Comparison of B, BF_2 & $B_{18}H_{22}$ for Extension and BF_2, $B_{18}H_{22}$ & In HALO Implantation for 32nm Node Using Various Diffusion-less Annealing Techniques

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Abstract. We compared various p-type dopant species for source drain extension (SDE) and pocket/HALO implantation when using diffusion-less annealing techniques for ultra-shallow junctions (USJ) at the 32nm node. For SDE, 200eVB, 900eVBF_2 and 3.8keV$B_{18}H_{22}$ with and without 5keVGe-PAI were studied and for HALO, 20keVBF_2, 45keVIn and 80keV$B_{18}H_{22}$. Diffusion-less Xe-lamp Flash anneal (FLA), 900^{o}C spike anneal, 700^{o}C SPE anneal and their combinations were examined for junction quality (dopant activation, junction leakage and implant damage annealing recovery) using RsL, photoluminescence (PLi) and thermal-wave (TW) rapid process optimization metrology techniques. Ge-PAI improved dopant activation (Rs) for the Flash and SPE anneals but not with spike anneal and BF_2 had the highest Rs values due to retained dose limits. Also Ge+BF_2 resulted in junction leakage degradation but the 900^{o}C spike anneal resulted in stable defects and complete implant damage recovery. For HALO, the dopant activation is dose limited for boron dopant species while for indium dopant it is solid solubility limited (anneal temperature dependent) so indium had the highest Rs values but no degradation in junction leakage were detected.

Keywords: Ultra-shallow junction, Source drain extension, HALO, sheet resistance, junction leakage current, thermal-wave, photoluminescence, Flash annealing, diffusion-less annealing, spike anneal.
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INTRODUCTION

For the 32nm node sub-10nm ultra-shallow junction (USJ) will be required. Usually Ge-PAI is used to achieve such shallow junctions with monomer B or BF_2 dopant species to eliminate boron channeling and enhance dopant activation with msec annealing (MSA) [1]. However, incomplete implant damage annealing can lead to unstable defects that can cause dopant deactivation and junction leakage degradation especially when using MSA [2] and by adding a low temperature anneal step results in stable defects [3-5]. Another concern is reducing device variation so detecting implantation and annealing micro-uniformity variation is also critical for rapid process optimization at the 32nm node [5-7].

EXPERIMENTATION

To continue the initial studies by Mineji [8] on various p-type dopants for SDE and HALO with diffusion-less annealing and Borland [5] on defect reduction and micro-uniformity improvement with MSA reported at IWJT 2007, in this study we used 300mm n-type wafers for all the p-type dopant implantations. For SDE implantation we compared: 1) B=200eV/1E15/cm^2, 2) BF_2=900eV/1E15/cm^2, 3) $B_{18}H_{22}$=3.8keV/5.56E13/cm^2, 4) Ge-PAI+B and 5) Ge-PAI+BF_2. A 5keV/5E14/cm^2 implant was used for Ge-PAI. For HALO implantation we used a 30 degree tilt and compared: 1) BF_2=20keV/3E13/cm^2, 2) Indium=45keV/3E13/cm^2 and 3) $B_{18}H_{22}$=80keV/1.67E12/cm^2.

For diffusion-less anneals we used the Dai-Nippon Screen (DNS) Xe-lamp Flash annealer and the Axcelis Summit RTA annealer comparing Flash, 700^{o}C SPE, 900^{o}C spike RTA, Flash+spike, spike+Flash, Flash+SPE and SPE+Flash annealing sequences. The wafers were then measured by RsL at Frontier Semiconductor for sheet resistance and junction leakage current, by PLi (photoluminescence) at Nanometrics and by TW (thermal-wave) at KLA-Tencor for implant annealing damage recovery and defect stability.

RESULTS

Source Drain Extension

The sheet resistance (Rs) results are shown in Fig.1 for the various diffusion-less annealing sequences. With Flash only Ge-PAI improved dopant activation and reduced Rs by about 50% for both B and BF_2. The lowest Rs was seen for Ge+B followed by B then Ge+BF_2 next $B_{18}H_{22}$ and finally BF_2 had the highest Rs value. The high Rs value seen with BF_2 compared to B for the 1E15/cm^2 dose, probably due to retained dose limit and surface sputtering effects reported by Borland for junctions <10nm deep and shown in Fig.2 [7].

