A Low Cost SiCN Homojunction for High Temperature Ultraviolet Detecting Applications
研製低成本高溫氮化碳化矽同質接面紫外線光偵測器

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Abstract: In this work, low cost and high temperature ultraviolet (UV) detecting performances based on n-SiCN/i-SiCN/p-SiCN homojunction on p-type (100) silicon substrate were demonstrated. The current ratio of the homojunction are 3180 and 150.26 under –5 V bias, at 25 ℃ and 175 ℃, respectively. Compared to the reported UV detectors with 4H-SiC or AlGaN, the developed homojunction has the better current ratio in both room and high temperature.

Keywords: SiCN, homojunction, ultraviolet (UV), photodetector, silicon (Si).

摘要：本文章在 p-Si(100)基板上研製低成本高溫氮化碳化矽(SiCN)紫外線(ultraviolet, UV)光偵測器之同質接面 p-i-n 二極體元件。在環境溫度為 25 ℃ 與 175 ℃ 下，同質接面 p-i-n 二極體元件之電流比各為 3180 與 150.26 在–5 伏特偏壓下，此結果優於以 4H-SiC 或 AlGaN 結構紫外光偵測器。因此發展同質接面 p-i-n 紫外光偵測器元件有較佳電流比在室溫與高溫環境下。

關鍵詞：氮化碳化矽，同質接面，紫外線，光偵測器，矽。

1. Introduction

Ultraviolet (UV) sensors were developed with GaN, β-SiC on Si, 4H-SiC, diamond, and 6H-SiC in the past few years. The GaN or 6H-SiC UV sensors has better characteristics in higher temperature [1], but unfortunately is more expensive [2]. Although developing the β-SiC on Si substrate is inexpensive and has already been studied widely for its lower cost. Its photo/dark current ratio (PDCR) is low, especially in high temperature [3]. Hence, searching a new material for low cost high temperature UV detecting applications has become an issue. Silicon carbon nitride (SiCN), a wide band gap semiconductor, has many interesting physical characteristics such as hardness, high thermal stability, oxidation resistance, and corrosion resistance [4]. Moreover, the epitaxial SiCN on Si substrate offers the advantages of economic Si material and VLSI-compatible processing. Therefore, the material SiCN can lower the cost to enhance the applications.

2. Experiments

Sample with junction area of 0.25 cm^2 was prepared on p-type Si (100) substrates by a rapid thermal chemical vapor deposition (RTCVD) system. Figure 1 shows the schematic diagram. The Si substrate was sent to chamber after cleaning, and then rapidly raised the substrate temperature to 1150 ℃ and held for 10 minutes to deposit the 4000 Å thick p-SiCN film with growth rate of 400 Å/min. A 6000 Å thick un-doped photosensitive i-SiCN film under 1150 ℃ for 15 minutes is followed by. Next, a 4000 Å thick n-SiCN film under 1150 ℃ for 10 minutes is deposited. Sequentially, Ni metal was evaporated on the surface of n-SiCN for top finger electrode, and the thickness is about 1500 Å. Finally, the sample was annealed at 450 ℃ under nitrogen ambient for 15 minutes in order to form the ohmic contact. The crystalline SiCN (c-SiCN) film was examined by transmission electron diffraction (TEM) and X-ray diffraction (XRD), while the morphology by scanning electron microscopy (SEM) and atomic force microscopy (AFM). Moreover, the band gap energy of the c-SiCN film was examined by photo-luminescence (PL) measurement system.

