surface** (depth <5nm) transient and therefore **simplify the subsequent data quantification**.

The purpose of this application note is to discuss the benefits and limits of two acknowledged SIMS analytical methods applied for accurate shallow profile measurements, thus providing SIMS analysts with objective criteria to choose the best appropriate method for fulfilling their analytical requirements.

From low to ultra-low energy implants

One of these two recipes, known as PCOR™, has become the best known method for measuring low energy B implants in Si. It delivers accurate dose and profile shape measurements for mid-low energy B implants, provided B profile abruptness exceeds 2nm/decade. This is the typical decay length of B profiles in Si substrate in case of shallow implant with channeling effect or PLAD implantation process. **However, it is recognized that PCOR™ is not a universal protocol for ultra-shallow profiling.** In case of very steep concentration profiles, the PCOR™ profile shows significant deviation from the "true" profile. The details of the PCOR™ recipe have never been disclosed, but it is assumed that this limit is inherent to the use of a **medium impact energy range for the primary ions**.

The CAMECA Solution: EXLIE SIMS instruments & data reduction algorithm

Recent CAMECA SIMS instrumentation developments together with improvements in data reduction models have allowed the introduction of an **EX**tremely **L**ow **I**mpact **E**nergy (EXLIE) recipe that successfully replaces the PCOR™ technique when the latter reaches its limits. One of the most important improvements originates in the **RF-plasma excitation gas source** now available for the CAMECA **IMS Wf** and **SC Ultra**, developed in collaboration with Oregon Physics ***(J. Vac. Sci. Technol. B, 8 (2010) C1C48)***. **This new source allows performing depth profile at 150eV with sputter rate exceeding 2 nm/minute**, thus making the EXLIE recipe consistent with reasonable analysis times for routine analyses.

Data reduction in EXLIE mode is based on a variable sputter rate, in the transient regime as well as in the two different matrices (SiO_2 & Si). Accurate data quantification can be successfully applied to B implants done through thermal oxides of various thicknesses. It requires a characterization of the surface oxide layer prior to SIMS profiling and the knowledge of the relative sputter rate in steady state sputtering between Si and SiO_2 matrices. The EXLIE data reduction algorithm is described in details in ***Surf. Interface Anal., 43, (2011), pp. 522-524.***

Before addressing the main benefits of EXLIE for ultra high depth resolution, it must be emphasized that **the EXLIE protocol delivers equally precise data in the application fields traditionally covered by PCOR™ such as mid-energy B implants or low enrgy PLAD implants**. Figure 1 shows the comparison of a 500eV PLAD implant analyzed by PCOR™ (600eV energy) and EXLIE (250 and 600eV) methods. EXLIE and PCOR™ results superimpose very well.

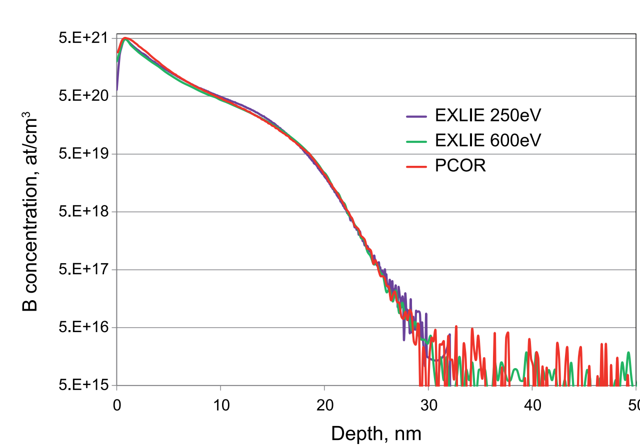


Fig. 1: Overlay of PCOR and EXLIE profiles for a 500eV PLAD implant

*Only **EX**treme **L**ow **I**mpact **E**nergy SIMS can ensure **high resolution depth profiling***

The main purpose of the EXLIE recipe is to combine sub-nm depth resolution with an accurate near surface quantification. A **sub-nanometer depth resolution capability of 0.7nm/dec** has been demonstrated for EXLIE on sharp interfaces of epitaxial grown structures (B doped delta layer) and very shallow implants (mono-energetic implantation with no channeling effect). For the same sample type, the typical decay length obtained in the PCOR™ depth profile exceeds 2nm/decade. The clear advantage of EXLIE comes from the use of an impact energy <250eV.

