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Light Enhancement of Si-Nanocrystals-Embedded SiO_x film on Silicon-on-Insulator Substrate

Cheng-Chang Chen[1], Yung-Hsaing Lin[3], M. H. Shih[1,2], Gong-Ru Lin[3], Hao-Chung Kuo[1]
[1]Department of Photonic & Institute of Electro-Optical Engineering, National Chiao Tung University, Taiwan.
[2]Research Center for Applied Sciences (RCAS), Academia Sinica, Taiwan.
[3]Department of Electrical Engineering, Graduate Institute of Photonics and Optoelectronics, National Taiwan Univesity, Taiwan.
Phone: +886-3-5712121 ext 56354; Fax: +886-3-5716631; E-mail: d9524817@gmail.com

Abstract

We reported the light enhancement obtained from a Si-nanocrystals-embedded SiO_x film on a silicon-on-insulator (SOI) and Si substrates in visible light range. A strong emission from the SOI substrate was observed due to the better optical confinement. We also compare the vertical distribution of the electric field in vertical direction of the two structures.

1. Introduction

In recent years, silicon still is the most important semiconductor for the microelectronics industry. Si-based light sources compatible with the mainstream complementary metal-oxide semiconductor (CMOS) technology have been attracted much attention. They are easier to integrate with electronic components on the same chip. Besides, they have a low manufacturing cost relative to III/V semiconductor diodes. Therefore, Si-based materials have potential for optoelectronic device integration[1, 2]. In this report, light emission from a Si-nanocrystals-embeded SiO_x film on a silicon-on-insulator (SOI) substrate was investigated. A strong light enhancement from the SiO_x film on SOI substrate was observed due to the improvement in vertical optical confinement.

2. Fabrication Process

This SOI wafer was prepared with horizontal furnace system. A 2.3μm thick SiO_2 layer was first grown on a Si substrate followed by the growth of a 250 nm thick poly-Si layer on the top of the SiO_2 layer. A 360 nm thick Si-rich SiO_x film was grown on the SOI substrate by the plasma-enhanced chemical vapor deposition (PECVD) system with parameters in the previous works [3, 4]. The SiO_x film was annealed in a quartz furnace with N_2 gas at 1100 °C for 90 min to precipitate Si nanocrystals. We also fabricated the SiO_x film on a bare Si substrate as the reference. The illustrations of the SiO_x/Si and SiO_x/SOI structures are shown in Fig. 1(a). Fig. 1(b) shows a SEM cross-sectional image of the SiO_x/SOI structure.

3.Results and Discussion

To observe the light emission from the Si-nanocrystals-embeded SiO_x film on the SOI and Si substrates, the devices were optically pumped by using a CW He-Cd laser at 325 nm with an incident power of 40mW and a pumped spot size of 30μm. Fig. 2 shows the photography of a SiO_x/SOI structure. Fig. 3 shows the measured emission spectra from the different devices. The black solid curve in the Fig. 3 is the emission spectrum from a SiO_x film without the annealing procedure. It shows a very low emission from the as-grown SiO_x film. The blue-dashed and red-dotted curves are the emission spectra from the SiO_x films on Si and SOI substrates, respectively. The light emission of SiO_x film is enhanced more than ten times after annealing step. By comparing the blue and red spectra, the light emission from the SiO_x/SOI structure is two times higher than the emission from the SiO_x/Si structure under the same pumped conditions.

In order to understand the detailed of the optical mode in the SiO_x/SOI and Si/SOI structures, we calculate the vertical distribution of optical filed in two structures. The distribution of the index and the fundamental mode of the electric field in the vertical direction were calculated as shown in Fig. 4 (a) and (b). According to the calculated results, we estimate the effective refractive index neff of the fundamental mode and the fraction of the electric field within the SiO_x gain material layer. The estimated fraction of the electrical field in SiO_x layers of the SiO_x/SOI and SiO_x/Si structures are 1.3% and 0.0213%, respectively. As a consequence, the tail of the electric field related to the SiO_x layer in SOI would be more extended than that in Si substrate. Therefore we can conclude that higher emission of SiO_x film on SOI substrate is because of the better optical confinement from the lager index contrast of the SiO_x/SOI structure.

We should also note that light emission from the SiO_x film on SOI substrate has different optical modes due to the SiO_2 layer in Fig. 3. Since the SiO_x/SOI structure was pumped by 325nm laser from the top surface, the light emission from SiO_x film was only partially absorbed by thinner poly-Si layer before reaching the SiO_2 layer. Those different light emission resonant modes can be analyzed by the following equation:

$$\Delta\lambda = \frac{\lambda^2}{2nd}$$

Where λ is wavelength of the emission light, n and d is the index and thickness of the SiO_2 film, and Δλ is known as the free spectral range. The calculated result of the free spectral range Δλ is about 50nm, and is good agreement with the measured result.

4. Conclusions

In short, we have demonstrated the light enhancement from the PECVD grown Si-nanoparticles-embeded SiO_x film on SOI and Si substrates in visible light region. The emission is enhanced by ten times with the annealing process, and two times with better optical confinement in SOI structure. We also examined confinement factors of 1.3% and 0.0213% in the SiO_x gain layer from two structures. Based on the strong light enhancement of the

SiO_x/SOI device, the SiO_x nanocrystals material could be a potential platform for Si-based light sources in the future applications.

