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Highly ESD reliable nitride-based heterostructure p-i-n photodetectors with a p-AlGaN blocking layer

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For nitride-based devices prepared on sapphire substrates, it is known that electrostatic discharge (ESD) is a serious problem. Nitride-based PDs also suffer from ESD, particularly when operated at high-temperature and/or high-humidity conditions [1]. Very recently, it has been shown that one can combine a Si complementary-metal-oxide-semiconductor (CMOS) chip with a nitride-based Schottky barrier PD chip to achieve a PD module with high ESD reliability [2]. With the Si COMS chip, however, extra bonding steps are required. This inevitably results in lower production yield and higher production cost. One possible way to solve this problem is to use heterostructure. It is known that heterostructure can effectively confine carriers. By forming two-dimensional carrier gas, one can achieve a much smaller resistivity in the in-plane lateral directions, as compared to that in the vertical direction. When an electrical pulse is imposed onto the heterostructure p-i-n PDs, current should spread easily in the lateral directions [3]. We can thus prevent the damage on the active region and enhance ESD reliability of the devices.

Samples used in this study were all grown on c-face (0001) sapphire substrates by metalorganic chemical vapor deposition (MOCVD). The sample consists of a 30-nm-thick low-temperature GaN nucleation layer, a 4- μ m-thick n^+-GaN layer, a 0.5- μ m-thick unintentionally doped i-GaN layer, a p-$Al_{0.1}Ga_{0.9}N$ blocking layer and a 30-nm-thick p-GaN cap layer. The thickness of the p-AlGaN blocking layer was either 300 nm (i.e., sample 1) or 150 nm (i.e., sample 2). For comparison, conventional homostructure PDs without the p-AlGaN blocking layer were also fabricated (i.e., sample 3). Nitride-based p-i-n PDs were then fabricated by photolithography and inductively coupled plasma (ICP) etching. After etching, Ti/Al (20 nm/120 nm) was deposited onto the exposed n^+-GaN to serve as the n-contact. Semi-transparent Ni/Au (50Å/50Å) contact layers were subsequently evaporated onto sample surfaces followed by furnace annealed at 500ºC in N_2 ambient for 9 min to serve as the p-contact. We then deposited Ti/Au (400Å/10000Å) layers to serve as the bonding pads.

Figures 1(a) and 1(b) show I-V characteristics of conventional homostructure PD (i.e., samples 3) and heterostructure PD with 300-nm-thick p-$Al_{0.10}Ga_{0.9}N$ blocking layer (i.e., sample 1), respectively, before and after -1000 V ESD stressing. With the same -5 V bias, it was found that the reverse leakage current increased by 7 orders of magnitude after stressing for sample 3. The forward voltage (i.e., I_F = 10 μ A) also decreased from 2.5 V to 1.3 V. These results indicate that the conventional homostructure PDs were severely damaged with the -1000 V ESD stressing. In contrast, I-V characteristics were almost identical before and after stressing for sample 1. This should be attributed to the use of heterostructure to reduce the in-plane resistivity so that ESD surge current could spread easily in the lateral directions [3]. To investigate the effects of p-AlGaN layer thickness, we applied -8000 V ESD stressing onto samples 1 and 2. As shown in figure 2, it was found that dark current (i.e., V_R = -5 V) observed from sample 2 was more than one order of magnitude larger than that of sample 1. This is probably due to the fact that current blocking ability is better for the PD with thicker p-AlGaN layer. Figure 3 shows spectra responses of sample 3 before and after -1000 V ESD stressing. In the long wavelength region, it was found that the below bandgap response increased significantly. Here, we define UV-to-visible rejection ratio as the response measure at 355 nm divided by the response measured at 450 nm. With this definition, it was found that UV-to-visible rejection ratios were 1024 and 38 for sample 1 before and after -1000 V ESD stressing, respectively. The much smaller UV-to-visible rejection ratio observed from sample 1 after stressing again indicates that conventional homostructure PDs were destroyed easily even with relatively small -1000 V ESD stressing. With the heterostructure, one can reduce the in-plane resistivity so that ESD surge current could spread easily in the lateral directions [3]. Figure 4 shows spectra responses of sample 1 before and after -8000 V ESD stressing. It was found that these two spectra responses were almost identical with about the same UV-to-visible rejection ratio (i.e., ~1028). Such a result indicates that the heterostructure PDs with a 300-nm-thick p-$Al_{0.10}Ga_{0.9}N$ blocking layer can endure an extremely large -8000 V ESD surge.

