Light emission from size reduced nanocrystal silicon quantum dots

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Abstract: We performed HF treatment to silicon quantum dots with diameter of 8nm±1nm fabricated by VHF plasma decomposition process. We observed PL wavelength shift from 750nm to 620nm for 8nm to 2.5nm diameter nc-Si dots.

OCIS codes: (230.3670) Light-emitting diode; (250.5230) Photoluminescence

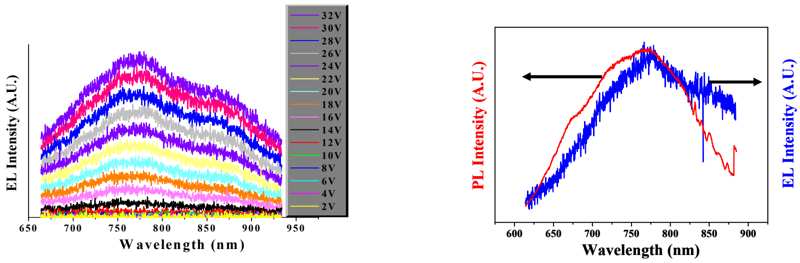
1. Introduction

Silicon is the most useful semiconductor material for the integrated-circuit (IC) industry, but its applications in the areas of optics and optoelectronics are limited because of its indirect band-gap characteristics. Thus, converting silicon to a highly efficient light-emitting material is a challenging subject for research. In the last decade, many efforts have been invested to overcome the indirect band-gap characteristics of silicon. They include porous silicon [1], Si^+-implanted SiO_2, Er-doped Si [2] and nanocrystalline Si [3] material systems.

In spite of a large amount of experimental reports on the PL properties of the nc-Si, only a few groups have reported on the electroluminescence (EL) characteristics of nc-Si [4-6], mainly because of the difficulty of the carrier injection into SiO_2. In our work, we investigated the possibility of manufacturing light emitting diodes nc-Si dots, with a stable EL at room temperature and operable at low voltages. In order to improve the carrier injection, one can possibly reduce the thickness of the oxide layer and also reduce the size of nanocrystal silicon.

2. Experimental results and discussion

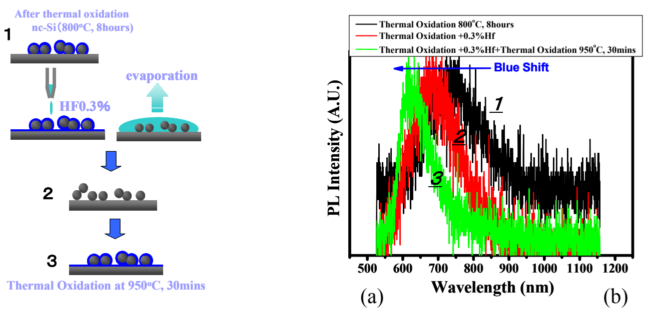
We prepared silicon quantum dots onto lightly doped p-type silicon wafer (100) using very high frequency (VHF, 144MHz) plasma decomposition of SiH_4 diluted by Ar gas. Silicon quantum dot layers with thickness of 100nm were grown. Flow rates of SiH_4 and Ar were set at 1.6sccm and 90sccm respectively, with a chamber pressure of 0.03torr and the plasma power at 1.5W. For the fine control of the nc-Si dots size, pulsed SiH_4 gas was supplied in Ar gas [7]. This method enables the control of the growth time of the nc-Si dots. We observed the size of nc-Si dots from a high-resolution transmission electron microscopy (TEM) image and we measured an average diameter of about 8nm±1nm. After deposition, the film was thermally oxidized at 800°C for 8, 4 and 2hours. PL measurements were performed by pumping with the 442nm line of a He-Cd laser at room temperature. We observed that PL spectra show a blue shift and an increase in intensity with thermal oxidation time at room temperature. After oxidation, we deposited phosphorus doped poly-Si. Al was deposited on the top of the films for electrode, and Ohmic contacts were formed on the backside of the substrate. We observed EL only under the forward bias condition with a turn on voltage of about 12V. We could observe the light emission with the naked eye at room temperature. We also observed an increase in the EL intensity with increasing bias (Fig. 1(a)). Fig. 1(b) shows the PL and EL spectra measured for the same device. It is interesting to note that the EL and PL central peaks are very similar in position. It clearly shows that this emission is due to electron-hole recombination in the nc-Si dots, as it was demonstrated by Koshida *et al.* [8]. We also observed that the light emission increases with the oxidation time. This can easily be explained. The longer the oxidation time, the smaller the nc-Si. While the crystal size is reduced, the band gap is widened and, due to the quantum confinement, the light emission increases. However, the SiO_2 thickness also increases with the oxidation time, which makes the current injection lower. This results in an increase in the turn on voltage. It is therefore clear from these results that on the one hand, one has to decrease the oxide thickness in order to improve the carrier injection, and on the other, one has to reduce the size of nanocrystal silicon in order to increase the light emission. It may be difficult to reduce the thickness of SiO_2 and the size of nc-Si at the same time. However, we can go round this problem by dropping HF (Hydrofluoric acid).



