Self-Powered High Performance AlGaN-Based Solar Blind UV MSM Photodetector

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***Abstract*— In this research article, we attempt to show the performance of a self-powered Aluminum Gallium Nitride (AlGaN)-based solar-blind ultraviolet (SBUV) metal-semiconductor-metal photodetector. The excellent crystalline quality of the AlGaN film is evidenced by its low screw threading dislocation density (~10^8), which suppresses the dark current in the order of pA (i.e., 1.02 pA) and enhances the photocurrent (4×10^{-10} A). The device achieves a sensitivity greater than 10^2, a responsivity of 1.2 mA/W, and a detectivity of 2.42×10^8 Jones at 0 V bias. Hence, the device's low dark current, high sensitivity, excellent responsivity, and strong detection capability at zero bias establish AlGaN as a highly promising material for self-powered SBUV detection applications.**

Keywords—AlGaN, Solar-Blind, Self-Powered, Dark Current, Responsivity.

I. INTRODUCTION

The Solar-blind ultraviolet (SBUV) photodetectors have attracted significant research interest due to their wide range of applications in fields such as space exploration, missile warning, flame detection, and biomedical imaging [1]. Among various semiconductor materials, the wide bandgap AlGaN alloy [1-2] is particularly promising due to its tuneable bandgap, intrinsic solar-blind response, high thermal stability, and excellent chemical and physical robustness. Furthermore, the built-in polarization fields in AlGaN can be leveraged to develop self-powered photodetectors, thereby minimizing the reliance on external power sources [3].

Thus, in this research article, we demonstrate a self-powered AlGaN-based SBUV photodetector, utilizing the material's intrinsic polarization to achieve self-powered operation, thereby reducing dependance on external power sources.

II. DEVICE FABRICATION AND MATERIAL CHARACTERIZATION

The epilayers (AlN and $Al_xGa_{1-x}N$), as illustrated in the device schematic (Fig. 1a), were grown using plasma-assisted molecular beam epitaxy (PAMBE). Post-growth, the sample underwent sequential cleaning with trichloroethylene, acetone, isopropyl alcohol, and concentrated hydrochloric acid, followed by a rinse with deionized water. The standard photolithography was then used to define interdigitated electrode (IDT) patterns on the cleaned surface. A Ni/Au (40/120 nm) metal stack was used as the IDT structures, followed by an overnight lift-off process. The fabricated IDT patterns consist of fingers length (L) of 98 µm, fingers width (W) of 5 µm, and finger spacing (S) of 6 µm, as shown in Fig. 1(b).

The quality of the grown epilayer was analyses using high-resolution x-ray diffraction (HR-XRD) and x-ray rocking curve (XRC) measurements around the characteristic peaks.

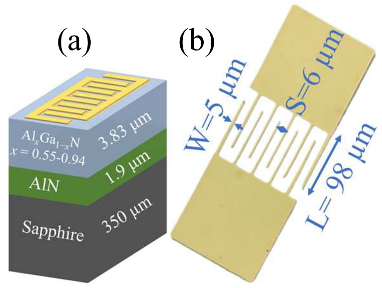

Fig. 1. Demonstrate the schematic of fabricated AlGaN-based deep UV MSM photodetector. The grown sample consists of an $Al_xGa_{1-x}N$ ($x = 0.55$-0.94) epilayer (3.83µm), AlN (1.9µm), and sapphire. The Ni/Au metal (40/120 nm) stack is deposited using standard photolithography process.

Additionally, atomic force microscopy (AFM) was used to evaluate the surface roughness of the film. A conventional characterization setup was utilized to measure the photoresponse and temporal response of the photodetector.

III. RESULTS AND DISCUSSIONS

Fig. 2(b) presents the HRXRD peak of the $Al_{0.55}Ga_{0.45}N$ (0002) at 35.39°, with a full width at half maximum (FWHM) of approximately 0.07°, indicating excellent crystalline quality of the $Al_{0.55}Ga_{0.45}N$ epilayer. The AlN (0002) peak, situated at 36.12°, confirms the successful growth of intermediate layers, which serve to alleviate the lattice mismatch between the active layer and the sapphire substrate. Additionally, the AFM image shows the rms roughness of 620 pm, indicated a smoothness of the grown film. It is well known that screw threading dislocations can provide additional conductive paths in a device, leading to increased leakage current. Therefore, the XRC scan (not shown) confirms a screw dislocation density (TDD) on the order of ~10^8 cm^{-2}, which is approximately two orders of magnitude lower than that reported in existing literature.

To characterize our device, we measured the photocurrent and dark current as a function of applied voltage, as shown in Fig. 3(a). Since the goal is to demonstrate self-powered operation (i.e., at 0 V bias), the measured dark current and photocurrent at 0 V were 1.02 pA and 4×10^{-10} A, respectively. The low dark current is attributed to the high

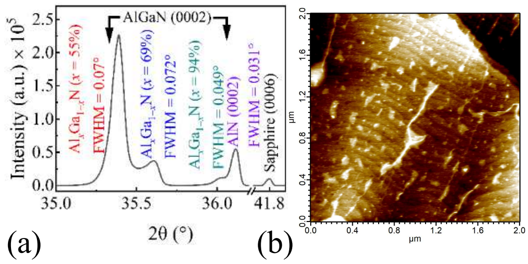

Fig. 2. Displays (a) the HRXRD peaks of the AlGaN/AlN/Sapphire-based MSM photodetector sample. (b) the AFM of the AlGaN photoactive epilayer, revealing a root mean square surface roughness of 620 pm over an area of 2µm×2µm.

