Laser Annealing for Ultra-shallow Junction Formation in Advanced CMOS

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Introduction. One of the bottle-necks in scaling down planar MOSFET devices is the formation of highly-activated (low sheet resistance R_{sh}), abrupt, ultra-shallow junctions (USJ) for the source/drain extensions. It has been shown that Sb implants with a subsequent spike anneal is a viable alternative for n+/p junctions for sub-50 nm CMOS generations[1-2]. For p+/n junctions, B remains the best dopant[3], however alternative activation methods have to be found to minimize junction depth (X_j) while maintaining high-level of B activation. In this paper we will demonstrate the benefits of laser annealing for formation of both p+/n (using B) and n+/p (using Sb) USJ, with excellent X_j-R_{sh} trade-off and abruptness values.

Experimental. In this study, antimony was implanted (3e15 cm^{-2}@10 keV) into Si (100) substrates without a screen oxide to form n+/p junctions. For the p+/n junctions we investigated three approaches: (*i*) Ge pre-amorphization, followed by B (1e15 @ 0.5keV) implants; (*ii*) GeF_2 + BF_2 (1e15 @ 2.2keV); (*iii*) Ge + B (1e15 @ 0.5keV)+ deep F implant. Laser annealing was performed with a 308 nm wavelength XeCl excimer laser, with a pulse duration of 30 ns. The energy density was varied in the range from 700 to 1100 mJ/cm^2 [4].

Results and discussion. Fig. 1 shows X-TEM pictures for (a) 1100 mJ/cm^2 and (b) 700 mJ/cm^2 laser anneals. Fig. 1a illustrates that the amorphous layer formed by the heavy Sb implantation was completely melted and subsequently, a mono-crystalline Si layer was re-grown through liquid phase epitaxy (LPE) re-crystallization. In this layer the Sb ions are incorporated and activated well above the solid solubility limit (~$1x10^{20}/cm^3$ at melting temperature), see SRP data in Fig. 2. We obtain a metastable super-saturated junction. The thermal stability of these junctions was also investigated (to be shown in the extended paper) using thermal budgets relevant for the post-processing in a full CMOS flow. Fig. 1b indicates that 700 mJ/cm^2 is not enough to melt the entire amorphous layer, therefore nucleation centers at the melted interface give rise in the LPE phase to poly-crystalline twin-plane structures. This results in very low carrier mobility in the junction region. This is reflected in Fig. 2 were we show the SIMS (solid lines) and SRP (Spreading Resistance Probing) (dashed lines) profiles for the two extreme cases. The best obtained result is a 26 nm junction with R_{sh}=216 Ohm/sq. at optimum laser anneal conditions of 1100 mJ/cm^2.

For the p+/n junction we show in Fig. 3 SIMS and SRP results for the samples annealed at the optimum laser energy density, 900 mJ/cm^2. The use of GeF_2 in combination with BF_2 shows a clear benefit, since it results in reduction of the channeling tail, better activation of the carriers and very high abruptness. The best junction exhibits X_j=20 nm, R_{sh}=319 Ohm/sq. and a record abruptness of 1.8 nm/decade.

Conclusions. This work demonstrates the great potential of laser annealing to fabricate highly-activated, abrupt, ultra-shallow junctions. Good re-crystallization of the implanted region can be obtained by choosing the appropriate laser energy density. An excellent trade-off between junction depth and sheet resistance is obtained for both n+/p and p+/n junctions.

References

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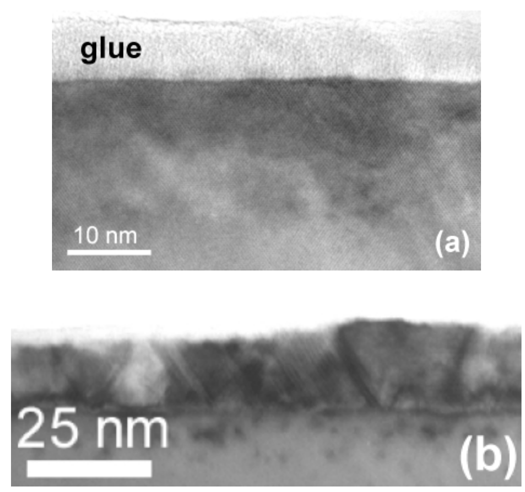

Fig. 1. X-TEM of the Sb implanted sample, laser annealed at (a) 1100 mJ/cm^2 laser anneal and (b) 700 mJ/cm^2

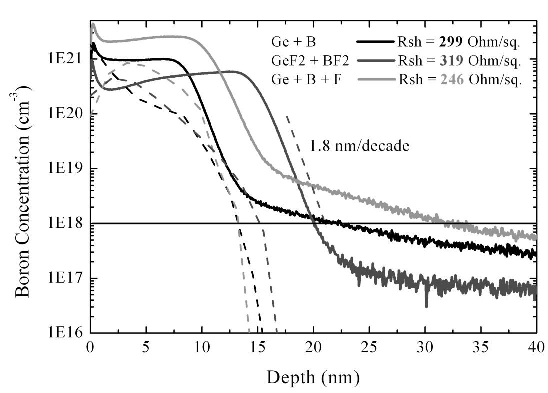

Fig. 2. SRP (dashed lines) and SIMS (solid lines) for the Sb implanted sample laser annealed at 700 mJ/cm^2 and 1100 mJ/cm^2.

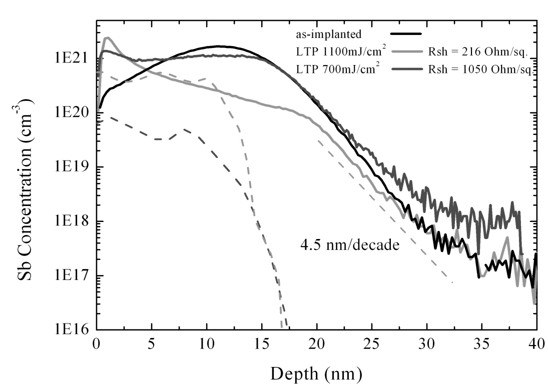

Fig. 3. SRP (dashed lines) and SIMS (solid lines) for the B/BF_2 implanted samples, laser annealed at 900 mJ/cm^2.