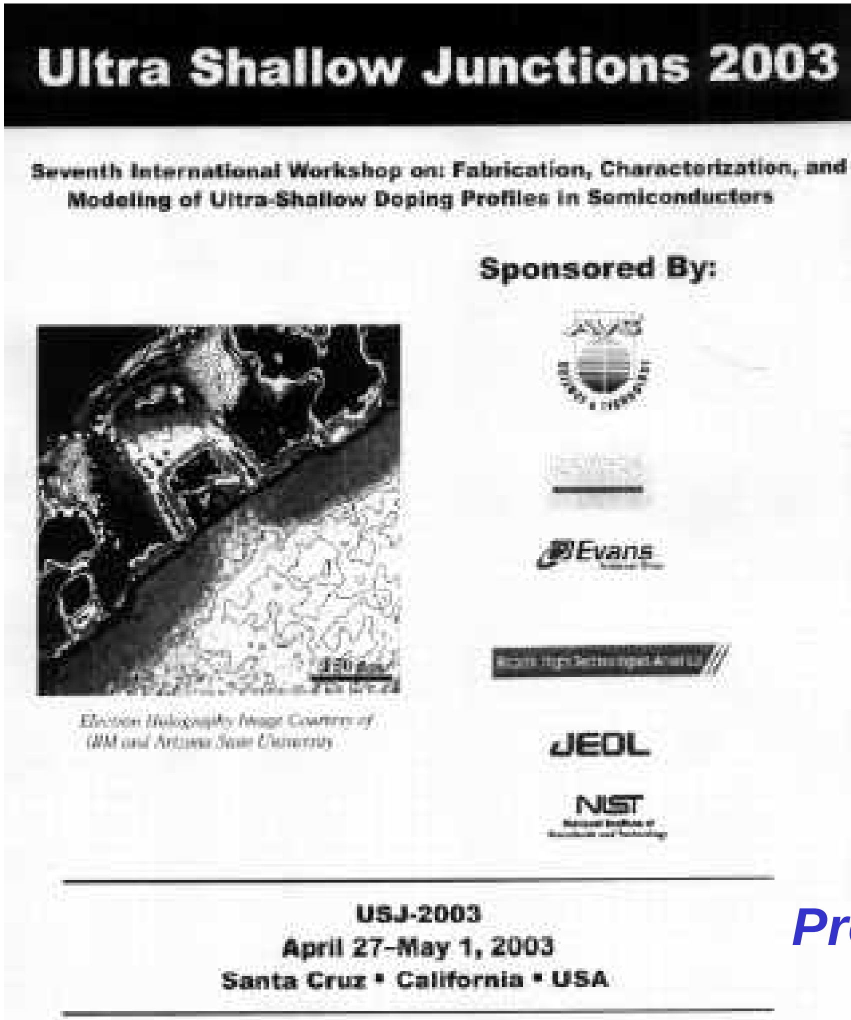
Ultra-shallow Junctions 2003:
Process Papers: Ap30-May1,'03


Ultra Shallow Junctions 2003

Seventh International Workshop on: Fabrication, Characterization, and Modeling of Ultra-Shallow Doping Profiles in Semiconductors

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Electron Holography Image Courtesy of IBM and Arizona State University

USJ-2003
April 27-May 1, 2003
Santa Cruz • California • USA

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Proceedings to appear in: JVSTB, Jan 04

USJ03: Santa Cruz, CA


Co-chairs for USJ05:
Kevin Jones
Mark Law


Electron Holography, Molly McCartney, ASU

Electron Holography for 2-D Dopant Profiling

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Electron holography in the transmission electron microscope is a technique that provides access to the 2-D electrostatic potential in semiconductor devices. The method is quantitative with a precision on the order of 0.1V at a spatial resolution of better than 10nm. Potential measurements have been used to evaluate models for 2-D simulator software and to analyze dopant activation in novel doping schemes for ultra-shallow junctions. Measurements

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Electron Holography,
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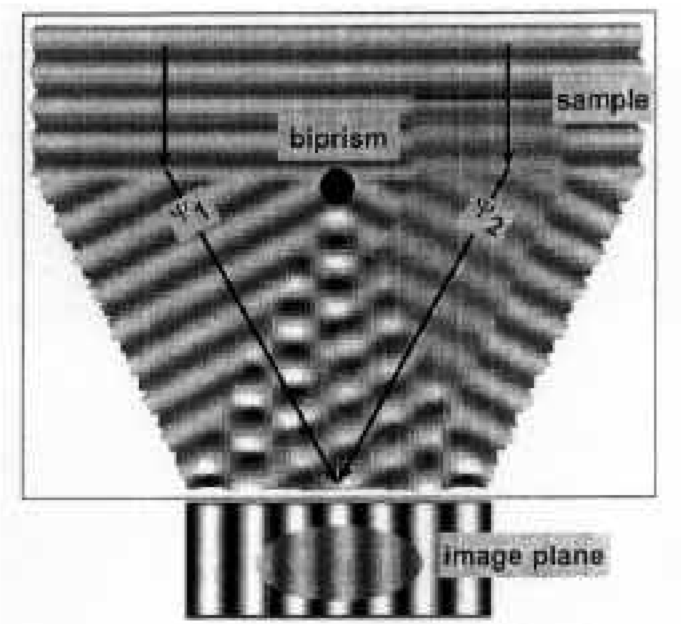

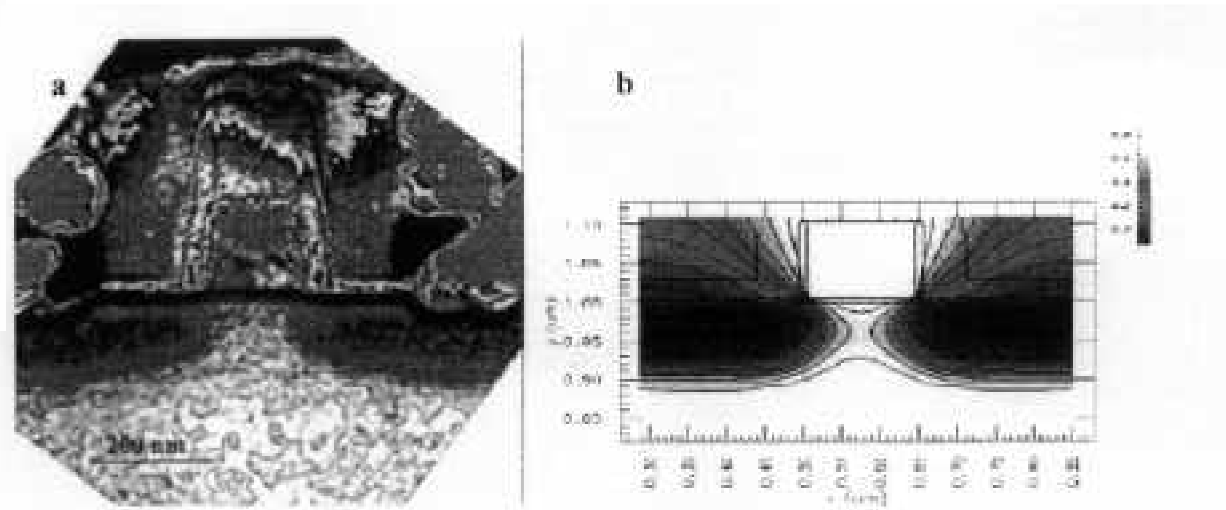

Fig. 4. a) Electron holographic phase image of 0.13μm pFET calibrated in volts and false colored. b) 2D simulated maps of Si device (4).

