ULTRA LOW ENERGY (ULE) IMPLANT DOSE & ACTIVATION MONITORING

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We report on ultra low energy implant dose and activation monitoring with junctions down to 10nm using new metrology techniques and equipment. Dopant electrical activation was determined by non-penetrating elastic material probe in either a single probe configuration for CV surface electrically active dopant measurement called Nsurf or 4-point probe (4PP) configuration for sheet resistance (Rs) measurements. Use of x-ray photoelectron spectroscopy (XPS) was demonstrated for implanter monitoring applications by means of surface atomic compositional mapping of the implanted As, P, or B and co-implanted species such as Ge and F as well as other elements, all independently in a single measurement. As-implanted dopant variation appears to track with surface oxide thickness uniformity measured by XPS maps.

INTRODUCTION

The 2003 ITRS roadmap defines the ultra-shallow junction (USJ) requirements as drain extension Xj (nm), maximum drain extension sheet resistance Rs (ohms/square) and lateral abruptness (nm/decade). The industry uses SIMS depth profile to define Xj at a chemical concentration level of 1E18/cm^3 for example and abruptness based on the chemical vertical depth profile. Rs is determined from 4PP measurements and the Rs versus Xj chart is created from those values for each technology node from 130nm down to 22nm as shown in Fig. 1. At 130nm node the USJ target of Xj=35nm and Rs=400ohms/sq. can be achieved with spike/RTA having approximately 15nm of diffusion and up to 8E19/cm^3 dopant electrical activation due to boron solid solubility (Bss) limit. With these deeper diffused junctions there is good agreement between 4PP Rs measurements, SRP (spreading resistance profile) measurements and SIMS in determining the electrically active dopant level and profile shape as shown in Fig. 2 (1). However, as the electrical junction depth scales below 25nm for 65nm node and beyond standard 4PP results become problematic due to probe penetration through the shallow junction (2). With zero diffusion annealing (diffusion-less activation) SIMS can no longer be used to determine junction depth, abruptness and electrically activate dopant level as illustrated in Fig. 3 for a diffusion-less activation boron structure comparing SIMS to SRP profiles (3). Because of these differences, new metrology techniques and equipment are being introduced to more accurately measure these ultra-shallow junctions (USJ) created by ULE implantation.

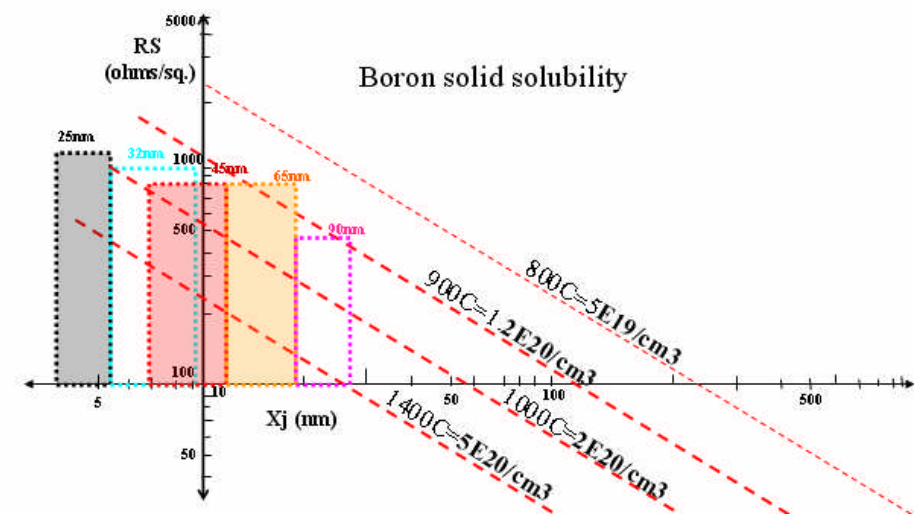


Fig. 1: Bss temperature dependence plotted as Rs versus Xj.

