Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 38-39

B-1-4

Modified Luminescence from Germanium Self-assembled Quantum Dots in Photonic Crystal Cavity at Room Temperature

Jinsong Xia[1], Norita Usami[2], Yuta Ikegami[1], Yasushi Nakata[3], and Yasuhiro Shiraki[1]

[1]Musashi Institute of Technology, Research Center for Silicon Nano-science
8-15-1 Todoroki, Setagaya-ku, Tokyo 158-0082 Japan
Phone: +81-3-5706-3299 E-mail: jxia@sc.musashi-tech.ac.jp
[2]Tohoku University, Institute for Materials Research
2-1-1 Katahira, Aoba-ku, Sendai 980-8577 Japan
Phone: +81-22-215-2014 E-mail: usa@imr.edu
[3]Horiba, Ltd. 1-7-8 Higashi-Kanda, Chiyoda-ku, Tokyo 101-0031, Japan
Phone: +81-3-3861-8231 E-mail: yasushi.nakata@horiba.com

1. Introduction

Silicon is prevented from dominating the photonics field by its indirect bandgap. But, in recent years, series of new progresses make it possible to carry out photonics&electronics hybrid-integration on silicon. Among these progresses, nano-sized quantum structures based on Si/Ge material attract more and more attention due to its potential of silicon-based light emitting devices. In silicon-based quantum structures, the low possibility of electron-hole radiative recombination due to the indirect bandgap is enhanced greatly by the quantum confining. However, the main problems of current Si-based light-emitting structures towards applications are poor spectral purity, low directionality, and low luminescence yield. Photonic crystal (PhC) can solve these problems in principle. In photonic crystals the optical bandgap exists, which will provide strong optical confining. Utilizing this confining, various kinds of structures can be formed, for example, microcavities, waveguides, and couplers and so on. In particular, a PhC microcavity[1-2] is a promising optical device that has big advantages such as selectivity of wavelength, good directionality, and high optical yield. Therefore, PhC microcavity has been one of the hottest research focuses these years. Using PhC structures the properties of emitted light from Si/Ge quantum structures can be improved greatly.

In this paper, we use microcavities to modify the spectrum of emitted light from Ge self-assembled quantum dots. The microcavities are formed by introducing defects into two dimensional photonic crystal slabs on silicon-on-insulator (SOI). Strong optical resonation inside the cavity is observed. The luminescence of the Ge quantum dots is modified greatly.

2. Experiment and Results

Silicon-on-insulator (SOI) wafer with a 70nm top silicon film and 400nm buried oxide (BOX) was used as the substrate. Three layers of Ge self-assembled quantum dots were grown on the SOI wafer in Stranski-Krastanov growth mode using gas source molecular beam epitaxy (GS-MBE). After a 50nm buffer layer was grown, the Ge quantum dot layers were grown at 700^0C with coverage of 5.8ML for each. They were separated by 20nm silicon spacing layers and caped by a 120nm silicon layer. The quantum dots with a typical base width of 110nm have a density around 10^9/cm^2. E-beam lithography was used to pattern the hexagonal PhC structures on the chip. The e-beam resist worked as the mask during etching. The guiding silicon Ge/Si layer was etched by reactive ion etching (RIE) using SF_6 and C_4F_8 gases. After etching, oxygen plasma was used to remove the remained resist. In order to strengthen the optical confining and increase the symmetry of the structure, the BOX was removed by HF solution to form a free-standing silicon PhC slab. Fig. 1 shows the schematic structure and scanning electron microscope image of a H2 cavity. The lattice constant and the hole diameter are 500nm and 350nm, respectively. The optical bandgap was designed to cover wavelength region of 1.3μm-1.5μm.

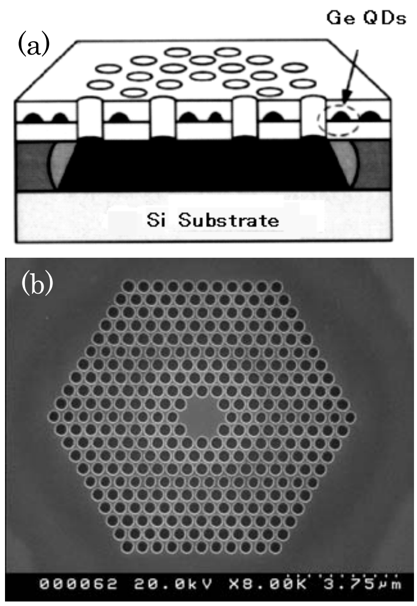

Fig. 1 (a) Schematic structure of the PhC cavity, (b) the scanning electron micrograph of a H2 cavity.

