# Numerical Simulation on the Effect of Operation Temperature on the Optical Transfer Characteristics for GaN/AlGaN SAM Avalanche Photodiodes

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***Abstract*—GaN/AlGaN avalanche photodiodes (APDs) have important application values and broad application potentials in the field of solar-blind ultraviolet (UV) detection. However, the self-heating effect has an obvious influence on the output characteristics of GaN/AlGaN APDs. In order to study the influence of self-heating temperature on its performance, the numerical model of GaN/AlGaN APDs is established and the dark current as well as response at different temperatures are studied.**

## I. Introduction

Wavelength between 240~290 nm is called solar-blind UV, which is because the solar radiation reaching the ground is strongly absorbed by ozone ($O_3$) when passing through the earth's atmosphere, making the solar radiation intensity with wavelength between 240~290 nm tend to be zero, so that the detector working in this band is hardly affected by solar radiation, which greatly reduces the background noise of the detector [1-3].

The band gap of (Al)GaN material is between 3.3~4.9 eV, which can be easily modulated by adjusting the composition. Therefore, the GaN/AlGaN APDs are very suitable for solar-blind UV detection. Hence, the GaN/AlGaN APDs have realized many applications including missile detection and interception, biological and chemical agent detection, flame and environment monitoring, and UV astronomy, involving national defense, civilian, and scientific research.

## II. Structral and Physical Models

The GaN/AlGaN device structure is shown in the Fig. 1. The concentrations of p-type layer, intrinsic layer and n-type layer are $3\times10^{18}$, $2\times10^{18}$ and $1\times10^{13}$ cm$^{-3}$. The p-type is realized by doping Magnesium element, while the n-type is achieved by doping Silicon element. Different from GaN APDs, the first layer of GaN/AlGaN APDs studied in this paper is n-type $Al_xGa_{1-x}N$, which has been revealed that for improving spectral response and preventing interface defects at the same time, Al composition $x$ lying in the range of 0~0.15 is preferred. As an example, Al composition $x$ is chosen as 0.15.

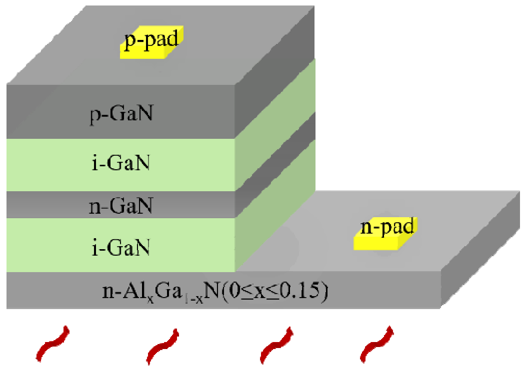


Fig. 1. Schematic diagram of back-illuminated SAM GaN/AlGaN APD.

The reported GaN-based Schottky, p-i-n and MSM UV photodetectors have good detection performance. However, the GaN APDs still face material, preparation and design problems. The numerical simulation method based on physical model is an effective and economical way to explore the physical mechanism behind the electrical and optical properties of GaN/AlGaN APD, which can effectively promote the progress of GaN/AlGaN APD technology. In this paper, the numerical model of GaN/AlGaN APD is established to deeply explore the working mechanism of the device.

## III. Results and Discussions

$Al_xGa_{1-x}N$ devices are high-power devices. At present, the maximum output power density at working frequency of 8 GHz can reach above 30 W/mm. At such a high power density, the Joule heat generated by the device has no time to dissipate and accumulate inside the device, resulting in the so-called self-heating effect, which seriously affects the output characteristics of the device and restricts the increase of the HEMT device maximum output power. Therefore, the dark current characteristics and response characteristics at different device temperatures are deeply studied in this paper.

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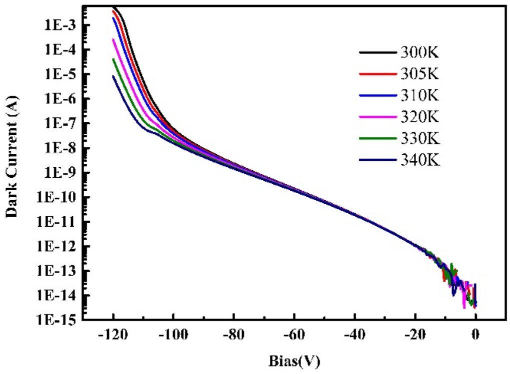


Fig. 2. Dark current at varing bias with different self-heating temperature.

