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Light-Emitting pn Homo-Junction Diode with Direct Doping into Porous Si

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Light-emitting pn homo-junction diodes with direct doping into porous silicon have been fabricated by using polymeric spin-on glass (SOG) and investigated by SIMS (secondary ion mass spectrometry). The same porous Si structure exists in p region and doped n region. The device series resistance is decreased by an order of 10^2 and intensive rectifying characteristics are observed in I-V curves.

Soon after visible light emission from porous silicon (PS) was demonstrated[1], a PS based light emitting diode was presented.[2] One type is Schottky diode where a metal contact is deposited on the PS surface, and the other is a pn diode fabricated by electrical etching through a pn junction silicon wafer. This type of pn diode shows different structure in PS p region and n region. On the other hand, direct doping into the PS has hitherto not been carried out because the thermal anneal causes the light emission to disappear.

In this letter, a new fabrication technology and the properties of a light-emitting pn homo-junction diode with direct doping into porous silicon are described.

A p^+ contact was formed on the back side of the p type silicon wafers(9-10 Ω cm). The PS layer was formed by electrochemical etching in HF solution. The SOG was spun on the PS and baked. Phosphorous was diffused into the PS to form a n^+ layer. The junction depth is about 0.4 μm. After doping, the samples were electrochemically etched. A PS p^- layer was formed underneath the PS n^+ layer. The total PS layer thickness was 3-10 μm. The ITO electrodes were deposited on the top surface in an area of 1 mm^2.

Figure 1 shows photoluminescence (PL) spectra from (a)as-doped and (b)after electrical etching at room temperature. The orange-red PL disappeared after annealing in the impurity doping process, But recovered completely after electrochemical etching. There was no structural difference in PS p layer and n layer for the fabricated pn diode as shown in Figure 2. Since the bandgap cannot be different in p region and n region, pn junction can be homo-junction. The phosphorous concentration is in the range of 10^{18}-10^{20} /cm^3 in SIMS profiles in Figure 3.

The pn diode emitted red-orange light under forward bias condition (under 5 V) which is clearly visible to the naked eyes. Figure 4 shows the I-V characteristics at room temperature of a pn diode and a Schottky diode fabricated under the same condition as the pn diode without doping. The resistance of forward bias at 5 V for the pn diode is decreased to about 1/700. The rectifying ratio of 430 increased 5 times compared with the Schottky diode. From the I-V curve for the pn diode, and by considering junction resistance, the series resistance was estimated to be 22 Ω. The resistivity of PS is estimated to be about 50 times larger than bulk Si. The resistivity of PS was reported to be 10^3 to 10^4 times larger than that of bulk Si. In this experiment, the high junction resistance between the contact and the PS was eliminated by an ohmic contact formed by doping, which may be the main factor accounting for the difference.

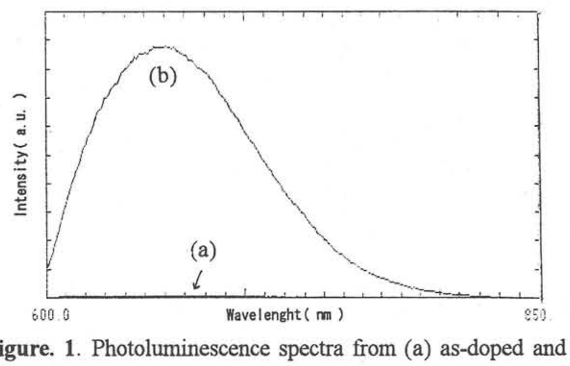

Figure. 1. Photoluminescence spectra from (a) as-doped and (b) after electrical etching at room temperature.

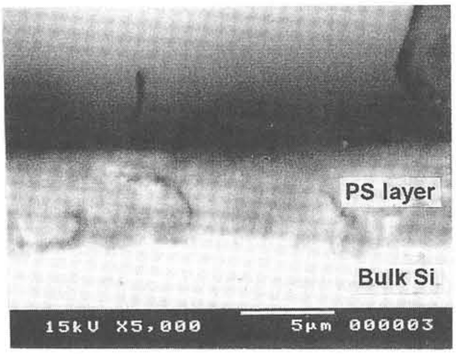

Figure 2. SEM cross section of a pn homo-junction diode.

