SiGe epitaxial growth via pulsed laser annealing of Al-Ge pastes on Si

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Silicon-germanium-tin (SiGeSn) is expected to have superior properties to Si such as direct transition and high carrier mobility. Recently, we have demonstrated a low-cost SiGe growth process by screen-printing and annealing of aluminum (Al) pastes containing Ge particles on Si [1]. Meanwhile, since it is in principle difficult to exceed Sn solubility limit in Si and Ge, the non-equilibrium growth process must be explored for metastable Sn-rich SiGe films. In this work, as a simple model study for the SiGeSn ternary system, we present SiGe epitaxial growth via pulsed laser annealing (PLA) of two different Al-Ge mixed and alloyed pastes on Si substrates. The Al-Ge pastes with a mixing ratio of Al:Ge=7:3 were screen-printed on Si(001) substrates. A 1064-nm pulsed laser was irradiated onto the samples with a spot diameter of ~150 μm. The repetition rate and shot numbers were selected to be 50-125 kHz and 10^3-10^6, respectively. In particular, the pulse width was varied in a wide range of t_p ~ 20-1000 ns while constant pulse energy was dosed by controlling the laser fluence below F ~ 18 J/cm^2. Eventually, Al residues on the surface were removed by etching with a dilute HF solution. Figure 1(a) displays the surface topography of the laser-irradiated regions for the samples prepared by the two pastes. In contrast with the alloyed paste case, a deep center dimple was formed for the mixed paste sample. Figure 1(b) shows the detailed analysis of total volume change with respect to the reference plane as a function of F at t_p = 250 and 1000 ns. This result reveals that the ablation effect from the irradiated regions is dominant beyond a specific threshold of F ~ 10 J/cm^2 for the mixed pastes, whereas SiGe epitaxial growth is accompanied by an increase of a total volume for the alloyed pastes. The difference between ablation and growth may manifest itself as a result of melting point depression and high heat conductivity of the Al-Ge alloyed samples. Moreover, the pulse intensity and shot numbers are tuned to suppress the ablation effect, which results in the efficient formation of Al-doped SiGe layers. Then the Marangoni convection of Al-Ge-Si molten layers produces convex regions at the periphery of the laser-irradiated areas [see Fig. 1(c)], where the Ge composition x_{Ge} has a correlated trend with the relative height Δz while the in-plane strain $\varepsilon_{//}$ exhibits a compressive side. Furthermore, it is shown that a shortened pulse irradiation enables to achieve higher Ge concentration owing to the suppression of Si-Ge intermixing. Hence the PLA-based epitaxial growth using Al alloyed pastes may open a route for SiGeSn device applications.

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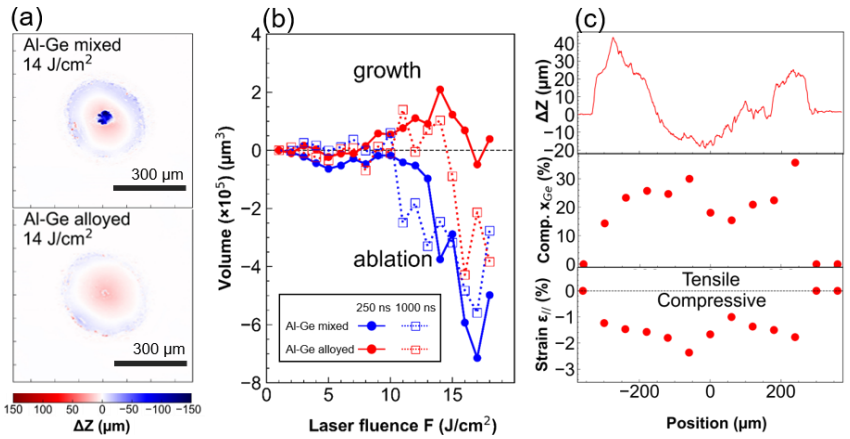

Fig. 1: (a) Comparison of surface morphology after pulsed laser annealing of two distinct Al-Ge pastes on Si. (b) Total volume variation plotted as a function of laser fluence F. (c) 1D profiles of relative height Δz, Ge composition x_{Ge}, and in-plane strain $\varepsilon_{//}$ in the SiGe-grown regions for alloyed paste samples.

References [1] Fukuda K et al. Epitaxial growth of SiGe films by annealing Al-Ge alloyed pastes on Si substrate. Sci. Rep.2022;12:14770.