Photoemission Study on Si and Ge Segregation on $Al/Si_{0.8}Ge_{0.2}$ Structures

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Abstract

Recently, a metal-induced solid-phase crystallization process has attracted considerable attention because the Si and/or Ge thickness of the surface segregated ultrathin layer can be controlled by annealing conditions. In our previous works, the growth of ultrathin Si and Ge layers was successfully demonstrated by the segregation of Si and Ge atoms on the Ag surface from the substrate by annealing the Ag/Si(111) and Ag/Ge(111) structures. [1, 2)] However, for the case of Al/Ge structures, controlling Ge segregation is challenging due to the high solid solubility of Ge in Al, and the significant amount of Ge segregation in response to temperature changes. In addition, in Al/Si structures, the amount of segregated Si is less than one atomic layer thick. So in this work, we evaluated the effects of thermal annealing on the segregation of Si and Ge from the Al/SiGe(111) structures.

After a standard RCA cleaning step, 85 nm-thick $Si_{0.8}Ge_{0.2}$ films were epitaxially grown on the n-Si(111) using a H_2-SiH_4-GeH_4 at 600ºC. Subsequently, an Al layer with a thickness of ∼25 nm was deposited by thermal evaporation. Finally, thermal annealing in N_2 ambient was carried out within a temperature range from 200 to 500ºC, where the annealing times were changed from 10 to 120 min.

AFM image shows uniform surface roughness with a root mean square roughness as low as ~0.9 nm after the Al deposition, which was almost the same as that of the $Si_{0.8}Ge_{0.2}$ (111) surface. Although the AFM image taken after annealing at 400ºC confirms no significant changes in the RMS roughness, the surface roughness after 500ºC annealing is double. Further as the annealing temperature increases, the RMS roughness increases. Considering the eutectic temperature, an increase in the surface roughness might be attributable to the surface segregation of the underlying Si and Ge atoms, despite the surface migration of the Al atoms.

To evaluate the change in the chemical bonding features near the surface, Al 2p, Ge 3d, and Si 2p spectra taken at a take-off angle of 90º were measured by x-ray photoelectron spectroscopy. Before and after the annealing, no significant change in the binding energy of the metallic Al signal originating from the Al thin film was observed. In addition, Al oxide components were observed in all of the samples, which might be explained by native oxidation caused by air exposure or surface oxidation due to residual oxygen in the furnace during the thermal annealing. It should be noted that, although large signals are observed in the Si 2p spectra due to the signals originating from the Si–O bond units being superimposed on the plasmon loss peak due to the Al–Al bonding component, Si–Si and Ge–Ge components were clearly detected and their peak intensities increased as the annealing temperature increased. These results indicate that ultrathin Si and Ge layers were formed near the surface. Furthermore, the oxidation of Ge was hardly observed in the case of $Al/Si_{0.8}Ge_{0.2}$(111) after annealing, although the oxidation of segregated Ge was observed in the Al/Ge(111) structure annealed at temperatures over 400ºC[2)].

To gain an insight into the Si and Ge segregation thickness observed near the surface, we also evaluated the Si and Ge layer thickness from the Al/$Si_{0.8}Ge_{0.2}$(111). The amount of Ge and Si segregation from the Al/$Si_{0.8}Ge_{0.2}$(111) structure increases linearly with increasing annealing temperature. Although the amount of Si segregation is similar to that from the Al/Si(111) structure despite a Si composition ratio of 80% in the virtual substrate, the amount of Ge is significantly suppressed compared to that from the Al/Ge(111) structure. These results suggest that the Ge segregation rate is reduced in the SiGe virtual substrate because Si and Ge melt in the Al film, and Si is preferentially segregated on the Al surface, followed by the segregation of Ge. The results will lead to the development of Ge 2D crystals as the Si segregation is suppressed. In fact, by controlling the N_2 annealing temperature and duration, the formation of the ultrathin Ge layer was realized, as shown in Fig. 1. After rapid thermal annealing at 400ºC in N_2 ambient, cross-section transmission electron microscopy energy-dispersive X-ray spectroscopy mapping images clearly show Ge segregation after RTA, with the results being consistent with those obtained from the XPS analysis. These results indicate that highly selective segregation of Ge can be realized by using the Al/$Si_{0.8}Ge_{0.2}$(111) structure.

i. Matsushita et al., Jpn. J. Appl. Phys. **61**, SH1012 (2022).

ii. Sakai et al. Jpn. J. Appl. Phys. **62**, SC1059 (2023).

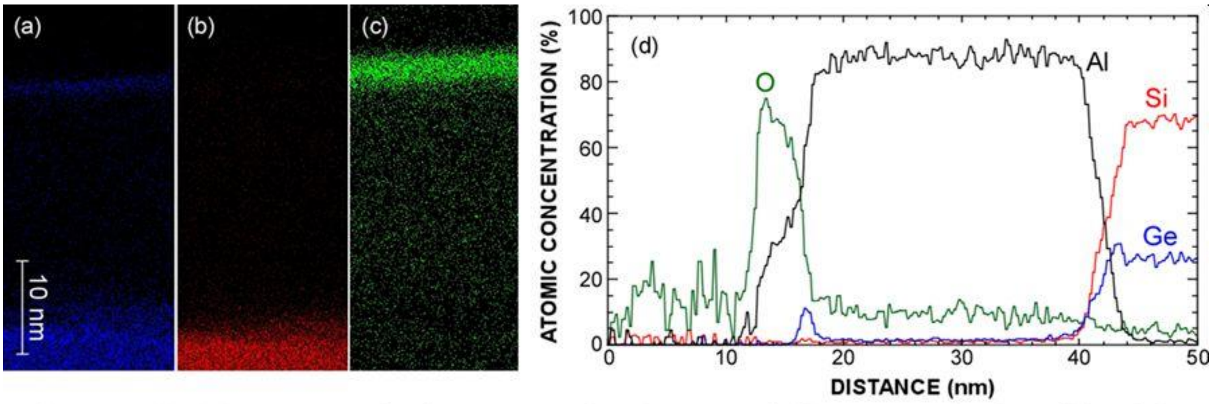

Figure 1. (a)–(c) Cross-sectional EDX mapping images and (d) cross-sectional profile of the Al/$Si_{0.8}Ge_{0.2}$(111)/Si(111) structure taken after rapid thermal annealing at 400ºC in N_2 ambient. In the EDX mapping images, the blue, red, and green colors correspond to Ge, Si, and O, respectively.

Figure 1