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A study of deposition single crystal SiCN thin film on porous silicon for ultraviolet light detecting applications

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1. Introduction

Recently, it is urgently needed to develop an UV detector with good ultraviolet absorption, high temperature, lower cost, and be compatible with silicon process for massive industry applications. In the past, major compact UV sensors were developed with GaN, β-SiC on Si, 4H-SiC, and 6H-SiC. The GaN or 6H-SiC UV sensor has better high temperature characteristics [1-2], but is more expensive [3-4]. Even, the β-SiC on Si substrate is low cost, and has been studied widely for its lower cost. Nevertheless, its photocurrent/dark current ratio (PDCR) is low, especially in high temperature. Therefore, it is interesting to search a new material for low cost high temperature UV detecting applications. On the other hand, the high resistivity and the flexibility of the porous silicon (PS) layer can suppress the dark current of an optical sensing device at high temperature [5-6], and the wide band gap semiconductor, silicon carbon nitride (SiCN) has many interesting physical characteristics such as hardness, oxidation resistance, high thermal stability, and corrosion resistance [7]. Hence, in this work both materials were employed to construct c-SiCN/PS heterojunction for the low cost UV detecting application

In this paper, two structures were developed, i.e., lateral n-SiCN/p-PS and vertical n-SiCN/p-PS heterojunction. The PDCR of both structures under 254 nm wavelength light source at various operating temperatures were measured and compared. Experimental results found the lateral n-SiCN/p-PS heterojunction has the better PDCR than the vertical heterojunction.

2. Device Fabrication

Figure 1 illustrates the structure diagram of samples for the study. In preparing the samples, an electrochemical anodization method was used to form the PS layer on (100) p-type Si substrate with resistivity of 4-10 Ω-cm. Prior to the anodization, Al (3000-5000 Å) film was deposited on the back side of the samples and annealed at 450°C for 15 minutes in forming gas to distribute the etching current uniformly. The anodic etching was carried out in an HF-ethanol solution (HF: H_2O: C_2H_5OH=1:2:2), at a constant current density of 30 mA/cm^2 for 10 minutes to get a PS layer with thickness 1.0 μm to 1.2 μm [5-6]. The junction area is 0.8 x 0.8 cm^2 for both structures. To prepare the lateral n-SiCN/p-PS heterojunctions, the p-PS/Si substrate after cleaning was sent to chamber, then rapidly raised the substrate temperature to 1150°C and held for 15 minutes to deposit the 6000 Å thick photosensitive n-SiCN film by a rapid thermal chemical vapor deposition (RTCVD). Sequentially, the Ni (1500 Å) and Al (3000-5000 Å) metals were evaporated on n-SiCN surface and p-PS surface to form the top finger electrode, respectively. Finally, the samples were annealed at 450°C for 15 minutes to form the ohmic contact. The flow rates of SiH_4 (reaction gas), C_3H_8 (carbon source), NH_3 (reaction gas), PH_3 (doping gas), are 80 sccm, 80 sccm, 80 sccm, 10 sccm, respectively. The growth rate is about 400 Å/min. The same processes were also applied to complete the vertical n-SiCN/p-PS heterojunction, except Al now is deposited on the top of PS, instead on the back of Si substrate, to as another terminal contact. A more detailed description for growing c-SiCN and subsequent material characterizations can be found in elsewhere [7].

