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Improvement of Electroluminescent Efficiency of Light-Emitting Porous Silicon

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Since Canham and his coworkers discovered the visible light emission from porous silicon (PS) [1], a great deal of attention has been paid both on the investigation of the mechanism of the luminescence and on the exploitation of its possible device applications. In addition to the strong photoluminescence (PL) , the solid state EL effect has been achieved recently by a number of groups. Unlike the high quantum efficiency of PL, which is about 1% under the ultra-violet (UV) light illumination, the efficiency of EL of PS is extremely poor, i.e. about five orders of magnitude smaller than that of PL. The EL spectrum is usually observed at relatively high voltage and current density. Koshida and Koyama observed the EL spectra from a Au/PS/Si structure under the positive bias condition of 7V,90mA/cm^2 [2]. Richter et al achieved EL of PS at very high bias voltage (200V) and relatively low current (5mA) [3]. To improve the EL efficiency of PS is now being a key problem before any kind of optoelectronic devices fabricated by PS could be put into practical use. In this work, we find that the I-V characteristic and the EL efficiency of metal/PS/Si structure could be greatly improved by using some post pore-forming treatment.

The samples used were p-type Si(100) single crystal wafers with the resistivity of 18-23Ω·cm. The anodic process took 5 min. at the current density of 10mA/cm^2 and under the illumination of natural light. After the above treatment, the porous silicon layer could emit strong visible light in the red or orange colour under the illumination of UV light.

To achieve EL, it is necessary to make a semi-transparent metal electrode, which is Au in our case, on the top of PS. Since the surface of the PS film is very rough, a Au film with the thickness of 20 nm on it could not form a good conducting layer in a surface area of several mm^2. To make the surface of the PS flat and smooth, the wafer was oxidized in boiling HNO_3 for 3-5 min.. After HNO_3 post -treatment, the semi-transparent Au film deposited on PS surface may behave very good in its conducting property.

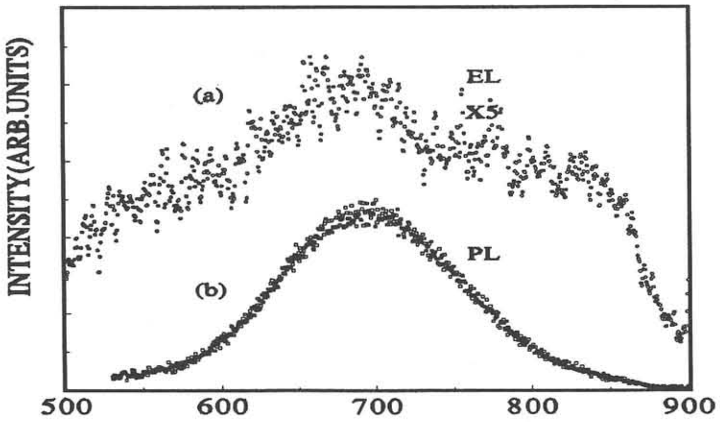

Fig.1

Fig.1 shows the comparison between the PL and the EL spectra of our sample. The light emitting area is about 8x8 mm^2. The peak of EL spectrum(680 nm) shifts slightly towards higher energy as compared with that of PL (700 nm).

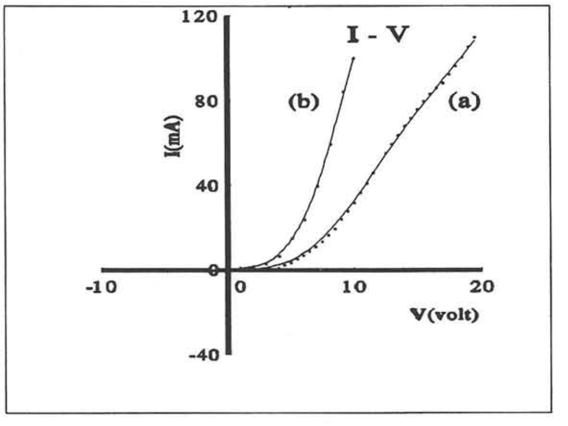

Fig.2

The I-V characteristic of the Au/PS/p-Si/Ag structure is shown by curve (a) in Fig.2. The reverse current is very small in the range of 0.1 mA up to a voltage of 10V. The light emission occurs at a forward voltage of 15V and current density of $100mA/cm^2$. The large voltage threshold is believed due to the existence of a thin tunneling oxide film between the Au electrode and the PS, while the large current density is due to the partial short circuit occurred between the Au film and the Si pores. It means that the low EL efficiency is extrinsic rather than intrinsic. Therefore, to improve the EL efficiency the first step one should take is to reduce the leakage current. In our case, the PS wafer was anodically oxidized in 3% HCl solution before it was treated by boiling HNO_3. The idea is to passivate the surface of the Si substrate exposed at the bottoms of the pores. The result is shown by the curve (b) in Fig.2, where the forward I-V characteristic is improved. The ideal factor of forward I-V curve at small current density is about 7, which is much smaller than the value of 420 reported by Koshida and Koyama. The luminescence threshold are now 6V and $30mA/cm^2$, which are smaller than that reported by previous papers. Of course, in order to reach the goal of making a prototype of LED by PS, there is still a long way to go.

Acknowledgement

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1. L. T. Canham, Appl. Phys. Lett., 57 (1990) 1046
2. N. Koshida and Koyama, Appl. Phys. Lett., 60 (1992) 347
3. A. Richter, P. Steiner, F. Kozlowski and W. Lang, IEEE Electron Device Letters, 12(1991) 691