High Performance Germanium n^+/p Shallow Junction for the Scaled nMOSFET

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Abstract

In this work, we study excimer laser annealing (ELA) on phosphorus-implanted germanium with implantation energies and doses of 30 keV, 5x10^{15} cm^{-2}, and 10 keV, 5x10^{14} cm^{-2}, respectively. A well-behaved Ge n^+/p shallow junction with a record rectification ratio of ~ 10^7 and low leakage current density of 8.3×10^{-5} A/cm^2 is achieved by a combination of low temperature pre-annealing (LTPA) and ELA, which is great beneficial to the scaled Ge nMOSFET technology.

1. Introduction

Germanium is a promising alternative channel material for extremely downscaled complementary metal oxide semiconductor (CMOS) technology due to its higher carrier mobility and lower processing temperature compared to silicon [1]. However, the difficulty to achieve a high activation n-type doping made it hard to realize excellent n^+/p shallow junctions for S/D in the scaled nMOSFET [2].

In this work, we investigate the effect of laser energy density on the phosphorus (P) diffusion in P-implanted Ge substrate and make high performance Ge n^+/p shallow junctions.

2. Experiments

A p-type Ge (100) wafer with a resistivity of 0.088 Ω·cm was used in this study. Ge n^+/p junctions were made by P^+ implantation at 30 keV/5x10^{15} cm^{-2} or 10 keV/5x10^{14} cm^{-2}, and one pulse ELA with or without LTPA process. Ge n^+/p diodes and the contact of Al/n^+Ge were fabricated by conventional etching and lift-off process. All of the contact electrodes were aluminum.

3. Results and Discussion

ELA on P-implanted Ge was studied firstly with the implantation energy and dose of 30keV, 5x10^{15}cm^{-2}. A significant diffusion of P after ELA at 200 and 300 mJ/cm^2 can be seen in Fig. 1. The amorphous Ge (a-Ge) induced by ion implantation can be efficiently re-crystallized after ELA at 200 mJ/cm^2 and above (Fig. 2). The contact resistivity (ρ_C) is low to 1.61x10^{-6} Ω cm^2 (Fig. 3). Compared to our previous results for the samples annealed by rapid thermal annealing [3], the value of ρ_C is improved by about three orders of magnitude. Ge n^+/p diodes (I_{on}/I_{off} ~ 2x10^5 with an ideality factor η ~1.28) realized using ELA (Fig. 4). As laser fluence is increased from 0 to 250 mJ/cm^2, the reverse current I_{off} of n^+/p diode decreases due to the improvement of crystallization (Fig. 4).

The fabricated n^+/p junction has a large junction depth with only ELA. A novel approach is proposed with a combination of LTPA and ELA to achieve Ge n^+/p shallow junction. The phosphorus implantation energy and dose is about 10 keV, 5x10^{14} cm^{-2}.

As shown in Fig. 5 and Fig. 6, the temperature of LTPA and the fluence of ELA are optimized by the J-V characteristics of Ge n^+/p junction diodes. The rectification ratio of Ge n^+/p diodes and the ρ_C of Al/n^+Ge are extracted (Fig. 7). A well-behaved Ge n^+/p junction with a record I_{on}/I_{off} ~ 10^7, low I_{off} ~ 8.3x10^{-5} A/cm^2 and an ideality factor η ~ 1.07 has been achieved when the samples are pre-annealed at 400 ^{o}C-10 min plus ELA at 150 mJ/cm^2. The SIMS profiles after one pulse ELA with or without LTPA can be well fitted by the diffusion model [4] (Fig. 9). The diffusion coefficient of phosphorus extracted in the samples after only ELA is about 3.5x10^{-4} cm^2/s, and 2.9x10^{-4} cm^2/s for the samples with LTPA. It is worth noting that the LTPA process can significantly suppress the diffusion of P in Ge during ELA (Fig. 8 and Fig. 9). Moreover, the carrier concentration reaches to 6x10^{19} cm^{-3} and the junction depth is only 44 nm at 1x10^{18} cm^{-3} (Fig. 8). The TEM images of the samples before and after thermal treatments are shown in Fig. 10. After the sample LTPA at 400 ^{o}C-10 min, the implantation damages are healed preliminarily (Fig. 10 (b)), and plus ELA at 150 mJ/cm^2, no obvious defects can be observed in the film (Fig. 10 (c)).