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Electron Holography

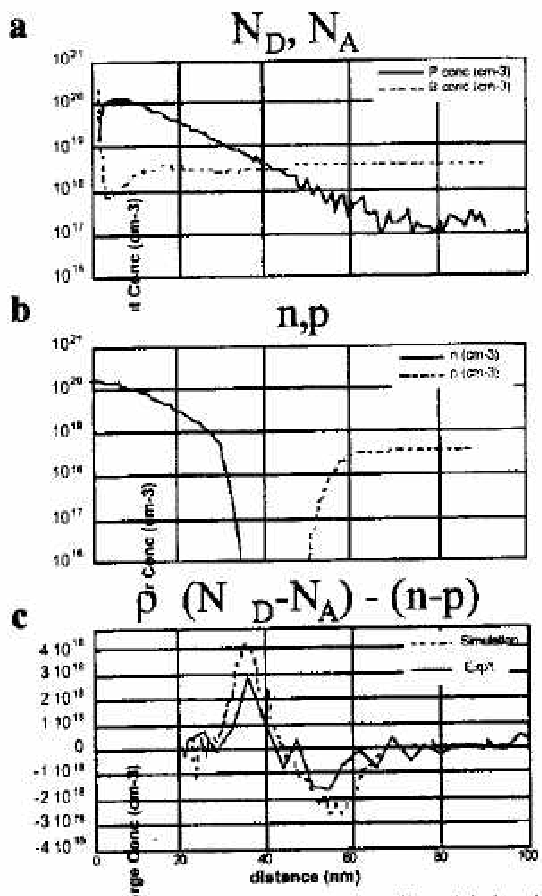

Fig. 5 a) SIMS data for USJ produced by annealing high phosphorus content spin-on glass at 850°C for 10s. b) Simulation of carrier concentrations based on SIMS data c) Comparison of net charge from simulation and 2nd derivative of holographic voltage profile

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Dopant Pileup
J. Fruehauf, Infineon/IMEC

CHARACTERIZATION OF THE B AND As PILE-UP AT THE Si-SiO_2 INTERFACE

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ABSTRACT

During spike annealing of ultra-shallow junctions, large fractions of the dopants segregate to the interface between silicon and the screening oxide layer, creating a pile-up of partially active dopants. In this paper, we combine the results of SIMS (Secondary Ion Mass Spectrometry) and high-resolution ERD (Elastic Recoil Detection) measurements with sheet resistance measurements to investigate the behaviour of B and As dopants close to the Si/SiO_2 interface. Our results show that up to 60% of the dopants that remain in the junction after anneal are actually segregated to the interface, depending on the anneal and the type of oxide used. Only a small part of these dopants is active, however active concentrations above 1-2e21cm^{-3} are observed, well above solid solubility for all dopants. Results indicate that segregation to the pile-up is strongly enhanced by oxidation during anneal. Oxide induced stress and interfacial trapping are believed to allow active concentrations above bulk solid solubility.

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Dopant Pileup
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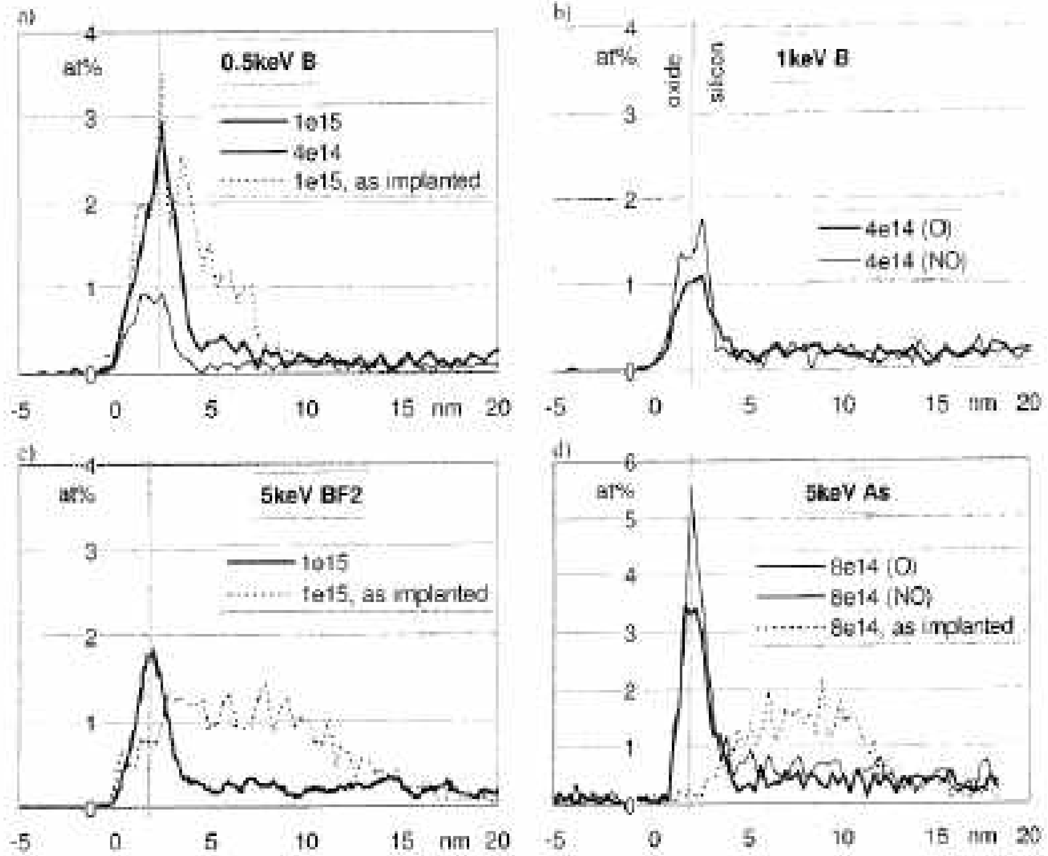

Figure 1 – ERD profiles of B and As dopants for implants at different energies and doses through oxide (O) and oxynitride (NO). All samples were spike annealed at 1070C, 1s. The gray vertical lines indicate the interface between oxide and silicon.

