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High-Performance P-Channel Polycrystalline-Germanium Thin Film Transistors via Excimer Laser Crystallization and Counter Doping

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Abstract

High-quality Ge films have been fabricated via excimer laser crystallization (ELC). Moreover, the counter-doping (CD) process was employed in order to compensate the holes generated from defects in Ge films. High-performance Ge thin-film transistors (TFTs) with a high field-effect mobility and a large on/off current ratio have been achieved via ELC and CD process.

1. Introduction

Germanium (Ge) has been widely investigated for thin-film transistors (TFTs) applications to realize the sequential CMOS stacking (or so-called 3-D device integration) due to its higher carrier mobility and lower process temperature than those of Si [1]. However, most of Ge films produced by deposition without any doping process used in previous researches were polycrystalline and showed electrical p-type property with a high hole concentration owing to hole generation from defects [2]. This issue would cause a severe device degradation and should be overcome to realize high-performance Ge TFTs [3].

In this work, excimer laser crystallization (ELC) was used to improve the film quality and a counter-doping (CD) process was employed to compensate the holes generated from defects. The property of Ge films and the characteristics of resulting p-channel Ge TFTs would be discussed.

2. Experimental details

A Si substrate with a thick thermal oxide on it was served as the starting substrate. First, an 100-nm-thick Ge film was deposited by HDPCVD. After that, a 40-nm-thick TEOS oxide was deposited by PECVD as the capping oxide. Selected samples were then irradiated using KrF excimer laser (λ = 248 nm) with various energy densities and 40 shots per area in a vacuum chamber at room temperature to perform ELC process. Afterwards, the capping oxide was removed by BOE. Some samples were capped again with a thin TEOS oxide by PECVD and then subjected to phosphorus ion implantation (5×10^{13} cm^{-2} and 50 keV). Dopant activation was then carried out by furnace anneal at 500 °C for 2 h in a N_2 ambience, followed by the removal of the capping oxide to finish the CD process. The material analysis for the resulting Ge films were later investigated by SEM and Hall-effect measurement.

After the CD process mentioned above, the active region was defined for all the TFT samples. After the deposition of a thin TEOS oxide to avoid the channeling effect, the source and drain regions were defined by boron ion implantation (5×10^{15} cm^{-2} and 30 keV) and RTA at 500 °C for 60 s to activate the p-type dopants. After the removal of capping oxide, a sequential deposition of the gate stacked layers was performed with a 50-nm-thick TEOS oxide by PECVD and a 300-nm-thick Al-Si-Cu layer by PVD. The gate definition was then performed by patterning and etching, followed by the deposition of passivation oxide. Finally, contact hole opening and metallization were completed to finish the fabrication of the p-channel Ge TFTs.

3. Results and discussion

Fig. 1 shows the plan-view SEM images for Ge films after Secco etching to reveal the grain structure before and after ELC. It should be noted first that the as-deposited Ge films via HDPCVD were polycrystalline with an average grain size of 90 nm (Fig. 1(a)). Then after ELC a microstructural trend was observed. This trend started from the partial melting regime (Fig 1(b) at 260 mJ/cm^2), and reached the complete melting regime (Fig. 1(d) at 340 mJ/cm^2). Between these two regimes the super-lateral-growth (SLG) phenomenon could be observed after ELC at 300 mJ/cm^2 with a grain size larger than 0.5 μm. The evolution of the grain structure with increasing laser energy density for Ge films is similar to that for Si films [4].

Fig 2 reveals the carrier concentration extracted by the Hall effect measurement for Ge films after ELC at various laser energy densities. The hole concentration was first measured higher than 10^{19} cm^{-3} in the as-deposited Ge films without CD. A notable decrease of hole concentration was observed after ELC. This means that the melting and regrowth process during ELC could effectively reduce the intra-grain defects and improve the film quality. In addition, a minimal hole concentration was observed for samples via ELC at 300 mJ/cm^2 due to the fact of SLG phenomenon. The carrier concentrations for Ge films after CD process are also shown in this figure. The type of the majority carrier was successfully converted to n-type after ELC. Note that the implant dose was set the same for all samples. Hence, the activated P atoms could overcome the number of vacancy defects well as the generated hole concentration before CD was low.

The transfer characteristics at V_{DS} = -0.1 V of various kinds of p-channel Ge TFTs were shown in Fig. 3. TFTs produced on the as-deposited Ge films without CD did not possess any typical transfer characteristics due to extremely high hole concentration (higher than 10^{19} cm^{-3}) in Ge films. Ge TFTs fabricated by ELC at 300 mJ/cm^2 without CD showed an on/off current ratio of about 8.5, but the off leakage current was still high. In contrast, the Ge TFTs fabricated by ELC at 300 mJ/cm^2 with CD attained a typical transfer characteristics with a high current ratio of 1.1×10^3 since the type of the majority carrier in Ge films was well converted to n-type. Fig 4 shows the dependence of the field-effect mobility (μ_{FE}) and the on/off current ratio (I_{ON}/I_{OFF}) on the device dimension for Ge TFTs fabricated by ELC with CD. TFTs with $W = L = 0.5$ μm attained a high μ_{FE} (from 90 to 185 cm^2/V-s) and a large I_{ON}/I_{OFF} (larger than 10^3). Nevertheless, both μ_{FE} and I_{ON}/I_{OFF} dramatically degraded with the increasing device dimension since there were more grain boundaries within the channel region. It should be noted that though the Ge films were n-type as mentioned above, higher off current was still observed for TFTs with larger device dimension due to the high leakage current induced by the trap states located at the grain boundaries near the drain junction [5].