3. Results and discussion

Figure 2 presents the XRD of the c-SiCN film on Si substrate. As seen, peaks for SiCN at 45.46° [5], and 69.24° for Si are found [6]. The heteroepitaxial growth of c-SiCN film on the Si substrate causes this phenomenon, which is evidenced by the superimposed diffraction patterns of crystalline Si (c-Si) and c-SiCN observed in the corresponding TEM pattern inserted in Fig. 2. The d spacing is calculated by the TEM pattern. Compared to ICDD [6], the grown c-SiCN has a cubic structure with a FWHM of 1.01°. Fig. 3 shows the dark current and photocurrent measured under reversed bias with a HP4145B semiconductor parameter analyzer at room temperature. The photocurrent was measured under the irradiation of 254 nm and 366nm UV light source with 0.5 mW/cm^2 power. The measured photo/dark current is 0.834 mA/0.262 μA for the homojunction under -5 V bias. Furthermore, the PDCR is defined as

$$PDCR = \frac{I_p - I_d}{I_d}$$

where I_d is the dark current, and I_p is the photocurrent (i.e. the current under illumination).

Figure 4 presents the PDCR of n-SiCN/i-SiCN/p-SiCN homojunction measured under 5 V reverse bias, with and without an irradiation of 254 nm, 0.5 mW/cm^2 power UV light source for various measuring temperatures. At room temperature, the PDCR for homojuction is 3180, which is better than the reported ~ 460 for 4H-SiC UV detector [7], and ~ 332 for AlGaN UV detector [8], and ~ 60 for n-SiCN/i-SiCN/p-Si heterojunction. The thermal generation current in the full-depleted i-SiCN region contributes the major dark current as the temperature increases. It is well known, the thermal generation current is proportional to exp(– E_g/2KT), where E_g is the band gap of i-SiCN (3.2 ~ 4.4 eV), T is operation temperature, and K is Boltzmann constant. Therefore, as the dark current increases, the PDCR decreases rapidly with raising temperature. However, while the operation temperature is up to 175 ℃, the PDCR is still equal to 150.26. The better PDCR is ascribed to the reduced thermal generation dark current caused by the higher E_g of c-SiCN. Besides, the morphology was examined by the SEM top view photo and the AFM image for i-SiCN/p-SiCN/p-Si junction shown in Fig. 5. The roughness/RMS for the homojunction is 1.841/2.297 nm. These results indicate the deposited films are smooth and having high quality. We know that better film quality comes with a higher PDCR. Fig. 6 presents the room temperature spectral responsivity of the c-SiCN/p-Si junction with 5 volt applied bias. The structure is preferred for deep UV detecting applications since the 267nm peak is found. Additionally, the 329.2 nm (3.77 eV) peak with FWHM of 30 meV (4.1 nm) as shown in the typical PL spectrum of SiCN/p-Si sample (inset in Fig. 6) demonstrates the c-SiCN film has a band gap of 3.77 eV [2]. The higher band gap of c-SiCN enhances the thermal stability. Thus, the higher PDCR of the junction is developed.

4. Summary

The n-SiCN/i-SiCN/p-SiCN homojunction has been studied in detailed for low cost and high temperature UV detecting applications. The c-SiCN films deposited on p-Si (100) substrate with RTCVD has a high band gap, and fine film quality, thus results in a photo/dark current ratio of 3180 and 150.26 at room temperature, and 175℃, respectively. Thus the developed homojunction is more suitable for high temperature UV sensing applications.

References

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Figure Caption

Fig. 1 The schematic structure of n-i-p homojuction.

Fig. 2 The XRD pattern for the c-SiCN film on p-Si substrate, and insert gives the corresponding TEM pattern.

Fig. 3 Photo-excited current and dark current of the developed n-SiCN/i-SiCN/p-SiCN junction measured at room temperature under various reverse biases.

Fig. 4 The PDCR of n-SiCN/i-SiCN/p-SiCN junction under various temperatures and 5 V reverse bias, and insert gives the PDCR of n-SiCN/i-SiCN/p-SiCN junction measured at room temperature under different reverse biases.

Fig. 5 The AFM images and SEM photo (insert) of i-SiCN film on p-SiCN/p-Si.

Fig. 6 The current of spectral responsivity for the c-SiCN/p-Si junction under the room temperature, and 5 V applied voltage. The inset shows PL spectrum of c-SiCN/p-Si with 325 nm filter measured at room temperature.