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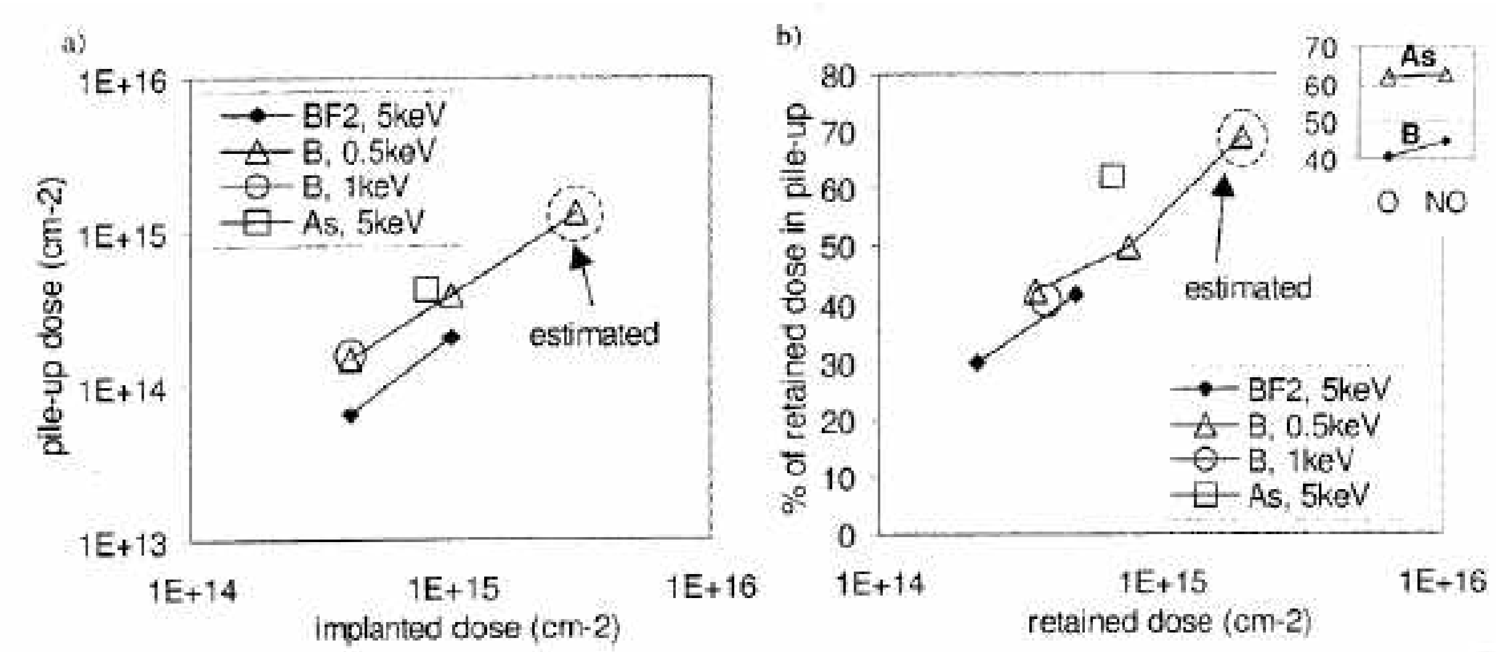

Figure 2 – a) Pile-up dose as a function of implanted dose (implanted through oxygen). For B, 0.5keV and 1keV give almost identical results. – b) Pile-up dose as percentile fraction of the retained dose after anneal. The insert compares implants through O and NO (1keV, 4e14 B and 5keV, 8e14 As implants). All samples were spike annealed at 1070C, 1s.

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F Effect on B: RTP & fRTP
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ROLE OF FLUORINE IN RAPID THERMAL PROCESSING METHODOLOGIES

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ABSTRACT

The ability to form ultra-shallow junctions using conventional implant methodologies coupled with Rapid Thermal Processing (RTP) is facing mounting challenges. In this paper, we evaluate the applicability of fluorine within p-type junctions activated via Spike Rapid Thermal Annealing (RTA) and Flash-Assist RTP™ (fRTP). Eight inch wafers were pre-amorphized with 2.5 keV Si^+ at a dose of $1x10^{15}$ atoms/cm^2. Ion implants of 1.1 keV BF_2 followed at a dose of $1x10^{15}$ atoms/cm^2, both with and without a 3 keV F^+ precursor implant at a dose of $2x10^{15}$ atoms/cm^2. Samples processed via Spike RTA were exposed to a peak temperature of 1110°C, while fRTP samples reached an intermediate temperature of 800°C and a flash temperature of 1300°C. SIMS results confirmed that fRTP generates shallower junctions than Spike RTA. Results comparing samples with and without additional fluorine show that while fluorine reduces the junction depth after Spike RTA by 22%, the effect is much less (7%) after fRTP.

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F Effect on B: RTP & fRTP
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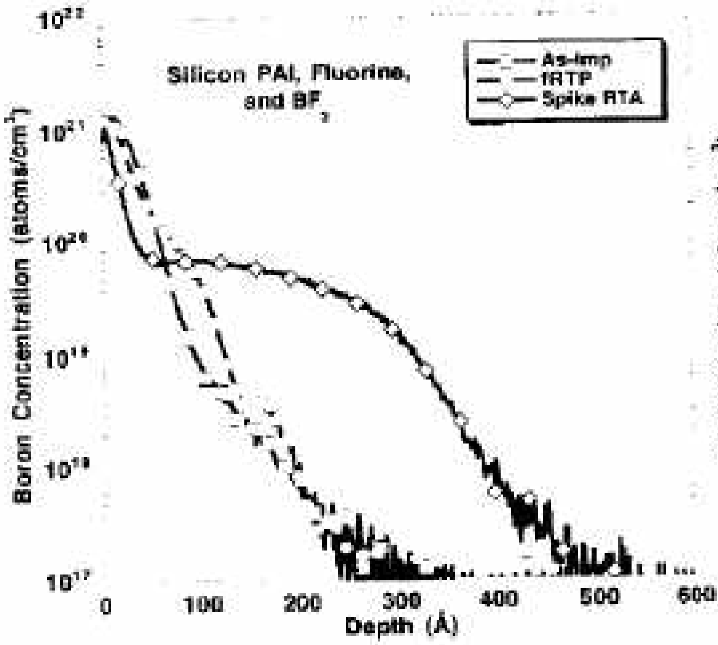

Figure 3: Boron Concentration Profiles for As-Implanted, Flash Annealed, and Spike Annealed Conditions. Samples received a 2.5 keV 1e15 Silicon PAI followed by 3 keV 2e15 Fluorine and 1.1 keV 1e15 BF_2 implants.

