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Bright red electroluminescence in diffused porous silicon *p–n* junction

V K JAIN, AMITA GUPTA, A KUMAR, G K SINGHAL, O P ARORA, T SRINIVASAN, D S AHUJA, P P PURI and VIKRAM KUMAR
Solid State Physics Laboratory, Lucknow Road, Delhi 110054, India

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Abstract. We report the first operation of light emitting *p–n* junction diode in porous silicon fabricated by diffusion.

Keywords. Electroluminescence; porous-silicon *p–n* junction.

The recent demonstration (Canham 1990) of visible photoluminescence from porous silicon (PSi) at room temperature has received worldwide attention. Several attempts have been reported for obtaining electroluminescence from this material. Detailed structural and optical investigations of the properties of this material have been reviewed recently by Searson *et al* (1992). The porosity is commonly generated by an electrochemical process which results in a nanometer size silicon ligament network. There have been different explanations invoking quantum size effects and formation of hydride layers for the observation of photoluminescence in this material.

Here we report two significant results which are likely to open up this material for optoelectronic applications. Firstly we have observed photoluminescence from the *p–n* junctions formed by diffusion of counter dopant. Secondly, we report the fabrication of electroluminescent diode with stable optical characteristics.

In these experiments both *n*- and *p*-type silicon having 2 ohm cm resistivity were used. Here we discuss only the work on *p* type silicon though similar results have been obtained on the *n* type material. First the back contact to the wafer was made by aluminum evaporation and alloying which is covered by acid resistant wax. The anodization was carried out in 48% HF:ethanol (1:1) solution using Pt electrode as cathode keeping the current density between 10 to 15 mA/cm^2. Phosphorous was diffused at 850°C for 30 min from a $POCl_3$ source. To measure the electrical properties of porous silicon, 5 mm diam Ti/Ag contacts were evaporated through metal mask.

Preliminary observation of photoluminescence was carried out by placing the sample in ultraviolet light. The undiffused samples gave a bright orange or red glow as usual. The photoluminescence spectra were taken by exciting with a 488 nm Ar laser beam varying the power from 20 to 200 mW. The typical photoluminescence shown by solid line in figure 1 extends over a wide range from 600 to 850 nm with peak at 725 nm for *p*-type PSi. This spectrum is common for this material.

It is commonly observed that heat treatment of PSi to about 300°C kills the photoluminescence. This was also observed in the present study. If diffusion is carried out to form p^+p or n^+n structures no photoluminescence is observed. However when the heat treatment is accompanied by counterdoping to form n^+p or p^+n structures, photoluminescence remains. The spectrum consists of a sharp peak as shown by dashed line in figure 1. This is the first report of this observation.

Next we form contacts to the PSi junction diode to observe electroluminescence. A prober was used to pass current of about 500 mA at 10 V to observe red light up

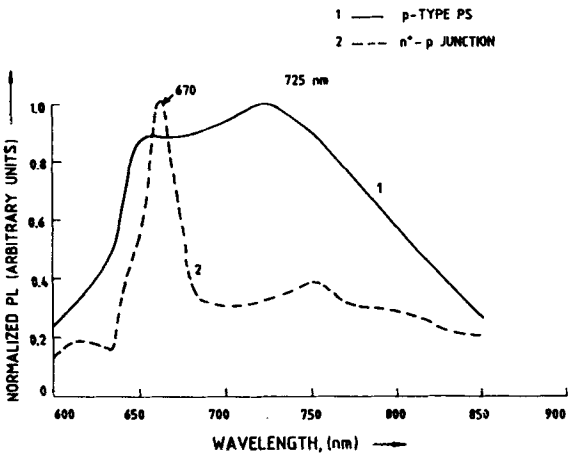

Figure 1. Photoluminescence spectrum of as-processed *p* type porous silicon (solid line) and after phosphorus diffusion (dashed line).

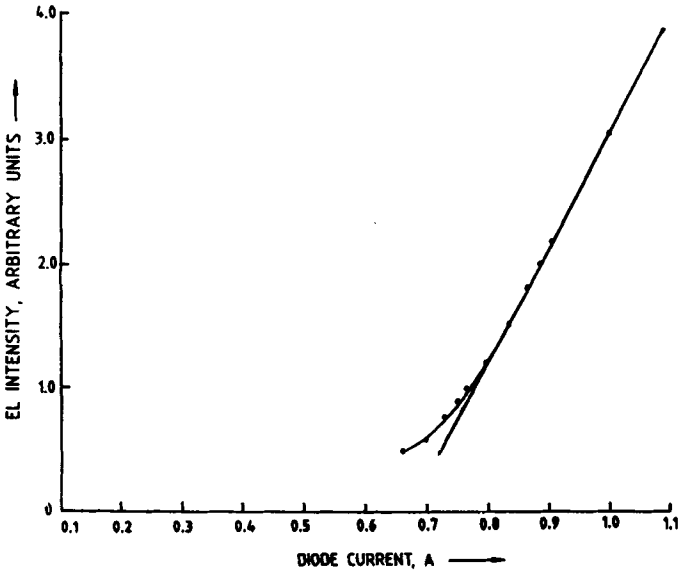

Figure 2. Electroluminescence intensity as function of forward current.

to 5 h from one sample. The light intensity measured with a photodiode is proportional to the forward current as shown in figure 2. This is the first fabrication of red light emitting diode with stable characteristics using diffused junction. Earlier observations of electroluminescence (Namavar *et al* 1992) in ITO–PSi–Si Schottky barrier like structures have been feeble and unstable.

We have carried out several other characterizations such as conductivity, photoconductivity, SIMS profiling etc as well as variation of process parameters to understand the phenomenon of photoluminescence from the diffused junction. We believe that the photoluminescence from the as-processed PSi is due to the presence of silicon hydride complexes (Prokes *et al* 1992) while the post-diffusion photoluminescence/electroluminescence is due to the quantum size effect. The junction which is shallow

in the silicon substrate serves as the source of minority carriers by injection into the quantum wires where direct recombination takes place to give out light. Details of these studies will be published elsewhere.

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