The micro-photoluminescence (μPL) was measured at room temperature using an Ar+ laser beam of 514.5nm. The excitation and photoluminescence signal was focused and collected by the same 100× objective lens with a 0.7 numerical aperture. The signal was reflected into the monochromator and detected by a LN-cooled InGaAs photomultipliers array. Fig. 2 shows the photoluminescence spectrum of the H2 cavities compared with the photoluminescence spectrum recorded in the PhC pattern free region on the same chip.

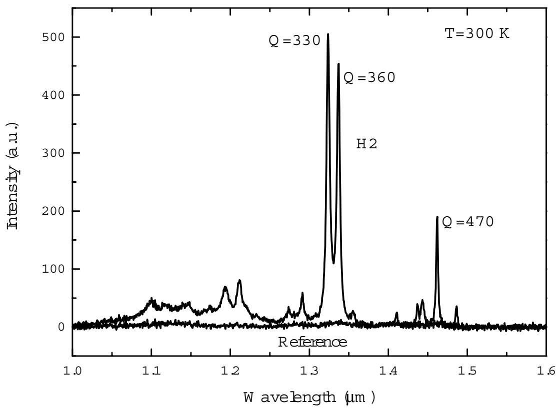

Fig.2 Room temperature photoluminescence of H2 (top curve) and reference (bottom curve) recorded in PhC free region.

As seen in this figure, several peaks exist, which corresponds to optical resonation inside the cavity. Each resonance peak corresponds to one cavity mode. In the PhC cavity, due to the Purcell effect[3], the lifetime of the exited carriers may decrease and the radiative recombination rate may increase, which leads to significant enhancement of the photoluminescence as shown in the figure. A ×100 enhancement at 1.32μm is observed as compared to the reference. A striking feature of this result is that only several sharp resonance peaks dominate the spectra, which is often observed in the similar structures based on III-V materials, but not reported based on Si/Ge materials. The excitation power used in our PL measurement is 1mW, which is much smaller than reported values. The detailed power dependence of the luminescence will be presented elsewhere. The full width of half maximum (FWHM) of the three peaks at 1.324μm, 1.337μm, and 1.462μm are 4.0nm, 3.7nm, and 3.1nm, respectively. The corresponding quality factors are 330, 360, and 470, respectively. Comparing with the broad luminescence from normal quantum dots, the present results prove the possibility to get a single peak by Si-based optical structures, which is much important for industrial applications. The presence of these peaks also proves that the luminescence in the Si-based system is not quenched by the electronic defect states at the interfaces generated by the etching process. It is also noted that the wavelength of the peak can be adjusted by the lattice constant, which give us a method to shift the peak to 1.3μm or 1.5μm for telecommunication applications.

3. Conclusion

We fabricated two-dimensional photonic crystals on silicon-on-insulator substrate. Ge/Si sefl-assembled quantum dots were embedded in the PhC cavity as a light emitter. The photoluminescence spectra of H2 cavity at room temperature showed strong optical resonation in the cavity. Significant enhancement of the luminescence was achieved, as evidenced by a ×100 enhancement factor in the micro-photoluminescence spectrum. Three main peaks dominated the spectrum, and the quality factor of 470 is measured at 1.46μm, which was highest ever reported. The results prove that combination photonic crystal with Ge quantum dots is a reasonable way to carry out Si-based light emitter for telecommunication applications.

Acknowledgements

The authors would like to thank Dr. Toshiko Okui for the help in the E-beam lithography, Dr. Kentaro Sawano for the help in etching and MBE growth, Prof. Tadashi Yoshida and Ms. Miyoko Okada for the help in PL measurements. The project was supported by the "High-Tech Research Center" Project for Private Universities: matching fund subsidy from MEXT, 2002-2006, and also partly supported by the grant of Musashi Inst. of Technology for young researcher.

References

[1]. S. David, M. Elkurdi, P. Boucaud, A. Chelnokov, V. Le Thanh, D. Bouchier, J.-M. Lourtioz, Appl. Phys. Lett. 83, 2509(2003).

[2]. T. Baba, D. Sano, K. Nozaki, K. Inoshita, Y. Kuroki, Appl. Phys. Lett. 85, 3989(2004).

[3]. E.M. Purcell, Phys. Rev. 69, 681 (1946).