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Preparation and Visible Electroluminescence of μc-SiC/Porous Si/C-Si PN Junctions

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We have fabricated three kinds of μc-SiC/PS/c-Si pn junction diodes and demonstrated a current-induced visible light emission from n-type μc-SiC/PS/p-type c-Si pn diodes. We have observed three types of visible light emissions which were a very weak white light emission, a strong orange-red light emission, and a uniform red light emission.

1.Introduction

Recently, the strong visible photoluminescence (PL) from porous silicon (PS) has attracted much interest,[1] because it offers many possibilities for a new function in Si integrated circuits. Now, there are some reports on electroluminescence (EL) in Au/PS and indium tin oxide (ITO)/PS Shottky-type junction diodes.[2,3] However, they are insufficient for practical use because of their high threshold voltage and low EL intensity. Since the pn junction diode injects carriers more effectively into a luminescent layer than the Shottky junction diode, there is the possibility of improving the EL characteristics. The fabrication of the PS-based pn junction diode, however, is very difficult, because a low temperature preparation process (<300°C), a wide band gap(~2.5eV), and high conductivity junction material are necessary.

We have fabricated microcrystalline silicon carbon (μc-SiC) films by electron cyclotron resonance plasma chemical vapor deposition (ECR CVD).[4] The μc-SiC film has an optical band gap from 2.1-2.4 eV, dark conductivity from 10^{-3}-1 S/cm, and its deposition process is less than 300°C. Therefore, a good pn junction is expected for PS. In this paper, we will show some characteristics of μc-SiC/PS/c-Si pn junction diodes and demonstrate a current-induced visible light emission from the n-type μc-SiC/PS/p-type c-Si pn diodes.

2.μc-SiC/PS diodes

Figure 1 shows the structure of the μc-SiC/PS diodes fabricated in this study. Three types of the porous Si were prepared by anodization of crystalline silicon (c-Si) substrate using HF ethanol solution ($HF:H_2O:C_2H_5OH=1:1:2$) under the conditions shown in Table 1. Immediately after the anodization, the samples were transferred into an ECRCVD apparatus, and then n-type μc-SiC (thickness, 150Å) and p-type μc-SiC (thickness, 300Å) were deposited onto the PS layers of samples (a) and (b) and sample (c), respectively.

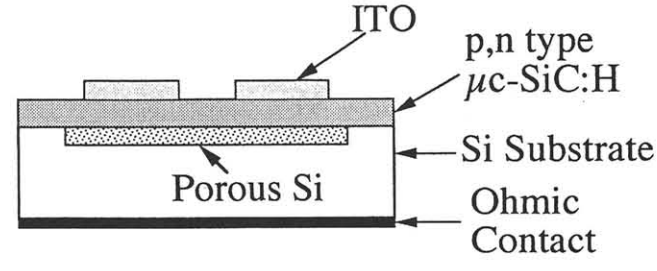


Fig.1 Structure of μc-SiC/porous Si diodes.

Table 1. Preparation condition of porous Si.

Sample	(a)	(b)	(c)
substrate	Si(100) (boron doped)	p-type	Si(100) n-type (phosphorus doped)
resistivity	3.5-4.5 Ωcm	0.2-0.4 Ωcm	1.25-1.75 Ωcm
anodization current	10 mA/cm^2	20 mA/cm^2	10 mA/cm^2
anodization time	5 min	3 min	3 min
etching after anodization	1% KOH in H_2O (a few second)	electrolyte HF solution (5 min)	electrolyte HF solution (3 min)

*) During anodization the substrates were illuminated with a 500W tungsten lamp.

The deposition condition of μc-SiC was as follows: the microwave power was 300W, the deposition temperature was 300°C, the gas pressure was 5mTorr, the gas ratios for n- and p-type μc-SiC were SiH_4:CH_4:PH_3:H_2=1:2:0.01:190 and SiH_4:CH_4:B_2H_6:H_2=1:1:0.01:234, respectively. The optical band gaps and the dark conductivities were 2.3eV and 10^{-1} S/cm for n-type μc-SiC and 2.3eV and 3×10^{-2}S/cm for p-type μc-SiC, respectively. These μc-SiC films were confirmed as showing no photoluminescence. After the deposition of μc-SiC, ITO (thickness, 600Å) was evaporated as a transparent electrode in an area of 1mm^2 for samples (a) and (c), and in an area of 1cm^2 for sample (b).

