成長後アニールによる高濃度 n 型 Ge の発光増強(2)

Enhanced photoluminescence from n^+-Ge by post-growth annealing (2)

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1. Introduction Ge has attracted attention as a material for near-infrared light sources in Si photonics. Ge laser diodes have been reported from two groups, although the threshold current densities are as high as 280 kA/cm^2 or larger [1,2]. In order to reduce the threshold current, non-radiative recombination (NRR) should be reduced and the optical gain should be maximized with band engineering, i.e., highly n-type doping to prefill the indirect L valley as well as tensile strain to reduce the energy difference between the indirect L and direct Γ valley bottoms in the conduction band [3]. In this work, photoluminescence (PL) intensities from hetero-epitaxial n-Ge layer on Si are examined, after post-growth cyclic annealing to reduce the density of defects such as threading dislocations (TDs) and the density of Si/Ge interface gap states.

2. Experimental Phosphorus-doped epitaxial n-type Ge layer was grown on p-Si (001) substrate by ultra-high vacuum chemical vapor deposition with GeH_4 and PH_3. A 100-nm-thick undoped Ge buffer layer was grown at 370˚C, succeeded by a P-doped n-Ge layer (~400 nm, n = 1.0×10^{19} cm^{-3}) growth at 600˚C. Then a 5-nm-thick Si cap layer was grown on the n-Ge layer using Si_2H_6 to prevent the out-diffusion of P dopants from the surface. The sample was annealed in N_2 cyclically for 1 to 50 times at temperatures between 780 and 900˚C. As a reference, a 400-nm-thick undoped Ge layer was also prepared. For the undoped samples, the top Si cap layer was removed before annealing to exclude the effect of SiGe alloying at the interfaces. Micro-PL spectra were measured by 785-nm laser excitation at the power density of 36 kW/cm^2. Before the PL measurement, natural oxides, GeO_x or SiO_2, were removed by HF solution.

3. Results and discussion Figure 1(a) shows PL spectra for undoped Ge with annealing cycles as a parameter. The PL intensity increased with the annealing cycles owing to the decrease of TD density that reduces the NRR. However, only a small increase in the PL intensity was observed for the annealing cycles from 3 to 50. This is due to small reduction of TD density in this range of annealing cycles. Figure 1(b) shows PL spectra for n-Ge samples. The PL intensities were several times larger than those for the undoped ones, resulting from the n-type doping. Similar to the undoped case, increase of PL intensities were observed with the annealing cycles up to 40, while the intensity was reduced for the annealing cycles of 50, in contrast to the undoped one's case, as shown in Fig. 1(c). This is attributed to the SiGe alloy formation at the top and bottom Si/Ge interfaces resulting in a larger L - Γ separation. This Si/Ge intermixing will be also discussed in terms of NRR at the Si/Ge interface.

4. Summary The PL intensity from undoped/n-type Ge increased by the post-growth cyclic annealing. NRR should be reduced owing to the reduction of TD density.

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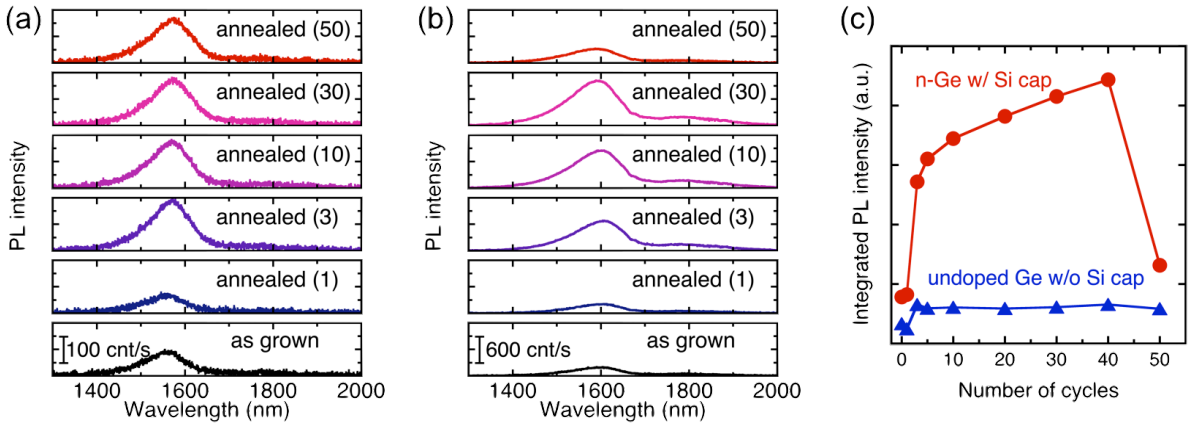

Fig. 1 PL spectra from (a) undoped Ge, and (b) n-Ge. (c) Integrated PL intensity versus number of annealing cycles. Samples were cyclically annealed between 780˚C and 900˚C for 1 - 50 times.