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Nitride-based p-i-n Photodetectors with ITO p-contacts

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1. Introduction

The superior radiation hardness and high temperature resistance of GaN make it a suitable material for UV photodetectors working in extreme conditions for various military and commercial applications. To date, several groups have reported encouraging results for GaN-based UV photodetectors with various structures such as p-n junction diode, p-i-n diode, Schottky barrier detector and metal-semiconductor-metal (MSM) photodiode. Among these structures, p-i-n photodetector has a high break down voltage, a low dark current, a sharp cut-off and a high responsivity. Due to the low hole concentration in p-(Al)GaN layer, it is necessary to deposit current spreading p-contact layers on top of the nitride-based p-i-n photodetectors. However, photon blocking of the semi-transparent p-contact layers could result in reduced quantum efficiency for p-i-n photodetectors. Indium-tin-oxide (ITO) is a hard and chemically inert transparent material with a high electrical conductivity and a low optical absorption coefficient [1, 2]. In this paper, we report the fabrication of nitride-based p-i-n photodetectors with ITO contacts. Optical and electrical properties of the fabricated photodetectors will also be reported.

2. Experiments

Nitride-based p-i-n photodetectors used in this study consists of a 30-nm-thick GaN nucleation layer grown at 560^{o}C, a 3-μm-thick Si-doped n^+-GaN ($n=3\times10^{18}cm^{-3}$) layer, a 0.5-μm-thick unintentionally doped GaN absorption layer ($n=3\times10^{16}cm^{-3}$), and an Mg-doped $Al_{0.12}Ga_{0.88}N$/GaN strain layer superlattice (SLS) structure ($p=2\times10^{18}cm^{-3}$). The $Al_{0.12}Ga_{0.88}N$/GaN SLS structure used in this study consists twelve pairs of 0.8-nm-thick $Al_{0.12}Ga_{0.88}N$ layers and 1.6-nm-thick GaN layers. The purpose of using p-AlGaN/GaN SLS structure is to achieve a higher hole concentration in the p-region. Compared with conventional photodiodes, it has been shown that photodiodes with such p-AlGaN/GaN SLS structure exhibit lower turn-on voltage and large photocurrent to dark current ratio [3]. Nitride-based p-i-n photodetectors were then fabricated by photolithography and inductively coupled plasma (ICP) etching. Ti/Al was subsequently deposited onto the exposed n^+-GaN to serve as the n-side contact by E-beam evaporator. For the p-side contact, we used ITO(70nm), ITO(330nm) and Ni(5nm)/Au(5nm). After p-contact deposition, we furnace annealed the samples at 500^{o}C in N_2 ambient for 9 min. Finally, Ti/Au was deposited to serve as bonding pads.

3. Results And Discussion

Figure 1 shows the transmittance of the ITO (70nm), ITO (330nm) and Ni/Au films. It was found that the transmittance was 54%, 79% and 75% at 355nm and was 35%, 28% and 10% at 300nm for 500^{o}C-annealed Ni/Au, ITO (70nm) and ITO (330nm), respectively. Figure 2 shows I-V characteristics of ITO(70nm), ITO(330nm) and Ni(5nm)/Au(5nm) on this p-AlGaN/GaN SLS structure. Although non-annealed ITO(70nm) could form Ohmic contact on p-AlGaN/GaN SLS, the 4×10^{-1} Ω-cm^2 specific contact resistance was large. In contrast, it was found that specific contact resistances of the 500^{o}C-annealed ITO (70nm), ITO (330nm) and Ni(5nm)/Au(5nm) on p-AlGaN/GaN SLS were all around $5\sim6\times10^{-2}$ Ω-cm^2. I-V characteristics of the fabricated p-i-n photodetectors with 500^{o}C-annealed ITO(70nm), ITO(330nm) and Ni(5nm)/Au(5nm) p-contacts (i.e. samples 1~3) were shown in the inset of figure 3. It can be seen that the three samples exhibited similar I-V characteristics. With a 20 mA forward current injection, it was found that the forward voltages were all around 3 V for these three samples. Figure 3 shows an enlarged plot of the reverse I-V characteristics for the three photodetectors. It can be seen again that the dark leakage currents were almost identical for these three photodetectors. With a 10 V reverse bias, it was found that the dark leakage currents were about 5×10^{-10} A. Figure 4 shows spectra responses of sample 1 with various applied biases. It can be seen that these spectra were almost identical. Figure 5 shows spectra responses of the fabricated p-i-n photodetectors with zero bias. It was found that peak responsivities were 0.17, 0.17 and 0.06 A/W for samples 1, 2 and 3, respectively. External quantum efficiency of the fabricated photodetectors can also be determined from the measured spectra responses and the equation:

$$R = h \times \frac{q\,l}{hc} \qquad (1)$$

With an incident light wavelength of 355 nm, the maximum external quantum efficiencies were estimated to be 59%, 59% and 21% for samples 1, 2 and 3, respectively. Compared with sample 3 with conventional Ni/Au p-contacts, the much larger external quantum efficiencies observed from samples 1 and 2 should be attributed to the much more transparent nature of ITO. On the other hand, it can be also seen that the responsivity of sample 2 decreased more rapidly than sample 1 as incident light was shorter than 330nm. Such results could be attributed to the transmittance of 330nm-thick ITO decreased more rapidly than 70nm-thick ITO as shown in figure 1.

4. Conclusions

Nitride-based p-i-n photodetectors with ITO electrodes were fabricated and characterized. The photodetectors with 70nm-ITO p-contacts exhibited a small dark current of 5×10^{-10} A at 10V-reverse bias. The peak responsivity was estimated to be 0.17 A/W at 355 nm, corresponding to a quantum efficiency of 59%.

References

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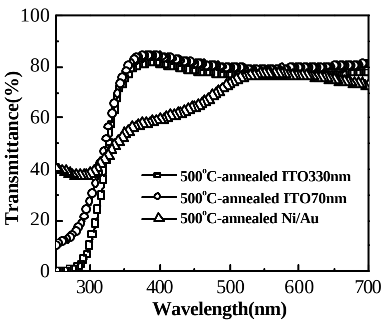

Fig. 1 The transmission spectra of the 500°C-annealed ITO (70nm), ITO (330nm) and Ni/Au films.

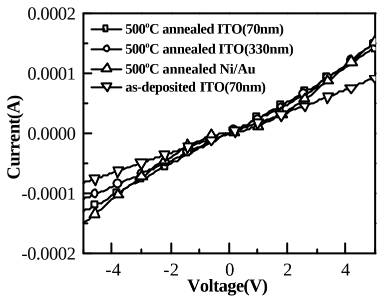

Fig. 2 I-V characteristics of ITO(70nm), ITO(330nm) and Ni/Au on p-AlGaN/GaN SLS structure.

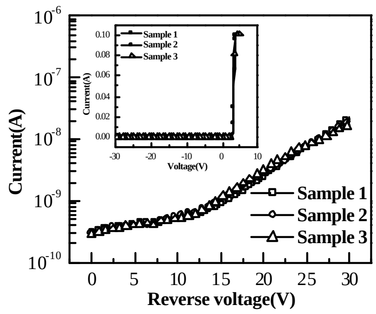

Fig. 3 Enlarged plot of the reverse I-V characteristics for the three photodetectors. Inset shows measured I-V characteristics.

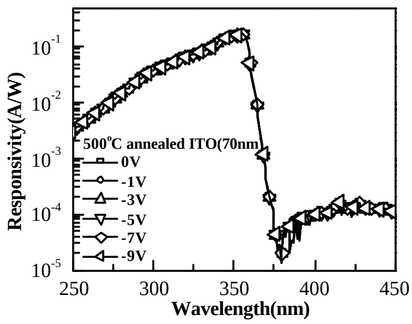

Fig. 4 Spectra responses of the fabricated p-i-n photodetector with 500°C-annealed ITO (70nm) p-contact with various applied biases.

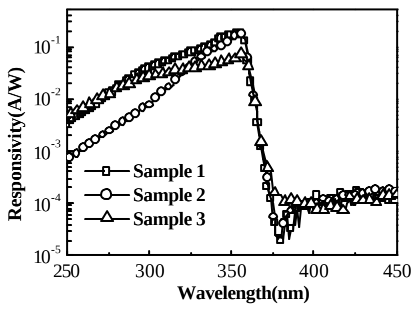

Fig. 5 Spectra responses of the fabricated p-i-n photodetectors with 500°C-annealed ITO (70nm), ITO (330nm) and Ni(5nm)/Au(5nm) p-contacts with zero bias.