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Low Temperature (< 130 °C) Formation of Crystalline Ge Film on Insulator by Stress Stimulated GILC

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Abstract

The effect of stress stimulation on gold induced lateral crystallization (GILC) of amorphous Ge on insulator was investigated. As a result, the GILC was significantly enhanced by using compressive residual stress in TEOS-SiO_2. In addition, it was found that the annealing temperature necessary to cause the GILC for short annealing time (60 min) can be decreased to 130 °C. We have demonstrated that GILC enhancement was caused by the stress stimulation contributed to bond rearrangement and Au easily diffused into Ge.

1. Introduction

Low temperature formation of crystalline Ge on insulating substrates are widely investigated to fabricate integrated circuits and display containing high performance thin-film transistors (TFTs) on an identical insulating flexible substrate [1-3]. However, thermal annealing above 200 °C is necessary to obtain crystalline Ge on insulating substrate by Gold (Au) induced lateral crystallization (GILC) method [3]. This annealing temperature is higher than the softening temperature of low-cost insulating flexible substrates (~ 150 °C). Thus, a new technique to reduce the crystallization temperature is strongly required. In present work, we have examined that the stress stimulated GILC of amorphous Ge on insulating substrate in order to decrease the crystallization temperature.

2. Experimental Procedure

Figure 1 schematically shows the experimental procedure. Cz n-type Si (100) substrates were covered with thermally oxidized SiO_2 films (thickness: 250 nm) after RCA cleaning. Then, amorphous Ge films (thickness 100 nm) were deposited on SiO_2 / Si substrate using DC magnetron sputtering system with an Ar plasmas at room temperature. And then, Au films (thickness: 200 nm, diameter: 3 mm ϕ) were patterned using a metal mask during the evaporation on amorphous Ge films in a vacuum chamber (base pressure: 1.5 x 10^{-2} Pa). Finally, tetraethyl-orthosilicate SiO_2 (TEOS-SiO_2) films (thickness: 500 nm) were deposited on patterned-Au / amorphous Ge / SiO_2 / Si substrates using a PD-100ST plasma chemical vapor deposition (CVD) system (samco Inc.) at 130 °C for 5 min (deposition rate: 100 nm / min). Here, TEOS-SiO_2 films have residual stress whose amount and direction (tensile or compressive) can be easily adjusted by CVD process conditions. We expected that weakening the Ge-Ge bond strength will decrease the activation energy and result in crystal nucleation at very low temperature. The samples were annealed below 300 °C for 60 min in N_2 ambient. After annealing, GILC of amorphous Ge on insulating substrate was evaluated by Nomarski optical microscopy, Raman spectroscopy and energy dispersive X-ray spectroscopy (EDX).

3. Results and Discussion

Figure 2 shows Nomarski optical micrographs of the samples without and with compressive stressed TEOS-SiO_2 cap layer, and Raman spectra at each region after annealing at 150 °C for 60 min. In the case of samples without TEOS-SiO_2 and covered with stress-free (almost 0 MPa) TEOS-SiO_2 cap layer are shown in Fig. 2(a) and (b), GILC for amorphous Ge on insulating substrates were not observed due to the observation of broad Raman peak corresponding to Ge-Ge bonds in amorphous Ge around 270 cm^{-1} at “B region” shown in Nomarski optical micrographs. By contrast, in the case of a sample covered with compressive stressed (200 MPa) TEOS-SiO_2 cap layer, the observation of a sharp Raman peak corresponding to Ge-Ge bonds in crystalline Ge was found around 300 cm^{-1} at “C region” shown in Fig. 2 (c). Therefore, GILC for amorphous Ge on insulating substrate was clearly observed after low temperature annealing.

GILC lengths calculated from Raman mapping results are summarized in Fig. 3 as a function of annealing temperature. The GILC lengths increased with increasing annealing temperature. There was no change in the isochronal characteristics of the samples without and with stress free (almost 0 MPa) TEOS-SiO_2 cap layer. This result indicates that only covering with TEOS-SiO_2 cap layer is not enough to realize the low temperature crystallization. On the other hand, GILC was significantly enhanced by using compressive stressed (200 MPa) TEOS-SiO_2 cap layer. In addition, low temperature crystallization below 130 °C became possible by utilizing compressive stress. These results suggest that applying extrinsic energy is effective for the decreasing of crystallization temperature for amorphous semiconductor on insulating substrate.

In order to investigate the mechanism of GILC enhancement by utilizing compressive stress, EDX measurement was

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performed. EDX line scan profiles of Au atoms of the samples without and with compressive stressed (200 MPa) TEOS-SiO_2 cap layer after annealing at 200 °C for 60 min are shown in Fig. 4 (a) and (b), respectively. Au atomic concentration gradually decreased from Au pattern edge toward Ge region. This result indicates that Au atoms diffusion into Ge region occurred in both of samples with and without compressive stress. Particularly, when compressive stress was utilized, it is found that Ge region contained more Au atoms compared to the sample without TEOS-SiO_2 cap layer. It suggests that the critical temperature of GILC can be decreased due to modulation of Ge-Ge bond strength by the combination of Au introduction and compressive stress stimulation. Moreover, it is known that the diffusion species concentration depends on the error function. We have examined the numerical calculation for EDX line scan profiles using error function. The estimated diffusion coefficients after annealing for 60 min are summarized as a function of annealing temperature shown in Fig. 4 (c). It is found that the diffusion coefficient was increased using compressive stressed (200 MPa) TEOS-SiO_2 cap layer. Hence, it is estimated that GILC lengths are expanded because the Au atoms are easily diffused far away from the Au pattern edge.

