Study on electroluminescence from porous silicon light-emitting diode

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Received July 13, 2005

Porous silicon (PS) light-emitting diode (LED) with an ITO/PS/p-Si/Al structure was fabricated by anodic oxidation method. Photoluminescence (PL) of the PS LED was measured with a peak at 593 nm, and electroluminescence (EL) was measured with a peak at 556 nm under the conditions of 7.5-V forward bias and 210-mA current intensity. The spectral width of EL was measured to be about 160 nm.

OCIS codes: 230.3670, 310.6860, 250.5230.

Crystalline silicon is the most important semiconductor material of integrated circuit and microelectronics. People hope for photoelectronics integration on silicon basis. However, due to silicon's indirect band gap structure, it could not be used for light emitting or laser diode. It was not until 1990 that Canham[1] first discovered its optical properties and opened the door to porous silicon (PS) for potential uses in light-emitting devices. People's investigation aim is that silicon materials can realize high luminescence efficiency. Different kinds of apparatus antetype of electroluminescence (EL) from PS were reported, such as: Schottky type structure[2−6], np heterojunction structure[7,8], PIN type diode structure[9−11] and MOS type structure[12]. In the present work, a 100-nm-thick indium tin oxide (ITO) thin film was deposited by pulsed laser on PS as n-type contact layer, we succeeded in making PS light-emitting diode (LED) with structure of ITO/PS/p-Si/Al and observed its EL emission for a few hours under 7.5-V forward bias conditions.

The substrates used in this experiment were p-type single-crystal (100) Si wafers (5—8 Ω·cm in the resistivity). An ohmic contact was formed by thin Al films on the back side. PS layer of this device was prepared by electrochemical anodic oxidation method in solution of hydrofluoric (HF) acid and ethanol ($V_{\mathrm{HF}} : V_{\mathrm{C_2H_5OH}} =$ 1:1), under constant current density of 8 mA/cm^2 for 20 min, performed in an apparatus schematically shown in Fig. 1. Photoluminescence (PL) and EL from PS LED were measured by fluorophotometer (RF-5301PC). Scanning electron microscopy (SEM) of ITO/PS/p-Si/Al was performed by field scanning electron microscope (JSM-6700F).

The SEM picture in Fig. 2 shows section of the EL device. The layered structure can easily be observed. Thickness of the remained crystalline silicon columns in PS layer is about 15 μm. The crystalline silicon columns have some cracks, which may be caused by outside force. There is fine electrical contact which leads to efficient carrier injection between PS layer and ITO layer. PS layer consists of an interconnected silicon skeleton and is described in terms of a "quantum sponge" which provides the concept of quantum confinement[13,14].

The experimental EL device consists of a semi-transparent ITO/PS layer, a p-type Si wafer, and an Al electrode, respectively, as shown in Fig. 3. Light emission emanating from the top surface is only observed under forward bias conditions. The light emission lasts at least 2 hours under 7.5-V forward bias conditions. Forward bias applied to the base silicon will tend to flatten the potential of the valence band, allowing holes to enter the PS region. Electrons can be injected into the PS from n-type ITO, and then EL results from recombination of injected electrons and majority-carrier holes within the silicon nanostructure[7].

Figure 4 shows a typical example of the I-V curve of the EL device. The EL device exhibits a rectifying junction behavior. When the forward current density exceeds a certain value (about 140 mA/cm^2 at 6 V), a stable visible

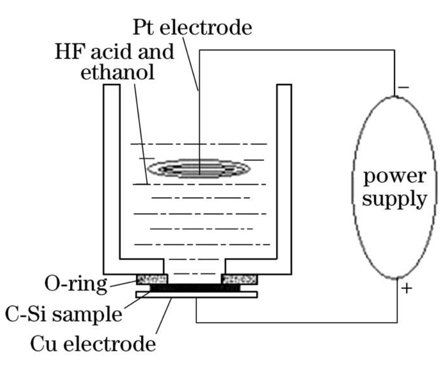

Fig. 1. Etching apparatus for PS LED.

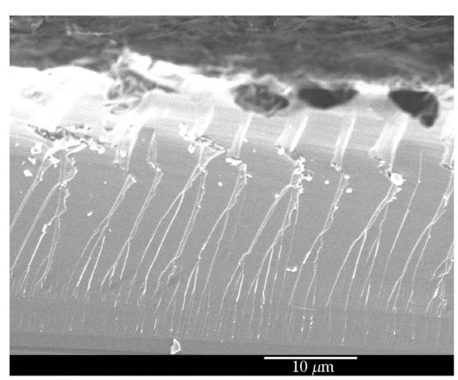

Fig. 2. SEM of section of PS LED.

