Crystallisation and mechanical properties of $Si_{1-x}Ge_x$ thin films

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Introduction: Pure silicon and germanium have been extensively used in micro-electronics applications while $Si_{1-x}Ge_x$ thin film has not received much attention. The ability to control the Si to Ge ratio gives an additional avenue to control the properties of the resulting material. This study investigates mechanical properties of biased target ion beam sputtered $Si_{1-x}Ge_x$ ($0 \leq x \leq 1$) thin films upon annealing as well as their crystallistion process.

Experimental procedures: 500 nm thick $Si_{1-x}Ge_x$ ($0 \leq x \leq 1$) thin films were sputtered onto (100) silicon substrates using low energy Ar ion beam source. Post deposition annealing was performed under vacuum condition for 30 minutes at ascended temperatures. Energy-dispersive X-ray spectroscopy (EDS) was used to determine thin film atomic content. Film crystallisation state was obtained through grazing incidence angle X-ray diffraction (GIXRD) method and Transmission electron microscopy (TEM).

Results: Fig. 1 shows the Young's modulus and hardness of the films determined by means of nano-indentation**.** GIXRD spectra (Fig. 2) indicates all the as-deposited $Si_{1-x}Ge_x$ are amorphous. In Fig. 3, As-deposited $Si_{1-x}Ge_x$ thin films are highly compressive and the stress reduces linearly as a function of increasing Ge percentage. The observed levels of compressive stress were successively reduced after annealing at temperatures increasing successively from 200°C up to 600°C for 30 minutes because of structural relaxation process. Pure germanium sample was annealed at a maximum temperature of 400°C due to film stability issue. The prepared $Si_{1-x}Ge_x$ thin films are amorphous and become crystallised after annealing at 700°C according to the GIXRD spectra (Fig. 4). The intensity of Reflection peaks, (1,1,1), (2,2,0) and (3,1,1), increases with increasing Ge content, which indicates that high germanium to silicon ratio will increase film crystallisation degree upon annealing. Fig.5 shows TEM images of a 500nm thick $Si_{0.3}Ge_{0.7}$ thin film annealed at 700°C. The bright part is amorphous and dark part is polycrystalline SiGe.

Conclusion

High compressive stress values are observed in all as-deposited $Si_{1-x}Ge_x$ samples with the stress levels being inversely proportional to the Ge content. These stress levels were reduced due to structural relaxation upon annealing. All the $Si_{1-x}Ge_x$ thin films crystallised after annealing at 700°C, where the crystallisation degree increases with higher Ge composition.