Two different low energy Boron implants have been selected to compare results between the EXLIE and PCOR™ methods.
- **Sample A:** 200eV B implant through thin native oxide layer (1.5nm approximately),
- **Sample B:** 200eV B implant through 3nm thermal oxide layer

Implant through thin native oxide

Figure 2 presents the overlay of EXLIE and PCOR™ profiles measured for Sample A (native oxide), together with a simulated "true" profile. The simulated depth profile shows a rather large decay length (1.8nm/dec) which indicates implantation conditions with channeling effects. **The decay length of the EXLIE profile at 250eV 46° perfectly fits with the profile simulation**, while the PCOR™ profile clearly shows a larger decay length. **Even for this implant with channeling effects, the PCOR recipe cannot give access to an accurate junction depth because of the use of a too high energy**. At the near surface, both EXLIE and PCOR™ provide an accurate profile shape.

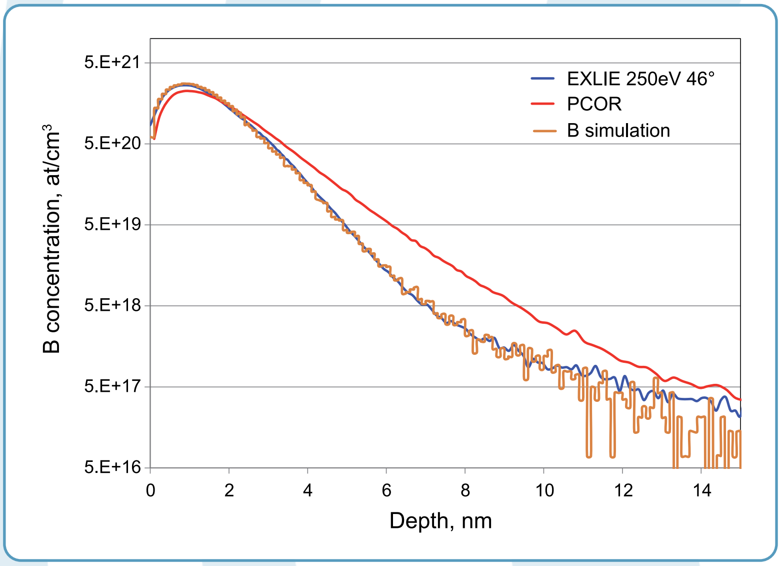


Fig. 2: Overlay of EXLIE , PCOR™ and simulated profiles 200eV implant through thin native oxide layer (Sample A)

Implant through thick thermal oxide layer

Figure 3 presents the overlay of EXLIE, PCOR™ and simulated profiles for Sample B (3nm thermal oxide). The thicker oxide layer inhibits channeling effects, and therefore the down slope of the implant profile is more abrupt than for sample A. Consequently, **the primary ion energy used for PCOR™ recipes prevents from measuring a correct junction depth.** Meanwhile the 150eV EXLIE recipe provides a down slope profile shape consistent with the simulation. **Near the surface, the raw EXLIE profile exhibits a surface peak. However, it disappears once an appropriate data quantification has been applied** (consisting in correcting the secondary ion intensity from the sputter yield variation in the transient regime). For sample B as well, only the low energy EXLIE recipe provides relevant information about B distribution.

