

Effects of Grain Boundary and Counter Doping on P-Channel Polycrystalline Germanium Thin-Film Transistors via Continuous-Wave Laser Crystallization

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Abstract

High-quality polycrystalline germanium (poly-Ge) films with the largest grain size of 1.5 μm have been fabricated via continuous-wave laser crystallization (CLC). Moreover, the counter-doping (CD) process was used to convert the p-type poly-Ge films into n-type poly-Ge films for realizing p-channel poly-Ge TFTs. The grain boundary and CD effects were investigated by thin-film transistors (TFTs) with different channel dimensions and various CD doses. Consequently, high-performance p-channel poly-Ge TFTs with $W_{\text{eff}}/L = 0.9/0.5 \mu\text{m}$ have been achieved via CLC and a relatively low CD dose.

1. Introduction

Germanium (Ge) has been widely investigated for thin-film transistors (TFTs) applications to realize the three-dimensional (3-D) device integration (or so-called monolithic 3-D integrated circuits) due to its high carrier mobility and low process temperature than those of Si [1]. However, most Ge films without any doping process were polycrystalline Ge (poly-Ge) in previous researches of TFTs and exhibited p-type property with high hole concentration owing to hole generation from defects in poly-Ge films [2]. This issue thereby cause poor electrical characteristics and should be overcome to realize high-performance p-channel poly-Ge TFTs [3].

In this work, continuous-wave laser crystallization (CLC) was used to improve the crystallinity of poly-Ge and a counter-doping (CD) process was employed to convert the p-type poly-Ge films into n-type poly-Ge films. The material property of poly-Ge films and the characteristics of p-channel poly-Ge TFTs will be investigated.

2. Experimental details

First, a 200-nm-thick poly-Ge film was deposited by HDPCVD on a Si substrate with a thick thermal oxide. Then, a 50-nm-thick TEOS oxide was deposited by PECVD as the capping oxide. Selected samples were then irradiated using continuous-wave laser ($\lambda = 532 \text{ nm}$) with laser power of 5.6 W and scanning speed of 30 mm/s at room temperature to perform CLC process. After CLC process, the capping oxide was removed by BOE. Several samples were capped again with a 10-nm-thick TEOS oxide by PECVD. Subsequently, the phosphorus ion implantation at an energy of 70 keV with various dopant doses of $5 \times 10^{12} \text{ cm}^{-2}$, $1 \times 10^{13} \text{ cm}^{-2}$, and $5 \times 10^{13} \text{ cm}^{-2}$ were utilized

for the CD process. CD dopants activation were then carried out by furnace annealing at 500 $^{\circ}\text{C}$ for 2 h in a N_2 ambience, followed by the removal of the capping oxide to complete the CD process. The material analysis for the resulting poly-Ge films were investigated by SEM and Hall-effect measurement.

After CD process, the active region was defined for all the TFT samples. After the deposition of a 10-nm-thick TEOS oxide to avoid the channeling effect, the source and drain (S/D) regions were defined by boron ion implantation at an energy of 50 keV with a dose of $5 \times 10^{15} \text{ cm}^{-2}$ and RTA at 500 $^{\circ}\text{C}$ for 60 s to activate the S/D 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 a 500-nm-thick passivation oxide. Finally, contact hole opening and metallization were performed to complete the fabrication of the p-channel poly-Ge TFTs.

3. Results and discussion

Fig. 1 shows the plan-view SEM images of the Secco-etched HDPCVD poly-Ge films and Secco-etched CLC poly-Ge films after CLC at 5.6 W. It should be noted that the HDPCVD poly-Ge were polycrystalline with an average grain size of about 100 nm, as shown in Fig. 1(a). Furthermore, the grain size of CLC poly-Ge significantly increased by CLC process at 5.6 W, as shown in Fig. 1(b). This point out that the melting and solidification (recrystallization) during CLC at enough energy of 5.6 W could effectively increase the grain size of poly-Ge films. For the optimal result, the largest grain size of 1.5 μm was achieved through CLC process.

