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# Growth of preferred orientation Ge film using inductively coupled plasma-assisted DC magnetron sputtering at low temperature

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ABSTRACT

Growth of low-temperature metal-free crystallized Ge film was investigated using inductively coupled plasma-assisted DC magnetron sputtering. The films were deposited both without and with inductively coupled plasma. The films deposited by a conventional DC magnetron sputtering system had randomly oriented crystalline structures. However, the addition of inductively coupled plasma developed crystal phase from an amorphous to a preferred oriented crystalline with increasing sputtering power. The optical band gaps of the amorphous and crystalline phases were 0.96 eV and 0.7 eV, respectively.



## 1. Introduction

Low-temperature deposition of polycrystalline (poly) Ge thin films on amorphous substrates has been attracting considerable attention from the viewpoint of thin-film transistors (TFTs) [1,2] and solar cells [3,4]. Since Ge thin films have a higher carrier mobility and lower onset crystallization temperature than Si thin films, Ge thin films have been investigated as a potential material that can replace Si TFTs. In addition to a TFT application, Ge thin films with a low band gap of 0.67 eV can absorb long-wavelength light, resulting in an enhancement of the optical absorption capability over a wider wavelength range.

Several techniques have been pursued to obtain good crystalline Ge thin films on insulators, such as rapid-melt growth, laser annealing, solid-phase crystallization, and metal-induced crystallization [5–10]. Among them, DC magnetron sputtering is an attractive technique because of the following reasons: (1) Its low deposition temperature; (2) The resulting thin films exhibit uniform thickness, strong adhesion, and high mechanical durability; (3) The films can possibly be applied to large-size substrates.

In this study, the Ge thin films were deposited on glass by DC magnetron sputtering both without and with an inductively coupled plasma (ICP) source. Under the ICP-assisted DC magnetron sputtering system, high-density low-energy ion flux can be created at the region between the substrate and the sputtering cathode. This enables deposition to be carried out at a lower power and a lower substrate temperature. Here, we report on the influence of sputtering power and ICP on the structural evolution of the Ge thin films, and we discuss and compare the results of different characterization methods.

## 2. Experimental details

A schematic diagram of the ICP-assisted DC magnetron sputtering system is shown in Fig. 1. A radio frequency (13.56 MHz) ICP system with a linear-type internal antenna, which was made of copper tube and shielded by an insulator of high-purity alumina, was used to obtain high-density plasma with good uniformity. A Ge (99.999%) target with a 3 inch diameter was mounted on the DC magnetron cathode. After the chamber was evacuated to a base pressure of less than $6.67 \times 10^{-4}$ Pa, Ar with a working pressure and flow rate of 0.93 Pa and 20 sccm, respectively, was introduced into the chamber. Ge thin films were deposited on a $1.5 \times 1.5$ $cm^2$ glass (Eagle 2000) substrate. The growth rates of films were obtained by measuring thickness of deposited films using a surface profiler (Alpha Step, Tencor AS-200). The entire film thickness was fixed to approximately 250 nm ($\pm$10 nm) by controlling working time, and it was rechecked. The substrate temperature was around 210 °C by additional substrate heating. Then the substrate temperature subsequently increased up to 230 °C due to the bombardment of the various energetic particles, such as sputtered neutral species, reflected Ar atoms, and plasma ions. In this study, ICP source and sputtering power were chosen as the main operating parameters. In one series of experiments, the deposition of Ge films was carried out at various target current without ICP

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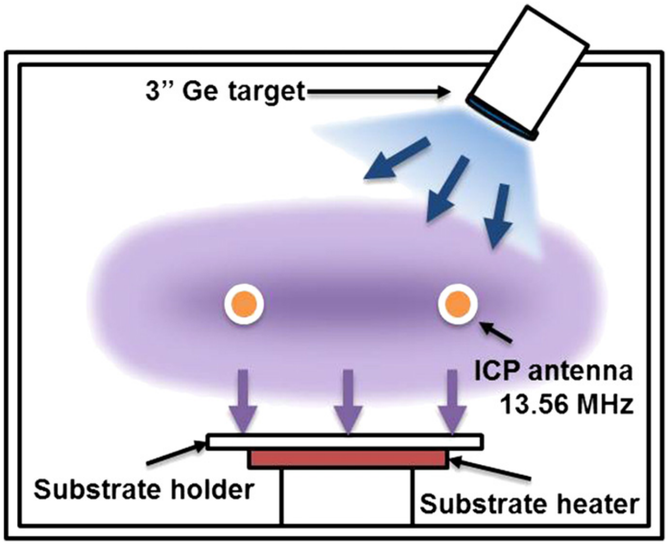


**Fig. 1.** Schematic diagram of the experimental apparatus.

source. In another series of experiments, the ICP power was kept at 200 W. Typical experimental conditions are summarized in Table 1.

The crystal phases of the Ge thin films were then analyzed by X-ray diffraction (XRD, D/MAX-2500, Rigaku, Cu Kα source). All the patterns were recorded between 25° and 70° with a scan rate of 2.25°/min. The Cu Ka line of a conventional X-ray source powered at 40 kV and 40 mA was used. The morphology, structure, and lattice of the samples were examined by field emission scanning electron microscopy (FE-SEM) and transmission electron microscopy (TEM, Tecnai F20). For FE-SEM measurements, the apparatus was a JEOL JSM-7500 F working at 15 keV. The optical transmittance/reflectance spectra of the samples in the wavelength of approximately 200–2000 nm were measured by using a UV–vis. spectrometer (PerkinElmer, LAMBDA 19 #B050-0874).

