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Crystallization and Activationof P^+ dope a-Ge film by Atmospheric Pressure Micro-Thermal-Plasma-Jet

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Abstract

We investigated the electrical properties of heavily phosphorus doped Ge films crystallized by micro-thermal-plasma-jet (μ-TPJ). The crystallized Ge films show long lateral grain (~28 μm), a high electron concentration of 2.0 × 10^{20} cm^{-3}, and a high mobility of 150 cm^2/Vs. μ-TPJ crystallized Ge films show good Ohmic contacts with Al electrode. High efficiency activation by performing crystallization and activation simultaneously by μ-TPJ is promising for fabrication of high performance n-type Ge transistors on insulating substrate.

1 Introduction

Fabrication of complementary metal oxide semiconductor (CMOS) on interlayer dielectric films is important to realize 3-dimentional (3D) integration which are promising for higher integrity beyond the scaling limits. Because of the high carrier mobility compared to that of silicon (Si), crystalline-germanium (c-Ge) is very attractive as a new channel material for 3D devices. To form a high quality c-Ge film on insulator, various crystallization techniques such as flash lamp annealing (FLA) and rapid thermal annealing (RTA), have been proposed [1-3]. We have proposed the application of atmospheric pressure DC arc discharge μ-TPJ to the crystallization of amorphous germanium (a-Ge) films [4-5]. Non-doped a-Ge films crystallized by μ-TPJ showed intrinsic p-type conduction and a hole Hall mobility as high as 1070 cm^2/Vs was obtained [6]. P-type thin film transistors (TFT) achieved field effect mobility (μ_{FE}) of 196 cm^2/Vs, ON/OFF ratio (RON/OFF) of 1.4 × 10^4. On the other hand, n-type c-Ge has two major issues; (i) hole generation from defects obstruct heavy n-type doping, (ii) Fermi level pining (FLP) induced by metal induced gap states (MIGS) make it quite difficult to have good metal-n^+Ge Ohmic contacts [7]. In this work, we attempted to induce HSLC by μ-TPJ irradiation on heavily phosphorus doped a-Ge, and investigated the electrical properties.

2 Experimental

80-nm-thick a-Ge films were formed on quartz substrate by plasma enhanced chemical vapor deposition (PECVD) using GeH_4 and H_2 at 200 °C. Phosphorus (P) ion implantation at the dose of 5.0 × 10^{15} cm^{-2} (100 keV) was performed and Ge patterns were formed by dry etching. After 550 nm SiO_2 capping layer formation by remote-PECVD, μ-TPJ was irradiated under atmospheric pressure with supplying power (*P*) of 0.8-1.1 kW, the Ar gas flow rate (*f*) of 1.0 L/min, and scanning speed (*v*) of 600-1800 mm/s for the purpose of crystallization and activation simultaneously. The distance between the plasma source and substrate (*d*) was 2.0 mm (Fig. 1). After formation of contact holes, Al electrodes were formed by evaporation method and TiN electrodes were formed by sputtering to compare contact characteristics. The grain boundaries (GBs) of Ge patterns were investigated by electron backscattering diffraction (EBSD) method.

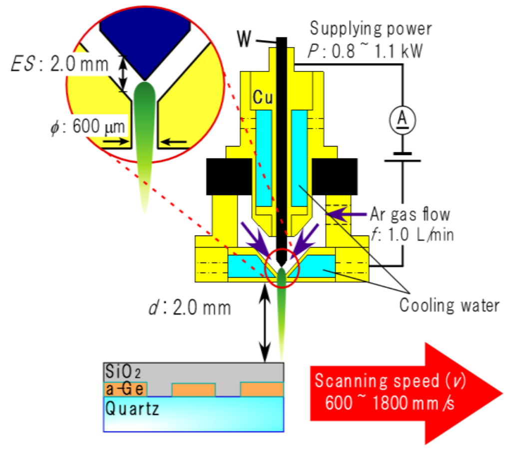

Fig. 1 Schematic diagram of μ-TPJ crystallization of a-Ge films on insulating substrate.

3 Results and Discussion

Figure 2 shows crystal grain boundary map (left) and EBSD (right) images of the HSLC-Ge. The maximum grain size was 28 μm in length and most of the GBs showed Σ3 coincidence site lattice (CSL). Figure 3 shows I–V curves of the μ-TPJ crystallized n^+-Ge films with (a) Al and (b) TiN electrodes. There are reports on TiN electrode showing good Ohmic contact with n-type Ge [8-9]. In the case of μ-TPJ crystallized n^+-Ge films, we obtained good Ohmic contacts not only by TiN electrodes, but by Al electrode also. This result suggests that μ-TPJ crystallization of heavily phosphorus doped a-Ge films induces highly efficient dopant activation and realizes heavy n^+ doping.