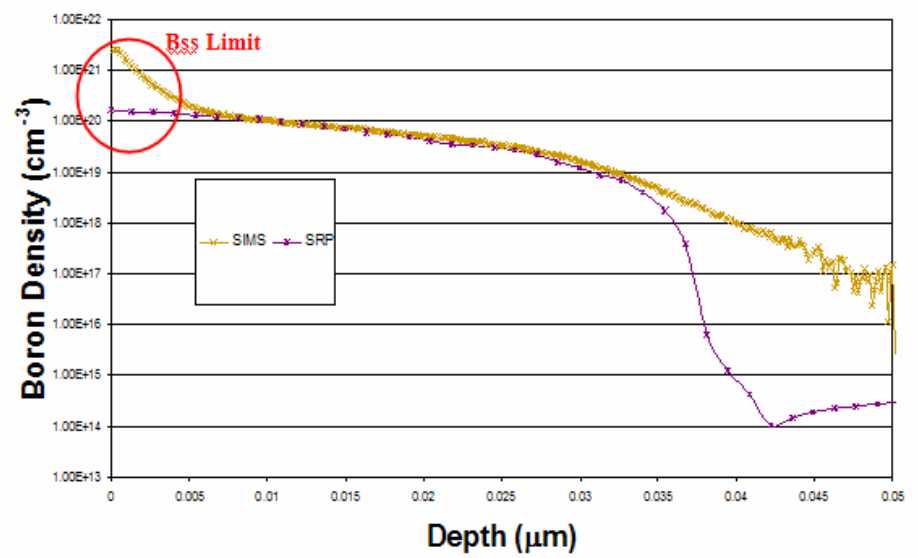


Fig. 2: Good agreement between SIMS and SRP profiles has been observed with significant diffusion (1).

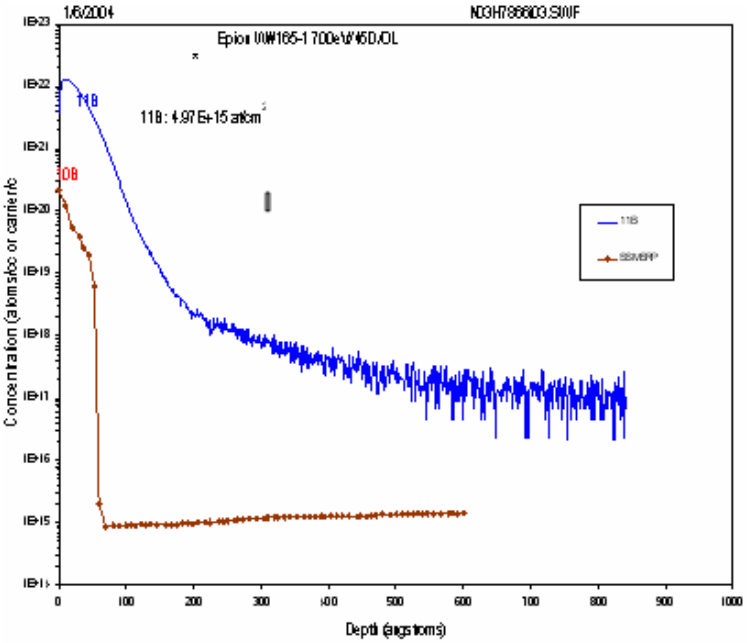


Fig. 3: Poor agreement between SIMS and SRP profile is observed with diffusion-less activation (3).

DOPANT ACTIVATION MONITORING

With diffusion-less activation the chemical dopant profile at the surface obtained from SIMS is mostly electrically inactive and can be as much as 2 orders of magnitude above the true surface electrically active dopant level of 1.3E20/cm^3 as shown above in Figs. 2 & 3. Therefore, without dopant diffusion, no accurate information can be obtained from the SIMS profile on the electrically active dopant species.

As USJ scales down to 14nm below 25nm node as illustrated in Fig. 4, Rs measurements by 4PP can lead to probe penetration through the shallow junction (2). This effect can be avoided by using non-penetrating 4PP such as elastic material (EM) probes. Rs results comparing penetrating to non-penetrating probes are shown in Fig. 5 for junctions between 10nm to 50nm (2). 300mm wafer Rs mapping using EM-4PP is shown in Fig. 6. Because a change in Rs measured by 4PP can be the result of either a change in junction depth (Xj) or change in dopant surface electrical activation level (Bss) as illustrated in Fig. 7 when plotted in Fig. 1. Therefore, a new technique was developed to directly measure the electrically active surface dopant level using a single EM probe by CV measurement called Nsurf. Nsurf is highly dependent upon activation level and will correlate with sheet resistance in those cases where activation modifications are made. Poor Nsurf correlation with R_S will be expected in cases where the surface activation is constant but the junction depth is changing. These two cases are illustrated in Fig. 8.

