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Crystallinity Improvement of Ge Waveguides Fabricated by Epitaxial Lateral Overgrowth and Chemical Mechanical Polishing

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Abstract

The crystallinity of Ge waveguides was successfully improved by combining epitaxial lateral overgrowth and chemical mechanical polishing. After dry etching of the defective region around the Ge/Si interface, five-times higher photoluminescence was obtained from the Ge waveguide compared with one containing the Ge/Si interface.

1. Introduction

The Ge laser is one of the most promising devices as a monolithic light source for high-speed optical interconnections due to its compatibility with Si processes, and optical gain has been observed [1, 2]. However, to ensure continuous wave operation of Ge lasers, process technologies for further improvement of crystallinity need to be developed [3, 4]. In this work, we fabricated high-quality Ge waveguides using epitaxial lateral overgrowth on a SiO_2 layer and chemical mechanical polishing, and we investigated its crystallographic and optical properties.

2. Experimental

An eight-inch Si wafer was used as a substrate, and a SiO_2 window was fabricated as a mask for Ge selective growth. After pre-cleaning of the Si surface within the SiO_2 window, a Ge layer was selectively grown by using low-pressure chemical vapor deposition along with GeH_4 and H_2 carrier gas. To prevent indirect transition by filling electrons into the L-valley in the conduction band [2], we also conducted in-situ n-type doping by supplying phosphine (PH_3). First, a Ge buffer layer was deposited within the SiO_2 window at low temperature and annealed at 750°C, then an additional Ge layer was selectively grown only on the Ge buffer layer at relatively high temperature. Finally, rapid thermal annealing was carried out at 850°C. Figure 1(a) shows a cross-sectional scanning electron microscopy (SEM) image of the selectively grown Ge layer on the Si substrate and the SiO_2 mask layer. By optimizing the growth pressure, the length of the epitaxial lateral overgrowth (ELO) on the SiO_2 layer was increased to more than 5 μm.

Because the thickness of the n-Ge layer increased as the length of the ELO increased, chemical mechanical polishing was applied to remove the top part of the n-Ge layer. Figure 1(b) shows a cross-sectional SEM image of the chemical mechanical polished Ge (CMP-Ge) layer following deposition of a 1-μm-thick SiO_2 layer. Then, a waveguide of a CMP-Ge layer (CMP-Ge-WG) was fabricated by dry etching to remove a part of the Ge layer that contained a lot of defects due to the lattice mismatch between Ge and Si. Figure 2 shows bird's-eye and plane SEM images of CMP-Ge-WG after dry etching with a position gap (Δx) of 2 μm to the SiO_2 window. Δx was determined as the length between the center positions of the SiO_2 windows and the CMP-Ge-WGs. In the case of Δx = 0 μm, the CMP-Ge-WG surely contained crystal defects at the Ge/Si interface that caused non-radiative carrier recombination. However, if the

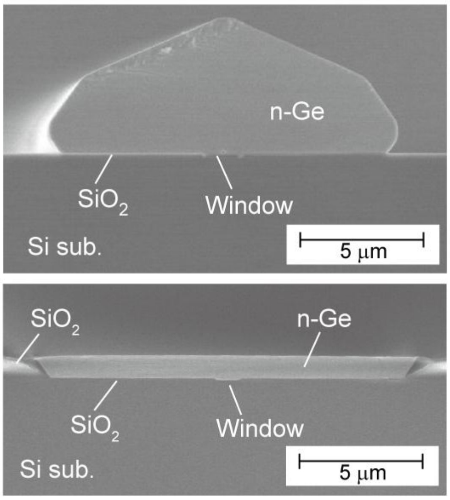

Fig. 1 Cross-sectional SEM images of Ge layers; (a) after selective epitaxial growth and (b) after CMP.

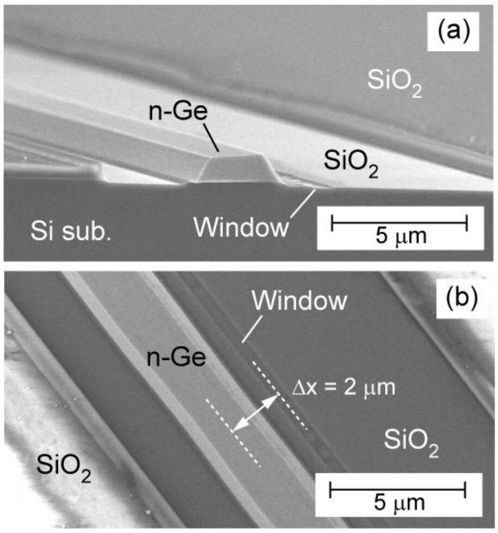

Fig. 2 (a) Bird's-eye and (b) plane SEM images of Ge-WG after dry etching at Δx = 2 μm

CMP-Ge-WG was fabricated apart from the Ge/Si interface, the crystallinity of the Ge layer must be improved (Fig. 2).

