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Characteristics of Boron and Arsenic Ultra-Shallow Junction Using Laser Annealing with Pre-Amorphization Implantation

C.M. Park, K. Min, S.D. Kim, S.A. Prussin, †M.K. Han, and J. C. S. Woo

Department of Electrical Engineering, University of California, Los Angeles, CA 90024, USA
Phone: 1-310-206-3279 Fax: 1-310-205-8495 E-mail: woo@icsl.ucla.edu
†School of Electrical Engineering, Seoul National University, 56-1 Shinrim-dong, Seoul 151-742, Korea

I. Introduction

As CMOS device is scaled below 100nm, highly doped and ultra-shallow junction is required [1]. Box-like profile with high doping concentration may satisfy this demand and is difficult to achieve by conventional technique such as ion implantation and rapid thermal annealing (RTA). Various advanced methods to obtain low resistance shallow junction were proposed [2]. However, conventional technologies are prone to transient enhanced diffusion (TED) and broaden the dopant profile [3][4]. Recently, laser annealing (LA) receives considerable interest as one of alternatives for ultra-shallow junction [4][5].

In this paper, laser annealing conjunction with pre-amorphization implantation (PAI) is discussed. Box-like profile was developed with LA-PAI.

II. Experiment and discussion

Since an amorphous silicon layer has ~300°C lower melting temperature than crystal silicon, the selective layer annealing process may be possible by combining LA with PAI. Furthermore, laser annealing energy is lowered with PAI. Since the amorphous thickness and therefore the melted thickness is precisely controlled by the pre-amorphization and dopant in the melted layer diffuses very fast, box-like profile is formed with large process window.

Silicon surface was amorphized using a 20 KeV, 1×10^{15} cm^{-2} Ge^+ implantation, resulting in a 38nm amorphous layer. Figure 1 shows a cross-sectional TEM image after pre-amorphize implantation. Subsequently, 1KeV, 1×10^{15} cm^{-2} of BF_2 or 2KeV, 1×10^{15} cm^{-2} of As was implanted. Figure 2 shows the as-implanted dopant profiles measured using SIMS. They show the typical Gaussian-like shapes. Comparing TEM image and SIMS profile, the interface of a-Si and crystal silicon was formed at ~ 1×10^{20} cm^{-3} Ge doping concentration. In our experiment, multi-shot is done with five pulses. Multi-shot laser annealing was also investigated.

Figure 3 shows that the boron sample, with PAI by 20 KeV Ge, can be activated with a very low single shot laser dose of 300 mJ/cm^2, while boron without PAI requires 600 mJ/cm^2 laser dose (Fig. 3). In addition, PAI has lower R_s than without PAI at each of the annealing condition. In case of multi-shot laser annealing, the resulting R_s is lower than those of single shot samples with PAI and saturated at the laser energy level 600 mJ/cm^2. The sheet resistance characteristics of arsenic show same trend as those of boron. Samples with PAI have much lower R_s and their R_s saturated at lower laser annealing energy. These low R_s values of boron and arsenic were obtained compatible to and smaller than values obtained from RTA using 1050 °C spike (Fig. 3, 4).

Doping profiles of boron and arsenic after PAI and laser annealing were measured by SIMS. The junction depth is almost same as the as-implanted samples, while the profile is box-like. TED effect of laser annealed sample with PAI was also examined using RTA at 900 °C for 20 seconds. Figure 5 show that multi-shot laser + RTA sample does not show TED, which is similar to the samples with only laser annealing.

Arsenic profiles also show almost the same box-like profiles with a junction of 40nm (Fig. 6), when the laser energy is high enough to melt the entire amorphous layer but not the crystalline substrate. In case of single shot with low laser energy (500 mJ/cm^2), the laser dose is not sufficient to melt the entire amorphous layer, resulting that an As (or B) junction depth is smaller than the ~38nm (the amorphous layer thickness). Furthermore, under such condition the amorphous layer is not fully crystallized.

Figure 7 shows the plan-view TEM images after optimal laser annealing. Furnace annealing at 800 °C for 20 minutes was followed after laser annealing to enhance the image of end of range (EOR) loop. As shown in Fig. 7 (c), low energy-multi-shot laser annealing method is more effective to eliminate EOR defects compared with high energy-single shot technique, resulting in the removal of TED

III. Conclusion

Doping profiles by various annealing conditions are discussed using SIMS profiles and TEM images. It is shown that laser annealing is a very promising technique to reduce TED. Box-like profile was successfully obtained using laser annealing technique by controlling the melting thickness of silicon layer with pre-amorphization. TEM images show that laser annealing can reduce residual defects by ion implantation, especially with low energy multi-shot laser annealing method, and therefore effectively prevent TED effect during subsequent thermal cycles.

IV. References

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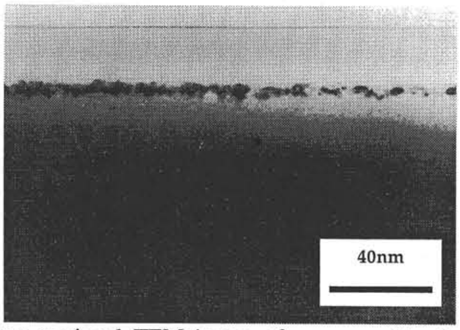

Fig. 1 Cross-sectional TEM image of pre-amorphized silicon by germanium.