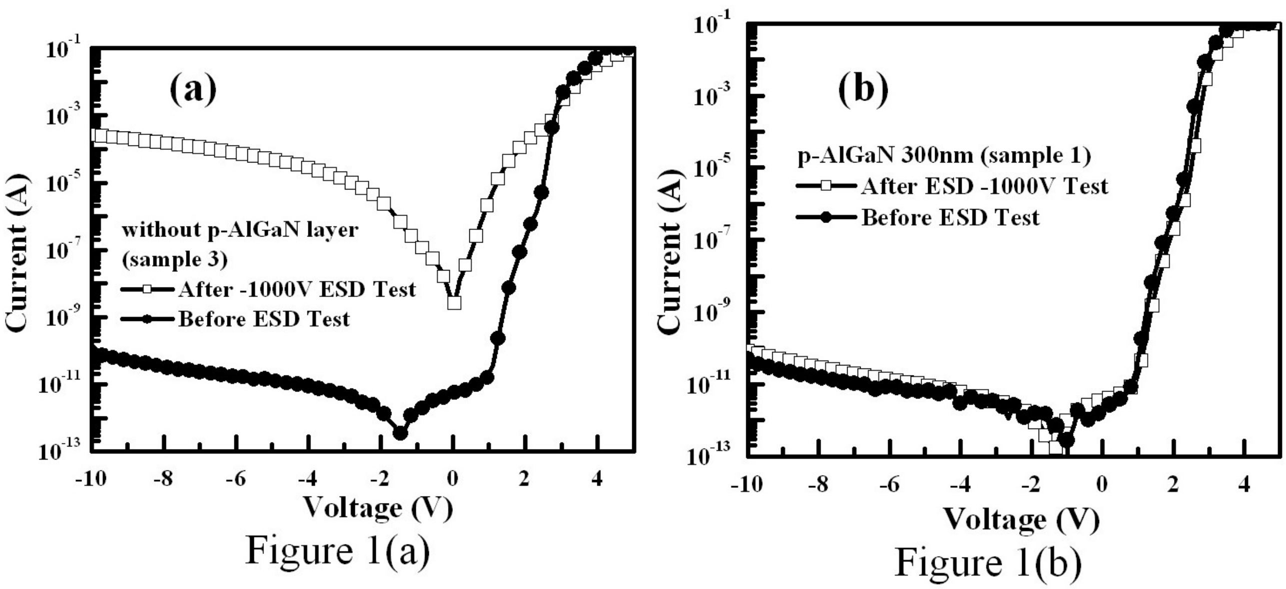

Figure 1 I-V characteristics of (a) conventional homostructure PD and (b) heterostructure PD with 300-nm-thick p-$Al_{0.10}Ga_{0.9}N$ blocking layer before and after -1000 V ESD stressing.

