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AlGaN MSM Photo Sensors with AlN/SiN Nucleation Layers

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1. Introduction

Recently, much attention has been focused on AlGaN-based materials due to their wide direct bandgap and robust material properties. These properties make AlGaN-based materials potentially useful in high sensitive and solar-blind ultraviolet (UV) photo sensors [1, 2]. The superior radiation hardness and high temperature resistance of $Al_xGa_{1-x}N$ also make it a suitable material for solar-blind photo sensors working in extreme conditions [3]. Such solar-blind UV photo sensors are important components in a variety of civil and military applications, such as engine control, solar UV monitoring, flame detection, astronomy detection, pollution monitoring, source calibration, and secure space-to-space communications [4]. Among the reported structures, MSM photo sensors can be operated with high speed. A typical MSM photo sensor consists of two back-to-back Schottky contacts deposited on top of an active layer. For MSM photo sensors, a low Schottky barrier height at the metal-semiconductor (MS) interface will result in a large dark current (leakage current). Leakage current at MS interface depends strongly on the quality of the semiconductor. Most nitride-based devices are prepared on sapphire substrates by metalorganic chemical vapor deposition (MOCVD). Thus, leakage current in these MSM photo sensors is quite high due to high threading dislocations (TDs) originated from the large mismatches in lattice constant and thermal expansion constant between AlGaN epitaxial layer and sapphire substrate [5, 6]. Very recently, it has been reported that one can reduce the TD density in nitride-based epitaxial layer using GaN/SiN, MgN/GaN, or InN/GaN as the nucleation or buffer layer [7, 8]. Similar concept can be focused on AlN/SiN multiple nucleation layer, which should be applied to the sensor applications. In this study, we report the fabrication of $Al_{0.4}Ga_{0.6}N$ MSM Photo sensors with the AlN/SiN multiple nucleation layer. The optical and electrical properties of the fabricated MSM Photo sensors will be discussed. Noise characteristics of these devices will also be analyzed.

2. Experimental procedure

The AlGaN-based MSM photo sensors in this experiment were all epitaxial grown on c-face (0001) sapphire substrates by metalorganic chemical vapor deposition (MOCVD) system. Before epitaxial growth, the sapphire substrates were annealed at 1200℃ in H_2 ambient to remove surface contamination. We subsequently deposited a 10-pair of AlN/SiN multiple nucleation layers at 680℃. When the 10-pair of AlN/SiN multiple nucleation layers were grown, the growth times of the AlN and SiN were 18 and 30 sec, respectively. The thickness of single AlN and SiN layer were 3 and 1 nm, respectively. After the nucleation layer was grown, the temperature was raised to 1180℃ to grow a 300-nm-thick unintentionally doped AlGaN epitaxial layer. Fig. 1 shows schematic diagram of the fabricated devices. For comparison, conventional LT-AlN nucleation layer was also grown. The growth time of the single LT-AlN nucleation layer was set to 240 seconds so as to achieve a LT-AlN layer thickness of 40nm. The AlGaN grown on 10-pairs of AlN/SiN multiple nucleation layer and LT-AlN layer were labeled as sensor A and B, respectively. The Al composition of AlGaN epitaxial layer was 0.4. For the fabrication of MSM photo sensors, Ni/Au (3/7 nm) contact electrodes were subsequently deposited onto the samples by thermal evaporation. Standard photolithography and lift-off processes were then used to define the two inter-digitated contact electrodes. The fingers of the contact electrodes were 10 μm wide and 150 μm long with a spacing of 10 μm, and the active area was 150×510 μm^2. Finally, a thick Ni (10 nm)/Au (35 nm) was deposited to serve as bonding pad.

3. Results and discussion

Figure 2 shows room temperature dark current-voltage (I-V) characteristics of the fabricated MSM Photo sensors. With 5 V applied bias, it was found that measured dark current of sensor B was 1.86×10^{-8} A. In contrast, dark current of sensor A was only around 3.54×10^{-9} A/cm^2. The almost one order of magnitude smaller dark current measured from sensor A should be attributed to reduced threshold dislocation density by the use of 10 pair AlN/SiN multiple nucleation layer. With the 10 pair AlN/SiN multiple nucleation layer, we can enhance lateral growth, reduce dislocation density, and thus, reduce surface state density. Furthermore, we can also obtain a better crystal quality of undoped $Al_{0.4}Ga_{0.6}N$ with high Al composition and with the use of the 10 pair AlN/SiN multiple nucleation layers. As a result, we achieved a significantly smaller dark current from sensor A with the use of 10 pair AlN/SiN multiple nucleation layer, as compared to sensor B with conventional LT-AlN nucleation layer.