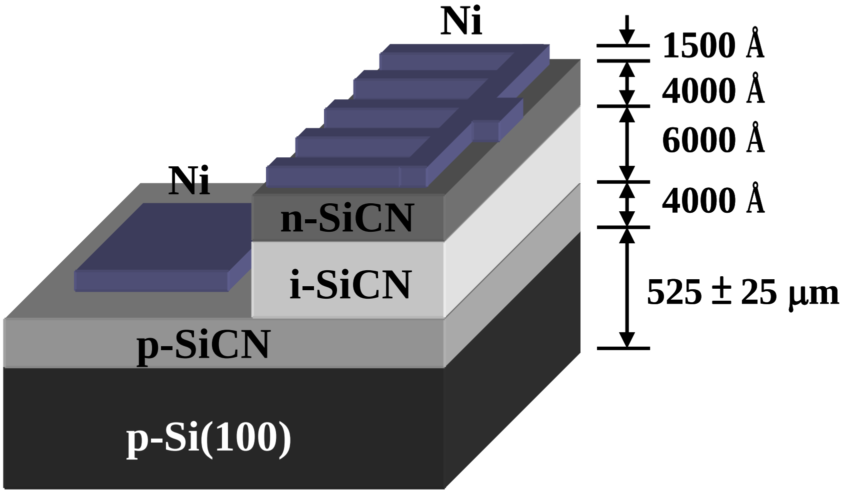

Ni
1500 Å
4000 Å
6000 Å
4000 Å
Ni
n-SiCN
i-SiCN
525 ± 25 μm
p-SiCN
p-Si(100)