Hall effect measurement was performed by van der Pawu method using L = 2 μm and W = 2 μm pattern shown in Fig.

4, and the result is summarized in Fig. 5. Previous report on n^+-Ge formation by FLA showed electron concentration and mobility of ~10^{19} cm^{-3} and ~140 cm^2/Vs, respectively. We obtained ~2.0×10^{20} cm^{-3} and ~150 cm^2/Vs, respectively, in the case of μ-TPJ crystallized n^+-Ge films (Fig. 5). The efficiency of activated electron conc. / phosphorus conc. reached 54 % and high efficiency activation was achieved. Because of the large grain size about ~15 μm compared to that of using FLA, μ-TPJ crystallization seems to induce less defects in active area, which enables heavy n-type doping. These results suggest that the Ge achieve high efficiency activation by performing crystallization and activation simultaneously using μ-TPJ.

4 Conclusion

We succeeded high efficiency activation by μ-TPJ irradiation on a-Ge. Ge films showed large grain size (28 μm) and high electron concentration (2.0×10^{20} cm^{-3}). Ge films with heavy phosphorus doping can form Ohmic contact by Al electrode and achieve high efficiency activation by performing crystallization and activation simultaneously using μ-TPJ.

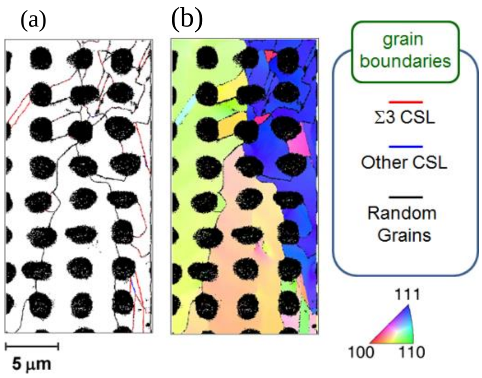

Fig. 2 Grain map (a) and grain boundaries (b) of μTPJ crystallized Ge films.

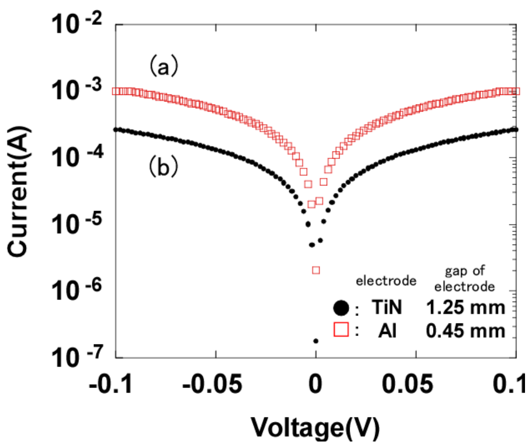

Fig. 3 I–V curves of the μ-TPJ crystallized n+-Ge with by (a) Al and (b) TiN electrode.

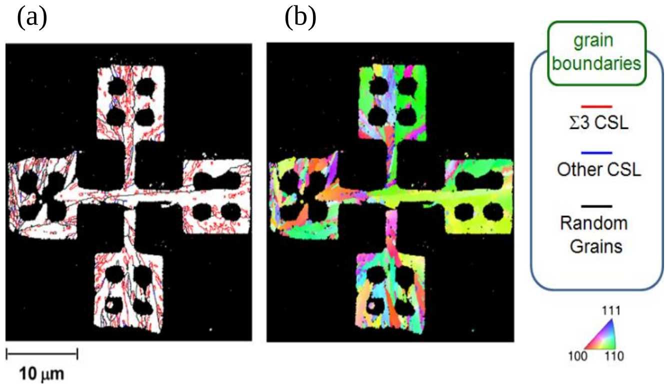

Fig. 4 Grain map (a) and grain boundaries (b) of μTPJ crystallized Ge of Hole effect measurement.

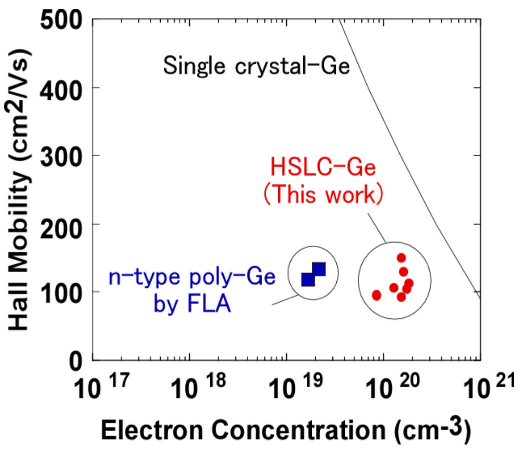

Fig. 5 Hole concentration and Hall mobility of HSLC-Ge.

Acknowledgements

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