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The Effect of Amorphization Conditions on the Measured Activation of Source Drain Extension Implants

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Abstract. Un-patterned wafers were processed using low-dose Indium or medium-dose Germanium pre-amorphization implants (PAI) followed by p-type dopant implants of BF₂ or carborane (CBH). The wafers were then annealed by RTA (spike), laser anneal (LSA) or combination of LSA and spike. Active dopant distributions calculated from SIMS and sheet resistance measurements compared favorably with those determined by differential Hall, which is a challenging technique for shallow profiles. The trends in B diffusion behavior and activation are discussed in relation to the different implant damage budgets, damage evolution during the anneals and presence of fluorine. In particular, for low thermal budget LSA only anneals, CBH implants appear to give higher activation than BF₂ due to the absence of fluorine.

Keywords: Pre-amorphization, ion implantation, transient enhanced diffusion, activation, laser annealing

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INTRODUCTION

Many schemes have been proposed for the production worthy manufacture of shallow, high conductivity, low leakage 32nm transistor junctions. The most challenging step of these schemes often involves formation of the PMOS source drain extension. This study compared two PAI schemes previously used at larger design rules, BF₂ and ortho-carborane (CBH[1]) doping implants and various anneal strategies. Co-implants were not included. The use of the differential Hall (DH) technique for shallow junction metrology was also evaluated.

EXPERIMENTAL CONDITIONS

All implants were carried out into 200mm Si wafers at Varian using a VISta HC implanter except for the Indium implants, which were carried out on a VISta 810 medium current tool at Texas Instruments. PAI conditions of Ge/20keV/3.5E14/cm² or In/15keV/3E13/cm² were followed by dopant implants at 0° tilt of CBH/6.8keV/1.4E14/cm², or BF₂/2keV/1.4E15/cm². It was noted (see Figure 2) that the B energies were not exactly matched for these conditions. The B from the CBH had a nominal

equivalent energy of 500eV whereas the B from the BF₂ was shallower, with an equivalent energy approximately 10% lower. The different combinations of implants were annealed with one of the following schemes: LSA at 1270°C for 0.8 ms; spike at 950°C for ~2 seconds; LSA followed by a spike (both with the same parameters as above). The sheet resistance, Rs, of each wafer was then measured by a KLA-Tencor RS100 4 point probe.

FIGURE 1. An Rs-Xj plot for the PAI, dopant combinations of this study. Ellipses enclose same anneal conditions; dotted lines are guides to the Rs-Xj trends.

TABLE 1. Comparison of CBH and BF₂ observations

Anneal	Activation	Diffusion	Mobility
Spike	Similar	CBH deeper	Similar
LSA	CBH higher	Similar	Similar
LSA+ Spike	Similar	CBH deeper	Similar

Next, pieces of each wafer were profiled by SIMS, which was carried out at Texas Instruments on a Cameca 6F with 500 eV O₂⁺ ions and oxygen leak for boron. The B SIMS profiles for the CBH implants shows ¹⁰B + ¹¹B, whilst the BF₂ shows ¹¹B only. In this study, the junction depth (X_j) was defined as the depth at which the B concentration was 5x10¹⁸ atoms/cm³. The Rs-X_j plots for the various samples are shown in Figure 1 and the SIMS profiles are in Figure 2.

The SIMS and Rs data could be combined to estimate the maximum concentration of electrically active boron in the following way. It was assumed that at low concentrations, the activated profile was same as the SIMS profile. However, near the surface where the chemical concentration was high, the active boron concentration was assumed to reach a maximum value. Using the hole mobility as a function of active boron concentration given by Schroder[2], the contribution to the sheet resistance of each part of the boron depth profile could be calculated. The maximum active boron concentration was chosen so that the calculated value of the total sheet resistance matched the measured value. The effects of surface oxide were ignored. The estimated maximum activation concentrations and their associated hole mobilities are reported in Figure 3. The activation levels calculated from SIMS/Rs often agreed with another qualitative estimate of the active B concentration, which was indicated in the SIMS profile where the diffusion tail breaks from the immobile, surface peak[3].

Further pieces of each wafer had van der Pauw structures fabricated on them at The University of Surrey, and DH measurements were carried out[4]. This technique makes repeated Hall and resistivity measurements after thin layers of the material have been removed. In this way, the depth profiles of the electrically activated boron concentrations and mobility could be measured. The Hall scattering factor (the ratio of field-free mobility to that in a

magnetic field) has been taken as unity. The technique is limited for shallow junctions by the accuracy of the material removal step. Also, depletion effects mean that the junction is distorted and can only be measured to a limited depth. For these reasons, the results are semi-quantitative but certainly indicative of trends.

Finally, junction leakage measurements were made on mesa diode structures of varying sizes fabricated on other pieces of each wafer at The University of Surrey. This is a more sensitive technique than assessing damage by cross sectional or planar TEM. The junction leakages for all the samples of this study were measured to be extremely small (~10⁻⁸ A/cm²).

