

ClusterBoron™ Implant Alternative to BF₂ PMOS SDE

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Abstract. As device geometries scale, the formation of the SDE becomes increasingly difficult and increasingly important. For advanced technologies, new methods such as ultra-low-energy boron implantation and millisecond annealing (flash or laser) are necessary to achieve the required junction characteristics. In addition, these processes must be compatible with the remainder of the process flow, which might include advanced dielectrics, stress technologies, SOI, etc. The emergence of ClusterBoron as a high productivity alternative for the low energy implant creates interest in device performance possible in a realistic process flow.

This paper will present an evaluation of the use of ClusterBoron for the PMOS SDE in an advanced 65nm logic process which includes laser annealing, e-SiGe stress layers and SOI. The conventional process uses a BF₂ SDE process. Complete device characteristics will be shown comparing the ClusterBoron SDE to the conventional BF₂. It will be shown that the ClusterBoron process achieves better boron activation, leading to enhanced transistor drive current. It will also be shown that the ClusterBoron is compatible with the SiGe stress layers and SOI structure. In summary, ClusterBoron presents an attractive alternative to the conventional BF₂ process for advanced PMOS SDE.

INTRODUCTION

One of the issues with continued scaling of transistor structures is the shallow junction required for the PMOS SDE. Scaling requires that the junction depth is reduced with each generation to maintain control of short channel effects. For the 45nm generation, a PMOS SDE junction depth of less than 20nm is required, while the 32 nm generation will require junction depths around 15nm. At the same time, it is desired to keep the sheet resistance of this junction around 1000 ohm per square to minimize impact on the drive current. This set of requirements makes low energy and high dose boron implants critical to successfully forming an appropriate junction. Boron implants of less than 400eV will be required to meet the 32 nm requirements, and conventional implant tools have very low throughput for this type of recipe, especially when the sensitivity to energy contamination is considered. Most organizations use a BF₂ implant to increase the productivity of the production process. The recent emergence of ClusterBoron implant as an alternative low energy boron process offers a high productivity solution to these issues. However, it must be shown that the ClusterBoron implant is compatible with the other process modules

already incorporated into a modern CMOS flow. In particular, this study addresses the compatibility of the ClusterBoron implant with e-SiGe stressors. The concern is that the self-amorphizing nature of the ClusterBoron implant may allow the relaxation of the SiGe stress. Our experiment looks at the use of ClusterBoron for both the SDE and SD on a 65nm SiGe/SOI technology.

EXPERIMENT

This experiment uses a straightforward split lot approach to evaluating the use of ClusterBoron implant for the PMOS SDE or SD junctions. The appropriate dose and energy of the alternative implant recipes cannot be calculated directly because the ClusterBoron implant and BF₂ implants behave differently during annealing, due to the fluorine inhibition of boron diffusion. Rather, an empirical approach with splits on ClusterBoron implant energy and dose was used. The matrix included three doses and two energies for the SDE and two energies and two doses for the SD. In all cases, only one ClusterBoron implant was included on any split; the Process-of-record (POR) BF₂ recipes were used for the other implants.

RESULTS

In general, the devices with ClusterBoron implant behaved appropriately and parametric trends were observed. In Figure 1, we show the unsilicided active resistance. It is seen that the ClusterBoron splits produced lower active resistance, except for the one with the lowest energy and dose. As ClusterBoron dose and energy are increased, the active resistance is reduced. It is also seen that the ClusterBoron splits for the SD implant also match the POR for unsilicided active resistance. These results show that the ClusterBoron implant activates as well or better than the BF2 POR with the production flow's annealing sequence.

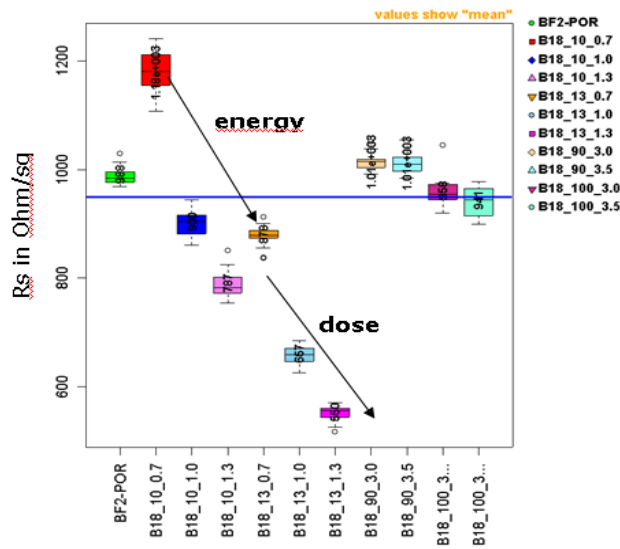


FIGURE 1. Unsilicided Active Resistance

The next parameter investigated is the threshold voltage. The data for V_{tsat} is shown in Figure 2. It is seen that the 10keV ClusterBoron SDE shows normal variation, with a sensitivity of 10mV/1E12. The POR is matched with a 10keV, 1.0E15 ClusterBoron implant. On the other hand, the 13keV ClusterBoron SDE show much higher sensitivity with 20mV/1E12. All of the 13keV splits gave V_{tsat} values that were higher than the POR. The V_{tsat} shows very low sensitivity to the SD implant splits and all of the ClusterBoron SD implants produced V_{tsat} values close to the POR.

