成長後アニールによる高濃度 n 型 Ge の発光増強

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

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1. Introduction

Ge has recently attracted interests as a material for near-infrared (NIR) light sources [1] in Si photonics, which enables high-speed optical communication with a low-cost fabrication and low-power consumption. In this work, effect of post-growth annealing (PGA) is studied on phosphorus-doped n-Ge ($n=1.0\times10^{19}$ cm^{-3}). Threading dislocation density (TDD) can be decreased effectively under high temperature (HT) annealing at >780˚C [2], though HT annealing also leads to dopant loss due to out-diffusion of P [3]. In order to prevent P out-diffusion, two kinds of diffusion barriers, Si and SiN_x, were deposited on n-Ge layer. Si overlayer works better than SiN_x as an out-diffusion barrier. Photoluminescence (PL) spectra were measured for samples annealed at 700~900˚C. As a result, PL intensity increases up to 750˚C, but PL quenching is observed at over 800˚C.

2. Experimental

Highly n-type Ge layer was grown at 600˚C with ultra-high vacuum chemical vapor deposition (UHV-CVD). GeH_4 (9% in Ar) and PH_3 (5% in H_2) were used as source gases. PGA was performed with rapid thermal annealing (RTA) at 700, 750, 800 and 900˚C in N_2 for 5min. There were two kinds of out-diffusion barriers: Si overlayer (~5 nm) grown at 600˚C by UHV-CVD, and a SiN_x overlayer (~150 nm) deposited at 200˚C by reactive sputtering. As a reference, bare Ge was annealed under the same condition. After RTA process, out-diffusion barriers were removed by wet etching for electrical/optical measurements. The electron density was determined by Hall effect measurement. PL spectra were taken at room temperature under fixed excitation power of 3.5±0.2 mW using 785-nm laser, whose penetration depth in Ge is ~100nm. In order to eliminate the difference in surface recombination, Ge surface was treated by diluted HF, and the objective lens with high magnification (×100) was used. The crystalline quality of Ge layer was evaluated by full-width at half maximum (FWHM) of Ge (004) peak in X-ray diffraction (XRD) ω scan.

3. Results and discussions

Figure 1 shows electron density and FWHM in XRD ω scan with different RTA temperatures. With increasing temperature, electron density decreased due to out-diffusion of P. The dopant loss was 67% for bare Ge at 800˚C. This dopant loss was reduced to 34% and 39% with Si and SiN_x overlayer, respectively. FWHM was decreased with increasing temperature, suggesting the decrease of TDD [4]. Figure 2 shows PL spectra for n-Ge annealed with Si overlayer at different temperatures. In spite of the decrease of electron density, PL intensity increased with temperature up to 750˚C probably due to the reduction of TDD. In contrast, PL quenching was observed at >800˚C. This quenching is possibly caused by formation of wider-gap SiGe, implied as PL blue-shift for 900˚C (Fig. 2). Shorter-time annealing might be necessary for further PL enhancement, preventing both P out-diffusion and Si/Ge inter-diffusion.

4. Summary

Si overlayer worked better than SiN_x as a barrier for P out-diffusion during RTA. With increasing RTA temperature, PL enhancement (<750˚C) and quenching (>800˚C) were observed.

Acknowledgements

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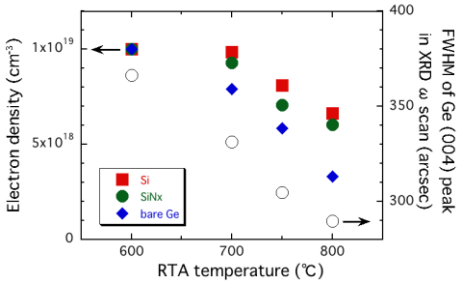

Fig. 1: Electron density and FWHM of Ge (004) diffraction peak for different RTA temperature.

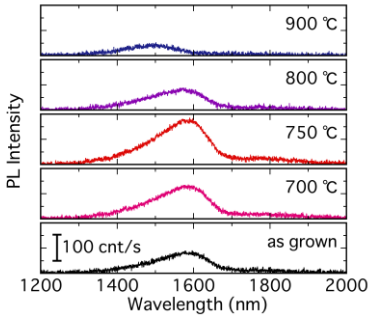

Fig. 2: PL spectra for n-Ge annealed with Si overlayer at different RTA temperature.