(a) (b)

Fig. 1(a) EL intensity with a operating voltage. (b) EL and PL comparision.

We tried to reduce the size of nc-Si dots and the SiO_2 thickness by dropping HF (Fig. 2(a)). We deposited nc-Si layers on the Si substrate. After deposition, the nc-Si dots were oxidized at 800°C for 8hours. Then, we dropped 0.3%HF on the sample to remove the SiO_2 layer and to expose the size reduced nc-Si dots. Finally, the film was once again annealed at 950°C, for 30min, in order to form a thin SiO_2 layer on the size reduced nc-Si dots. Fig. 2(b) shows that the PL spectrum shifted from 750nm to 620nm for 8nm to 2.5nm diameter nc-Si dots.



(a) (b)

Fig. 2(a) Prepared of sample. (b) PL spectrum of nc-Si dots by dropping HF.

3. Conclusion

We performed HF treatment for reducing the size of nc-Si and the SiO_2 thickness simultaneously. We observed the blue shift of the PL peak which is attributed to quantum confinement effect with the size reduced nc-Si dots.

References

[1] L. T. Canham, "Silicon quantum wire array fabrication by electrochemical and chemical dissolution of wafers", Appl. Phys. Lett. **57**, 1046 (1990).

[2] G. Franzo, F. Priolo, S. Coffa, A. Polman, and A. Carnera, "Room-temperature electroluminescence from Er-doped crystalline Si", Appl. Phys. Lett. **64**, 2235 (1994).

[3] K. Arai, J. Omachi, K. Nishiguchi and S. Oda, "Photoluminescence study of the self-limiting oxidation in nanocrystalline silicon quantum dots", Materials Research Society Symposium Proceedings; **664**A20.6 1-6(2001).

[4] N. Lalic, J. Linnros, "Light emitting diode structure based on Si nanocrystals formed by implantation into thermal oxide", Journal of LUMINESCENCE. **80**, 263 (1999).

[5] Wal Lek Ng, "An efficient room-temperature silicon-based light-emitting diode", Nature, **410**, 192 (2001).

[6] Liang-Yih Chen, Wen-Hua Chen, and Franklin Chau-Nan Hong, "Visible electroluminescence from silicon nanocrystals embedded on amorphous silicon nitride matrix", Appl. Phys. Lett. **86**, 193506 (2005).

[7] T. Ifuku, M. Otobe, A. Itoh and S. Oda, "Fabrication of Nanocrystalline Silicon with Small Spread of Particle Size by Pulsed Gas Plasma", Jpn. J. Appl. Phys. **36**, 4031 (1997).

[8] B. Gelloz, T. Shibata, and N. Koshida, "Stable electroluminescence of nanocrystalline silicon device activated by high pressure water vapor annealing", Appl. Phys. Lett. **89**, 1191103 (2006).