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Nitride-Based Schottky Barrier Sensor Module With High Electrostatic Discharge Reliability

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Gallium nitride (GaN) is one of the most promising materials for the fabrication of high-sensitive ultraviolet (UV) sensors, since it has a large direct band gap energy (3.41 eV at room temperature) and a high saturation electron drift velocity (310 cm/s). The superior radiation hardness and high temperature resistance of GaN also make it a suitable material for UV sensors working in extreme conditions. In the past few years, various types of nitride-based photodetectors have been proposed, such as p–n junction photodetectors (PDs), p–i–n PDs, p–p–n PDs, Schottky barrier PDs, and metal–semiconductor–metal (MSM) PDs. Compared with p–n junction PDs, the fabrication process of Schottky barrier PDs is much easier. The response speed of Schottky barrier PDs is also faster due to the limitation of minority-carrier storage problem.

It is well known that electrostatic discharge (ESD) is a serious problem for nitride-based devices prepared on sapphire substrates. For nitride-based LEDs, one can either build a parallel GaN Schottky diode or add an external Si diode to provide an electric pass when a reverse ESD surge occurs and thus solve the ESD problem. However, these methods cannot be applied to nitride-based Schottky barrier sensors since the sensors are operated in the reverse bias region.

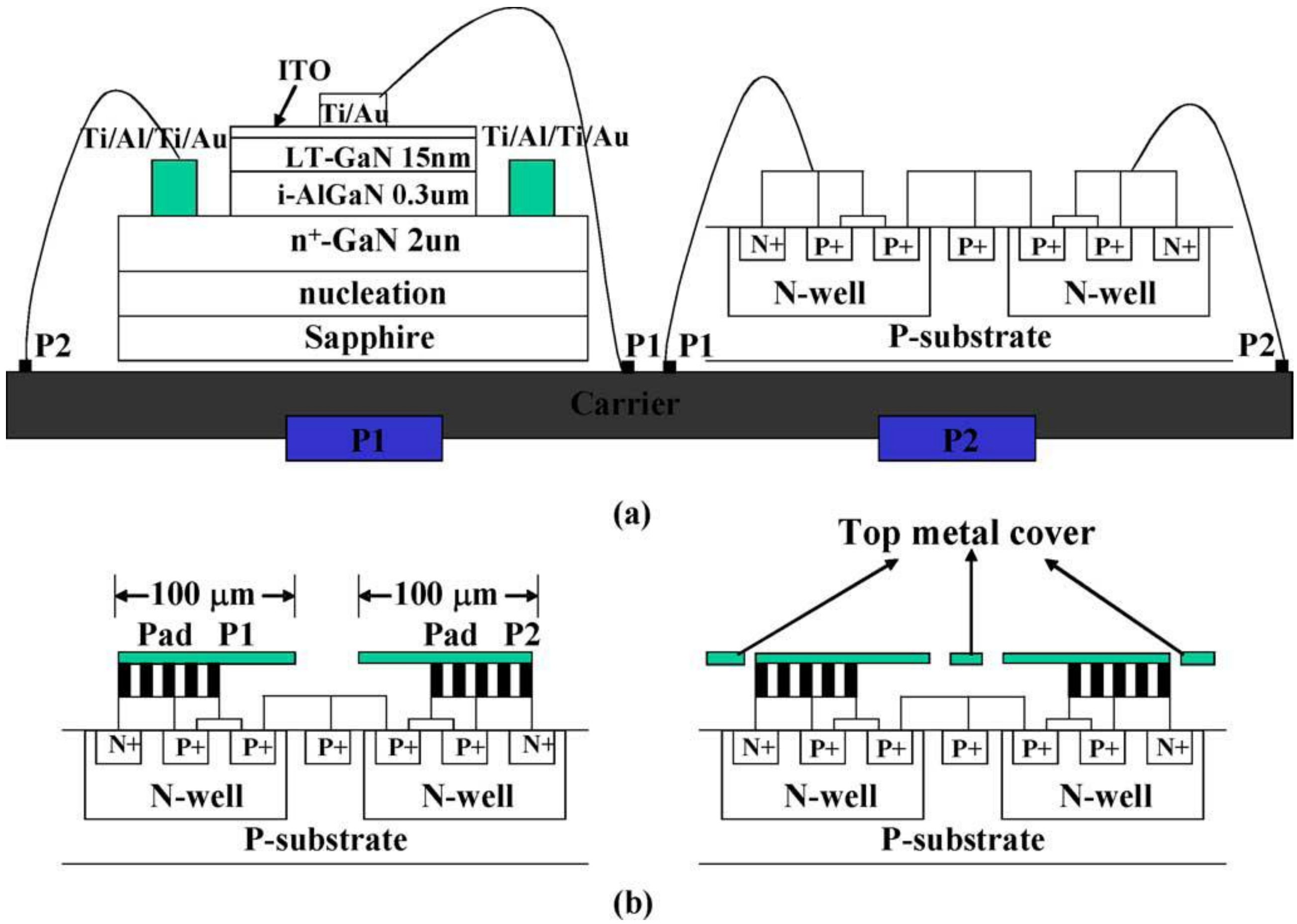

Fig. 1. Schematic diagrams of the entire module.