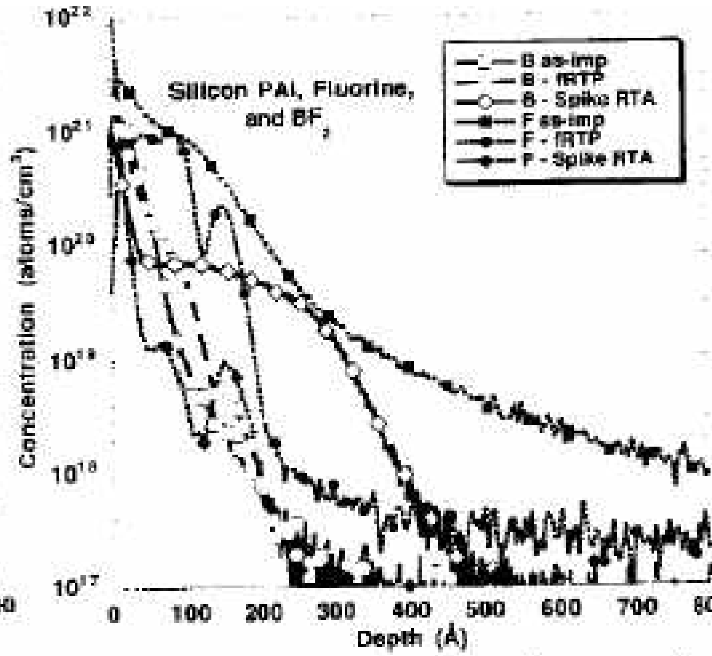

Figure 4: Boron and Fluorine Concentration Profiles for As-Implanted, Flash Annealed, and Spike Annealed Conditions. Samples received a 2.5 keV 1e15 Silicon PAI followed by 3 keV 2e15 Fluorine and 1.1 keV 1e15 BF_2 implants.

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F Effect on B: RTP & fRTP
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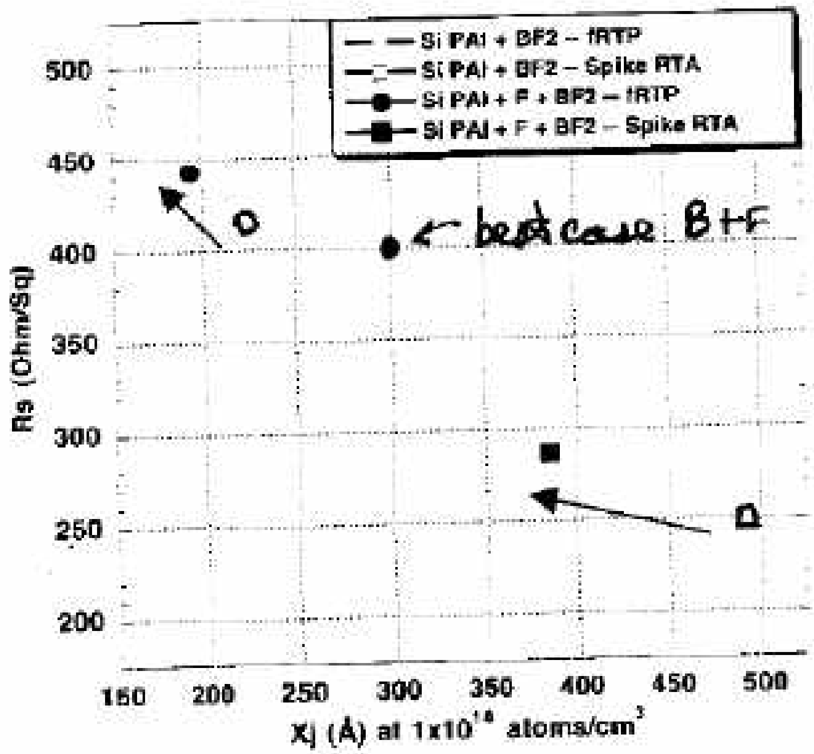

Figure 5: Sheet Resistance (ohm/sq) versus Junction Depth (Å) at 1x1018 atoms/cm3 data comparing the Flash and Spike Annealing Processes for various implant conditions incorporating Fluorine and Boron dopants.

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B Diffusion with Various PAI
H-J Li, Sematech/UT

B DIFFUSION IN SI WITH PRE-AMORPHIZATION OF DIFFERENT SPECIES

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The formation of an amorphous layer is needed to prevent channeling effect of B in the subsequent implant and hence, shallower as-implanted and annealed profiles could be expected. B diffusion in the pre-amorphization (PAI) Si has been studied extensively by many research groups and the diffusion has been explained by the interaction of B and defects generated by the PAI and B implant processes. In our previous study, we found that B diffusion can be affected by the incorporated species and therefore, B diffusion in the PAI Si should be expected to be different with different PAI species. In this paper, we reported different B diffusion behavior in bulk Si with respective to different PAI species. The species include GeF_2, Ge, F, BF_2, and In.

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B Diffusion with Various PAI
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TABLE 1

Experimental design and X_j/R_s measurements. The X_j was evaluated at the depth of 10^{18} cm^{3} and the R_s values in this table were the average values from 49 points measurement.