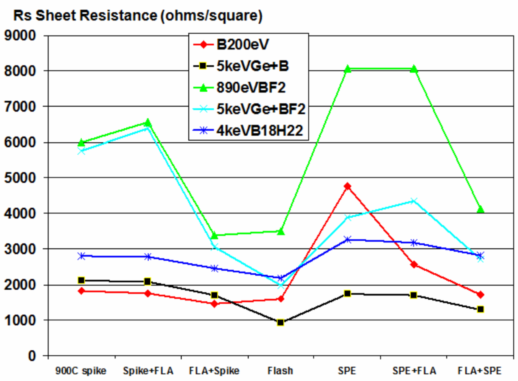

Figure 1: Rs sheet resistance results.

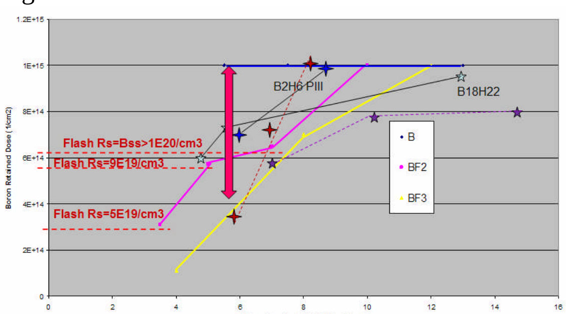

Figure 2: Boron retained dose limit issue for <10nm junctions with B, BF_2, BF_3, B_2H_6 & $B_{18}H_{22}$ [7].

Junction leakage results are shown in Fig.3 and with Flash anneal only the Ge+BF2 wafers showed junction leakage degradation of about 500x (>5E-5A/cm^2) compared to <1E-7A/cm^2 for the other wafers. These junction leakage results are better than those reported by Borland [5, 9, 10] using deeper Ge-PAI (10keV) implants with end of range (EOR) damage at 18nm depth. Mineji [11], Toda [4] and Camillo-Castillo [3] reported elimination of Ge-PAI EOR defects for energies <8keV but this was not the case with Ge+BF_2. The 900^{o}C spike anneal combination recovered the leakage back to the very low level of <1E-7A/cm^2 for the Ge+BF_2 wafers suggesting complete implant damage anneal recovery. This is also verified by the TW results in Fig.4 and PLi results in Fig.5. Note that after Flash anneal the TW value for Ge+B is 167 and for Ge+BF_2 is 160 but with a Flash+spike or spike+Flash anneal sequence the TW values all drop to below 50. Similar effect of damage recovery was measured by PLi in Fig.5. With Flash only the Ge-PAI damage level is <300 PLi units so the residual implant damage from Ge+B must be shallower than the Ge+BF_2 case and the EOR damage within the junction resulting in low leakage <1E-7A/cm^2 for Ge+B compared to 5E-5A/cm^2 for Ge+BF_2 shown in Fig.3. With a spike+FLA or FLA+spike the PLi values increased to >600 for Ge+BF_2 and >1400 for Ge+B. So a spike anneal combination is critical for complete implant damage recovery. Another explanation for the leakage degradation with Ge+BF_2 is the F interaction with EOR defects. At IWJT 2008 Yamamoto[12] reported F co-implant does lead to leakage degradation. In an amorphous layer, F diffuses out of the silicon surface with spike annealing but remains substitutional in silicon and does not diffuse out with MSA. This high level of F from the BF2 implant could degrade junction leakage like C co-implant with MSA causing 3 orders of magnitude degradation in junction leakage as reported by Falepin [13] also at IWJT 2008. Comparison of junction leakage to TW is shown in Fig.6 for B, Ge+B and Ge+BF_2. For all the spike anneals and combinations with spike TW was <100 and leakage <1E-7A/cm^2. Note that without spike anneal high TW values between 120 to 180 were detected suggesting unstable residual implant damage but junction leakage for B and Ge+B were all below 1E-7A/cm^2 so these EOR defects must be shallow and within the junction. Comparing spike+FLA to FLA+spike no difference is seen from junction leakage and residual implant damage however, FLA first results in the lowest Rs value as shown in Fig.1. Besides complete implant damage recovery, the FLA+spike anneal sequence also eliminates the FLA Xe-lamp annealing signature shown in Fig.7 for PLi wafer image maps.

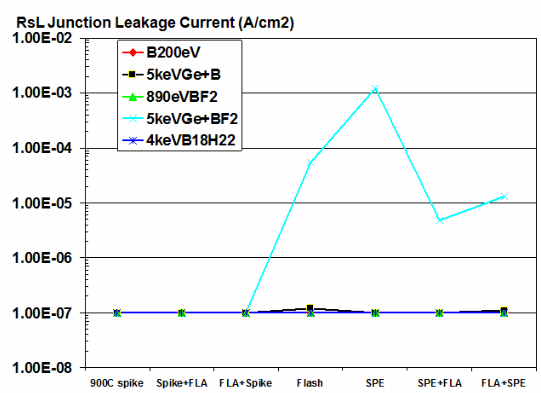

Figure 3: RsL junction leakage current results.