3. Results

Figure 3 shows a plane transmission electron microscopy (TEM) image of the selectively grown n-Ge layer at 1 μm above the bottom of the n-Ge layer. Although the dislocation and stacking faults were observed around a region of the Ge on the Si substrate, no dislocations were evident on the ELO-Ge region grown on the SiO_2 layer. Micro-Raman spectroscopy was conducted to evaluate the lattice strain of the CMP-Ge-WG. Figure 4 shows the one-dimensional profile of deviation in the Raman peak position across the CMP-Ge-WG, in which the deviation is normalized by a value from unstrained Ge. Although the Raman peak was observed at a lower wave number around the center of the WG, i.e., large tensile strain, it shows almost the same value (- 0.2 cm^{-1}) to the unpatented Ge layer on the Si substrate at the edge (±4-5 μm) due to flexibility on the edge of the selectively grown Ge layer.

Photoluminescence (PL) spectra from the CMP-Ge-WGs dry etched at Δx = 0, 2 μm are shown in Fig. 5. An obvious PL spectrum was observed from the CMP-Ge-WG at Δx = 2 μm with a peak wavelength above 1610 nm. The PL peak intensity was five-times higher than that corresponding to Δx = 0 μm. Figure 6 shows the PL intensity and the peak wavelength of the CMP-Ge-WGs as a function of Δx. The maximum PL intensity was obtained at Δx = 2 μm, corresponding to the intermediate region between the Ge/Si interface and the edge of the ELO-Ge layer. This result indicates that the better crystallinity of the Ge-WG was obtained at the position apart from both the Ge/Si interface and the edge of the ELO-Ge layer. Furthermore, a blue shift of the PL peak was observed in the PL spectra from the CMP-Ge-WGs at a smaller Δx. Because this dependence is inconsistent with the distribution of the tensile strain shown in Fig. 4, this result might be due

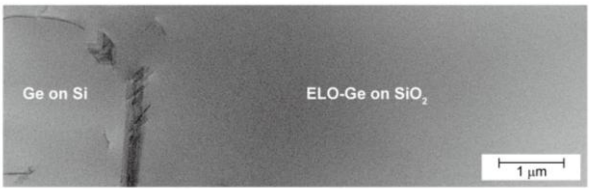

Fig. 3 Plane TEM image of selectively grown Ge layer on SiO_2 window at 1 μm above Ge/Si interface..

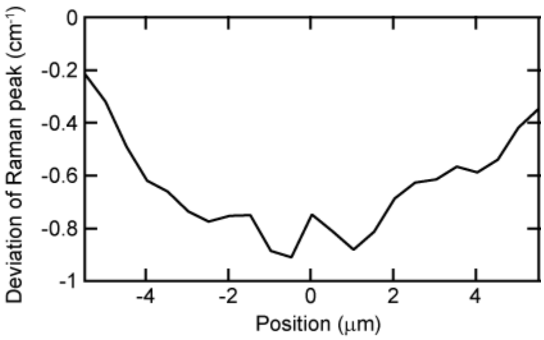

Fig. 4 Deviation of Raman peak position in CMP-Ge-WG.

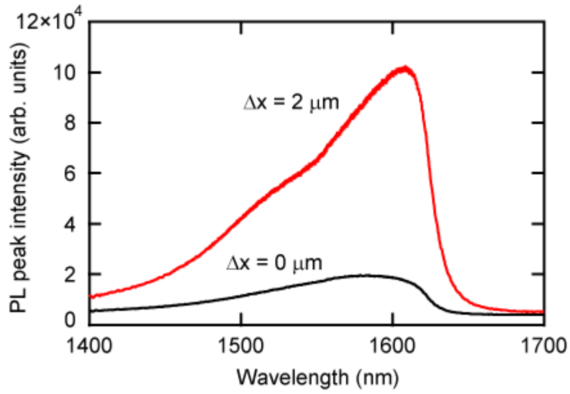

Fig. 5 PL spectra from Ge-WGs dry etched with Δx = 0 and 2 μm.

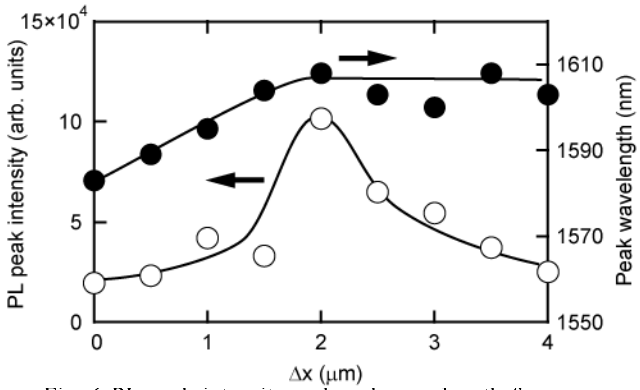

Fig. 6 PL peak intensity and peak wavelength from Ge-WGs dry-etched at various Δx.

to the deformation of the CMP-Ge-WGs after the dry etching process.

4. Summary

A combination of epitaxial lateral overgrowth, chemical mechanical polishing, and dry etching of selectively grown Ge layer on the SiO_2 pattern can improve the crystallinity of Ge waveguides. Accordingly, a steep PL spectrum with five-times higher peak intensity was successfully obtained. These results indicate that this combination technique efficiently improves the performance of Ge light-emitting devices.

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