Fig. 1

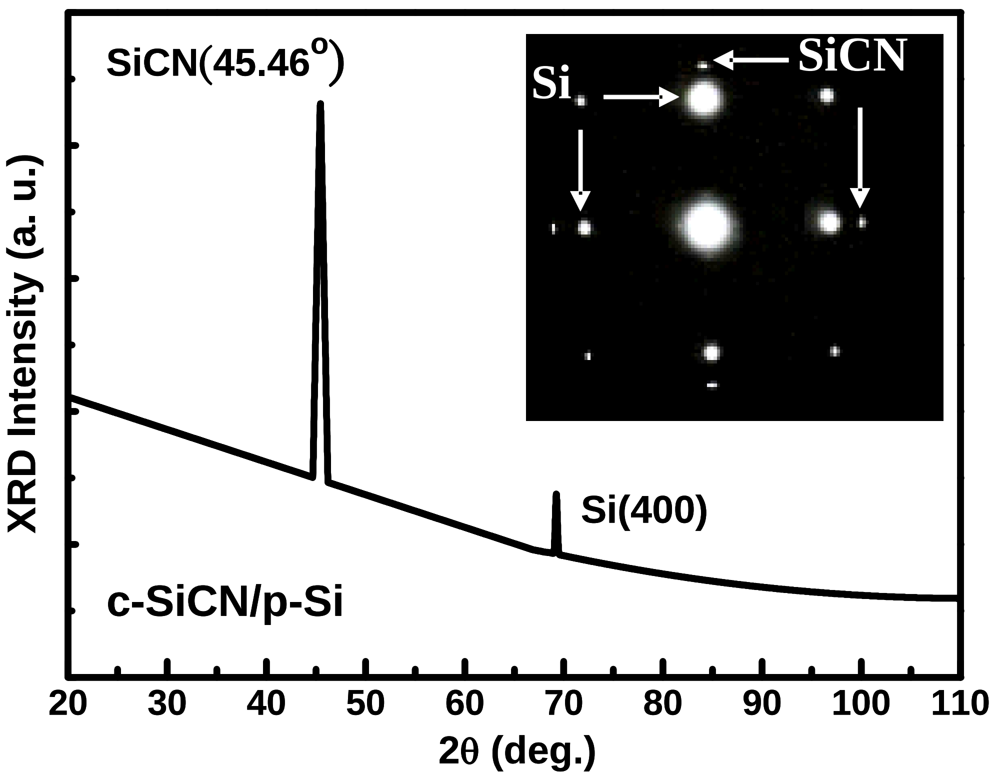