References

[1] K. S. Min, K. V. Shcheglov, C. M. Yang, H. A. Atwater, M. L. Brongersma, and A. Polman, Appl. Phys. Lett. **69**, 2033 (1996).

[2] M. L. Brongersma, A. Polman, K. S. Min, E. Boer, T. Tambo, and H. A. Atwater, Appl. Phys. Lett. **72**, 2577 (1998).

[3] G. R. Lin, C. J. Lin, Y. C. Chang, Appl. Phys. Lett. **90**, 151903 (2007).

[4] G. R. Lin, C. L. Wu, C. W. Lian, and H. C. Chang, Appl. Phys. Lett. **95**, 021106 (2009).

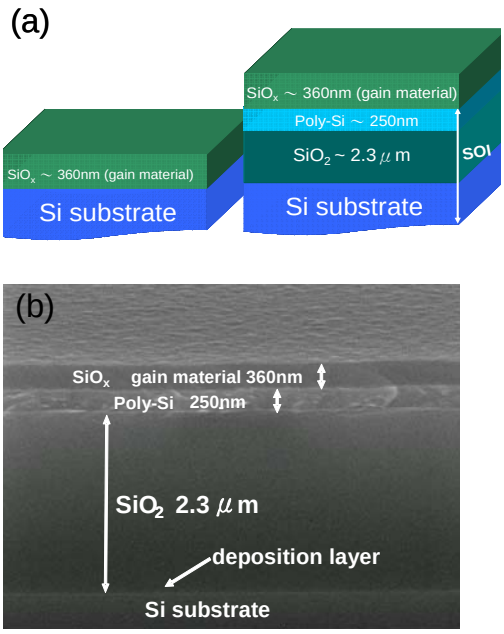

Fig. 1. (a) Schematic structure of SiO_x film on SOI and Si substrates. (b) The SEM image of the sample cross section angle-view.

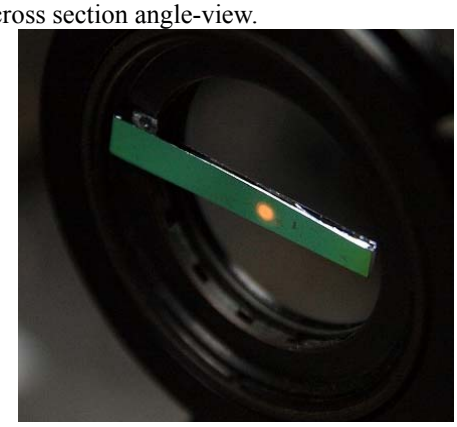

Fig. 2. The photography of the SiO_x/Si/SiO_2 device during the measured process.

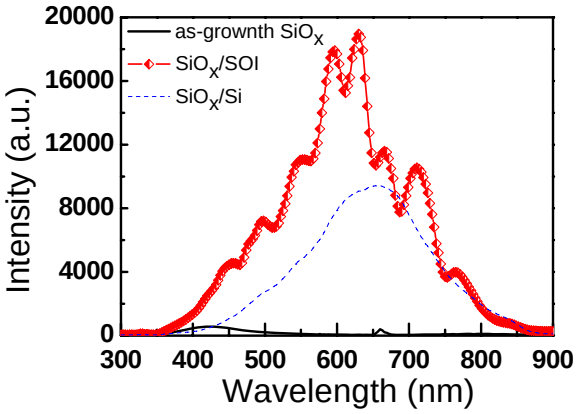

Fig. 3. The emission spectrum of SiO_x film on SOI and Si substrate in the visible range after annealing procedure. Different resonant modes of SiO_x/SOI structure was observed.

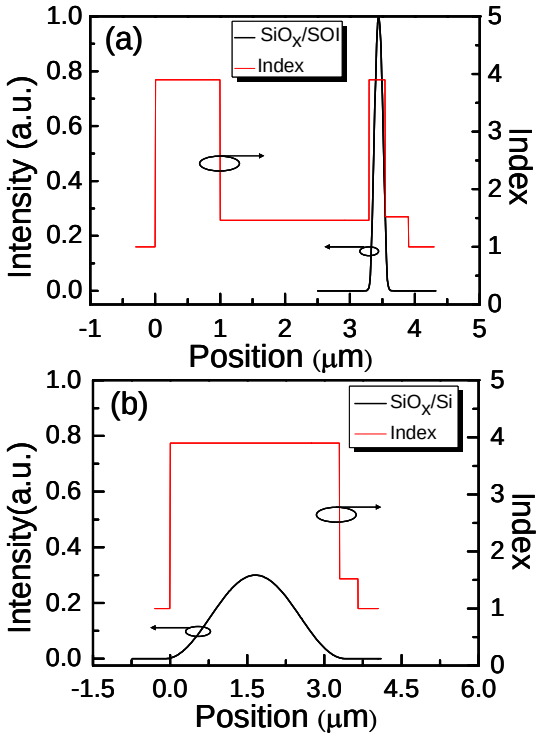

Fig. 4. The distribution of the index and the fundamental mode of the electric field in the vertical direction of SiO_x/SOI (a) and SiO_x/Si (b) structures. The calculated confinement factor from transfer matrix method of the SiO_x/SOI and SiO_x/Si structures are 1.3% and 0.0213%, respectively.