3. Results

The results of the pore electrochemical anodization procedure was investigated by means of scanning electron microscopy (SEM), and shown in Figures 2a, and 2b for the top PS surface on the Si substrate and the side view of a cleaved section respectively. Fig. 3 shows the spectral responsivity measurement for both n-SiCN/p-PS heterojunction under the room temperature. The peak value in the measured response of the device is around 260 nm. Figs 4, 5 and 6 show the dark currents, photocurrents, and PDCR measured under reversed bias and various temperatures with a HP4145B semiconductor parameter analyzer for both heterojunctions, respectively. The photocurrents were measured under the irradiation of 254 nm UV light source (Model: UVP, UVGL-58) with 0.5 mW/cm^2 power. The PDCR is defined as PDCR= (Ip-Id)/Id, where Id is the dark current; Ip is the photocurrent (i.e. the current under illumination). The photocurrents/dark currents of vertical n-SiCN/p-PS and lateral n-SiCN/p-PS heterojunctions at 25°C, 100°C, 150°C, 200°C are 1.01x10^{-5} mA / 1.18x10^{-7} mA, 1.23x10^{-5} mA / 2.38x10^{-7} mA, 1.12x10^{-4} mA / 7.41x10^{-6} mA, 2.61x10^{-4} mA / 3.54x10^{-5} mA, and 3.96x10^{-6} mA / 3.99x10^{-8} mA, 5.15x10^{-6} mA / 8.88x10^{-8} mA, 6.18x10^{-5} mA / 3.33x10^{-6} mA, 9.51x10^{-5} mA / 9.43x10^{-6} mA under -5 volts bias, respectively. As seen, at room temperature and high temperature, the PDCR for lateral/vertical heterojunctions are 98.4/84.6, and 9.08/6.37, respectively. These data are better than the reported ~ 5.4 in MSM structure [8] or 60 in p-i-n structure [6] of β-SiC UV detector. Figure 7 and insert present the SEM top view photo of n-SiCN film deposited on p-PS. We attribute the improvement in I/V characteristic to the interruption of the leakage path through the conductive silicon substrate by the high resistive and flexible material of the porous silicon layer (~3x10^7 Ω-cm). Besides, in the vertical heterojunction, the thick p-Si substrate (525 μm) loads partial reverse bias, results in a lower field across the n-SiCN region to enhance the photocurrent, and thus the lower PDCR. While for lateral heterojunction, the current is transported trough the PS layer laterally, which is longer than the cross section in the vertical heterojunction, thus results in less leakage. It is the two reasons lead to the higher photocurrent and the PDCR in lateral heterojunction. Fig. 7 and insert present the SEM, and AFM photos for the top view of n-SiCN film deposited on p-PS. As seen in SEM photo, the surface is smooth. The detailed surface morphology can be found in the AFM photos. The roughness/root mean square (RMS) for the device is 7.529 nm/9.628 nm. Fig. 8 shows the low angle x-ray diffraction (XRD) spectra of the n-SiCN/p-PS junction. Because of the hetero-epitaxial growth of SiCN film on the p-PS layer, both diffraction patterns of crystalline Si (c-Si) and crystalline SiCN (c-SiCN) are superimposed, thus, leads to the SiCN/p-PS layer has an obvious peak located at the diffraction angle 46.06° [9], and one peak at 69.07° for Si substrate.

4. Summary

Both of lateral n-SiCN/p-PS and vertical n-SiCN/p-PS heterojunctions have been investigated and compared for low cost and high temperature ultraviolet (UV) detecting applications. The cubic crystalline SiCN films were deposited on p-PS with RTCVD. At room temperature, the PDCR for lateral heterojunction and vertical hetrojuction are 98.4, and 84.6, respectively. At 200°C with and without irradiation of 254 nm UV light, under 0.5 mW/cm^2 and -5 V bias are 9.08 and 6.37, respectively. Compared to the reported UV detectors with SiCN deposited on conventional Si or β-SiC on conventional Si, the developed lateral n-SiCN/p-PS heterojunction has the better current ratio in both room, and high temperature, thus has higher potential applications for high temperature UV sensors.

Acknowledgement

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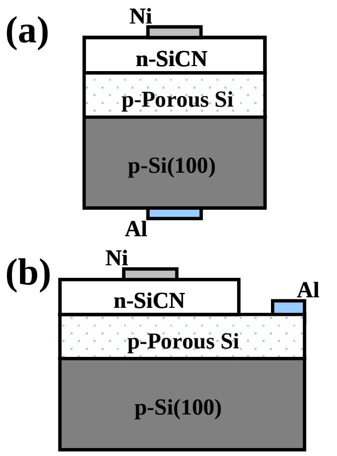

Fig.1 Schematic cross-section of n-SiCN/ p-PS junctions for (a) vertical, (b) lateral.

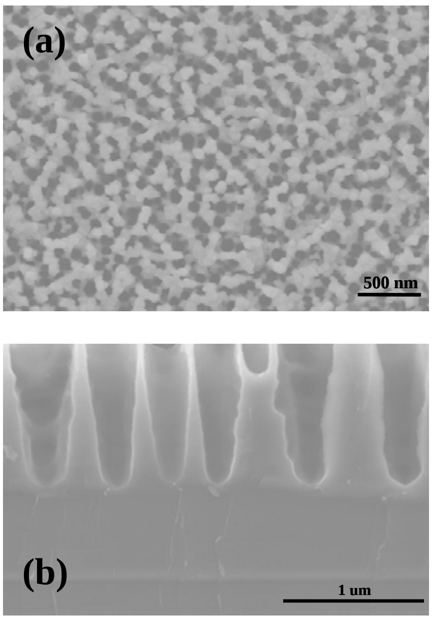

Fig.2 SEM photos of the PS layer on Si Substrate for (a) top view and (b) cross section side view.