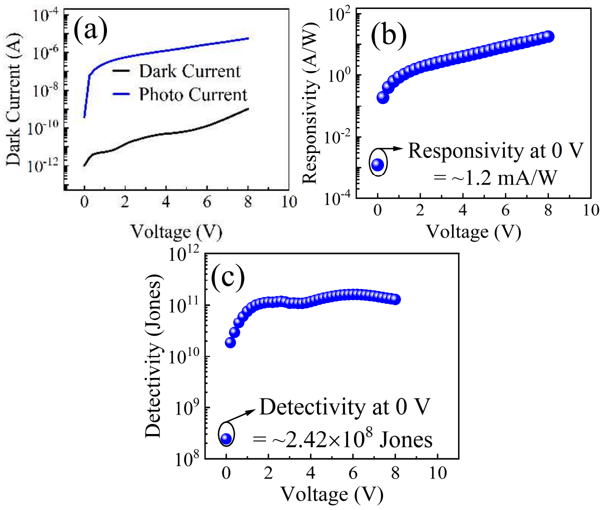

Fig. 3 shows (a). dark and photocurrent of photodetector. The measured dark current is suppressed to 1.02pA, indicating high crystalline quality, while the photocurrent reaches 4×10^{-10}A at 0V, demonstrating a high photo-to-dark current ratio of >10^2. (b) responsivity (c) detectivity of PD with varying bias. Our device shows the responsivity of 1.2 mA/W at self-biased mode. Also, it displays high detectivity of 2.42×10^8 Jones at 0 V signifying a lower noise level in the fabricated device at 0V.

crystalline quality of the epilayer, with a screw TDD on the order of ~10^8 cm^{-2}, which minimizes charge carrier trapping and consequently enhances the photocurrent at zero bias. This results in a high sensitivity (photo-to-dark current ratio) of the device, exceeding 10^2.

The responsivity (R), and detectivity (D) at 0 V bias were calculated using the following equations [4].

$$R = (I_P - I_D)/[(P/S)A] \quad (1)$$

$$D = R\sqrt{(A)}/\sqrt{(2q\, I_D)} \quad (2)$$

Thus, the calculated responsivity at 0 V is 1.2 mA/W, demonstrating the self-powered capability of our device, as displayed in Fig. 3(b). Fig. 3(c) demonstrates the detectivity of the device. The recorded detectivity at 0 V is 2.42 × 10^8 Jones, indicating a low noise level in the fabricated device under zero-bias condition. These performance metrics reflect the high crystalline quality of the grown epilayer.

We compared the responsivity of our device with previously reported results in the literature (Table I) and found that our device achieves a comparable responsivity of 1.2 mA/W, confirming its effectiveness in self-powered operation mode.

Table I. Responsivity comparison of self-powered SBUV PD

Device	Responsivity (mA/W)	Ref.
$Al_xGa_{1-x}N$/AlN/Sapphire Top epilayer x = 0.55	1.2	This Work
p-AlGaN/n-GaN	22.5	5
GaN/AlGaN	5	6
AlGaN Nanorod	3	7
ZnO/Ga_2O_3	9.7	8

IV. Conclusions

In In this article, we have demonstrated the growth of a high-quality AlGaN thin film for self-powered SBUV photodetector applications. The low screw threading dislocation density (TDD) and dark current (1.02 pA) confirm the superior crystalline quality of the AlGaN film. The device exhibits a sensitivity greater than 10^2, a responsivity of 1.2 mA/W, and a detectivity of 2.42 × 10^8 Jones at 0 V bias. Therefore, the combination of low dark current, high sensitivity, excellent responsivity, and strong detection capability at zero bias makes AlGaN a highly promising candidate for self-powered SB UV detection applications.

Further we aim to utilize machine learning (ML) techniques to extract key performance metrics (such as responsivity, external quantum efficiency, UV-to-visible rejection ratio, and detectivity) to validate existing models, particularly those based on gradient-boosted decision trees (e.g., XG Boost, and light gradient-boosting machine). We plan to vary parameters including the input power, Al composition in the AlGaN active layer, the dimensions of the IDT (i.e., length, width, and spacing), active layer thickness, and buffer layer thickness to train the model and accurately predict the performance metrics. The models effectively learn the nonlinear relationships between device parameters and performance and are expected to accurately replicate experimental results and reveal key sensitivities. We will apply ML-based models to our experimental data and evaluate their performance using error metrics such as rms error and mean absolute error. The low values of these error metrics of the most suitable model should lead to a strong agreement between the model predictions and the experimental data, thereby validating the model. This makes them a valuable tool for optimizing and meaningfully predicting the behaviour of MSM photodetectors.

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