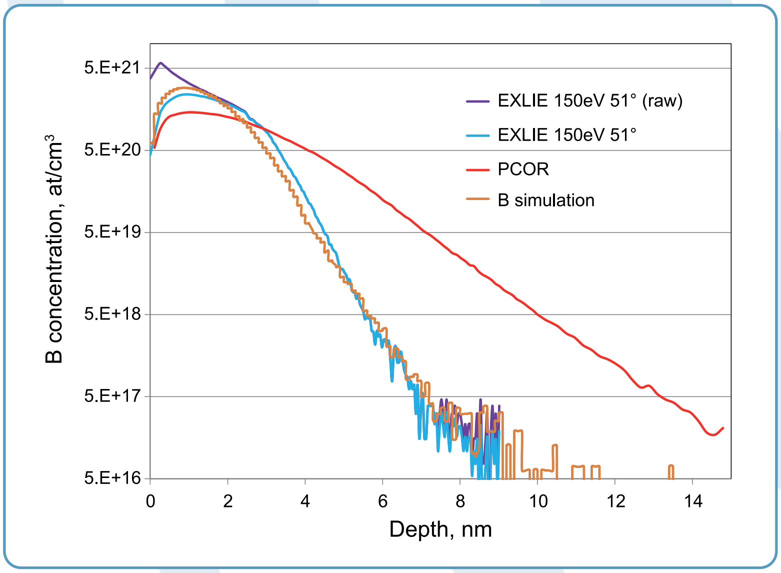
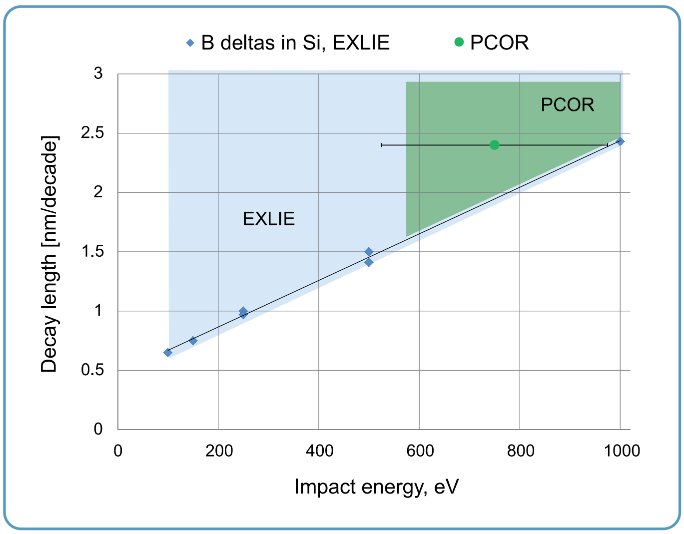


Fig. 2: Overlay of EXLIE , PCOR™ and simulated profiles 200eV implant through thick thermal oxide layer (Sample B)

Thanks to its flexibility in primary beam energy selection, EXLIE SIMS is the most accurate method for characterizing ultra shallow B implants in Si.

The analytical conditions applied in the PCOR™ technique are not always appropriate for SIMS analysis. Primary beam impact energy selection for depth profiling depends on the characteristics of the analyzed structure. The best probing energy must be selected to achieve the least profile distortion and to keep the highest sputter rate (analysis throughput). In the case of B implants, as a rule of thumb, the use of half of the implant energy as the profiling energy stands well. However selecting a profiling energy equal to the implant energy is applicable in case of plasma immersion doped samples, PLAD or alike.



Recommendations on depth profiling impact energy selection are proposed on the left. The figure shows the experimental EXLIE decay length obtained from a delta doped reference sample measured at different impact energies. These data define the ultimate depth resolution achievable at given sputtering conditions. Application domains for PCOR™ and EXLIE recipes are visualized through green and blue colored areas respectively. **While EXLIE can be successfully applied to measure B profile from very abrupt interface (down to 0.5nm/decade) up to a few nm/decade, it appears that PCOR™ cannot measure with a depth resolution better than 1.5 nm/decade.**

CAMECA is the reference in micro- and nano-analysis, providing cutting-edge science and metrology solutions with unequaled customer support through a worldwide network of subsidiaries and agents.

Corporate headquarters:

29 Quai des Grésillons • 92622 Gennevilliers Cedex • FRANCE
Tel : +33 1 43 34 62 00 • Fax : +33 1 43 34 63 50 • cameca.info@cameca.com

Subsidiaries:

AMETEK China CAMECA Business Unit • cameca-china.sales@ametek.com.cn
AMETEK India CAMECA Business Unit • cameca-india@ametek.com
CAMECA Germany • sales.cameca@ametek.de
AMETEK Japan CAMECA Business Unit • cameca-japan.info@ametek.co.jp
AMETEK Korea CAMECA Business Unit • cameca-korea.info@ametek.co.kr
CAMECA Taiwan Corp. Ltd. • sales.cameca@ametek.com.tw
CAMECA Instruments, Inc. USA • cameca.us-sales@ametek.com

www.cameca.com

CAMECA®
SCIENCE & METROLOGY SOLUTIONS

AMETEK®
MATERIALS ANALYSIS DIVISION

EXLIE/PCOR
Application note