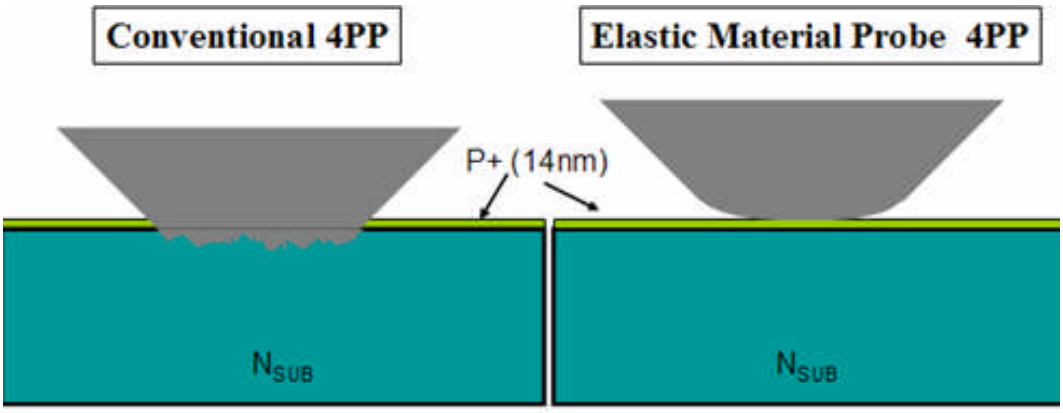


Fig. 4: Probe penetration through shallow junctions (2).

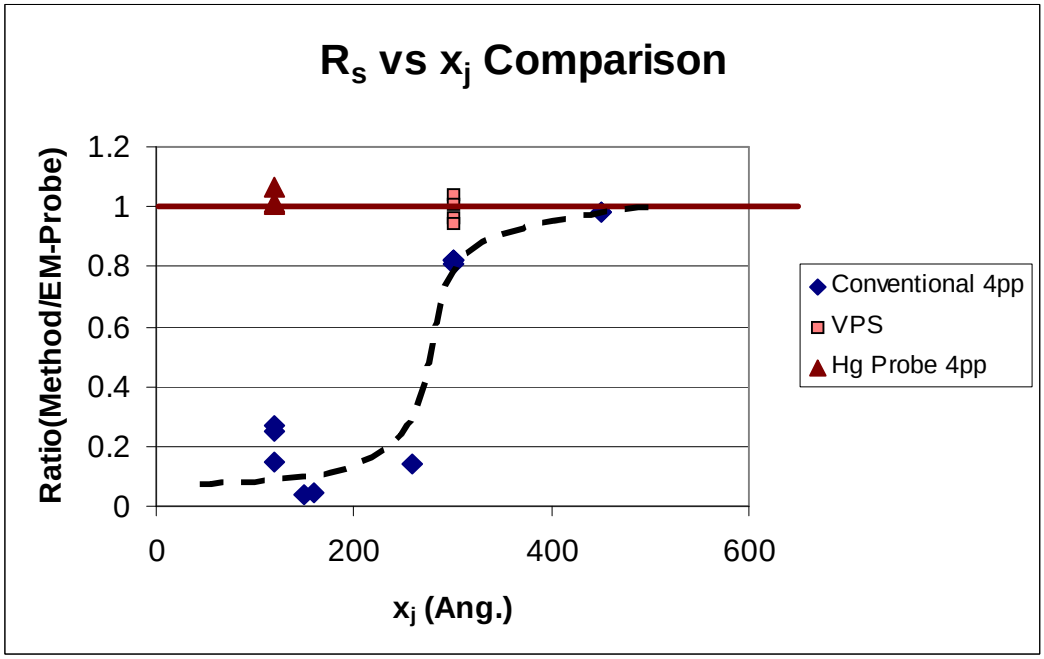


Fig. 5: Rs result comparison between penetrating and non-penetrating probes on shallow junctions from 50nm down to 14nm (2).