Fig. 2(a) reveals the carrier concentration extracted by the Hall-effect measurement for HDPCVD poly-Ge films and CLC poly-Ge films after CLC at 5.6 W. The hole concentration of HDPCVD poly-Ge film without CD was first measured higher than 10^{19} cm^{-3} . In contrast, the hole concentration notably decreased to a value about 10^{17} cm^{-3} after CLC at 5.6 W. This means that the melting and recrystallization process during CLC could effectively eliminate the grain boundaries and intra-grain defects. In addition, the carrier type and carrier concentration were observed for the CLC poly-Ge doped with various CD doses, as shown in Fig. 2(b). As can be seen, the CLC poly-Ge films via CD dose of $5 \times 10^{12} \text{ cm}^{-2}$ still showed p-type behavior, although

their hole concentration could be lower than undoped ones. However, the CLC poly-Ge films could be converted to n-type films via CD doses of $1 \times 10^{13} \text{ cm}^{-2}$ and $5 \times 10^{13} \text{ cm}^{-2}$. These n-type films could be used to realize p-channel poly-Ge TFTs.

Fig. 3 shows the transfer characteristics and field-effect mobility (μ_{FE}) of the p-channel poly-Ge TFTs with different channel dimensions ($W_{eff}/L = 0.9/0.5 \text{ }\mu\text{m}$ and $W_{eff}/L = 2.4/2.0 \text{ }\mu\text{m}$) and fabricated by CLC at 5.6 W and CD dose of $1 \times 10^{13} \text{ cm}^{-2}$. The p-channel poly-Ge TFTs with $W_{eff}/L = 0.9/0.5 \text{ }\mu\text{m}$ attained a superior μ_{FE} of $509.5 \text{ cm}^2/\text{V-s}$ and a higher on/off current ratio (I_{ON}/I_{OFF}) of 3.1×10^3 than those p-channel poly-Ge TFTs with $W_{eff}/L = 2.4/2.0 \text{ }\mu\text{m}$. The p-channel poly-Ge TFTs with $W_{eff}/L = 0.9/0.5 \text{ }\mu\text{m}$ exhibited superior electrical characteristics owing to the few potential barrier at grain boundaries in the relatively small channel region [4]. The carriers in the channel were obstructed by the potential barrier at grain boundaries.

Fig. 4 shows the transfer characteristics and μ_{FE} of the p-channel poly-Ge TFTs with $W_{eff}/L = 0.9/0.5 \text{ }\mu\text{m}$ and fabricated by CLC at 5.6 W and various CD doses of 1×10^{13} and $5 \times 10^{13} \text{ cm}^{-2}$. The p-channel poly-Ge TFTs at a CD dose of $1 \times 10^{13} \text{ cm}^{-2}$ attained a superior μ_{FE} of $509.5 \text{ cm}^2/\text{V-s}$ and a higher I_{ON}/I_{OFF} of 3.1×10^3 , while those at a CD dose of $5 \times 10^{13} \text{ cm}^{-2}$ showed a μ_{FE} of $417.3 \text{ cm}^2/\text{V-s}$ and a I_{ON}/I_{OFF} of 1.7×10^3 , respectively. The p-channel poly-Ge TFTs with a CD dose of $1 \times 10^{13} \text{ cm}^{-2}$ exhibited high μ_{FE} owing to the relatively low concentration of CD dopants, which are considered as ionized impurity scattering centers in the channel region [5]. The lower off-state current can be ascribed to the minor band-to-band tunneling current since a low electric field formed near the drain junction can be attained for the channel at a lower CD dose of $1 \times 10^{13} \text{ cm}^{-2}$.

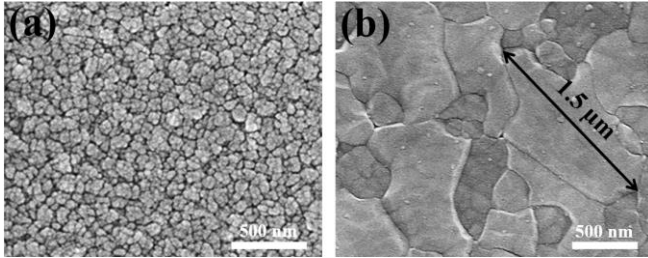


Fig. 1. The plan-view SEM images of the (a) Secco-etched HDPCVD poly-Ge films and (b) Secco-etched CLC poly-Ge films.