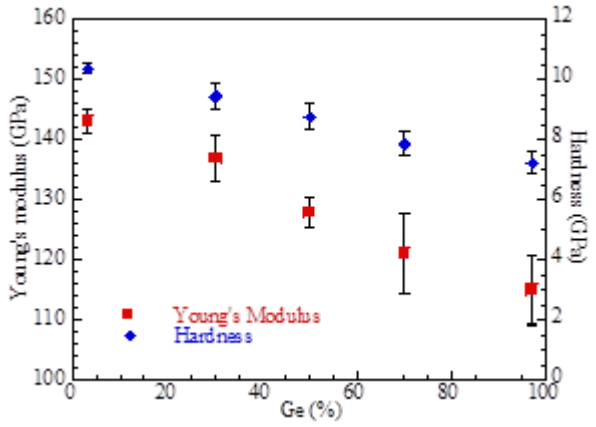

Fig.1 Young's modulus and hardness of $Si_{1-x}Ge_x$ thin films

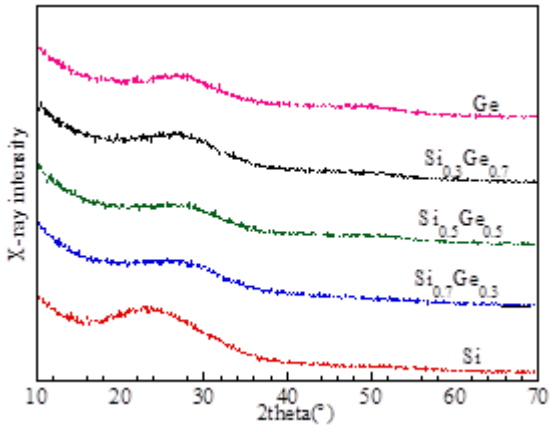

Fig.2 GIXRD spectra for the $Si_{1-x}Ge_x$ thin films

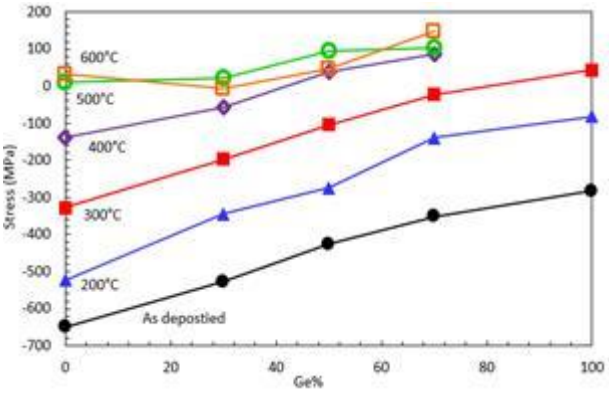

Fig. 3 Compressive stress levels of the $Si_{1-x}Ge_x$ thin films vs Ge% at different annealing temperatures.

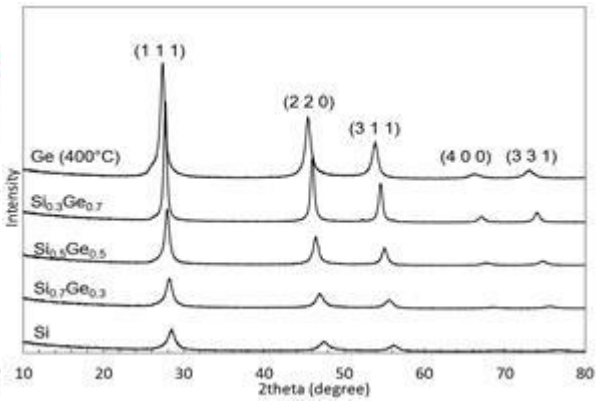

Fig. 4 GIXRD spectra for the $Si_{1-x}Ge_x$ thin films annealed at 700°C.

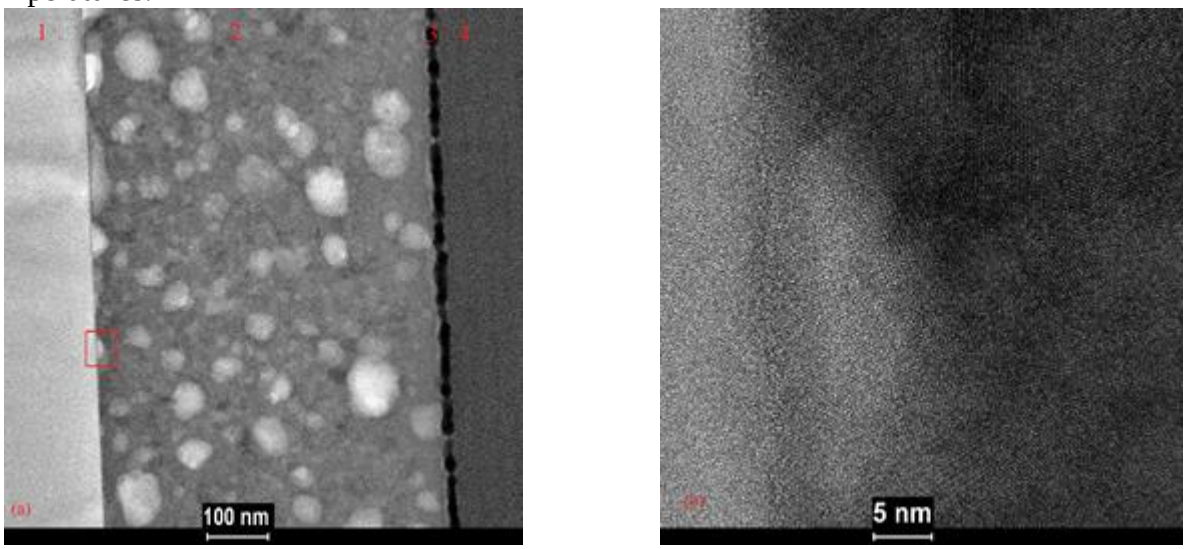

Fig. 5 TEM images of a $Si_{0.3}Ge_{0.7}$ thin film annealed at 700°C. (a) From left to right: 1: silicon substrate, 2: thin film, 3: 5nm platinum coating, and 4: platinum protection layer. (b) HRTEM image of the marked area in (a).