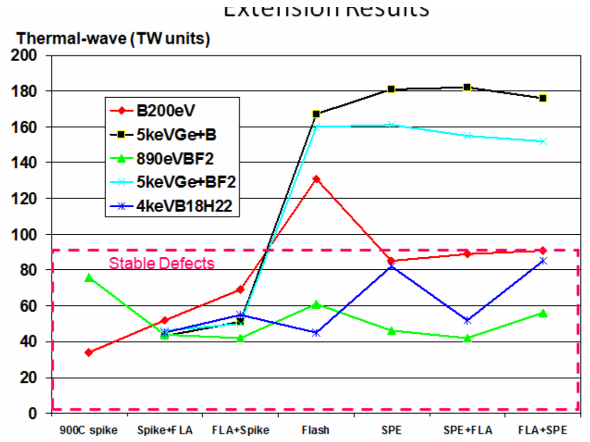

Figure 4: Thermal-wave results showing after anneal implant damage recovery.

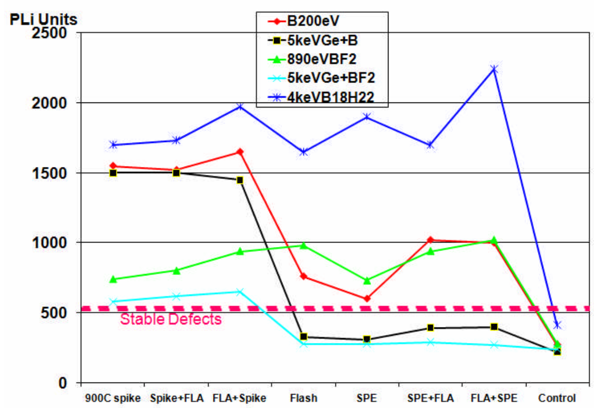

Figure 5: PLi results showing after anneal implant damage recovery.

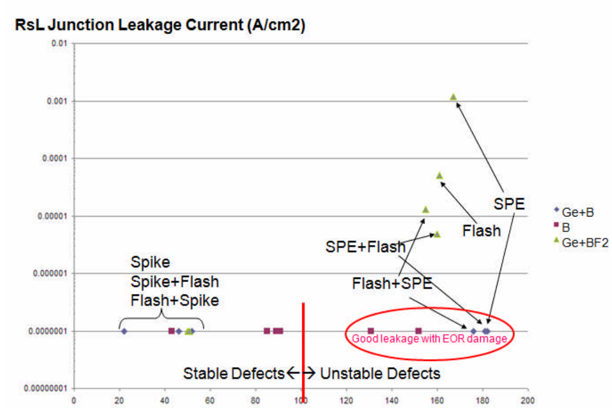

Figure 6: Correlation of junction leakage current to TW value.

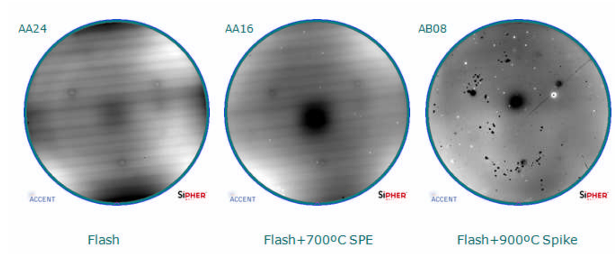

Figure 7: PLi wafer image showing elimination of Flash Xe-lamp anneal signature.

Halo

The Rs results are shown in Fig.8. For the boron doped HALOs there was no significant difference in Rs values for all the different anneals except for the SPE anneal because dopant activation for the 3E13/cm^2 dose is well below the boron solid solubility (Bss) limit so dose limited. For indium dopant activation was different and limited by the low indium solid solubility so with spike annealing and spike combination anneals the Rs value were all about 21,000 ohms/square while without spike anneal Rs was very high between 45,000 to 65,000 ohms/square. These Rs results for In are very different from those Mineji reported at IWJT 2007 [8], 4-5 times higher Rs while the B dopant Rs results are similar therefore this might be due to the different spike and Flash annealing equipment used as well as temperature calibration differences between these different annealers as reported by Borland [1] at IWJT 2008.