Split #	Implant # 1	Implant #2	Implant #3	1015 C spike	1000 C /10s	Xj	Rs
1	N/A	B11: 2-->0.5keV / 1E15	N/A	XXX		410	425
2	N/A	B11: 2-->0.5keV / 1E15	N/A		XXX	628	341
3	Ge: 10 keV / 1E15	B11: 2-->0.5keV / 1E15	N/A		XXX	606	316
4	In: 10 keV / 5E15	B11: 2-->0.5keV / 1E15	N/A		XXX	477	662
5	F: 1 keV / 2E15	B11: 2-->0.5keV / 1E15	N/A		XXX	577	348
6	N/A	BF2: 2.23keV / 1E15	N/A		XXX	494	521
7	N/A	BF2: 2.23keV / 1E15	N/A	XXX		321	623
8	Ge: 5.0 keV / 1E15	B11: 2-->0.5keV / 1E15	N/A		XXX	625	370
9	Ge: 5.0 keV / 1E15	BF2: 2.23keV / 1E15	N/A	XXX		284	874
10	Ge: 5.0 keV / 1E15	BF2: 2.23keV / 1E15	N/A		XXX	464	645
11	N/A	B11: 2-->0.5keV / 1E15	F(6keV/1E15)	XXX		461	442
12	N/A	B11: 2-->0.5keV / 1E15	F(6keV/1E15)		XXX	612	388
13	N/A	BF2: 2.23keV / 1E15	F(6keV/1E15)	XXX		380	608
14	N/A	BF2: 2.23keV / 1E15	F(6keV/1E15)		XXX	524	574
15	GeF2: 5.0 keV / 1E15	B11: 2-->0.5keV / 1E15	N/A	XXX		265	1930
16	GeF2: 5.0 keV / 1E15	B11: 2-->0.5keV / 1E15	N/A		XXX	406	1380
17	GeF2: 5.0 keV / 1E15	BF2: 2.23keV / 1E15	N/A		XXX	339	2400
18	GeF2: 5.0 keV / 1E15	BF2: 2.23keV / 1E15	N/A	XXX		230	3920
19	GeF2: 5.0 keV / 1E15	B11: 2-->0.5keV / 1E15	F(6keV/1E15)	XXX		331	1790
20	GeF2: 5.0 keV / 1E15	B11: 2-->0.5keV / 1E15	F(6keV/1E15)		XXX	453	1650
21	GeF2: 5.0 keV / 1E15	BF2: 2.23keV / 1E15	F(6keV/1E15)		XXX	406	3140
22	GeF2: 5.0 keV / 1E15	BF2: 2.23keV / 1E15	F(6keV/1E15)	XXX		329	3009

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B Diffusion with Various PAI
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1. 0.5 keV B, 1015 C spike
2. 0.5 keV B, 1000 C/10 s

15. 5 keV GeF2,

    0.5 keV B, 1015 C spike

16. 5 keV GeF2,

    0.5 keV B, 1000 C/10 s

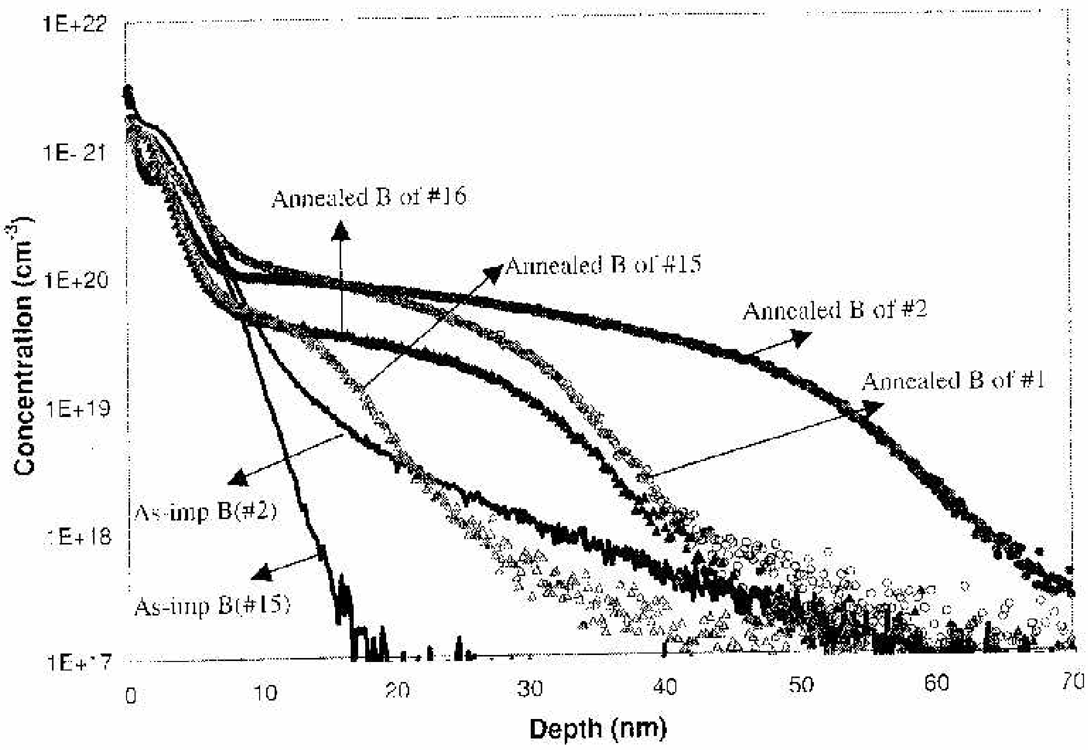

Fig. 3 Annealed B profiles of split# 1, 2, 15, and 16

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B Diffusion with Various PAI
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12. 0.5 keV B, 6 keV F