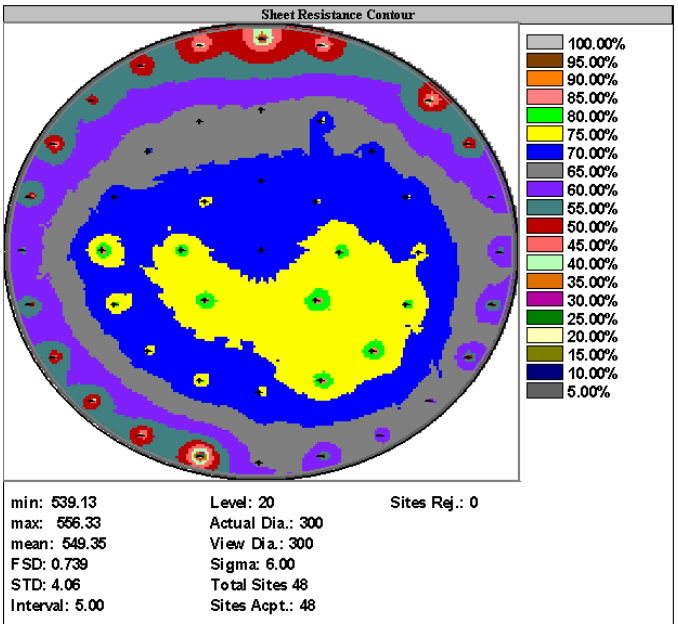


Fig. 6: 300mm wafer Rs mapping by EM-4PP.

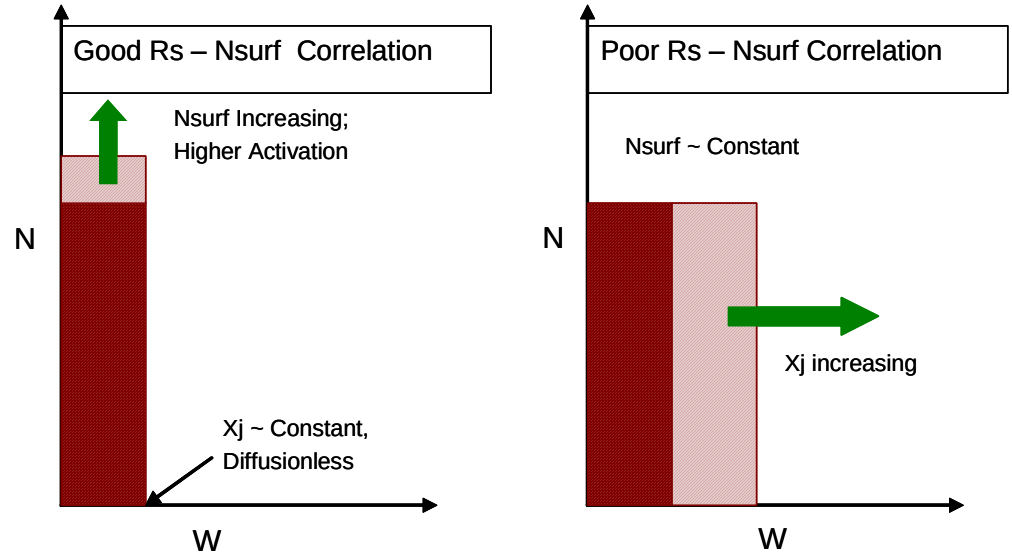


Fig. 7: Two profiles showing that either activation level or increased diffusion (deeper junction) can improve Rs measured by 4PP.

