Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp1179-1180

Photoluminescence from n^+-Ge microdisk on Si-on-insulator structure

Koki Takinai, Atsunori Yoshida, Yasuhiko Ishikawa and Kazumi Wada

Department of Materials Engineering. The University of Tokyo
7-3-1 Hongo, Bunkyo, Tokyo 113-8656, Japan
E-mail: kwada@material.t.u-tokyo.ac.jp

Tai Tsuchizawa, Toshifumi Watanabe, Koji Yamada and Seiichi Itabashi
NTT Microsystem Integration Laboratories, NTT Corporation
Morinosato-Wakamiya, Atsugi, Kanagawa, 243-0198, Japan

1. Introduction

Light-emitting devices on Si have been studied for on-chip light sources in Si photonics [1-10]. Although III-V based light emitters on Si have been reported utilizing a bonding technique [10], many studies have been performed using Si and related materials [1-9], which are suitable for the compatibility with complementary metal-oxide-semiconductor processes. Such group-IV materials are mostly indirect bandgap materials, while strong light emissions have been obtained using, e.g., quantum wells [1], micro-resonators [2-6], application of stress [7-9], heavy doping and their combinations [8,9]. In particular, tensile-strained Ge layers on Si with a heavily n-type doping have attracted interest [8,9], since the light emission due to the direct transition in the 1.55-μm range is enhanced. This enhancement results from (1) a reduced energy difference between the indirect L valley and the upper direct Γ valley and (2) a suppressed relaxation of electrons from the direct Γ valley to the indirect L valley. In fact, a lasing operation of Ge has been recently demonstrated in the 1.55-μm range under an optical pumping [9].

In this paper, microdisk resonators of n^+-Ge on Si-on-insulator (SOI) structure are studied to enhance the light emission. As a result, an oscillatory photoluminescence (PL) spectrum is observed due to the resonances, leading to an enhanced intensity of light emission.

2. Experiment

Microdisk structures of n^+-Ge were fabricated on p^+-Si layer of SOI structure, as schematically shown in Fig. 1. The disk radius was designed to be from 4.8 to 26.8 μm. The fabrication processes are as follows. First, the thickness of top Si layer on a 3-μm-thick buried oxide (BOX) layer was reduced from 250 nm to 70 nm with a sacrificial thermal oxidation. Boron atoms were implanted into the Si layer as the acceptors with the concentration in the order of 10^{18} cm^{-3}. This p^+ layer was formed for future studies on the electroluminescence. Next, a 130-nm-thick Ge and 50-nm-thick Si cap layers were grown at 600°C by ultrahigh-vacuum chemical vapor deposition (UHV-CVD) with the source gases of GeH_4 and Si_2H_6. A tensile strain as large as 0.1% should be generated in Ge due to the mismatch of thermal expansion coefficient between Ge and the thick Si substrate [11]. Then, phosphorous atoms were implanted for the n^+ doping of ~10^{19} cm^{-3}. After the deposition of 130-nm-thick SiO_2 layer by plasma-enhanced CVD, disk structures were patterned by electron beam lithography and dry etching. SiO_2 layer of 30~50 nm and the p^+-Si layer of ~50 nm outside the disk structures were remained. A small depression (~25 nm) with a circular shape was also formed at the center of top Si cap layer for the better confinement of light near the periphery of disk. Finally, 500-nm-thick SiO_2 was deposited to protect devices. A typical scanning electron microscope image is shown in Fig. 2.

Micro-PL spectra were measured for the disk structures at room temperature, using an excitation laser (457 nm) with the spot size of ~2 μm and the power of 5.0 mW. The emission was collected from the top, using an objective lens with the numerical aperture of 0.42. An InGaAs arrayed detector cooled at -100°C was used. As the references, PL spectra were also measured for the unpatterned regions of n^+-Ge on SOI structure as well as for an undoped Ge layer (500 nm) grown on bulk Si.

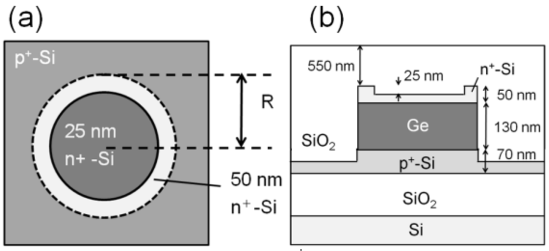

Fig. 1. Schematic illustrations for n^+-Ge disk on SOI structure. (a) Top view and (b) cross-sectional view.

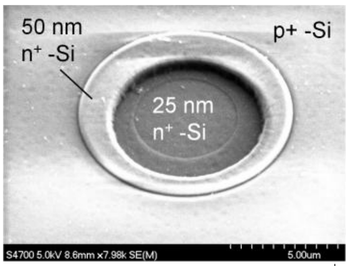

Fig. 2. A typical electron microscope image for n^+-Ge disk on SOI structure.