In this study, we built an ESD protection circuit in a Si complementary metal–oxide–semiconductor (CMOS) chip. We then combine the Si CMOS chip with an AlGaN Schottky barrier sensor chip to form the nitride-based Schottky barrier sensor module. Fig. 1 shows schematic diagram of the entire module. The Si CMOS ESD protection chip consists of two P-type MOS field effect transistors (PMOSFETs). We connected drain, gate, and n-well of one PMOSFET to the n-contact of the AlGaN Schottky barrier sensor chip (i.e., P2) while we connected drain, gate, and n-well of the other PMOSFET to the p-contact of the AlGaN Schottky barrier sensor chip (i.e., P1). We also connected sources of these two PMOSFETs to the p-type Si substrate. Under normal operation, the ESD protection circuit will not be turned on since the gates are tied to a high voltage level. Under large ESD stress, the ESD protection circuit will turn on to protect the AlGaN-based sensor chip under two possible operation modes. Under ESD stress, there are two possible modes: 1) PD mode, ESD stress on the anode of sensor chip with positive voltage with respect to cathode; and 2) ND mode, ESD stress on the anode of sensor chip with negative voltage with respect to cathode. Fig. 2(a) shows the equivalent circuit of the module operating under PD mode. From Figs. 1 and 2(a), it can be seen that the bipolar junction transistor Q1 is formed by lateral parasitic p-diffusion/n-well/p-diffusion, R1 is the internal resistance of n-well, R2 is the internal resistance of p-substrate, and diode D1 is formed by p-substrate/n-well parallel with p-diffusion/n-well. Under normal operation, Q1 is in high-impedance (off) state. Thus, the module will function normally. Under PD-mode ESD stress, however, Q1 will be triggered on so as to bypass the ESD current and thus can effectively protect the sensor chip from PD-mode ESD stress. Fig. 2(b) shows the equivalent circuit of the module operating under ND mode. Similarly, it can be seen that we can also effectively bypass the ESD current under ND mode.

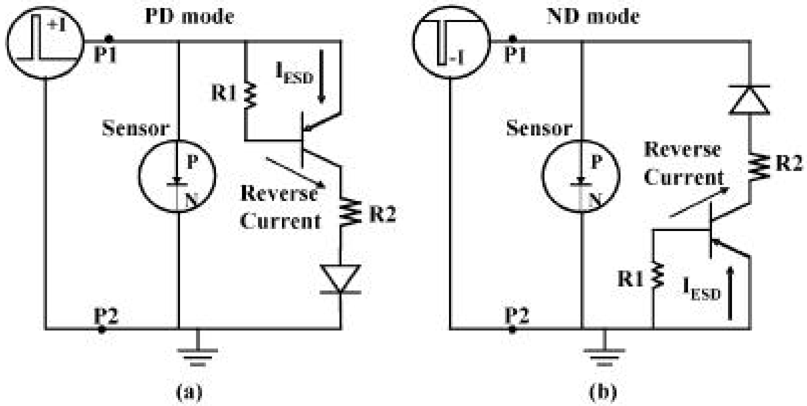

Fig. 2. Equivalent circuits of the module operated under (a) PD mode and (b) ND mode.

To evaluate ESD characteristics of the sensor modules, we first used the transmission line pulsing (TLP) method (IEEE Trans. Electron. Packag. Manuf., vol. 24, no. 2, Apr. 2001.) to separately measure current–voltage (I–V) curves of the Si-based ESD protection chip and the AlGaN Schottky barrier sensor chip. We also measured the human-body-model (HBM) ESD stress to compare the difference with TLP result. As shown in Fig. 3, it was found that a breakdown occurred at around ±11 V for the Si-based ESD protection chip. It was also found that the Si-based ESD protection chip can endure a second breakdown current of 4.2~5A (i.e., HBM 7 KV). On the other hand, it was found that the bare AlGaN Schottky barrier sensor chip is damaged easily under the ND mode. Under the PD mode, it was found that the turn on voltage of the bare sensor chip was around 3 V and the chip can endure a current to 4.5 A (i.e., HBM 6 kV). The Module II consists of an AlGaN Schottky barrier sensor chip and a Si-based ESD protection chip. It was found that the Module II exhibits excellent ESD characteristics not only under PD mode, but also under ND mode. Compared with the bare sensor chip, the improvement can be attributed to the inclusion of the ESD protection chip, as explained in Fig. 2(a) and (b). Furthermore, it was found that the Module II can endure an ND mode current of 5 A (i.e., HBM 7.5 KV) and a PD mode current as high as 9 A (i.e., HBM 8 KV). The extremely large endurable ESD voltage for module II under the PD mode can again be attributed to the inclusion of the ESD protection chip to provide a parallel current path under ESD stress.

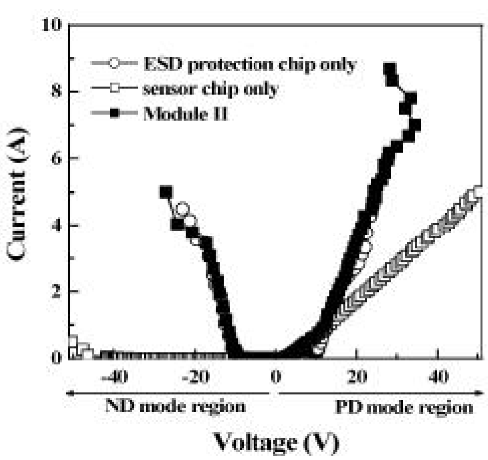

Fig. 3. ESD characteristics of Si-based ESD protection chip, AlGaN Schottky barrier sensor chip, and the entire module.

In conclusion, a nitride-based Schottky barrier sensor module with high ESD reliability was realized. By including a Si-based ESD protection chip into the module, we can significantly enhance endurable ESD voltages under both forward and reverse ESD stresses.