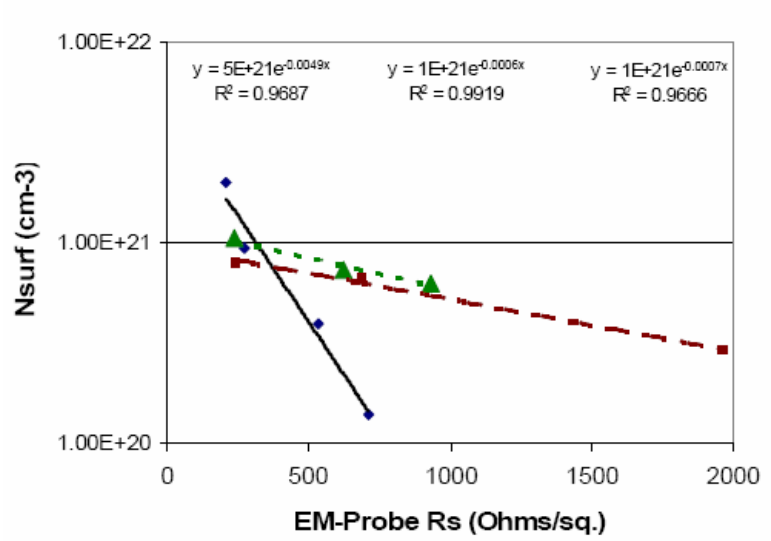


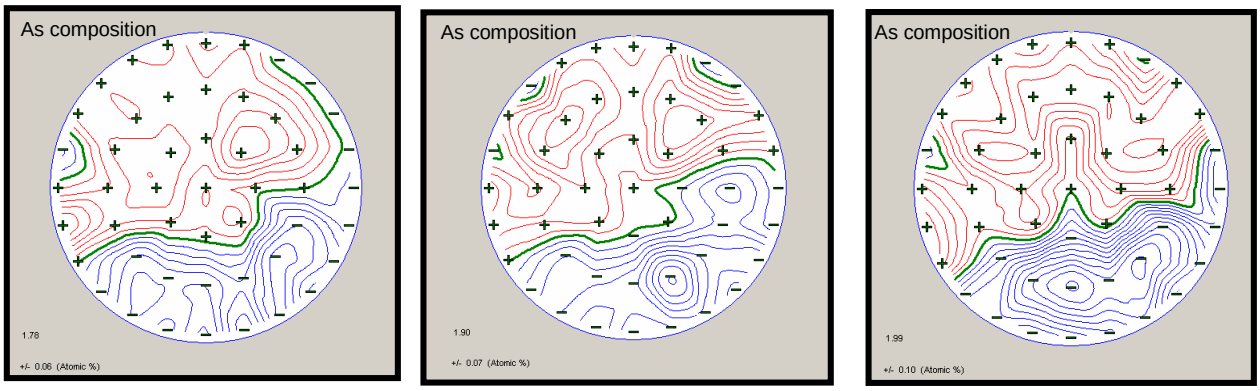
Fig. 8: Correlation plot of EM-Probe N_{SURF} versus EM-Probe 4pp R_S.

IMPLANT DOSE MONITORING

As mentioned above, use of Rs wafer mapping is no longer an accurate technique to monitor ULE implanter dose uniformity due to the significant difference at the surface between inactive and active electrical dopant species shown in Fig. 3. Rs measurement can still be used to monitor variations in dopant electrical activation such as Bss across the wafer caused by the diffusion-less activation annealing. However, industry is beginning to use x-ray techniques to monitor the implanter and ULE multiple co-implantation species as reported earlier (1,4,5). Both electrical dopant species (As, P, B) and non-electrical dopant elements (C, F, Ge, etc.) can be monitored and mapped using x-ray techniques. As junctions get shallower with each node the surface compositional mapping capability of XPS offers new process control schemes for production monitoring of implanters. Fig. 9 shows 49 pts XPS surface atomic composition maps of arsenic for 3 different As implanted wafers with increasing dose. Surface As composition tracked the expected dose for these 3 wafers. Note that the 1 sigma As composition uniformity across the wafer varies from 3.3% to 5% which is much larger than the 0.5% typical implant specification. Because of its spectroscopic detection flexibility, multiple elements can be detected with XPS with no change in detection hardware. Fig. 10 shows the XPS atomic composition mapping results of additional elements for wafer #C in Fig. 9 including As, Si, O, C, and F.