4. Conclusion

High performance Ge n^+/p shallow junctions have been realized by using a combination of LTPA and ELA, which is immensely beneficial to the scaled Ge nMOSFET applications.

Acknowledgements

This work was supported by 973 Program (2012CB933503, 2013CB632103), NSFC (61176092, 61036003, and 60837001)

Reference

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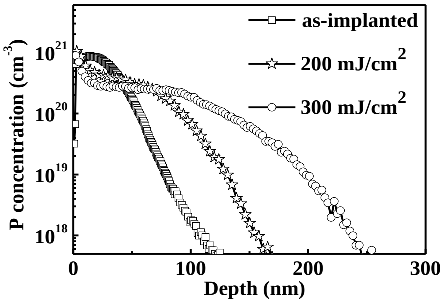

Fig. 1 Concentration profiles (SIMS) of as-implanted and laser annealed samples. (ion implantation – P$^+$, 30 keV, 5x10^{15} cm^{-2}, Laser Fluence – 200 mJ/cm^2, 300 mJ/cm^2).

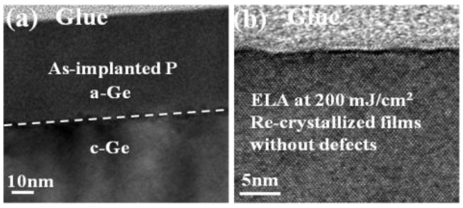

Fig. 2 TEM Micrographs.(ion implantation – P$^+$, 30 keV, 5x10^{15} cm^{-2}, Laser Fluence – 0 and 200 mJ/cm^2).

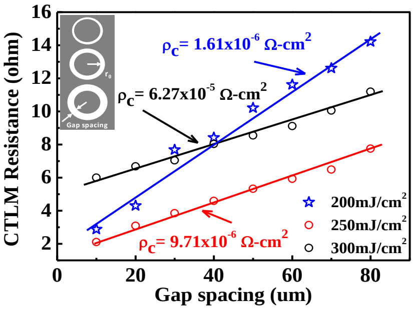

Fig. 3 CTLM resistance measured as a function of CTLM contact pad spacing. The y-intercept is an indication of ρ_C for Al/n$^+$Ge. (ion implantation– P$^+$, 30 keV, 5x10^{15} cm^{-2}, Laser Fluence – 200, 250 and 300 mJ/cm^2).

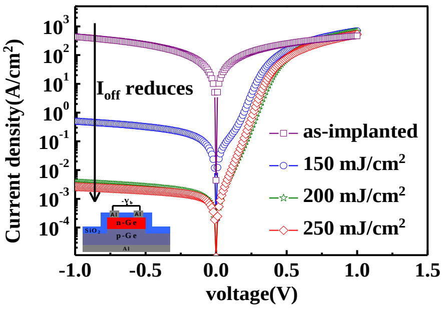

Fig. 4 Effect of laser fuence on the diode's off current. I$_{off}$ decreases and then saturates, as laser fluence increases. (ion implantation – P$^+$, 30keV, 5x10^{15}cm^{-2}, Laser Fluence – 0, 150, 200 and 250 mJ/cm^2).

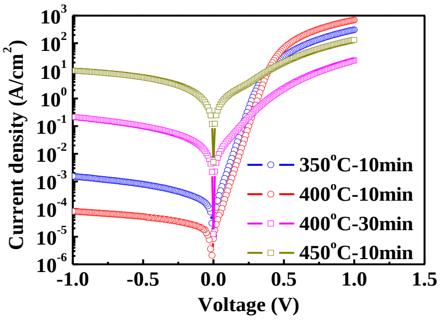

Fig. 5 J-V characteristics of Ge n$^+$/p junction diodes formed by ELA (150 mJ/cm^2) and LTPA at different conditions. (ion implantation – P$^+$, 10 keV, 5x10^{14} cm^{-2}).