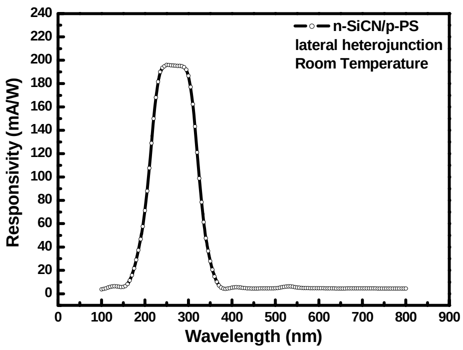

Fig.3 The typical responsivity of the lateral n-SiCN/p-Si heterojunction.

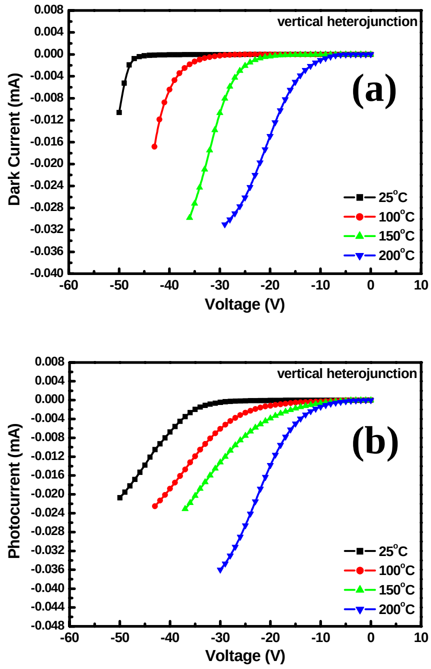

Fig. 4 The dark current (a), and photocurrent (b) for the vertical n-SiCN/p-PS heterojunction.

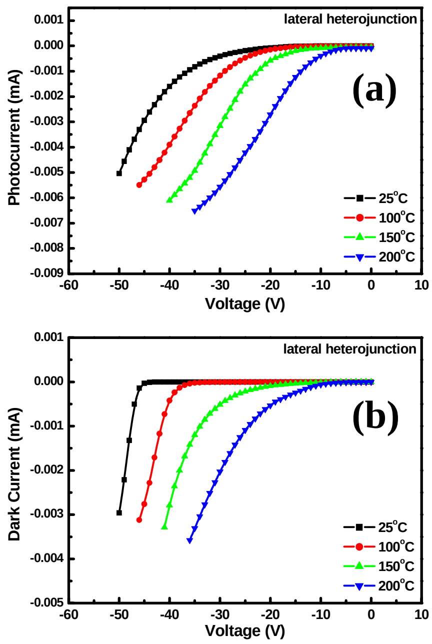

Fig. 5 The photocurrent (a), and dark current (b) for the lateral n-SiCN/p-PS heterojunction.

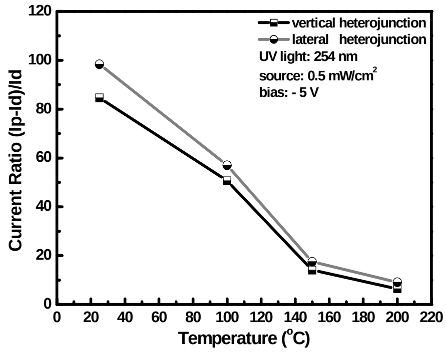

Fig.6 PDCR as a function of measuring temperature for both vertical and lateral n-SiCN/p-PS junctions.

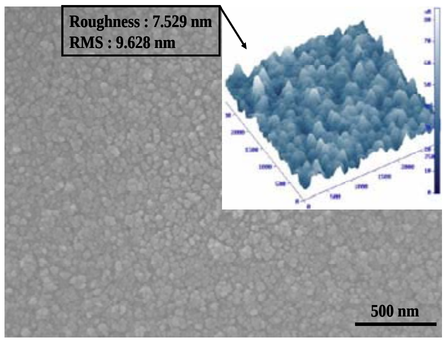

Fig. 7 SEM photo and AFM photo (insert) of the n-SiCN film deposited on p-PS layer.

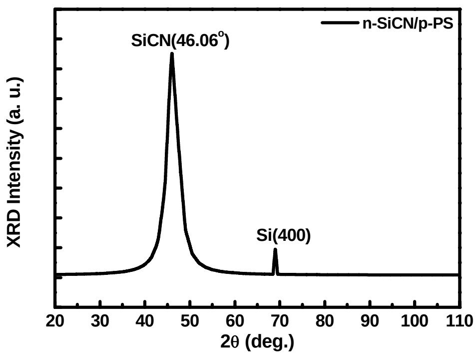

Fig.8 XRD spectra of the n-SiCN film deposited on p-PS layer.