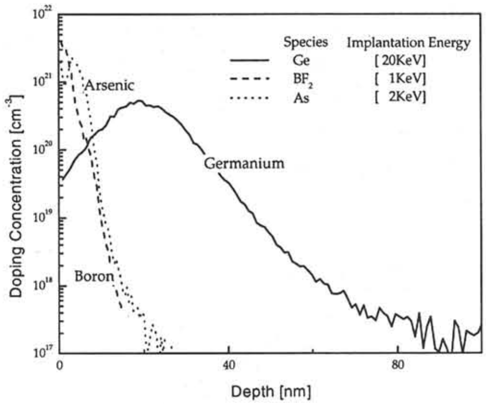

Fig. 2 SIMS profiles of Ge, As, and B before laser annealing.

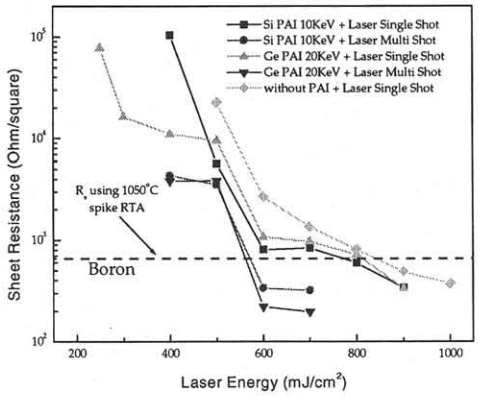

Fig. 3 Boron sheet resistances with or without PAI *vs.* laser annealing conditions.

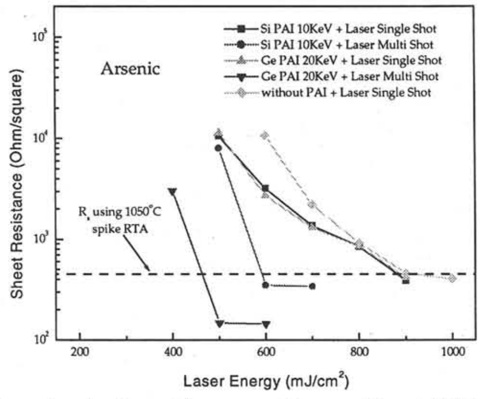

Fig. 4 Arsenic sheet resistances with or without PAI *vs.* laser annealing conditions.

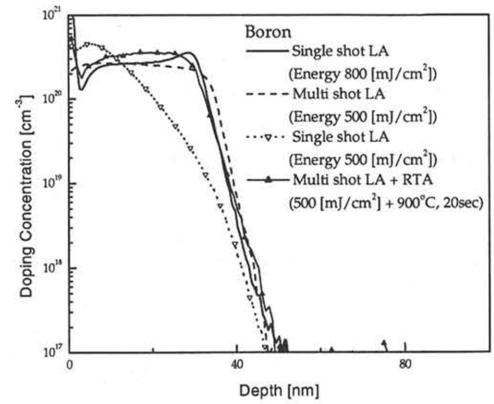

Fig. 5 Box like SIMS profile of boron after laser annealing with various conditions.

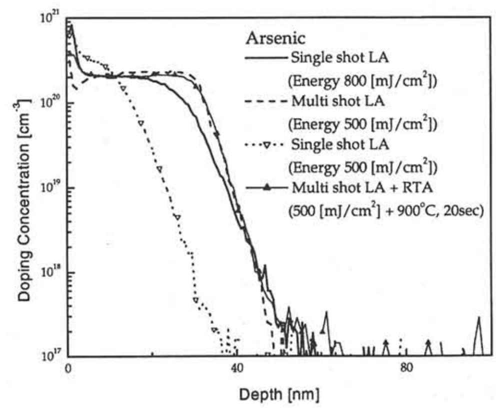

Fig. 6 Box like SIMS profile of arsenic after laser annealing with various conditions.

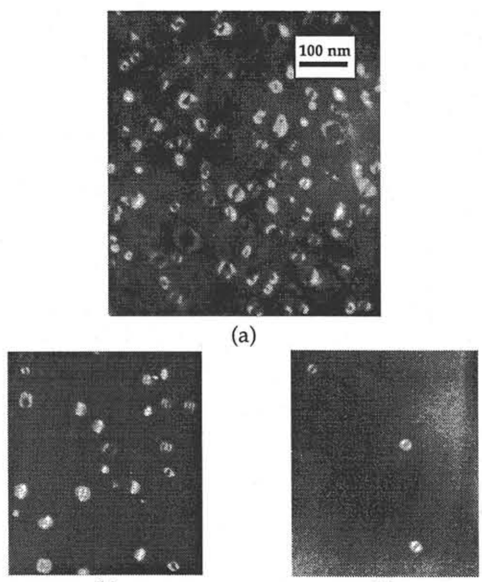

Fig. 7 Plan view TEM images of the EOR loop after annealing 800°C for 20 min. (a) without laser annealing, (b) 900 [mJ/cm^2] laser single shot annealing, (c) 500 [mJ/cm2] laser multi-shots annealing.