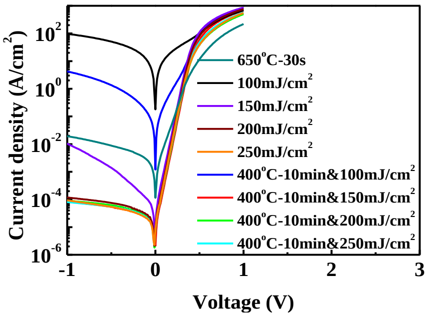

Fig. 6 J-V characteristics of Ge n$^+$/p junction diodes formed by ELA (100, 150, 200 and 250 mJ/cm^2) with LTPA at 400 ^{o}C-10 min. (ion implantation – P$^+$, 10 keV, 5x10^{14} cm^{-2}).

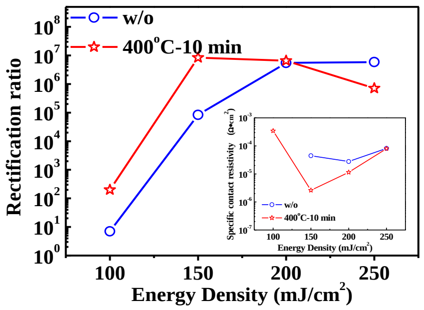

Fig. 7 Rectification ratio of junction diodes as a function of laser fluence with or without LTPA at 400 ^{o}C-10 min. The inset represents the ρ_C of Al/n$^+$Ge at different annealing conditions. (ion implantation – P$^+$, 10 keV, 5x10^{14} cm^{-2}).

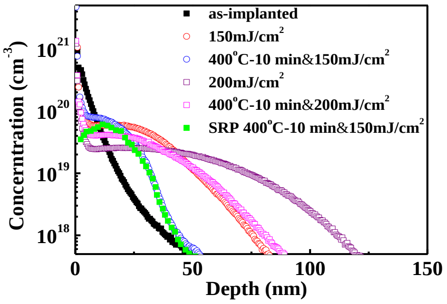

Fig. 8 Concentration profiles (SIMS and SRP) of as-implanted and laser annealed samples. (ion implantation – P$^+$, 10 keV, 5x10^{14} cm^{-2}, Laser Fluence – 150 and 200 mJ/cm^2 with or without LTPA at 400 ^{o}C-10 min).

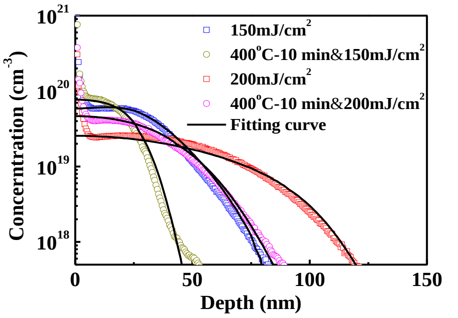

Fig. 9 Concentration profiles (SIMS) of as-implanted and laser annealed samples. (ion implantation –P$^+$, 10 keV, 5x10^{14} cm^{-2}, Laser Fluence – 150 and 200 mJ/cm^2 with or without LTPA at 400 ^{o}C-10 min). The continuous black lines represent best fits from the diffusion model [4].

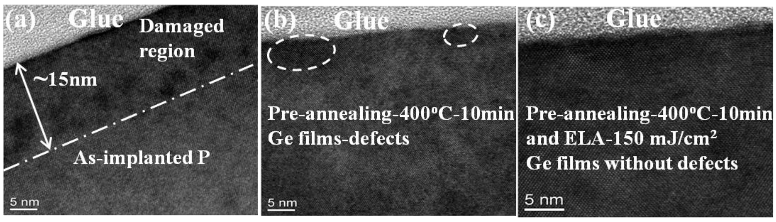

Fig. 10 TEM Micrographs. (ion implantation – P$^+$, 10 keV, 5x10^{14} cm^{-2}).