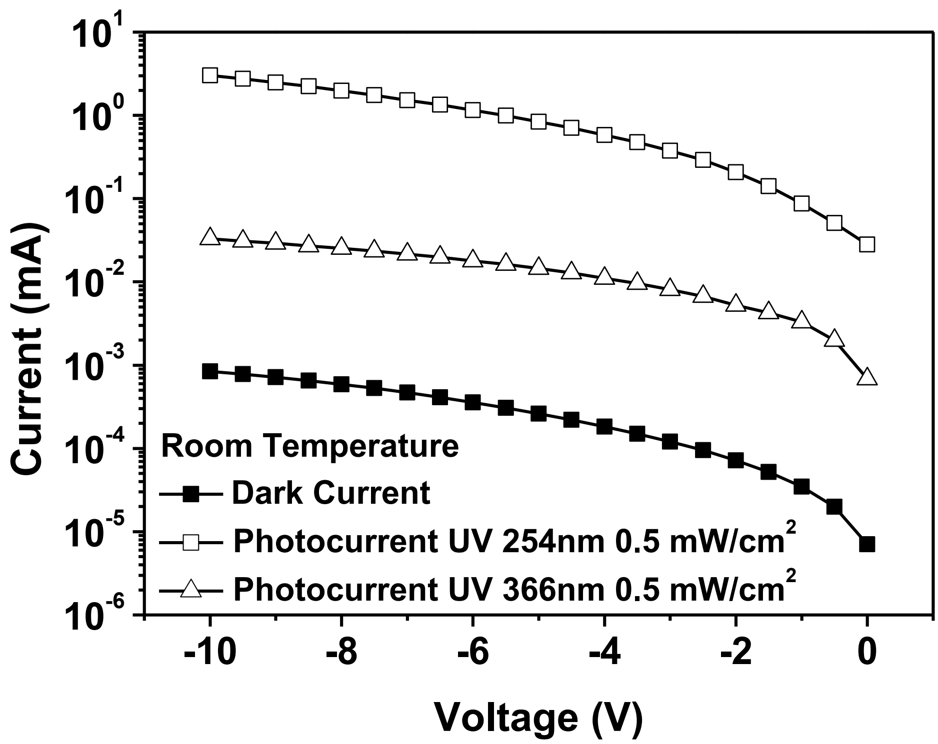
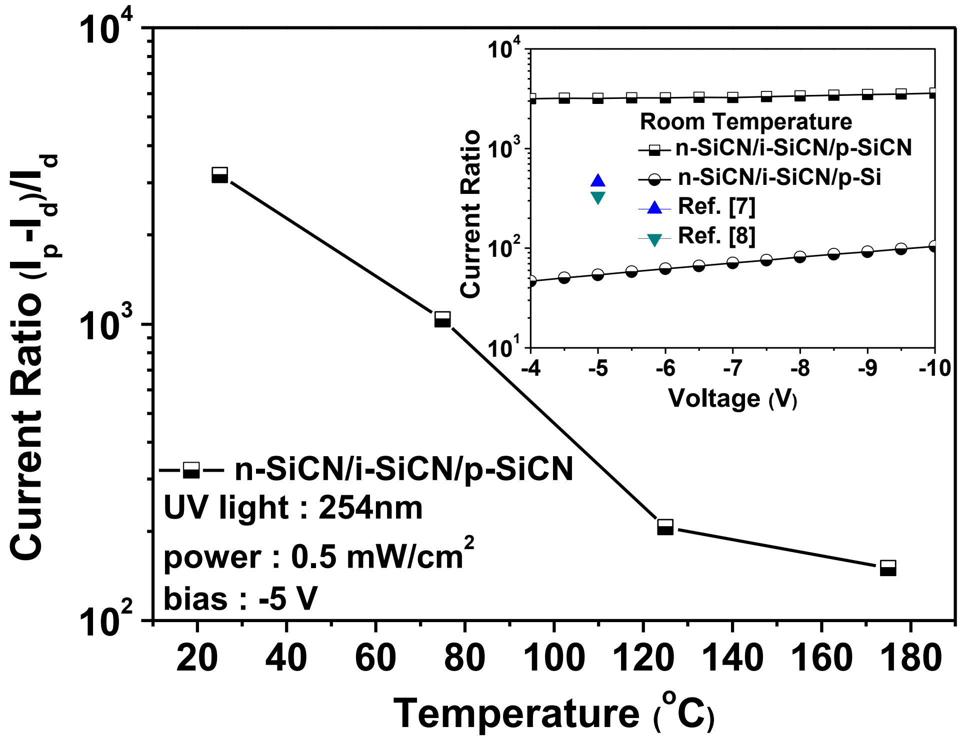

