Sub-20-nm Junction Formation by Heat-Assisted Laser Annealing

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1. Introduction

Currently, post-spike annealing methods, such as flash lamp annealing [1-3], solid phase regrowth [4] and laser annealing [5], are actively investigated for the scaling of source and drain (S/D) junctions and MOSFET performance improvements. We have reported Heat-Assisted Laser Annealing (HALA) [6] that is a combination of substrate heating and laser irradiation showing 20-nm depth ultra-shallow Sb-doped junction formation. The heat-assist at around 450-525°C led to good dopant activation with a relatively wide process window against laser energy density ($E_L$) and the heat-assist temperature.

In this paper, issues associated with sub-20-nm junction formation, such as irradiation damage and residual defects, are discussed.

2. Experimental Conditions

KrF excimer laser ($\lambda\sim248$ nm) was used for the laser annealing. Its pulse width was about 38 ns measured at FWHM (Full Width at Half Maximum). A single laser pulse was irradiated to each point on specimens. In the case of HALA, Si wafers were heated to 450°C or 525°C in nitrogen atmosphere.

Sb and B were used as dopants. For 20 nm junctions, Sb$^+$ was implanted at 10 keV through 5 nm screen oxides. For 10 nm junctions, after preamorphization implantation with 3.0 keV Ge$^+$, Sb$^+$ or B$^+$ was implanted at 3.5 keV or 0.3 keV without using the screen oxides, respectively.

3. $E_L$ Reduction by HALA and TiN Cap

Laser irradiation for S/D activation sometimes gives rise to melting or deformation of device regions around S/D. Figure 1(a) shows an example of the gate electrode deformation. In this case, 50-nm thick Mo was used as a gate material. Even Mo whose melting point is 2620°C shows severe deformation by laser irradiation at 600 mJ/cm$^2$ that is moderate condition to activate dopants with non-heat assist LA. Since the gate pad locates on a thick field oxide, its heating is much higher than that of bulk Si surface because of lower thermal conductivity of the oxide. However, by using HALA the laser energy density can be reduced to 300 mJ/cm$^2$ [6]. As a result, the gate pad deformation is relieved, as shown in Fig. 1(b). Thus $E_L$ reduction is fundamentally important for laser annealing. For the further reduction in $E_L$, effects of a TiN cap as laser light absorber was investigated. TiN was deposited on the 5 nm screen oxide after the 10 keV Sb$^+$ implantation through it. Variation in depth profiles by HALA and the TiN cap is shown in Fig. 2. Specimens are
annealed at 300 mJ/cm$^2$ that is moderate $E_L$ for non-capped HALA. The TiN capped case shows slight redistribution and HALA+TiN results in profile broadening due to c-Si melting [6]. Such variations are usually observed against $E_L$ as a parameter. Figure 3 summarizes threshold $E_L$ for the c-Si melting. By using either HALA or the TiN cap, the threshold $E_L$ was reduced to 500 mJ/m$^2$ and their combination reduced it to 300 mJ/cm$^2$. Thus, the TiN cap is also effective to reduce $E_L$. However, to avoid reaction between TiN and a Si substrate an oxide or other insulator layer is necessary between them. Therefore, process optimization is necessary to apply the TiN cap to screen-oxide-less shallower implantation.

4. Residual Defects

Residual defects and their influence to junction leakage is an important issue for evaluation of annealing methods. Figure 4 shows XTEM photographs after the laser irradiation. High density stacking faults are found in Fig. 4(a) for Sb 10keV and 450$^\circ$C HALA. These defects can be reduced by raising the temperature to 525$^\circ$C or using Ge$^+$ preamorphization (Fig. 4 (b) and (c)). Ge$^+$ and B$^+$ implanted specimen also shows low density residual defects, as shown in Fig. 4(d). Fig. 5 shows reverse I-V characteristics of Sb 20 nm n$^+$/p junction diodes formed with 525$^\circ$C HALA. Its I-V characteristics are comparable to that for a reference RTA specimen. This indicates that the defects are sufficiently annealed out by 525$^\circ$C HALA.

10 nm junctions were fabricated with HALA to show its feasibility for shallower junction formation. Figure 6 shows relationship between sheet resistance and $E_L$. The sheet resistance values of about 700 $\Omega$/sq. obtained at $E_L$ of 400 mJ/cm$^2$ for 10 nm junctions implies that dopants are sufficiently activated.

5. Summary

Ultra-shallow nm junctions were fabricated with HALA. By adding the TiN capping layer for light absorption, laser energy density necessary for dopant activation was reduced. Residula defects after HALA can be reduced by optimizing the heat-assist temperature and by the introduction of Ge$^+$ pre-amorphization process.

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References

Fig. 1 Plan-view optical microphotograph of Mo gate pad after laser irradiation to activate dopants. Mo Gate electrode shows deformation for (a) Non-heat-assisted case. $E_L$ reduction by HALA is effective to suppress the deformation.

Fig. 2 Sb SIMS depth profiles after LA. HALA and the TiN cap enhance redistribution of dopants, because they are effective to raise Si surface temperature.

Fig. 3 Effects of $E_L$ reduction techniques. Though $E_L$ for c-Si melt threshold is too high to form shallow junctions, the threshold is useful as an index of $E_L$ reduction magnitude.
Fig. 4 XTEM photographs to evaluate residual defects after HALA. Stacking faults seen in (a) are reduced by increasing heat-assist temperature or using Ge pre-amorphization.

Fig. 5 I-V characteristics of n⁺/p junction diodes.

Fig. 6 Relationship between sheet resistance and $E_L$. 

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