The changes dependent on the ideal n factor with forward bias are shown in Figure 5. The (a) ITO/PS Schottky diode and (b) ITO/Si Schottky diode n factor curves are very similar but, on the other hand, n factor of (c) PS pn homo-junction diode is lower than that of Schottky diodes. Thus, it is suggested that the fabricated diode has pn junction. The value for n factor in pn diode is 1 for diffusion current, 2 for recombination-generation current, and 4 for surface channel current[3]. It is likely that the ideal factor larger than 2 is attributable to a surface channel current and a tunnel current through surface oxide between ITO contact and PS.

In summary, light-emitting pn homo-junction diodes by direct doping into PS have been fabricated and investigated by SIMS. The series resistance of a pn diode is decreased by 1/700 compared with that of a Schottky diode, and shows strong rectifying characteristics. By electrochemical etching after doping,

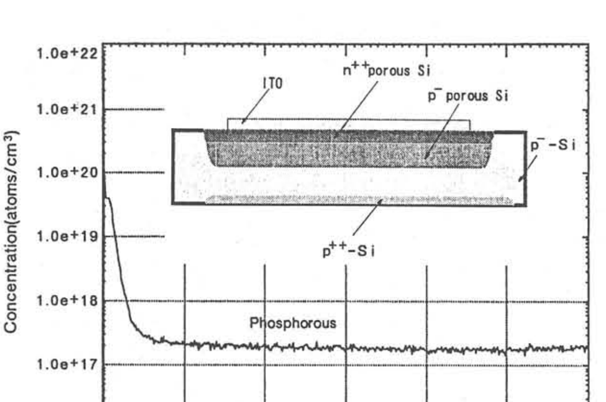

Figure 3. Depth profile of phosphorous obtained with SIMS for a pn homo-junction. Schematic depiction of the light emitting pn junction diode is also shown.

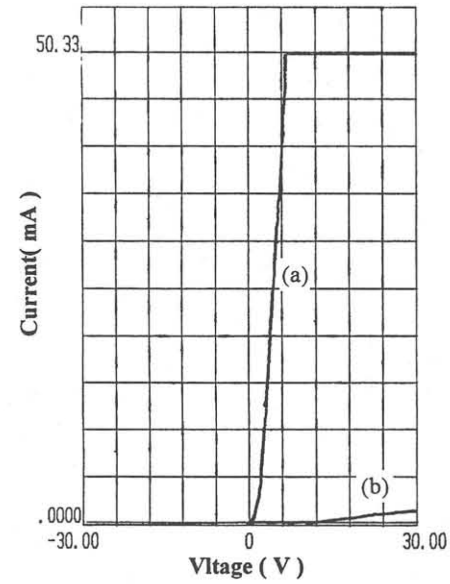

Figure 4. I-V characteristics of (a) a pn homo-junction diode and (b) a Schottky diode at room temperature.

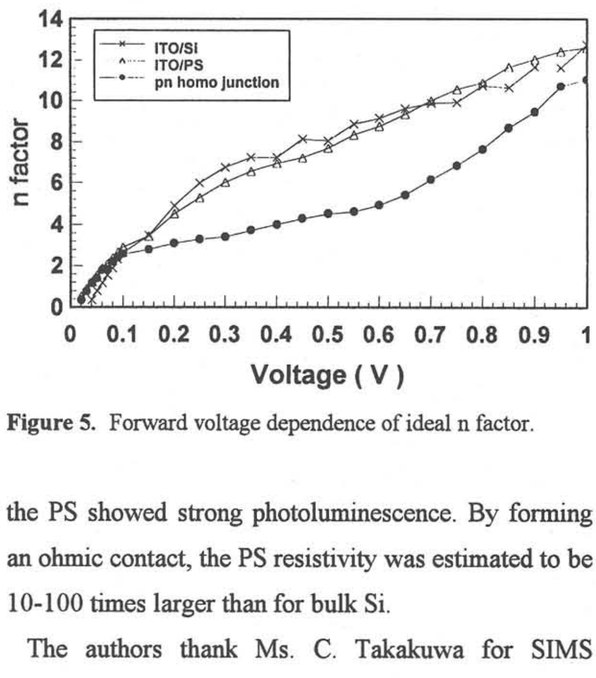

Figure 5. Forward voltage dependence of ideal n factor.

the PS showed strong photoluminescence. By forming an ohmic contact, the PS resistivity was estimated to be 10-100 times larger than for bulk Si.

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References

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