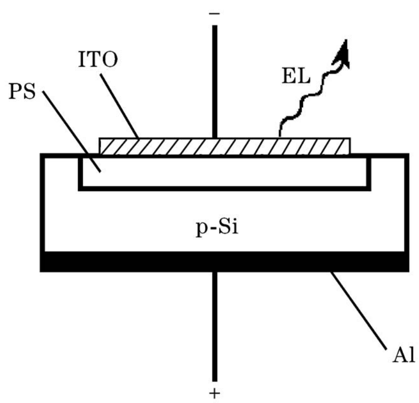

Fig. 3. Structure of ITO/PS/p-Si/Al.

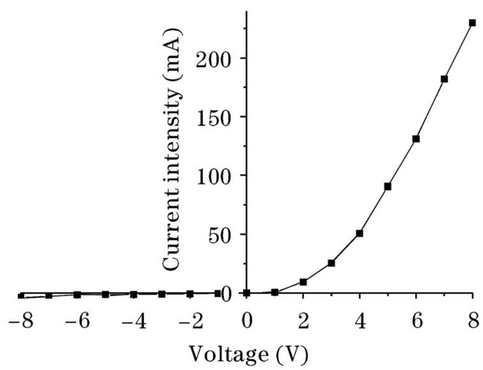

Fig. 4. *I*-*V* characteristic of PS LED.

light emission is observed through the semi-transparent ITO electrode. EL emission is clearly observed in the dark. Under reverse bias conditions, current density is significantly small, and correspondingly, no EL emission is observed.

EL and PL spectra of the same PS sample are shown in Fig. 5. The PL spectra were measured on RF5301 fluorescence spectrophotometer with 320-nm wavelength excitation beam from 150-W xenon lamp. It should be noted that the EL spectrum is close to the PL spectrum obtained from the shorter-wavelength excitation. The EL and PL spectra are basically similar in both width and peak wavelength. The peak wavelength of the EL

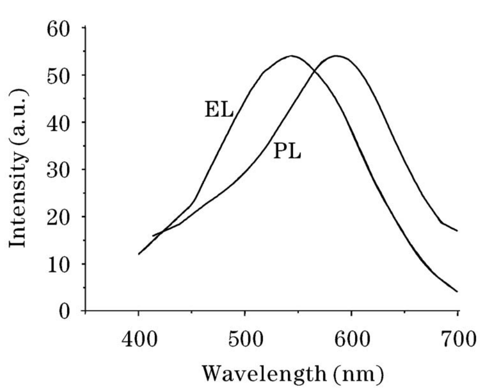

Fig. 5. PL and EL spectra from the same PS sample.

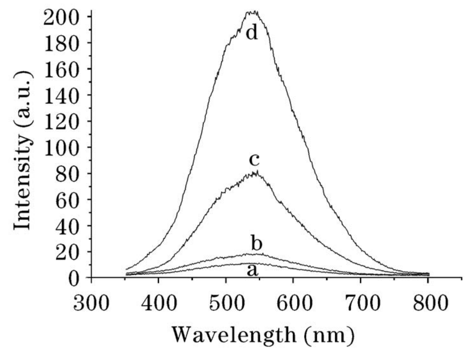

Fig. 6. Effect of current density on the EL spectra of PS. (a) 50; (b) 60; (c) 80; (d) 100 mA/cm^2.

spectrum (556 nm) was somewhat short in comparison to that of the PL spectrum (593 nm), but with similar linewidth. The different peak wavelength between PL and EL may be attributed to different positions of carrier recombination inside the PS. Figure 6 shows the effect of current density on EL intensity. The EL intensity increases with the increasing of forward current density. This shows that the EL emission from PS is based on the carrier injection mechanism.

In conclusion, a PS LED was fabricated and its EL and PL properties were studied experimentally. It was shown from the PS LED *I*-*V* characteristic that EL intensity increases with the increasing of forward current density. This implies that the EL emission from PS is based on the carrier injection mechanism.

This work was supported by the Natural Science Foundation of Shandong Province (No. Y2002A09). Y. Yang's e-mail address is yangyajun_76@163.com.

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