    1000 C/10 s

17. 5 keV GeF2, 2.2 keV BF2

    1000 C/10 s

21. 5 keV GeF2, 2.2 keV BF2,

    6 keV F

    1000 C/10 s

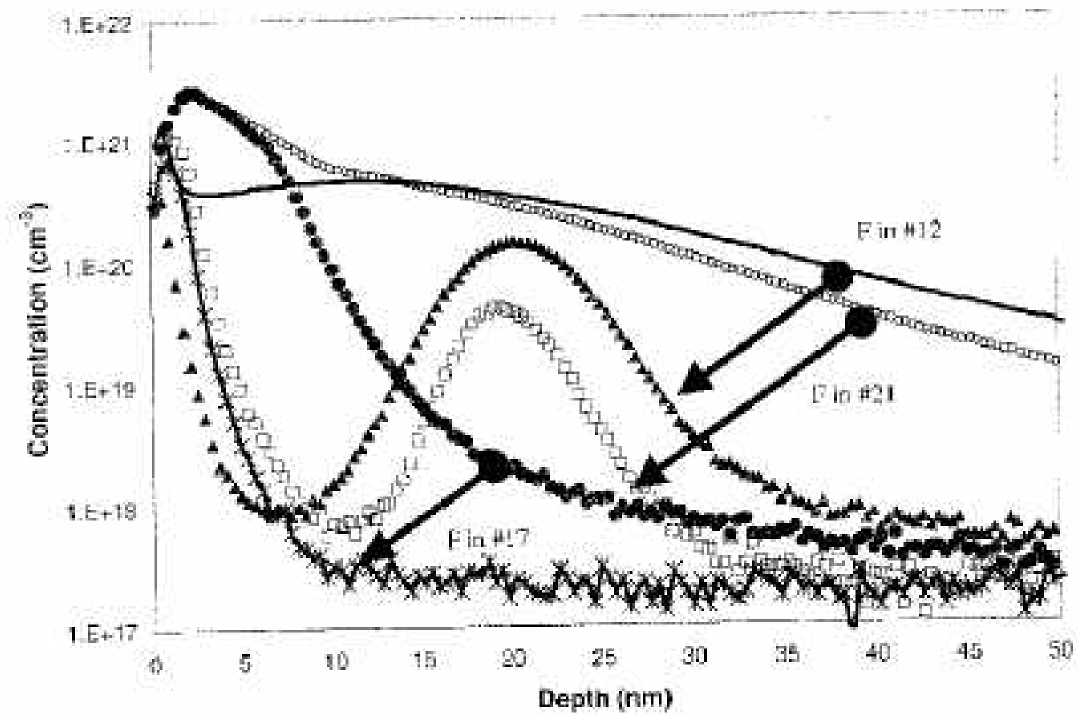

Fig. 4 F profiles in split# 12, 17 and 21. The arrow starts from as-implanted profile to annealed profile.

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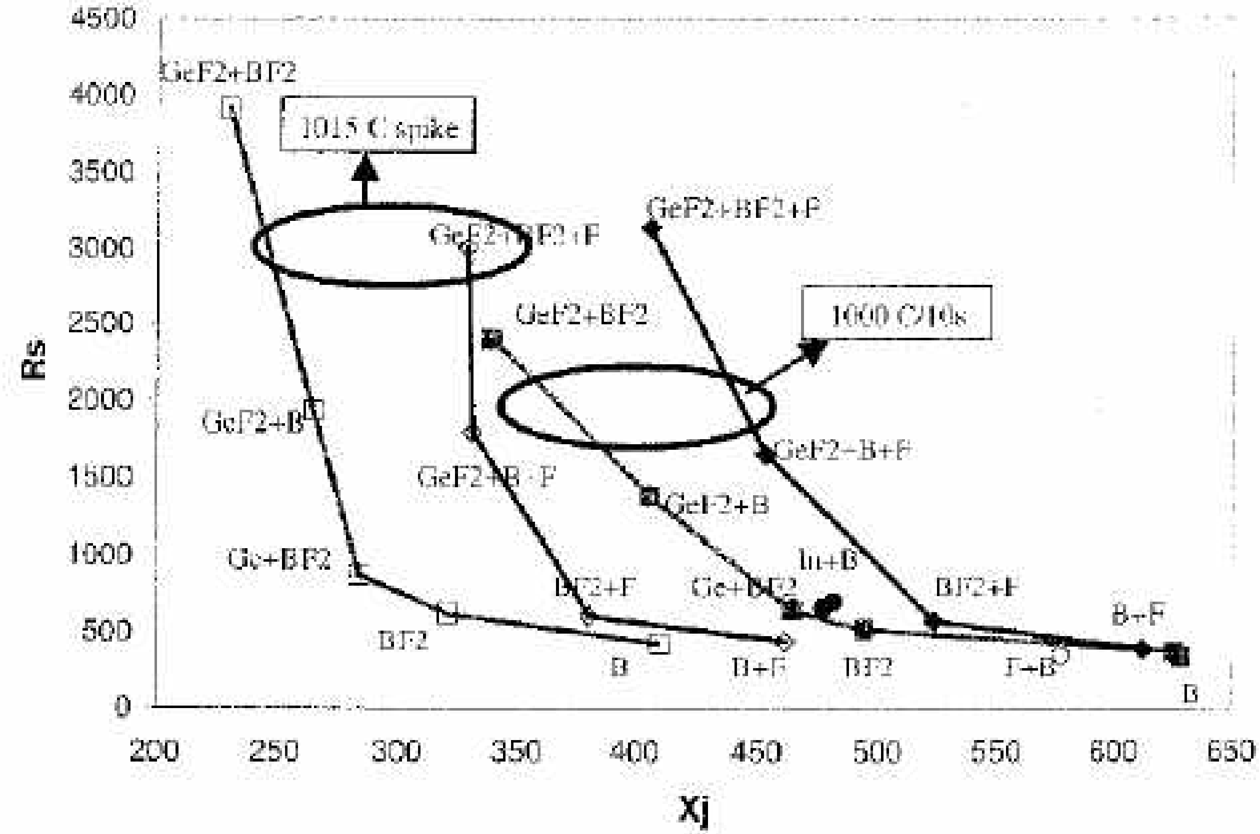

Fig. 6 Summary of Xj vs. Rs in this study

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Nitride/TEOS Spacer Effect on B
P. Kohli, UT

EFFECT OF NITRIDE SIDEWALL SPACER PROCESS ON BORON DOSE LOSS IN ULTRA SHALLOW JUNCTION FORMATION

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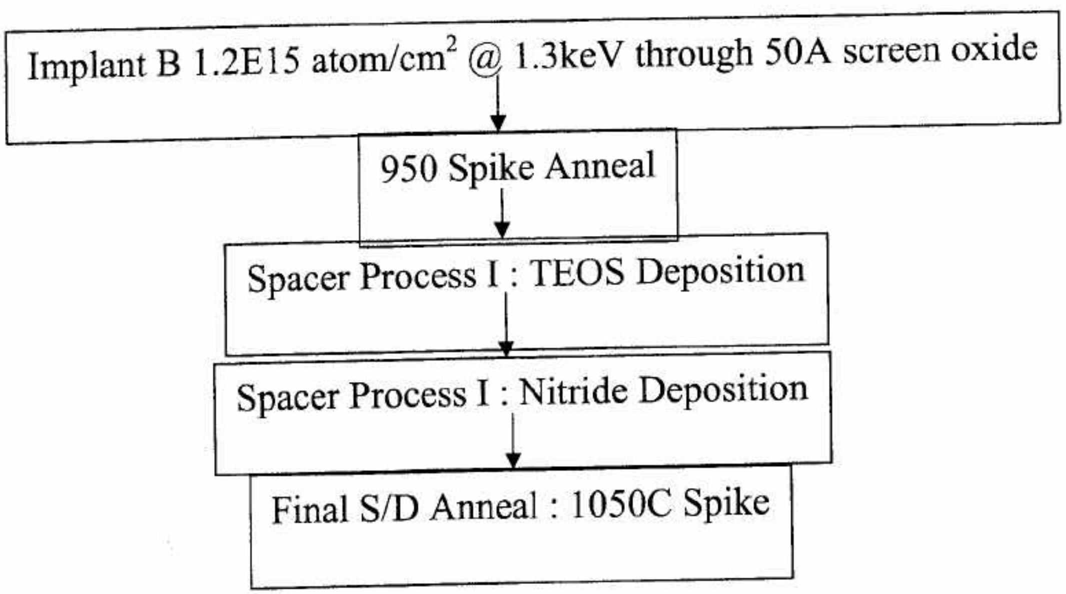
ABSTRACT

A nitride spacer with an underlying deposited TEOS oxide, that behaves as a convenient etch stop layer, is a popular choice for sidewall spacer in modern CMOS process flow. In this work we have investigated the effect of the nitride spacer process on the B profile in Si and the related dose loss of B from the Si into the oxide. We find that the nitride influences the concentration of H in the oxide during the final source/drain anneal. The presence of H enhances the diffusivity of B in the oxide and thereby results in a significant dose loss from the Si into the oxide. In this work we have shown that by altering the nitride stoichiometry we can affect the oxide so as to reduce the dose loss into the oxide.