Figure 2 shows a current-voltage (I-V) characteristic of the n-type μc-SiC/PS (sample (a)) diode. Open circles and solid circles refer to the positive bias applied to p-type c-Si substrate (forward direction) and negative bias (reverse direction), respectively. The μc-SiC/PS(sample(a)) diode showed a clear rectification behavior and the rectification ratio was 2×10^4 at ±1V. The n-factor calculated between 0.1V and 0.4V was 2.03. When the forward current exceeded a certain value (about 90mA at about 20V), white light emission was seen and become stronger with increasing applied voltage, although it was extremely weak.

After that, when we applied a forward voltage of more than 24V, the current suddenly increased to 619mA which is the current limitation of the voltage source used in these experiments, and at the same time, a strong orange-red light emission appeared. We observed the current - induced visible light emission in only the forward direction. No light emission was observed in the reverse voltage up to 60V.

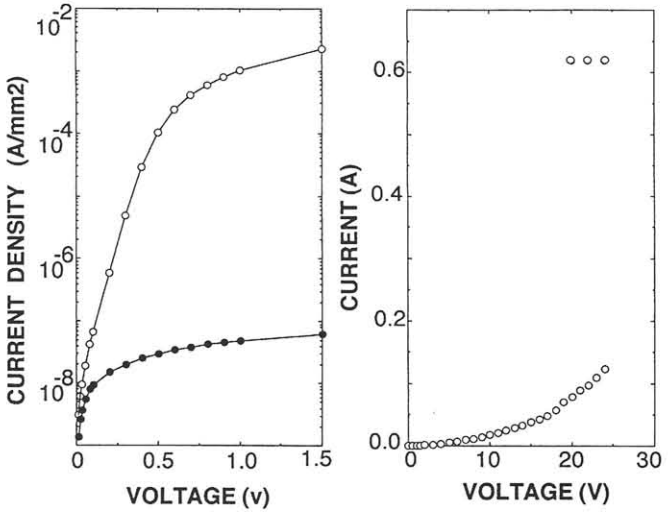


Fig.2 I-V characteristics of n-type μc-SiC/ PS(sample(a)) diode.

Figure 3-(I) shows a current-voltage characteristic of the p-type μc-SiC/ PS (sample (c)) pn junction diode. Good rectification behavior was observed and the rectification ratio was 1.4×10^5 at ±1V. The n-factor between 0.1V and 0.5V was 1.82. The μc-SiC/PS(Sample(c)) diode showed no light emission even at a forward voltage more than 50V. Before the deposition of p-type μc-SiC, the n-type PS layer showed an efficient visible PL emission. However, after the deposition of p-type μc-SiC:H, the PS showed no

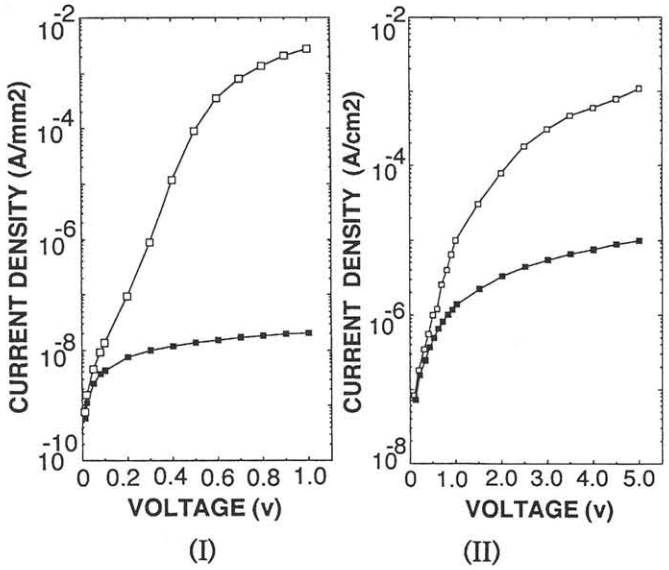


Fig.3 I-V characteristics of p-type μc-SiC/ PS(sample(c)):(I) and n-type μc-SiC/ PS(sample(b)):(II)