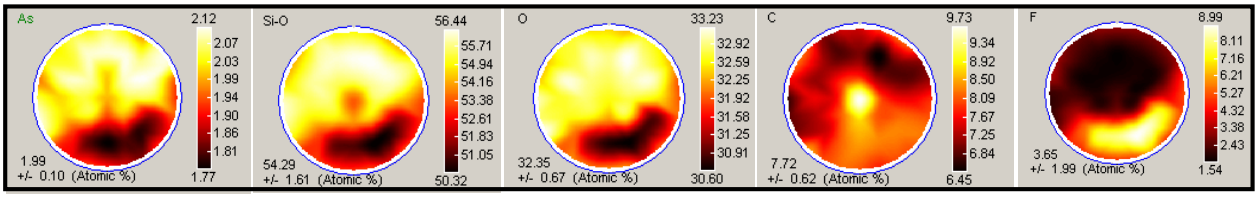
XPS has the unique ability among X-ray based metrologies to provide chemical state information. The multiple bonding states of Si2P peak have been used to generate 49 pts thickness maps of surface native oxide after implantation as shown in Fig. 11 for the three As implanted wafers A, B & C from Fig. 9. These results suggest that the native oxide thickness uniformity influences the implanted As composition uniformity. This needs further investigation. XPS fluorine composition map results of the same three wafers A, B & C are shown in Fig. 12. The high levels of F are believed to be from cross contamination in the implanter from prior BF_2 implants.

XPS results for a 9.7nm deep 1E15/cm^2 B-infusion doped wafer are shown in Fig. 13 with a boron composition uniformity of 2.4%. P implantation can also be monitored by XPS as shown in Fig. 14 where atomic composition uniformity of P is 2%.



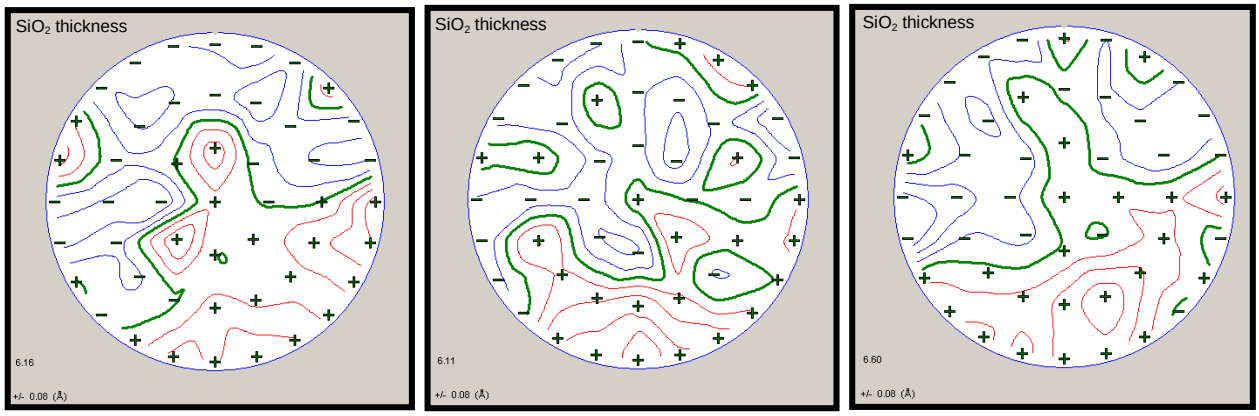
RVX 1000	Wfr A (%)	Wfr B (%)	Wfr C (%)
Ave	1.78	1.9	1.99
Uniformity, 1σ	0.06	0.07	0.1
Rsd, 1σ	3.37	3.68	5.03

Fig. 9: 49 pts XPS composition maps of surface Arsenic track implanted dose.



WfrC	As (at %)	Si (at%)	O (at%)	C (at%)	F (at%)
Ave	1.99	54.29	32.35	7.72	3.65
1s	0.1	1.61	0.67	0.62	1.99

Fig. 10: XPS atomic composition wafer uniformity mapping (49 pts) including C and F.



RVX 1000 Thk	Wfr A	Wfr B	Wfr C
Ave (A)	6.16	6.11	6.60
Uniformity, 1σ	0.08	0.08	0.08
Rsd, 1σ	1.30	1.31	1.21

Fig. 11: XPS wafer mapping of the surface native oxide thickness on these As implanted wafers.