Nitride/TEOS Spacer Effect on B
P. Kohli, UT



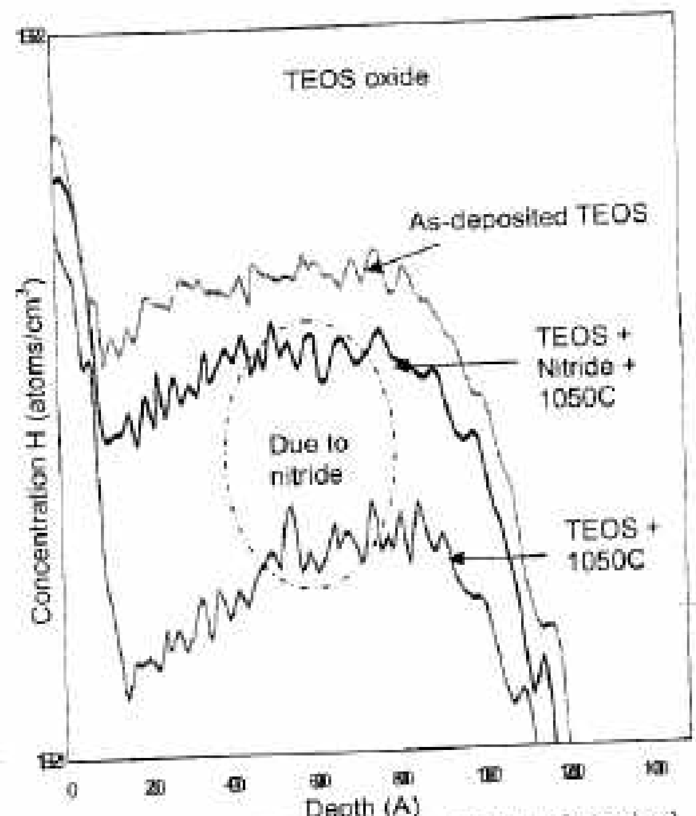


Figure 9 : NRA H data showing that as-deposited TEOS has high levels of H. Nitride acts as a barrier for H out-diffusion.

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Nitride/TEOS Spacer Effect on B
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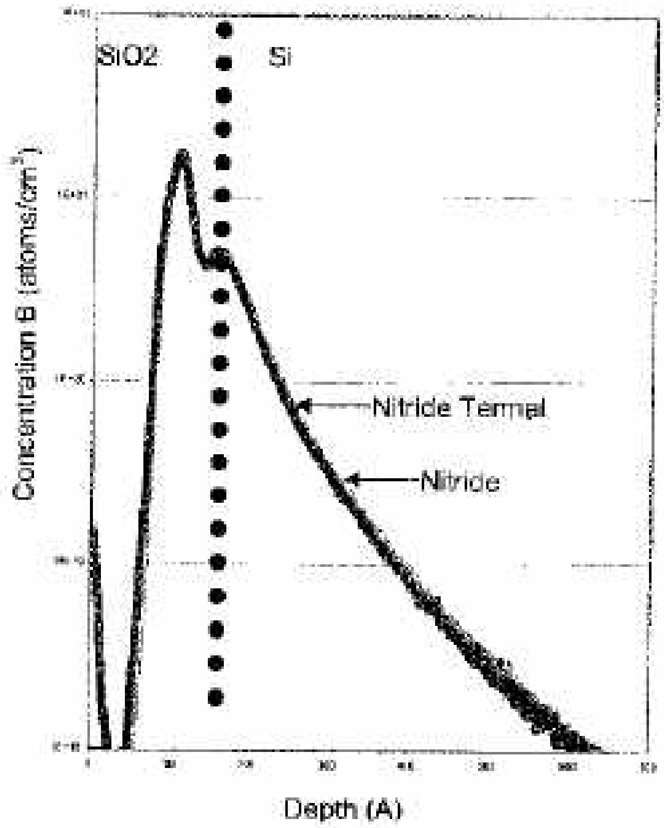

Figure 2 : B diffusion profiles right before the 1050C anneal are identical for both the samples with and without the nitride. B was implanted in these samples.

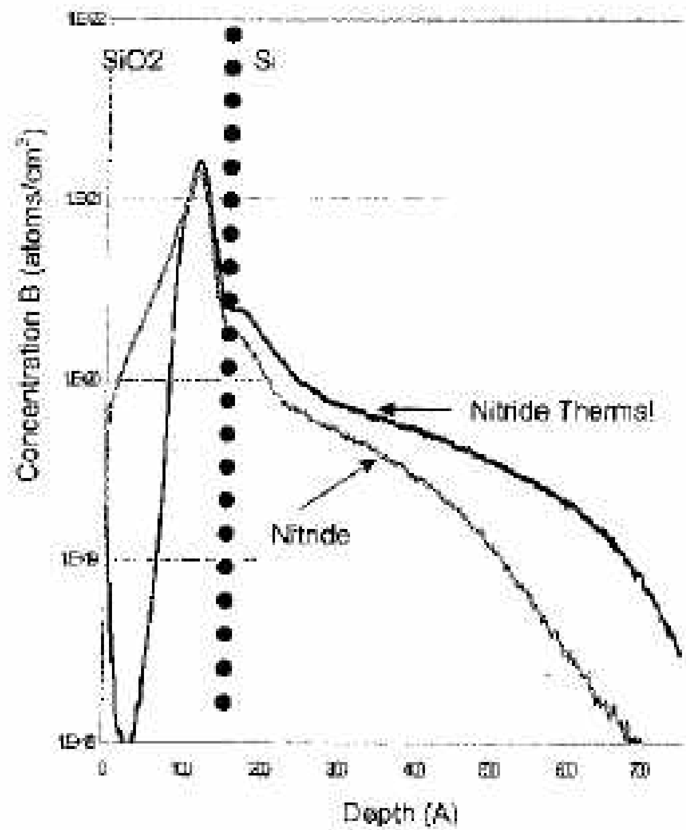

Figure 3 : B diffusion profiles after 1050C anneal. Ir the presence of nitride less B is retained in Si anc more B is lost into the oxide. B was implanted ir these samples.