4. Summary

We have investigated the stress stimulation effect on GILC of amorphous Ge on insulating substrate. The results demonstrated that the GILC of amorphous Ge on insulating substrate was significantly enhanced by using residual compressive stress of TEOS-SiO_2 films. Furthermore, the critical temperature to cause GILC was decreased to 130 °C. This enhancement was attributed to the weakening the Ge-Ge bond strength and the ease of Au atom diffusion into Ge region. These results suggest that low temperature formation of crystalline Ge becomes possible below the softening temperature of low-cost insulating flexible substrates.

Acknowledgements

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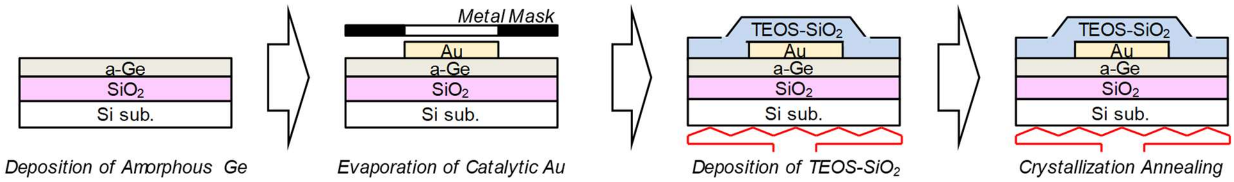

Fig. 1 Experimental procedure

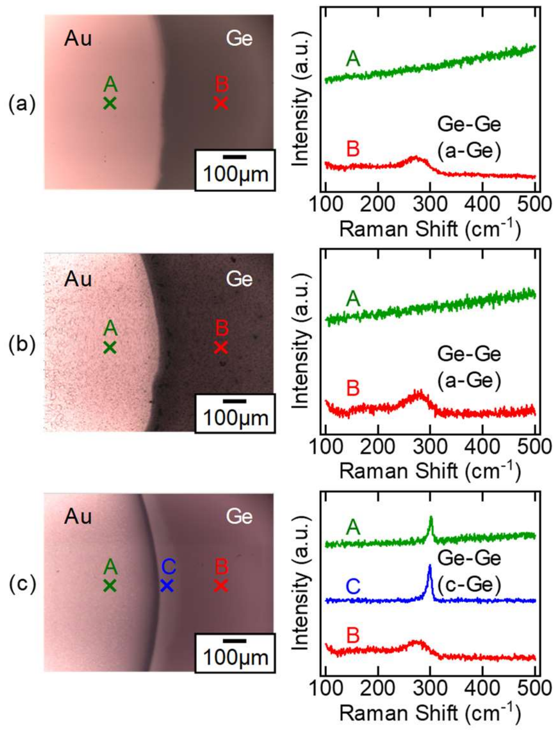

Fig. 2 Nomarski optical micrographs of the samples and Raman spectra after annealing at 150 °C for 60 min
(a) w/o TEOS-SiO_2 (b) w/ stress-free TEOS-SiO_2
(c) w/ stressed TEOS-SiO_2.

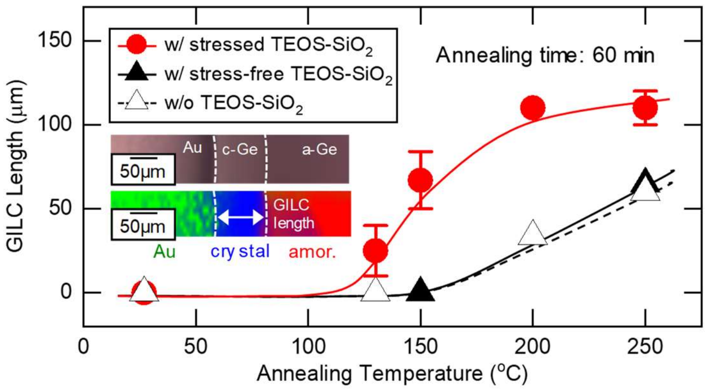

Fig. 3 Dependence of GILC length on annealing temperature.

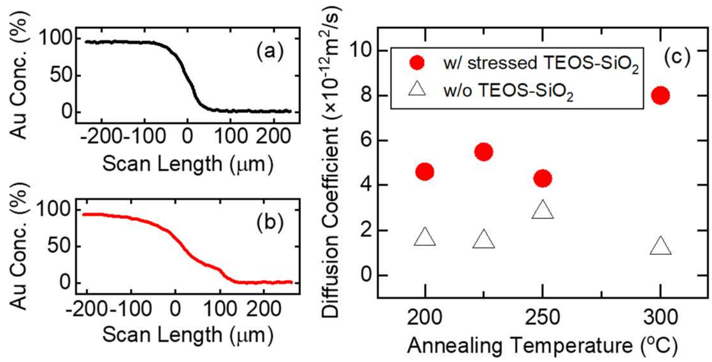

Fig. 4 EDX line scan profiles of the samples (a) w/o TEOS-SiO_2
(b) w/ stressed TEOS-SiO_2 after annealing at 200 °C for 60 min.
(c) Diffusion coefficients of the samples after annealing for 60min.