Figure 3 shows the spectral response of sensor A and B. It can be seen that cutoff occurred at around 280 nm for both samples, which indicated that the Al composition of AlGaN was about 0.4. With incident light of 280 nm and an applied bias of 3 V, it was found that the measured responsivity of sensor A was 0.252

A/W while that of sensor B was around 0.124 A/W. The larger responsivity observed from sensor A should be attributed to its low TD density so that we can achieve a high photocurrent and responsivity. Furthermore, we defined rejection ratio as the responsivity measured at 280 nm divided by that at 360 nm. With 3 V applied bias, it was found that rejection ratios were 39.78 and 30.05 for sample A and B, respectively. In other words, we could enhance the rejection ratio by using this 10-pairs AlN/SiN nucleation layer. Such an improvement could also be attributed to the reduced threading dislocation density by the use of the 10-pairs AlN/SiN nucleation layer. This finding again indicates an enhancement of rejection ratio as result of inserting a 10-pairs AlN/SiN nucleation layer into the photo sensors.

4. Conclusions

In summary, AlGaN MSM UV photo sensors with AlN/SiN multiple nucleation layer were fabricated and characterized. It was found that we can achieve smaller dark current and larger photocurrent to dark current contrast ratio from the proposed sensor. We also achieved larger rejection ratio of photoresponse at 280-360 nm from the sensors with AlN/SiN nucleation layer. These improvements should all be attributed to the effective suppression of TDs by using the AlN/SiN nucleation layer.

5. Acknowledgments

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6. References

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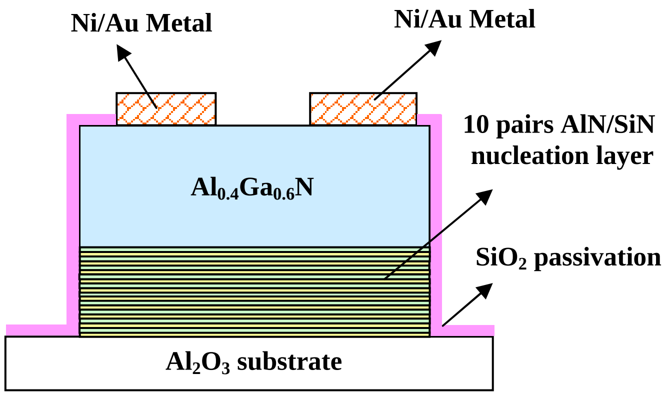

Fig.1 The schematic structure of AlGaN MSM photo sensor with AlN/SiN nucleation layers.

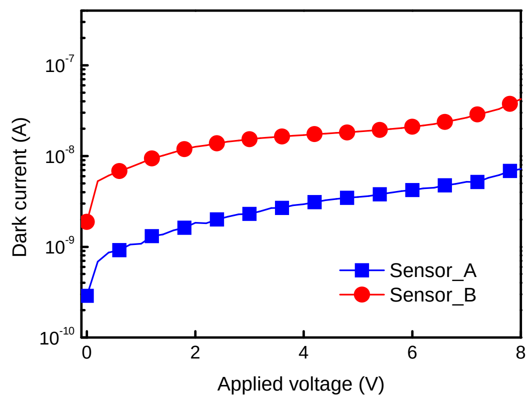

Fig. 2 I-V characteristics of the two fabricated MSM photo sensors measured in dark.

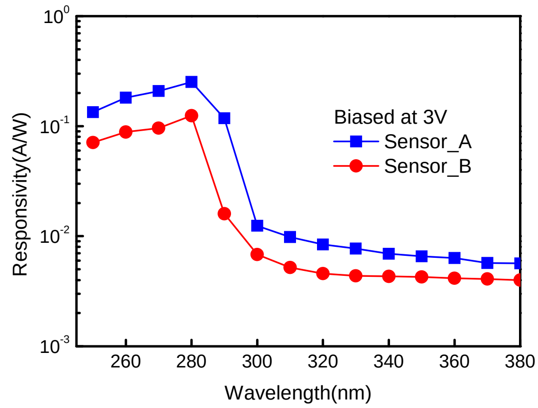

Fig. 3 The spectral response of the two MSM photo sensors.