2-D Si Diffusion by SCM
F. Giannazzo, U Catania

INVESTIGATION OF TWO DIMENSIONAL DIFFUSION OF THE SELF-INTERSTITIALS IN CRYSTALLINE SI AT 800 °C AND AT ROOM TEMPERATURE

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The two dimensional diffusion of self- interstitials in Si, both at room temperature and at 800 °C, has been studied by quantitative SCM measurements. The 2D *I* emission from a *I* source laterally confined down to sub-micron dimensions, obtained by low–energy implantation through an oxide mask, has been observed. At room temperature, *I* diffusion was monitored by measuring the electrical deactivation of B corresponding to the diffusing interstitial tail, while at 800 °C it was monitored by measuring the TED of B spikes due to interstitial supersaturation produced during the annealing. In both cases, a dependence of the *I* depth- penetration on the original source size has been shown.

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2-D Si Diffusion by SCM
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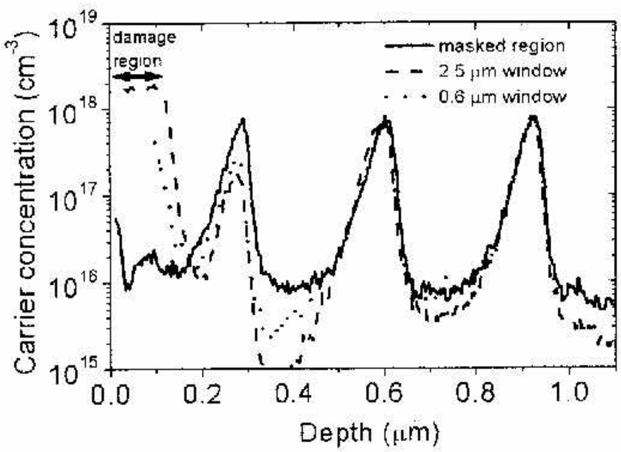

Fig. 2 Comparison between the 1D carrier concentration vs. depth profiles in the oxide masked region and at the center of the larger window (2.5 μm) or the narrower one (0.6 μm) for the sample as-implanted with 20 keV Si, 5×10^{13} atoms/cm^2.

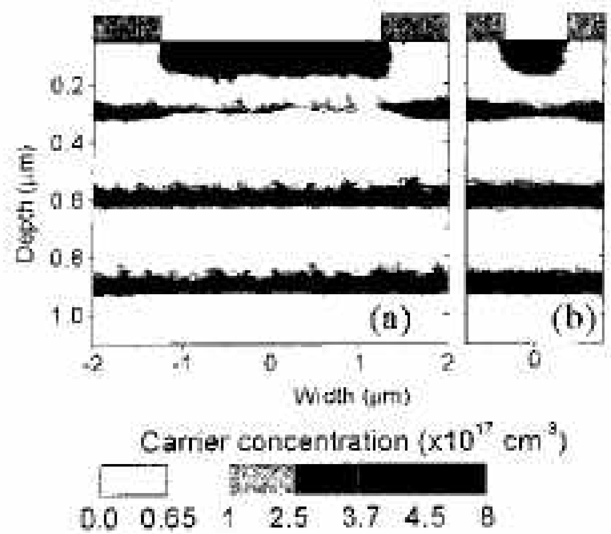

Fig.1 Comparison between the 2D maps of B concentration for two different window openings (2.5 μm (a) and 0.6 μm (b)) in the sample as-implanted with 20 keV Si, 5×10^{13} atoms/cm^2. The 2D maps of B concentration are reported as a grey scale with six different gradations defined by six concentration levels.

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2-D Si Diffusion by SCM
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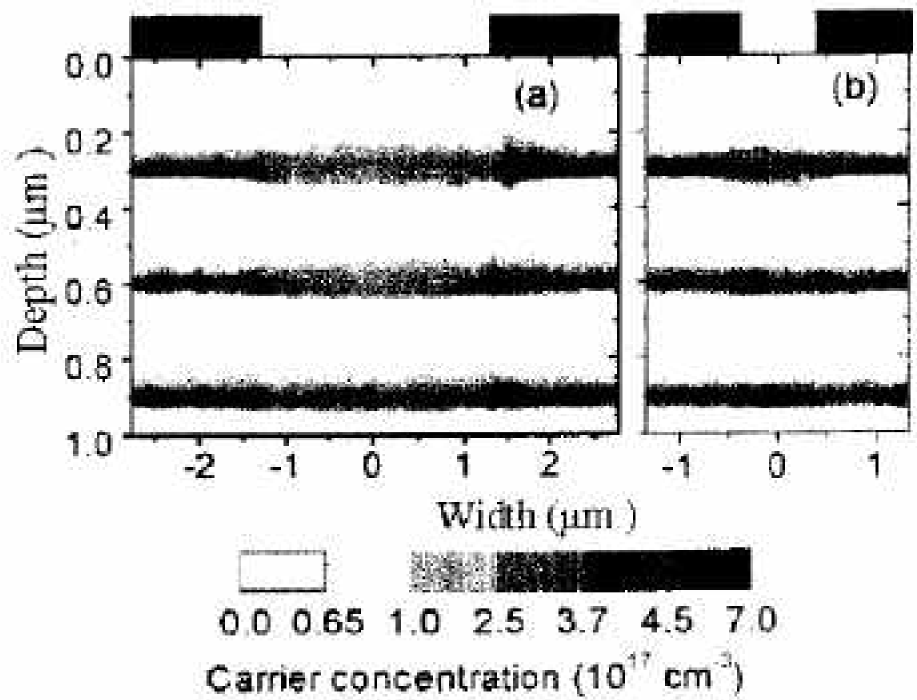

Fig. 3 Comparison between the 2D maps of B concentration in two different window opening regions (2.7 μm (a) and 0.7 μm (b)) for the sample implanted with 20 keV Si, 5×10^{13} atoms/cm^2, and annealed at 800 °C, 5 minutes. The maps are reported as grey scales with six different gradations defined by six concentration levels.

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USJ03(April ‘03, SantaCruz)>>>
>>>USJ05 (≈March ‘05, Florida)