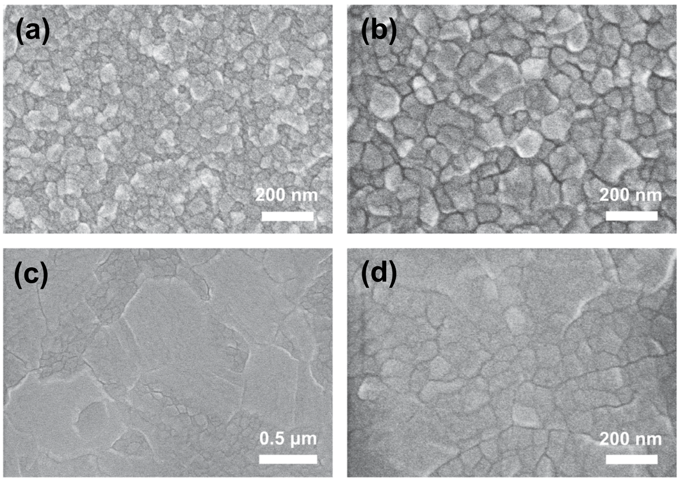

Fig. 1 Plan-view SEM images after Secco etching for (a) as-deposited Ge films, and for samples via ELC at (b) 260 mJ/cm^2, (c) 300 mJ/cm^2, and (d) 340 mJ/cm^2, respectively.

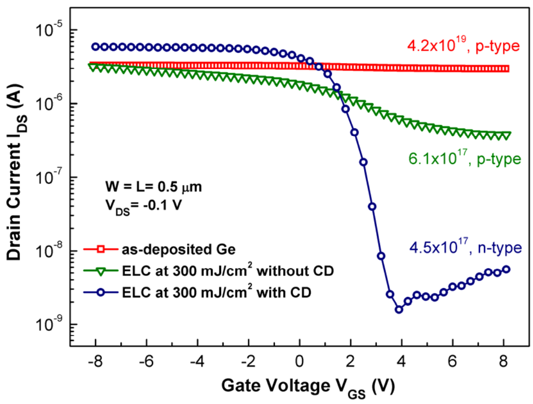

Fig. 3 Transfer characteristics of various kinds of p-channel Ge TFTs. The type and the concentration of the majority carrier in Ge films for each samples extracted by Hall effect measurement are denoted beside the corresponding I_D-V_G curves.

4. Conclusions

In summary, the ELC process could effectively reduce the hole concentration in Ge films generated from defects. The CD process with a suitable implant dose could successfully converted poly-Ge films after ELC to n-type. High-performance poly-Ge TFTs were achieved via the combination of ELC and CD and attained a high μ_{FE} (up to 185 cm^2/V-s) and a large I_{ON}/I_{OFF} (larger than 10^3).

Acknowledgements

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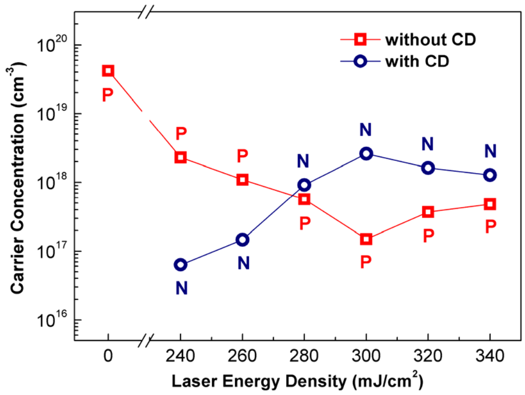

Fig. 2 Carrier concentration extracted by Hall effect measurement for Ge films after ELC at various energy densities with or without CD. Note that the types of the majority carrier for each samples are denoted beside the corresponding points, and the result for as-deposited Ge films is shown at 0 mJ/cm^2.

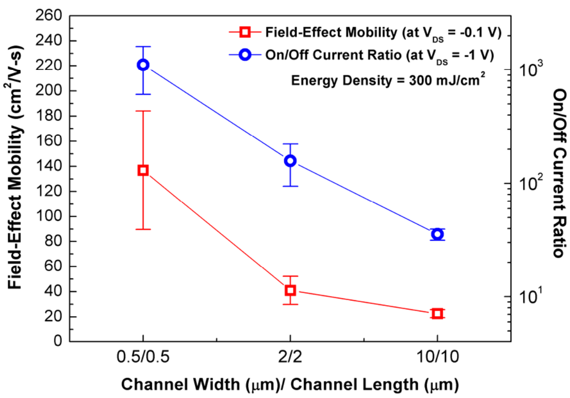

Fig. 4 Dependence of the μ_{FE} and I_{ON}/I_{OFF} on the device dimension for the Ge TFTs fabricated by ELC at 300 mJ/cm^2 with CD. Note that the μ_{FE} and I_{ON}/I_{OFF} are extracted from the transfer characteristics at V_{DS} = -0.1 V and -1 V, respectively.