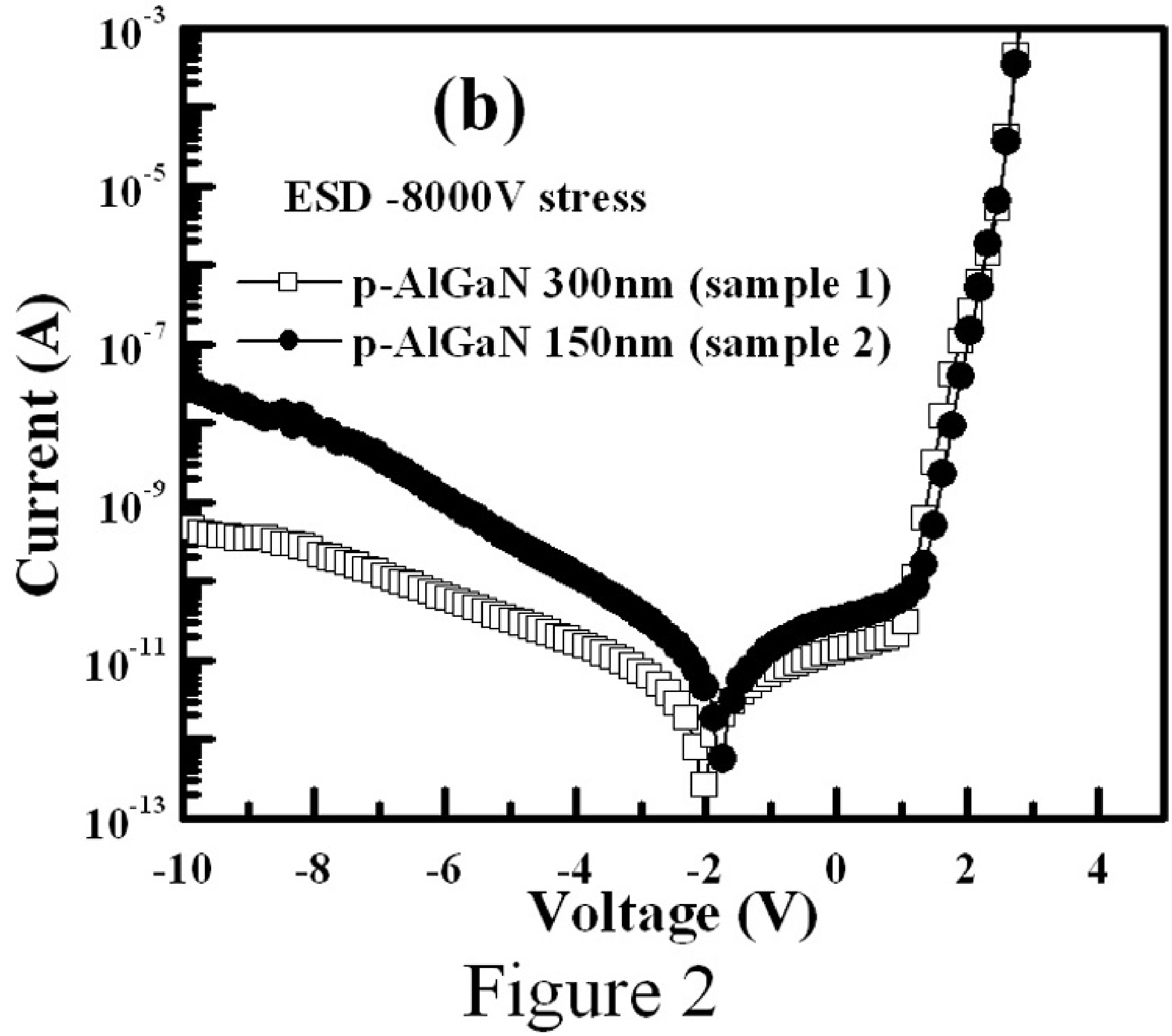

Figure 2 I-V characteristics of heterostructure PDs with 150-nm-thick and 300-nm-thick p-$Al_{0.10}Ga_{0.9}N$ blocking layers after -8000 V ESD stressing.