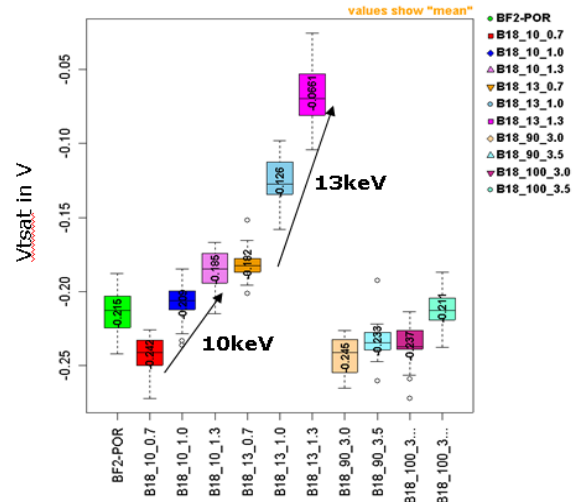


FIGURE 2. V_{tsat} (nominal devices).

The results for junction capacitance are shown in Figure 3. It is seen that the ClusterBoron SDE produces a junction capacitance similar to the POR. All of the 10keV ClusterBoron SDE splits have junction capacitance values that are close to the POR, with the higher dose splits having slightly lower junction capacitance. Similarly, the 13keV ClusterBoron SDE splits show decreasing junction capacitance as the dose is increased. The ClusterBoron SD splits show that the lower dose matches the POR regardless of energy, while the higher dose gives a lower junction capacitance.

The most important results of this work are shown in Figure 4, where we show the universal curve for the SDE implant splits. It is seen that all of the ClusterBoron SDE splits show better performance when compared to the POR. The improvement of performance is approximately 13% for all ClusterBoron SDE recipes. The 10keV ClusterBoron splits are shown in Figure 4a while the 13keV ClusterBoron SDEs are shown in Figure 4b. For the 10keV SDE, it is seen that the behavior is essentially independent of dose, with all the data falling about the same line. In addition to the higher drive current, the slope of the universal curve is also improved and the off state distribution is similar to the POR. For the 13keV SDEs shown in Fig 4b, the drive current is enhanced but the slope is the same as the POR and the off-state currents are slightly elevated compared to the POR.

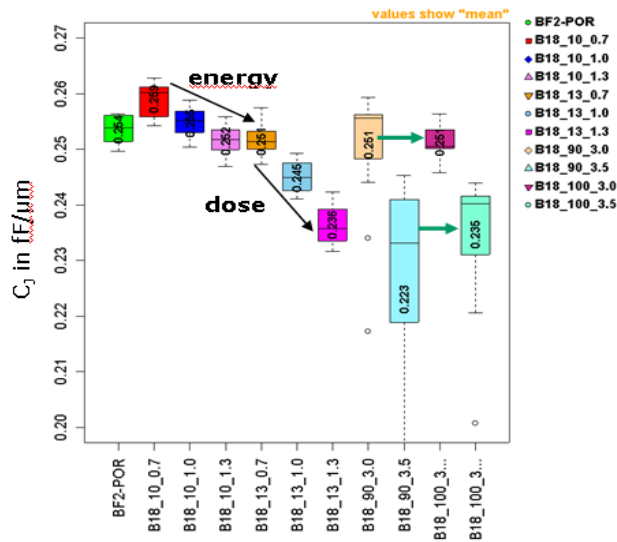


FIGURE 3. Junction Capacitance

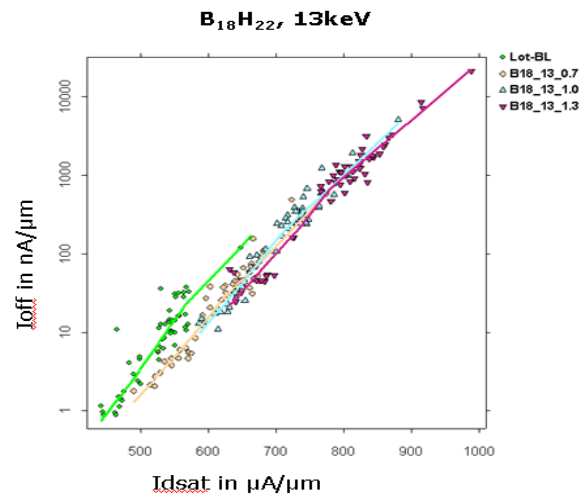


FIGURE 4b. Universal curve for ClusterBoron SDE implants with 13keV energy.