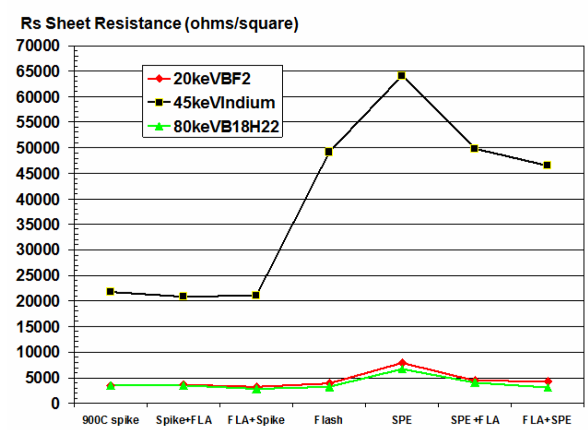

Figure 8: Rs sheet resistance results.

Junction leakage current results are shown in Fig.9 and all the results showed very good low leakage levels E-7A/cm^2 or below. Again these results were different from the In HALO leakage results reported by Mineji [8] were they observed E-5A/cm^2 leakage levels for indium HALO with Flash anneal and E-4A/cm^2 leakage levels for SPE annealing while in Fig.9 we report all <2E-7A/cm^2. Again, differences are annealing equipment for both Flash and spike anneals so absolute temperature differences are possible. The leaky junctions in the Mineji study may also explain the lower Rs values in their report. Defect detection using TW and PLi for after anneal residual implant damage are shown in Figs. 10 and 11 respectively. No clear trends can be seen suggesting complete implant damage annealing for these 3E13/cm^2 dose dopant level.

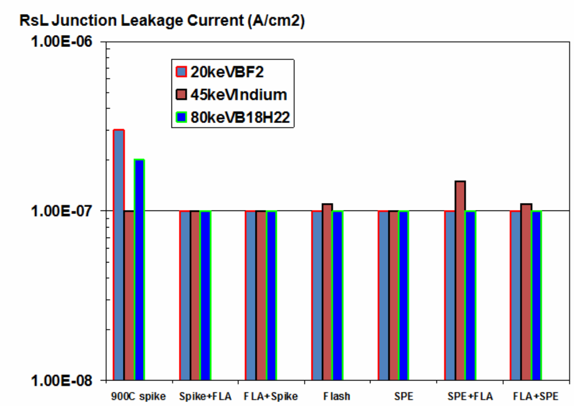

Figure 9: RsL junction leakage current results.

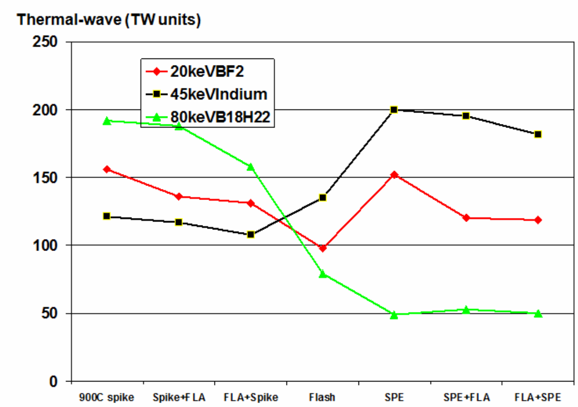

Figure 10: Thermal-wave after anneal implant damage recovery.

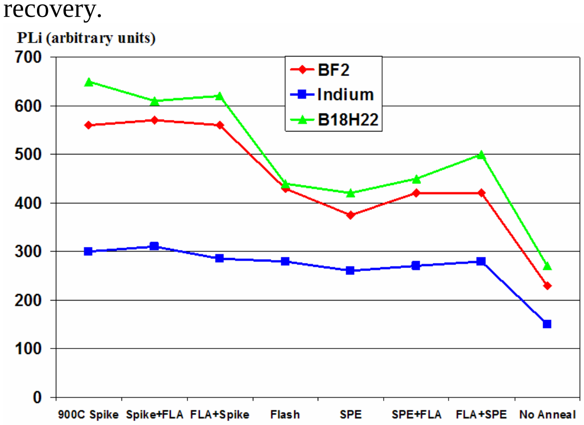

Figure 11: PLi after anneal implant damage recovery.

SUMMARY

32nm node p-type dopants were studied comparing B, BF_2, $B_{18}H_{22}$, Ge+B & Ge+BF_2 for extension and BF_2, $B_{18}H_{22}$ & In for HALO dopant implantation. Junction quality was determined using rapid process optimization metrology such as RsL for sheet resistance and junction leakage measurements while TW and PLi were used to determine implant damage recovery after annealing. With Flash annealing, only the Ge+BF_2 for SDE and In for HALO implants resulted in poor quality junctions. The Flash+spike annealing sequence resulted in high quality junctions for all the implants studied and also eliminated the Flash annealing signature micro-uniformity variation. Similar studies for n-type SDE and HALO dopant species are under investigation by many.

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