SiCN(45.46°)
SiCN
Si
XRD Intensity (a. u.)
Si(400)
c-SiCN/p-Si
20
30
40
50
60
70
80
90
100
110
2θ (deg.)

Fig. 2



Current (mA)
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
-10
-8
-6
-4
-2
0
Voltage (V)
Room Temperature
Dark Current
Photocurrent UV 254nm 0.5 mW/cm^2
Photocurrent UV 366nm 0.5 mW/cm^2

Fig. 3



Current Ratio (Ip-Id)/Id
Temperature (°C)
n-SiCN/i-SiCN/p-SiCN
UV light : 254nm
power : 0.5 mW/cm2
bias : -5 V
Current Ratio
Voltage (V)
Room Temperature
n-SiCN/i-SiCN/p-SiCN
n-SiCN/i-SiCN/p-Si
Ref. [7]
Ref. [8]

Fig. 4

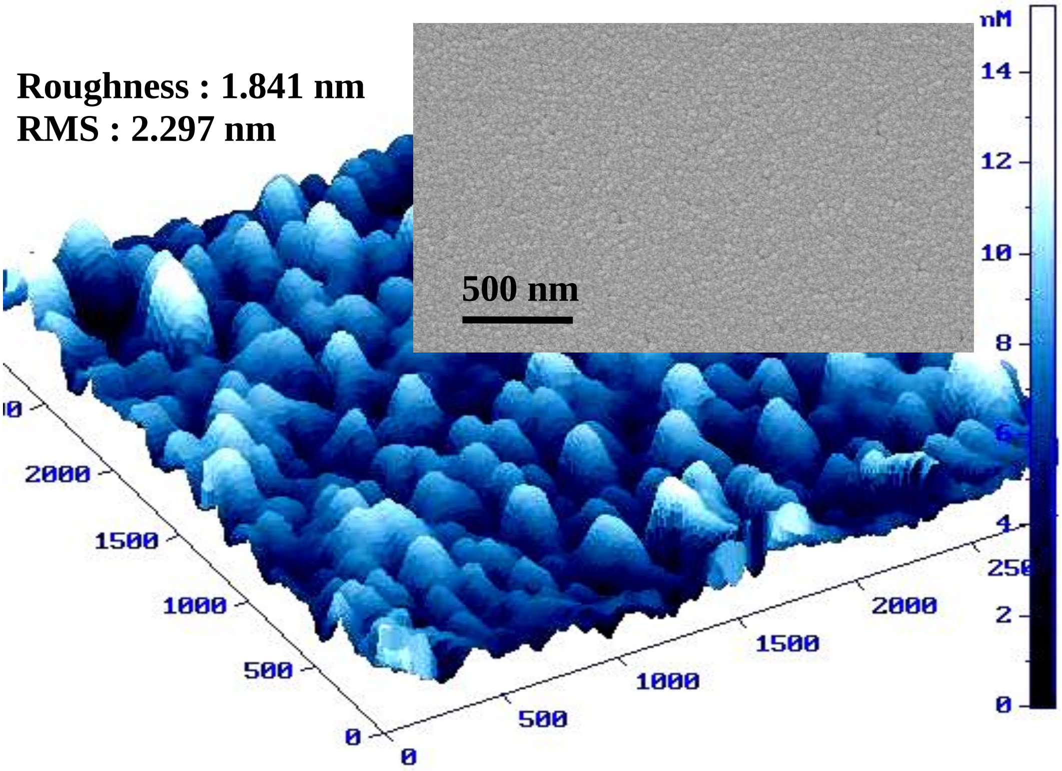

Roughness : 1.841 nm
RMS : 2.297 nm
500 nm
nM
14
12
10
8
6
4
2
0
2000
1500
1000
500
0
0
500
1000
1500
2000

Fig. 5

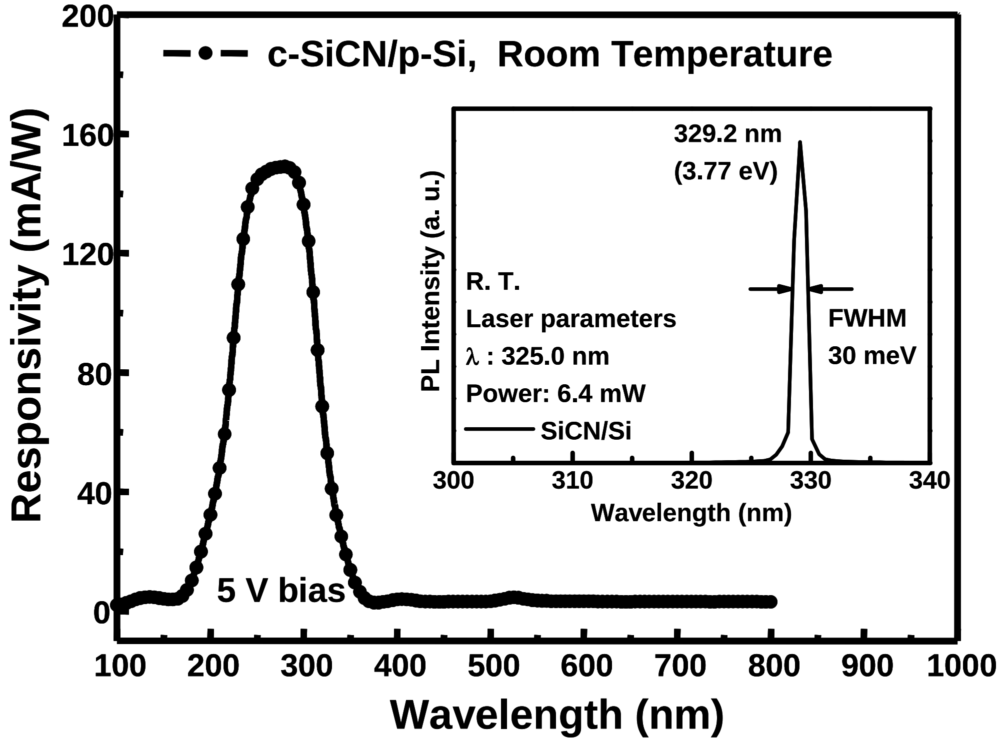

c-SiCN/p-Si, Room Temperature
Responsivity (mA/W)
Wavelength (nm)
5 V bias
200
160
120
80
40
0
100
200
300
400
500
600
700
800
900
1000
329.2 nm
(3.77 eV)
PL Intensity (a. u.)
R. T.
Laser parameters
λ : 325.0 nm
Power: 6.4 mW
SiCN/Si
FWHM
30 meV
300
310
320
330
340
Wavelength (nm)

Fig. 6