3. Results and discussion

3.1 PL spectra for unpatterned n^+-Ge on SOI and undoped Ge on bulk Si

Figure 3 shows PL spectra for the Ge layer grown on bulk Si and for the unpatterned region of n^+-Ge on SOI. For the Ge layer on bulk Si, a luminescence was clearly seen at ~1.55 μm, corresponds to the direct transition in Ge. On the other hand, the unpatterned n^+-Ge on SOI showed a broader peak at a shorter wavelength of ~1.5 μm, and the other small peak was also observed at ~1.3 μm. These two peaks are found to be derived from the multiple reflections at the interfaces of layered structure of SiO_2/Si/Ge/Si/SiO_2 (BOX)/Si substrate, leading to a modification of extraction efficiency for the light from the Ge layer. The dashed line in Fig. 3 shows a simulated spectrum of extracted light from Ge on SOI, taking into account the effect of multiple reflections.

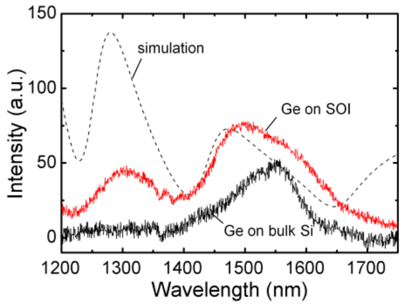

Fig. 3. Typical PL spectra for undoped Ge on bulk Si and for n^+-Ge on SOI.

3.2 PL spectra for n^+-Ge disk on SOI

In Fig. 4, a typical PL spectrum is shown for n^+-Ge disk on SOI with the radius of 5.10 μm, together with the one for the unpatterned n^+-Ge layer on SOI. The intensity was found to increase by ~7 times in comparison with the unpatterned one. Such an increase is similar to PL for Si microring resonators [5], and the enhancement is probably derived from the limited diffusion of generated carriers in the lateral direction, maintaining the high density of carriers responsible for the direct transition. Furthermore, an oscillation was superimposed on the broad spectrum. This oscillation should be derived from the resonance in the disk. In fact, as shown in Fig. 5, the oscillation peak positions as well as the spacings between the peaks were changed with the disk radius.

4. Conclusion

Microdisk resonators of n^+-Ge on Si were studied to enhance the light emission. An oscillatory PL spectrum with an enhanced intensity was observed due to the resonances.

Acknowledgements

The author would like to thank to Dr. J. Osaka, Dr. N. Kawai, Dr. T. Makino and Mr. Y. Horie for valuable discussions.

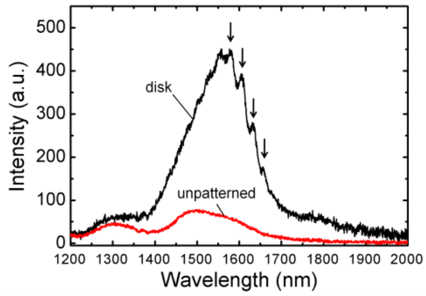

Fig. 4. Typical PL spectra for n^+-Ge disk on SOI (radius: 5.10 μm) and unpatterned n^+-Ge on SOI.

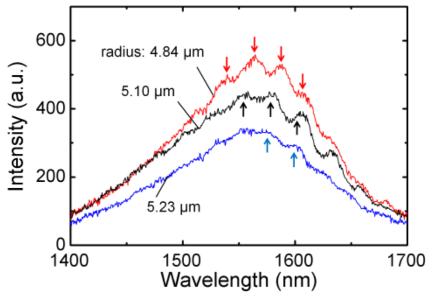

Fig. 5. Typical PL spectra for n^+-Ge disks on SOI with different radii of 4.84, 5.10 and 5.23 μm.

References

[1] S. Saito et al., Appl. Phys. Lett. **95** (2009) 241101.
[2] M. Fujita et al., IEEE J. Sel. Topics Quantum Electron. **14** (2008) 1090.
[3] S. Iwamoto et al., Appl. Phys. Lett. **91** (2007) 211104.
[4] J. S. Xia et al., Appl. Phys. Lett. **90** (2007) 141102.
[5] S. Lin et al., Appl. Phys. Lett. **92** (2008) 021113.
[6] P. H. Lim et al., Appl. Phys. Lett. **93** (2008) 041103.
[7] P. H. Lim et al., Opt. Express **17** (2009) 16358.
[8] X. Sun et al., Appl. Phys. Lett. **95** (2009) 011911.
[9] J. Liu et al., Opt. Lett. **35** (2010) 679.
[10] A. W. Fang et al., Opt. Express **14** (2006) 9203.
[11] Y. Ishikawa et al., Appl. Phys. Lett. **82** (2003) 2044.