## 3. Results and discussion

Fig. 2 shows the XRD patterns of the Ge thin films as a function of the DC power: (a) without an ICP source and (b) with an ICP source. As shown in Fig. 2(a), the film deposited at 319 V without an ICP source (S-1) shows diffraction peaks at around 28°, 47°, and 54°, corresponding to the (111), (220), and (311) crystal planes of Ge, respectively. The film consisted of randomly oriented polygonal grains. In addition, the substrate temperature of 230 °C was sufficient to growth of crystallized Ge thin film in the DC magnetron sputtering system. It can be seen that the onset temperature of crystalline structure growth required for Ge-film-deposition DC magnetron sputtering is lower than that required for Ge-film-deposition by RF magnetron sputtering and the solid-phase crystallization process [8,11]. In the DC sputtering process,

**Table 1**
Typical experimental conditions.

| Sample | ICP | Target current (mA) | Target voltage (V) | Sputtering power (W) | Growth rate (nm/min) | Structure |
|---|---|---|---|---|---|---|
| **S-1** | Off | 55 | 319 | 17.55 | 1.33 | Random orientation |
| **S-2** | | 110 | 375 | 41.25 | 3.45 | Random orientation |
| **S-3** | | 200 | 395 | 79.00 | 7.17 | Random orientation |
| **ICP-S-1** | On | 110 | 280 | 30.80 | 2.9 | Amorphous |
| **ICP-S-2** | (200 W) | 150 | 340 | 51.00 | 4.6 | Amorphous |
| **ICP-S-3** | | 200 | 371 | 74.20 | 7.1 | Preferred orientation |

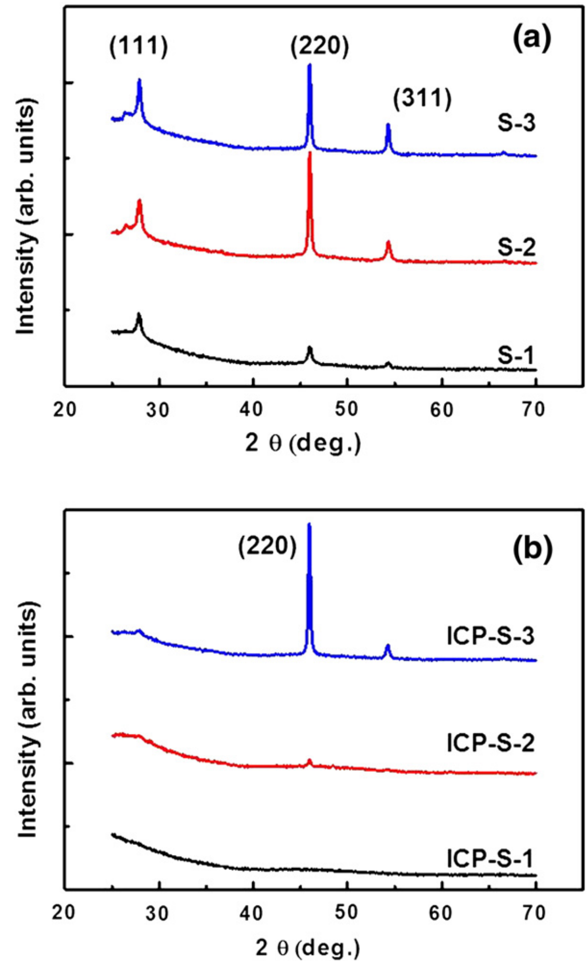


**Fig. 2.** XRD patterns of Ge thin films on glass substrate as a function of DC sputtering power: (a) without ICP source and (b) with ICP source.

the adatom mobility and surface diffusion are mainly controlled by substrate temperature and energetic particle bombardment. The surface mobility, which affects the onset temperature of crystalline film growth, is enhanced as the substrate temperature or the particle bombardment energy increases. The surface of Ge thin films during the sputtering process was bombarded by sputtered Ge atoms and energetic neutral Ar atoms, which were neutralized and reflected at the sputtering target; the mobile adatoms received additional randomized momentum. The crystalline film growth and grain growth processes were accelerated by increased adatom mobility [12]. Upon increasing the Ge target voltage to 375 V, the intensity of the (220) orientation increased dramatically, whereas that of the (111) orientation increased only slightly. The intensity of all peaks flattened out at higher voltages, which means that the increasing kinetic energy of the energetic particles does not necessarily result in crystalline growth enhancement above a threshold voltage. In contrast to the non-ICP sputtering, ICP-assisted sputtering is influential in aligning film. The film deposited at 280 V (ICP-S-1) revealed amorphous behavior as no characteristic peaks (Fig. 2b). When the target voltage was increased to 340 V, the diffraction peak appeared at approximately 47° with small intensity and the film displayed (220) preferred orientation. The intensity of the (220) orientation gradually increased with the increase in the target voltage to 371 V. Then the peak intensity of the (220) continues to increase as increasing sputtering voltage. The development of the preferred orientation may be caused by a channeling effect, which is common in an ion beam-assisted process [13,14]. The film orientation corresponding to the most open channeling direction is favored due to anisotropy in ion irradiation collision cascades. The ion energy in open channeling