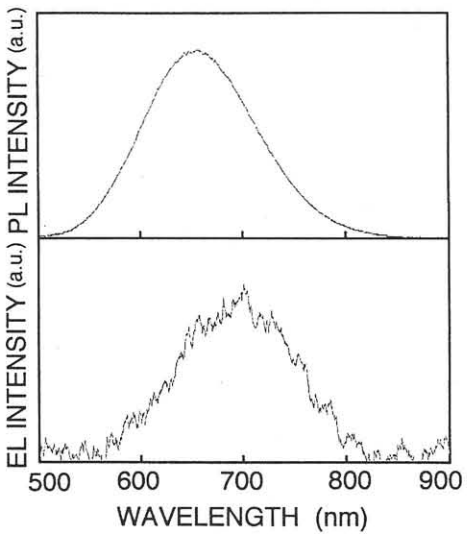
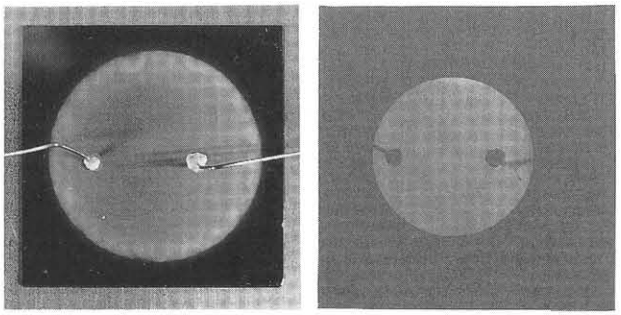


Fig.4 PL spectrum of porous Si(sample(b)) and EL spectrum of n-type μc-SiC/PS(sample(b)) pn diode.

PL emission. This is probably due to the destruction of the luminescent structure in the n-type PS which results from hydrogen ion damage during the deposition of p-type μc-SiC by ECR plasma CVD.

Figure 3-(II) shows a current-voltage characteristic of n-type μc-SiC:H/PS (sample (b)) pn junction diode with an ITO area of $1cm^2$. The μc-SiC/PS(sample(b)) diode showed poor rectification behavior. The rectification ratio was around 10 at ±1V. The n-factor was quite large. When the forward current density exceeded a certain value (around 12mA at 18V), a stable red light emission was observed from the whole ITO area. The red-light emission was quite uniform. The EL intensity increased consistently with the forward current density of the diode.

Figure 4 shows the EL spectrum of μc-SiC/PS(sample(b)) diode. For a comparison, the PL spectrum of the PS(sample(b)) is also shown in Fig.4. The EL spectrum was measured at the forward current density of $20mA/cm^2$ and the applied voltage of 29V. The EL spectrum exhibited a very broad spectrum with a peak at 700 nm. The peak wavelength of the EL spectrum is about 40nm longer than that of the PL spectrum. This result is contrary to that reported by Koshida[2] in which the EL peak wavelength(680nm) was shorter than the PL peak wavelength (700nm).



(I) (II)

Fig.5 Photographs of n-type μc-SiC/PS(sample(b)) pn diode:(I) and EL emission from (I) in the dark:(II).

Figure 5 shows photographs of the n-type μc-SiC/PS(sample(b)) diode and the red light emission from this EL devices in the dark. The applied voltage and the current density were 29V and $20mA/cm^2$, respectively.

3.Conclusion

We have fabricated three kinds of μc-SiC/PS/c-Si pn junction diodes and demonstrated current-induced visible light emission from n-type μc-SiC/PS/p-type c-Si pn diodes. We have obtained a clear rectification behavior for all samples. We have also observed three types of visible light emissions which were a very weak white light emission, a strong orange-red light emission, and a uniform red light emission.

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