The variation of the device dark current with the bias under the temperature of 300~340 K are as follow: when the bias is lower than 80 V, the dark current level is low, and the influence of temperature change on the dark current is weak. When the bias is higher than 80 V, the circuit level increases gradually, and the influence of temperature increases gradually. At 120 V, the device dark current level with operating temperature of 300 K and 340 K has a gap of three orders of magnitude. At the same time, it can be seen from the figure that the device has obvious breakdown characteristics between 100~110 V.

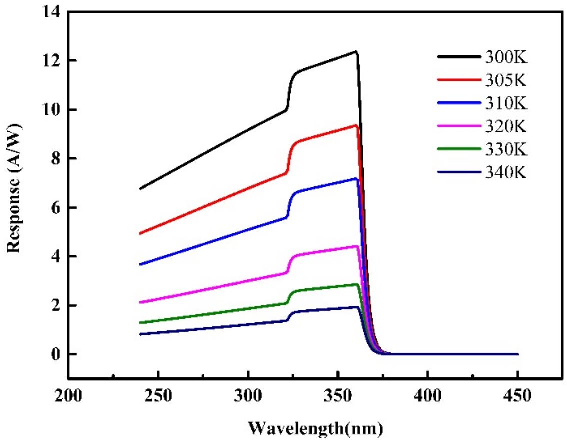


Fig. 3. Response with different self-heating temperature at 88V.

The response of the device in the range of 230~450 nm at different temperatures is shown in the Fig. 3. The core detection wavelength of the device is between 325~370 nm, which is related to the band gap of GaN/AlGaN semiconductor materials. When the wavelength is less than 325 nm, the device still has response because the photon energy is greater than the band gap of GaN/AlGaN material. However, when the wavelength is larger than 370 nm, the photon energy is less than the band gap. The energy is not enough to make the electrons in the valence band transition to the conduction band, so the response drops rapidly to 0.

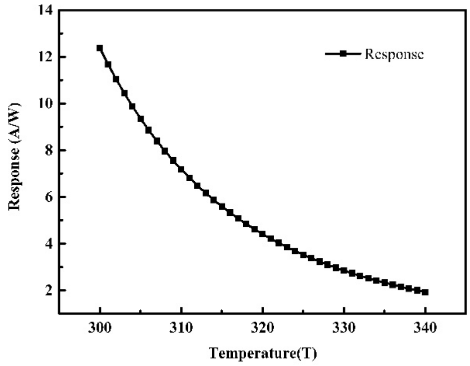


Fig. 4. Peak response with different self-heating temperature at 88V.

Peak response of the device in the working temperature range of 300~340 K is studied as shown in the Fig. 4. The peak response reaches 12 A/W at the working temperature of 300 K. However, when the self-heating temperature of the device reaches 340 K, the peak response of the device decreases significantly to 2 A/W. Therefore, the self-heating efficiency of the device will significantly reduce the performance of the device, which increases the necessity of high-quality heat dissipation of the device.

## IV. Conclusion

In this work, numerical model of GaN/AlGaN APDs is established, and its dark current and response are studied. The results show that when the bias voltage is larger than 80 K, the device temperature has a significant impact on the dark current characteristics. At the same time, with the increase of the device self-heating temperature, the response drops from 12 A/W to 2 A/W in the temperature range of 300~340 K, showing a monotonic downward trend. Therefore, the thermal management of GaN/AlGaN APDs are very important. The adoption of high thermal conductivity substrate and other measures can accelerate the heat dissipation of the device at high power, which is of great significance to improve the performance of devices.

## Acknowledgment

This work was sponsored by Program of Shanghai Academic/Technology Research Leader (Grant No. 21XD14231423600), Young Elite Scientists Sponsorship Program by CAST (Grant No. 2018QNRC001), the National Natural Science Foundation of China (Grant Nos. 62171286, and 61705201), Shanghai Sailing Program (Grant Nos. 22YF1446200, and 22YF1446300), and Shanghai Youth Top-Notch Talent Development Program.

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