Visible Electroluminescence from Size-Controlled Silicon Quantum Dots

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Abstract: We studied visible EL from size-controlled silicon quantum dots with diameter of 8nm±1nm fabricated by VHF plasma decomposition process. We observed EL from nc-Si quantum dots with applied voltage above 12V.

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

1. Introduction

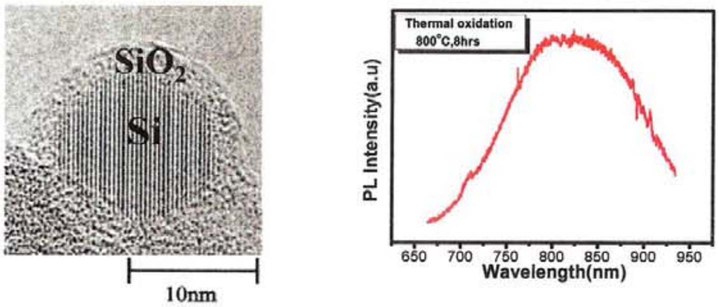
Silicon is the most useful semiconductor material for the integrated-circuit(IC) industry, but its applications in the areas of optics and optoelectronics are limited because of their indirect band-gap characteristics. Thus converting silicon to a highly efficient light-emitting material is a challenging 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]. However none of them have succeeded the fabrication of size-controlled nc-Si limited by their own fabrication processes.

In this paper, we report the electroluminescence from size-controlled silicon quantum dots with diameter of 8nm ± 1nm fabricated by VHF plasma decomposition process. We have already observed the quasi-direct transition in these nc-Si quantum dots by reducing the core diameter below 5nm which correspond to the exciton Bohr radius in silicon [7-8]. And we observed EL from the size-reduced nc-Si quantum dots with applied voltage above 12V.

2. Experimental and results

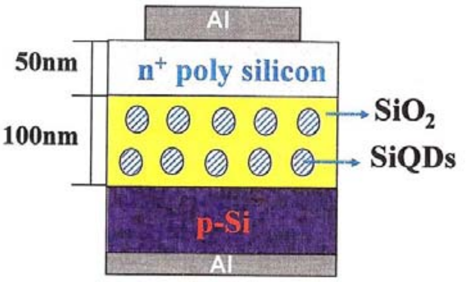
We prepared silicon quantum dots on low doped p-type silicon wafer (100) using high frequency (VHF, 144MHz) plasma decomposition of SiH_4 diluted by Ar gas. SiH_4 flow rate of 1.6sccm and Ar flow rate of 90sccm, with a chamber pressure of 0.03torr and the plasma power was 1.5W. For the fine control of the size, pulsed SiH_4 gas was supplied in Ar gas [9]. This method enables the control of the growth time of the nc-Si dots. Fig. 1(a) shows a high-resolution transmission electron microscopy (TEM) image of nc-Si dots. This sample was oxidized at 800°C for 8 hours. PL measurements were performed by pumping with the 422nm line of a He-Cd laser at room temperature. We observed PL emission at room temperature (Fig. 1(b)).



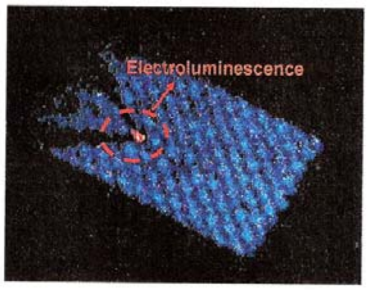
(a) (b)

Fig. 1(a) TEM image of a nc-Si dot. (b) PL spectrum of nc-Si dots

After oxidation we deposited phosphorus doped poly-Si. Al was evaporated on the top the films for electrode, and ohmic contacts were formed on the backside of the substrate. The whole structure of the Electroluminescence (EL) device is schematically shown in Fig. 2(a). The EL was recognized by the naked eye in the dark above 12V in the forward bias condition (Fig. 2(b)).



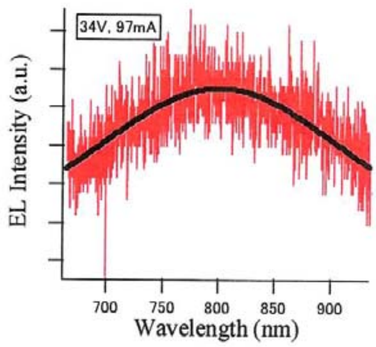
(a)



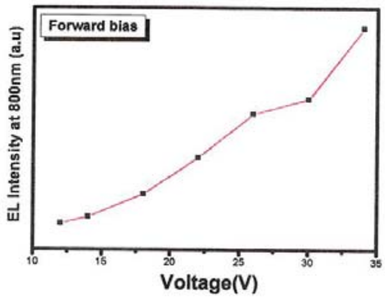
(b)

Fig. 2(a) Schematic of the whole device structure. (b) Electroluminescence from nc-Si dots.

Fig. 3(a) shows the EL spectrum from 650 to 950nm with a central peak at 800nm. We observed EL only under the forward bias condition. In the reverse bias condition, the current density was relatively small and EL emission was not observed. The dependence of the EL intensity on the applied voltage is shown in Fig. 3(b).



(a)



(b)

Fig. 3(a) EL spectrum with an applied voltage of 34V. (b) Dependence of the EL intensity on the applied voltage at 800nm.

3. 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] P.Photopoulos and A.G.. Nassiopoulou, "Room- and low-temperature voltage tunable electroluminescence from a single layer of silicon quantum dots in between two thin SiO_2 layers", Appl. Phys. Lett. 77, 1816 (2000).

[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**, 193506-1 (2005).

[7] K.ARAI, J.OMACHI, and S.Oda, "Observation of the Quasi-direct recombination nanocrystalline silicon dots by reducing the core diameter", Electrochemical Society Proceeding Volume **2002-09**, 109 (2002).

[8] S.Oda, "NeoSilicon materials and silicon nanodevices", Materials Science and Engineering B. **101,** 19 (2003).

[9] 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).