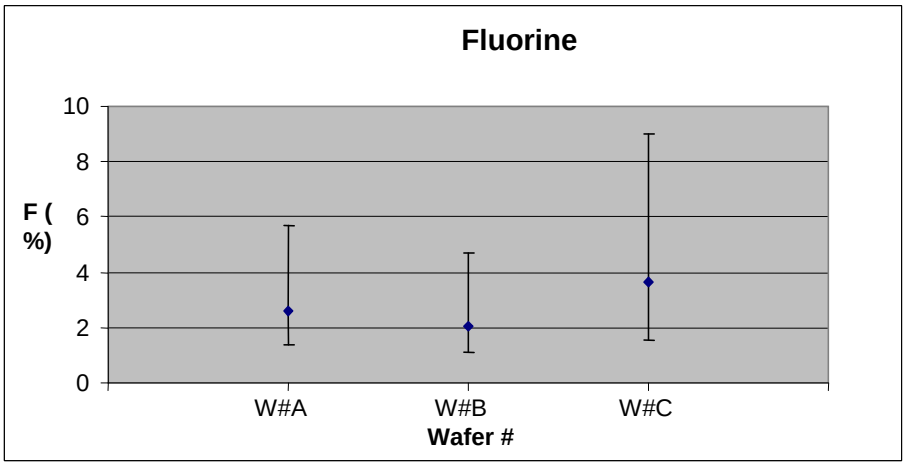


Fig. 12: XPS detected high levels of F cross contamination. Error bars reflect range of F composition

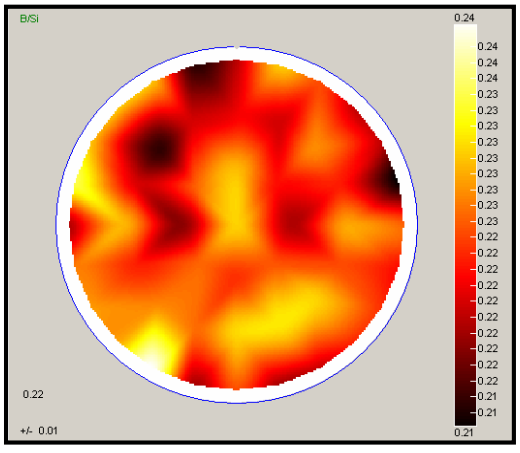


Fig. 13: XPS of 9.7nm deep B-infusion doping.

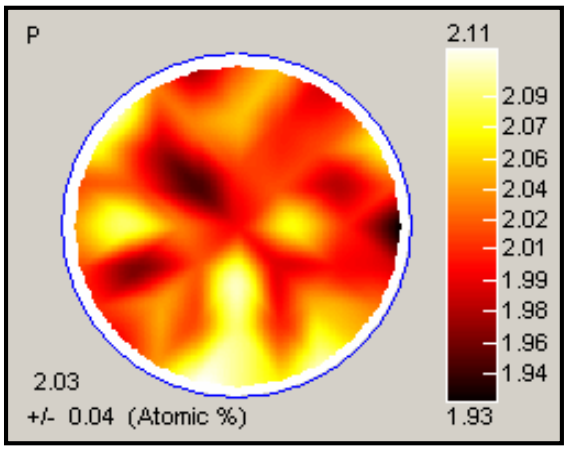


Fig. 14: XPS of P implantation.

SUMMARY

New metrology techniques and equipment were developed to monitor ultra low energy implantation. Non-penetrating elastic material probes in 4PP configuration was used to accurately measure Rs on junctions down to 10nm deep. A new Nsurf CV measurement technique was used to determine the electrically active surface dopant level. XPS technique was used to map surface atomic compositions of both the electrical dopant species and non-electrical elements. This technique can be applied to monitor implantation and co-implantation dose uniformity for As, P, B, Ge, C, F, etc. XPS was also used to determine the surface native oxide thickness and this seems to have an influence on the implant uniformity. Also, F cross contamination in the implanter was detected with XPS.

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