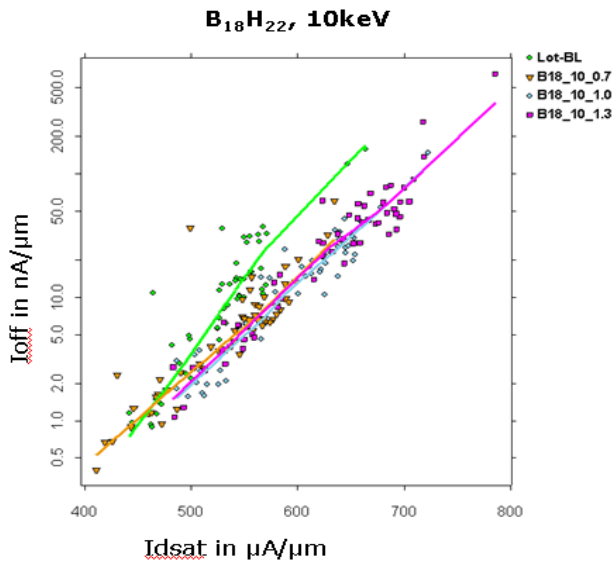


FIGURE 4a. Universal Curve for SDE implants with ClusterBoron energy of 10keV.

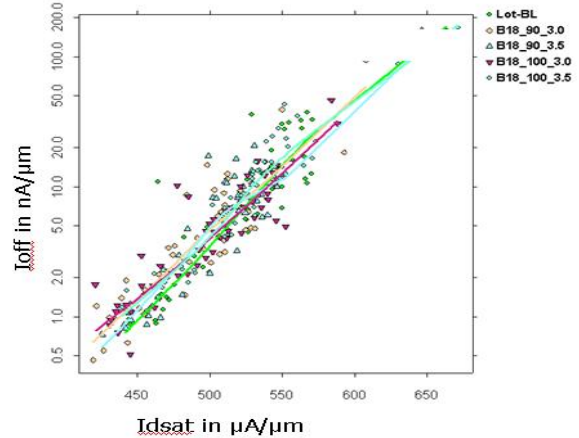


FIGURE 5. Universal curve for ClusterBoron SD implants.

In Figure 5 we show the universal curve for the splits with ClusterBoron for the SD. It is seen that all the data fits within the same distribution. There is no performance gain observed by the use of ClusterBoron for the SD implant. However, it is still significant that the results are the same. The deep SD implant occupies the same volume as the e-SiGe which enhances the device performance by placing stress on the channel. By producing the same universal curve, the ClusterBoron SD implants must also be producing the same stress effect, that is, the ClusterBoron self-amorphization does not degrade the stress enhancement from the e-SiGe.

The junction leakage characteristics are shown in Figure 6. While most of the data show leakage that is very similar to the POR, there are slight differences. The behavior of the two energies used for SDE are slightly different, with the 13keV SDE showing lower leakage values. For the ClusterBoron SD splits, all data show junction leakage in the same range as the POR.

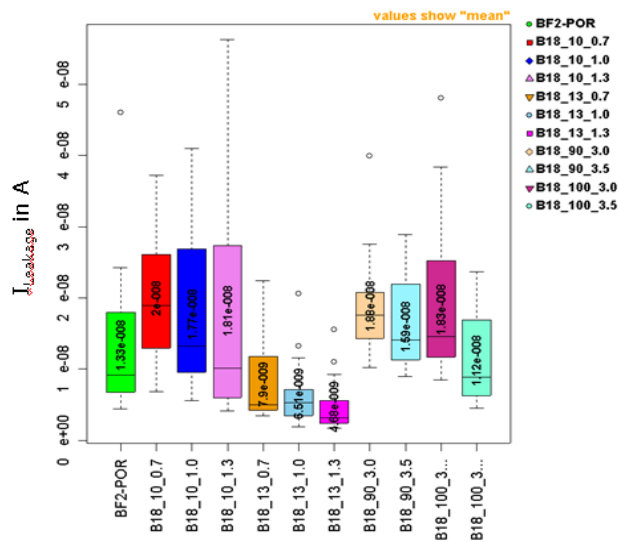


FIGURE 6. Junction leakage data.

SUMMARY

The results of this work show that the ClusterBoron implant can be used as an alternative to the conventional BF2 SDE without any degradation of performance. In addition, ClusterBoron can be used to replace the SD implant also without performance degradation.

In fact, the experiment shown here produced a performance enhancement of >10% when ClusterBoron was used for the SDE. These results show definitively that the unique characteristics of the ClusterBoron implant, such as self-amorphization, do not degrade the stress enhancement produced by incorporating e-SiGe structures in the PMOS SD regions. Thus, the high productivity offered by the ClusterBoron implant can be realized without device degradation.

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