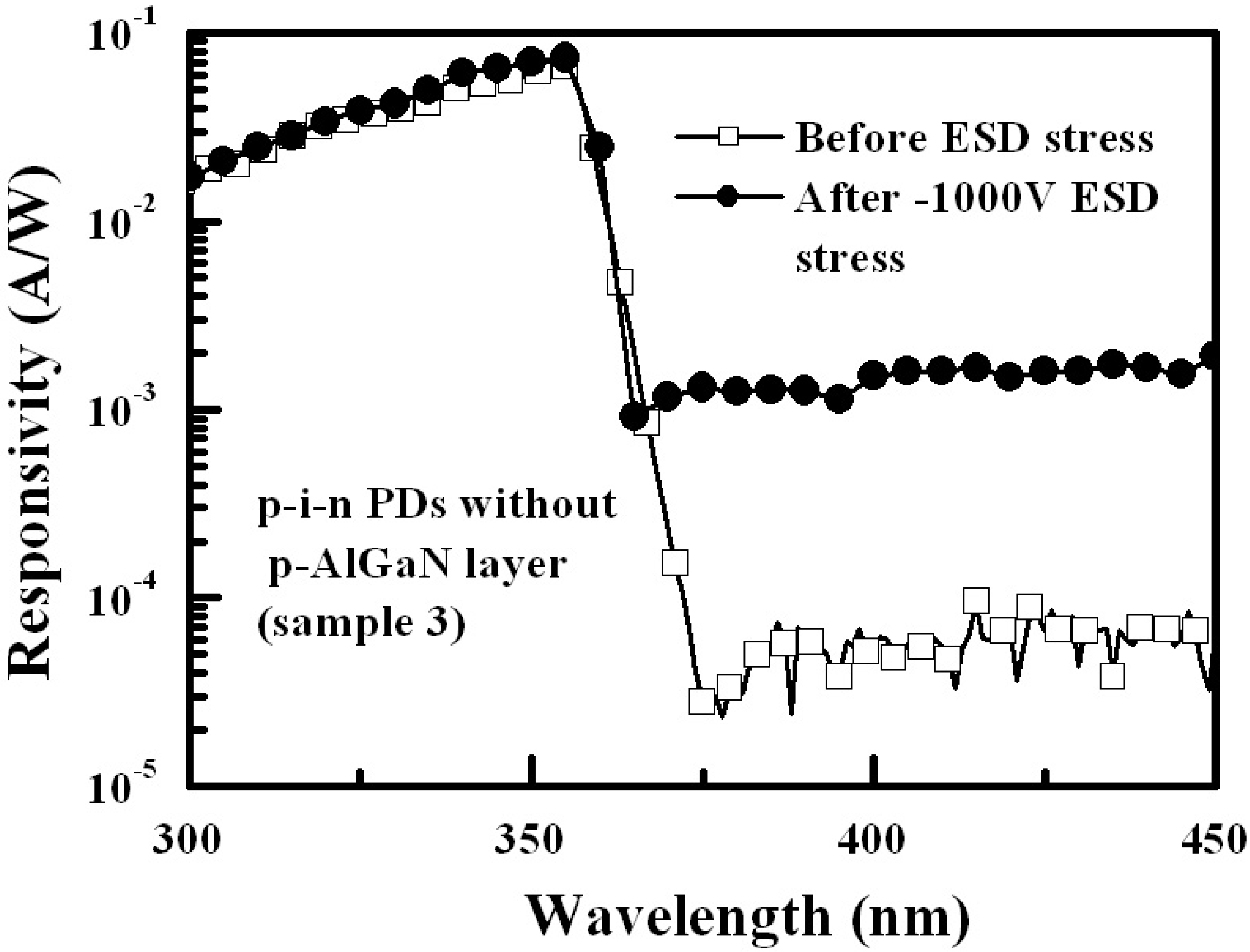

Figure 3

Figure 3 Spectra responses of conventional homostructure PD before and after -1000 V ESD stressing.