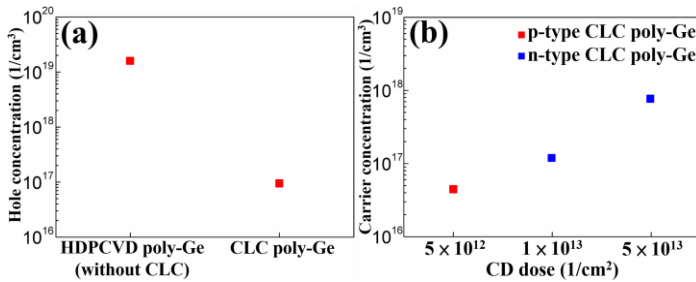


Fig. 2. The carrier concentration extracted by the Hall-effect measurement for (a) HDPCVD poly-Ge films, CLC poly-Ge films, and (b) CLC poly-Ge films doped with various CD doses.

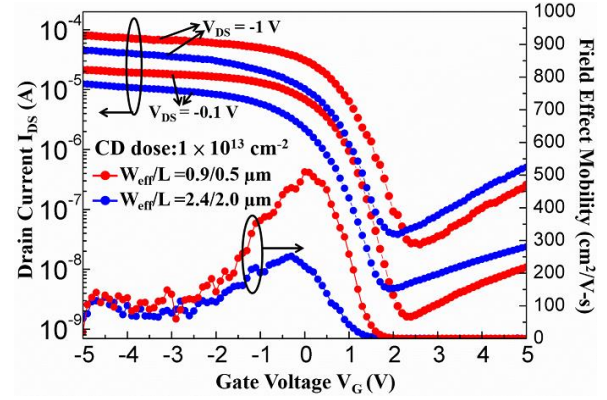


Fig. 3. The transfer characteristics and μ_{FE} of the p-channel poly-Ge TFTs with different channel dimensions ($W_{eff}/L = 0.9/0.5 \text{ }\mu\text{m}$ and $W_{eff}/L = 2.4/2.0 \text{ }\mu\text{m}$) and fabricated by CLC at 5.6 W and CD dose of $1 \times 10^{13} \text{ cm}^{-2}$.

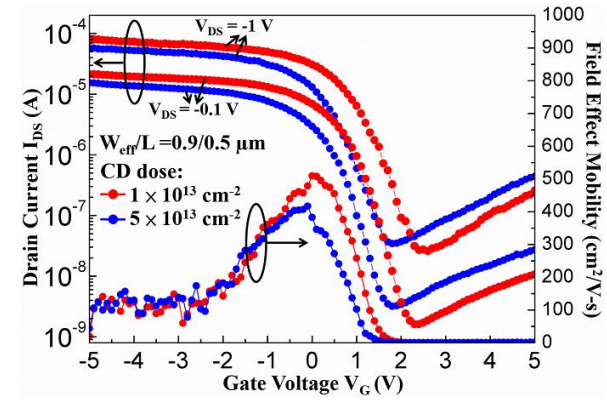


Fig. 4. The transfer characteristics and μ_{FE} of the p-channel poly-Ge TFTs with $W_{eff}/L = 0.9/0.5 \text{ }\mu\text{m}$ and fabricated by CLC at 5.6 W and various CD doses of 1×10^{13} and $5 \times 10^{13} \text{ cm}^{-2}$.

4. Conclusions

In summary, the CLC process could effectively reduce the hole concentration generated from defects in poly-Ge films. For the optimal result, the largest grain size of $1.5 \text{ }\mu\text{m}$ was achieved through CLC process. Moreover, the CD process with a light dose of $1 \times 10^{13} \text{ cm}^{-2}$ could successfully converted p-type CLC poly-Ge films to n-type CLC poly-Ge films. Consequently, high-performance p-channel poly-Ge TFTs were achieved via the combination of CLC and CD with light dose and attained a high μ_{FE} (up to $509 \text{ cm}^2/\text{V-s}$) and a high I_{ON}/I_{OFF} (higher than 10^3).

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References

- [1] C.-C. Yang *et al.*, IEDM Tech. Dig., 2014, p. 410.
- [2] K. Usuda *et al.*, Appl. Phys. Express 7 (2014) 056501.
- [3] Y. Kamata *et al.*, VLSI Symp. Tech. Dig., 2013, p. T94.
- [4] A. T. Voutsas, IEEE Trans. Electron Devices 50 (2003) 1494.
- [5] M. B. Prince, Phys. Rev. 92 (1953) 681.