RESULTS AND DISCUSSION

The trends in the DH and SIMS/Rs results for activation and mobility (Figure 3) follow each other quite closely. Indeed, applying a reasonable Hall scattering factor of ~0.6 would bring the maximum activated B and mobilities into good agreement. The DH would still suggest higher activation (and lower mobility) for the LSA cases than the SIMS/Rs calculations. In most cases, the relative depths of the DH profiles for the various conditions in Figure 2 agree with the relative depths of the SIMS profiles. Hence DH was a useful technique for this study.

The total damage remaining at the completion of the implants, how this evolved during the various anneals and the presence of fluorine is an important framework within which to explain the observations of diffusion and activation behavior in this study.

When comparing the results for the two PAI conditions on the Rs-X_j plot (Figure 1), it can be seen that Ge always showed lower Rs and deeper X_j than In. TEM data confirms the TRIM prediction that the In PAI creates only a little damage, located close to the surface. The more complete and deeper damage created by Ge PAI released more interstitials from the EOR damage during the anneals. This may explain the observation of greater B diffusion after Ge, compared to In PAI. The activation measurements (Figure 3) suggest that the lower Rs values for Ge were a consequence of the deeper dopant profiles, rather than higher peak B activation.

TABLE 2. Comparison of observations for the various anneal conditions

Anneal	B Tail and F Out-Diffusion	EOR Decoration by F	Activation	Same Rs-X _j trend for In & Ge
Spike	High TED	No	Low	No
LSA	Low TED	Yes	High	Yes
LSA + Spike	Intermediate CED	No	High	Yes

FIGURE 2. SIMS profiles (lines only) before and after annealing and differential Hall profiles (lines and symbols) after annealing for: B from CBH; B from BF₂; F from BF₂ implants.

The effects of the different dopant species are summarized in Table 1. The fact that different amounts of diffusion can be observed after BF_2 and CBH implants may be a consequence of the fluorine introduced by the BF_2 . F is known to annihilate interstitials, which mediate B diffusion, through its ability to getter vacancies[3]. Other experiments suggest that the intrinsic C implanted as part of the CBH molecular implants has little effect on diffusion[1]. (In contrast, when the C is implanted separately, the deeper C impedes the EOR interstitial flux from interacting with the shallow B[5]). In addition, the CBH would be expected to retain more damage after implant than BF_2 due to the molecular effect[6] (and the CBH energy was also slightly higher). For the In PAI case, where the dopant damage was a significant addition to the total damage budget, this mechanism may account for the larger difference in X_j between CBH and BF_2 , compared to the Ge case, where the dopant damage was swamped by that from the Ge.

The effects of the anneal conditions are summarized in Table 2. The observations of the SIMS profiles are consistent with the spike anneal promoting the greatest amount of damage evolution and interstitial release, leading to the deep tails indicative of transient enhanced diffusion (TED). In contrast the LSA evolved the damage such that few interstitials were released and the profiles remained shallow. The spike after the LSA appears to not have been able to release as many interstitials as the spike alone, as there is little further TED in the tail. However, the profiles become boxier as concentration enhanced diffusion (CED), driven by the boron activated during the LSA step, occurs.

The clearest trends in the activation measurements (Figure 3) are that the LSA gave much higher activation than either spike or LSA + spike, and that CBH showed higher activation than BF_2 after the LSA anneals. As the formation of Boron Interstitial Clusters (BICs) is an important mechanism in the de-activation of B, the first observation is consistent with the explanation again that the LSA released the lowest number of interstitials for BIC formation. The difference in activation for the dopant species after LSA may be explained by a lower competition for lattice sites between B and C after CBH implants compared to that between F and B after BF_2 . There is a hint that CBH may have had slightly lower activation than BF_2 for the In PAI cases that were followed by spike and LSA + spike anneals. Similar to the diffusion argument, this may be explained by the dopant damage being a large fraction of the total damage budget (and the total damage was more surface peaked) for the In PAI so that the spike anneals may have allowed more extensive BIC

formation after CBH than BF_2 . After Ge PAI, the presence of F appears to be a more important factor.

FIGURE 3. Boron activation: (■) calculated from Rs/SIMS; (□) measured by differential Hall; and mobility: (◆) from Rs/SIMS; (◇) differential Hall

CONCLUSIONS

Differential Hall has shown itself to be a useful, semi-quantitative technique for 32nm junction metrology. Many of the observations of PAI, dopant and anneal schemes could be explained by considering implant damage, thermal budgets and the presence of fluorine. In particular, the higher levels of boron activation after laser anneals for CBH compared to BF_2 implants, regardless of PAI scheme, appears to be attributed to the absence of fluorine, rather than damage considerations.

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