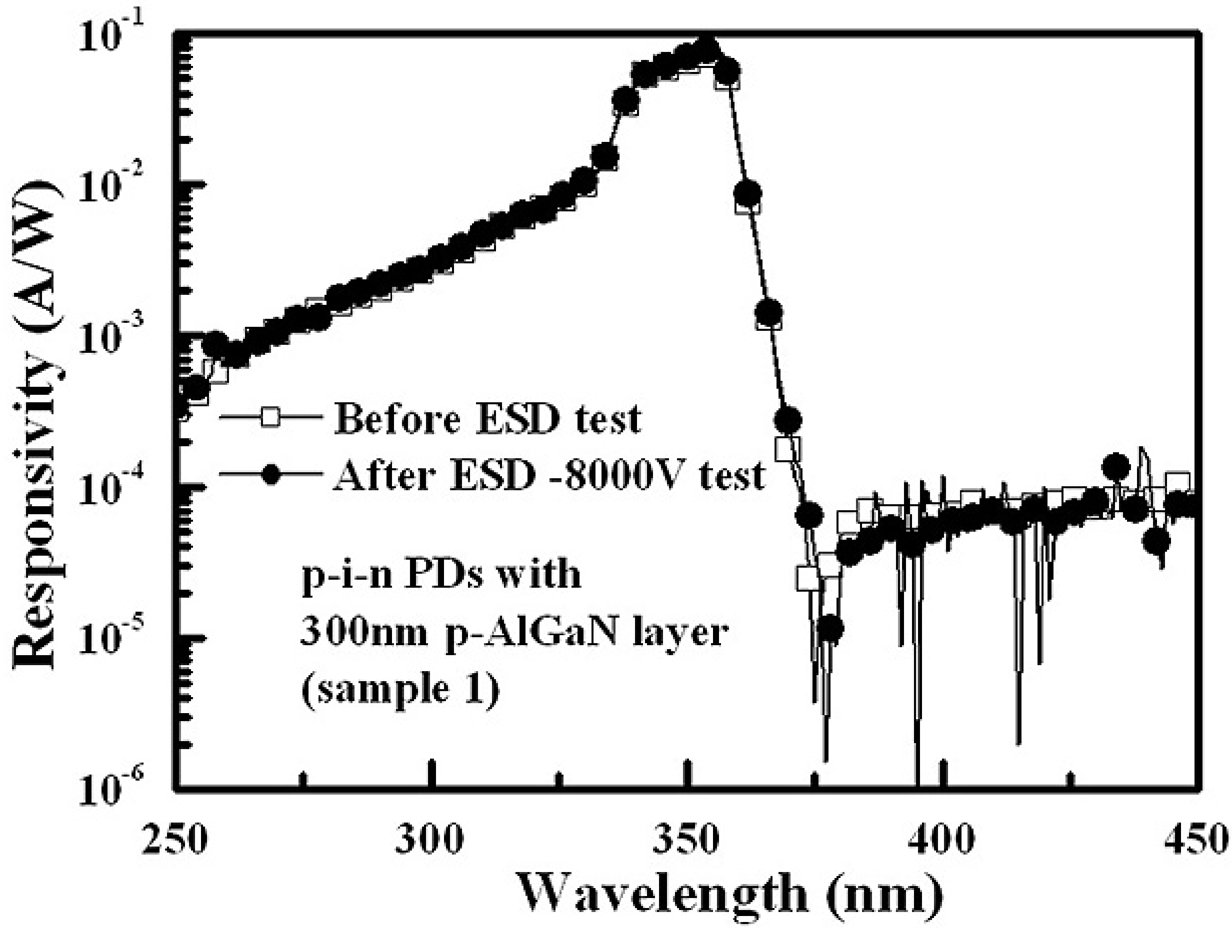

Figure 4

Figure 4 Spectra responses of heterostructure PD with 300-nm-thick p-$Al_{0.10}Ga_{0.9}N$ blocking layer before and after -8000 V ESD stressing.

In summary, we have successfully fabricated highly ESD reliable nitride-based p-i-n PDs. By inserting a p-AlGaN blocking layer, we can significantly improve ESD reliability of the PDs. It was also found that ESD characteristics of the PDs depend on the thickness of the inserted p-AlGaN blocking layer.

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