Characterization of fast particle detectors fabricated with wide bandgap semiconductors using a picosecond UV laser

A. Kaur[1]*, R. Jeena[1], P. Chetry[2], E. George[1], S. Dhar[1] and P. Sarin[1]
[1]*Department of Physics, Indian Institute of Technology Bombay, Powai, Mumbai 400076*
[2]*IIT Bombay Monash Research Academy, Indian Institute of Technology Bombay, Powai, Mumbai 400076*
** email: 194123008@iitb.ac.in*

Introduction

Wide bandgap semiconductors like diamond, SiC, and GaN have emerged as attractive alternatives to traditional silicon detectors for particle detection in harsh high radiation environments [1][2], [3].

Due to the large bandgap, the detectors feature a simple geometry – multiple lithographic doping processes are typically not required. A metal-semiconductor-metal (MSM) detector structure on a thin epitaxial film is adequate to detect signals from a large particle flux. The dark current is inherently suppressed by the large bandgap. However, for calibration, it is necessary to determine the detector response to single particle incidence. In the absence of sufficient signal deposition by single α or β particles in the thin detector layer, we have developed an alternative technique to characterize the detector response using fast UV laser pulses.

In this work, we have demonstrated the characterization of a prototype detector with a picosecond laser.

Experimental details

1. Detector prototype used for testing

A metal-semiconductor-metal (MSM) detector prototype was fabricated using photolithography technique on 3 µm thick c-GaN epitaxial layer grown on c-sapphire substrate. Prior to the fabrication, the samples were cleaned with trichloroethylene (TCE), Acetone, and propanol (IPA). After patterning, the stack of Ni/Pt/Au (10/30/80 nm) was deposited Finally, the lift-off was done to obtain the interdigitated MSM structures, comprising 4 µm finger width, 8 µm spacing, and 100 µm finger length.

Fig. 1 shows the dark current of the device. Due to the wide bandgap, the dark current is quite suppressed and shows Ohmic behavior with sub-µA dark current up to ±40V. Hence bias voltage of either polarity can be used to extract signal. The inset shows the optical image of the detector

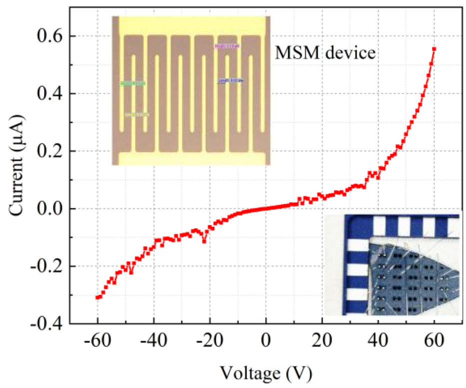

Fig. 1 Dark IV characteristics of the device. The upper inset shows the optical image of GaN interdigitated device with finger width 4 µm, 8 µm spacing, and 100 µm finger length. The lower inset shows the device mounted on a chip carrier.

2. Experimental setup

The experimental setup is shown in Fig. 2. The device was illuminated with a 266 nm pulsed UV laser with pulse width of 400 ps and an 8kHz repetition rate. For the alignment, an x-y translational stage was used. Voltage biasing to the device was applied with Stanford research systems Model PS325. The device signal was amplified with a Cividec C2 transimpedance amplifier and digitized on a LeCroy WaveRunner 8254M, 2.5GHz oscilloscope.

Results and discussion

Fig. 3 shows the response of the prototype detector to a pulsed laser with applied bias

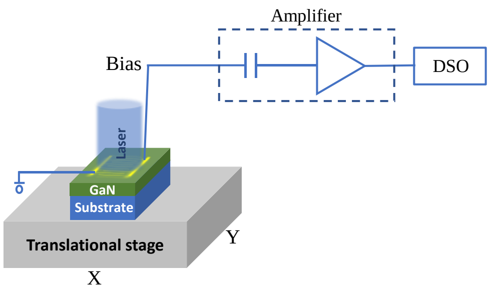

Fig. 2 Schematic of the experimental setup.

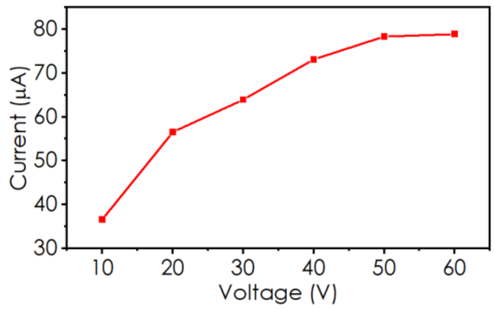

Fig. 4 Peak current as a function of applied bias.

ranging from 10V to 60V. For a light pulse injection lasting 0.4 ns, the width of the signal is ~2ns. The device photocurrent returns to zero baseline between pulses. This may indicate that the detector response is limited by the drift of the photoexcited carriers between contacts. In GaN, holes are low mobility carriers [4], therefore the response is limited by hole mobility. Moreover, with an increase in bias voltage, the signal increases linearly as shown in Fig. 4, showing the linear dependence of drift velocity with the applied field up to 40V.

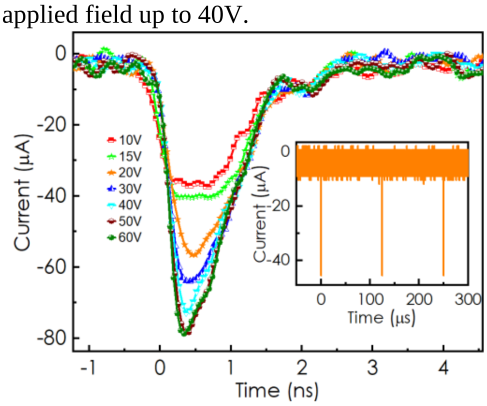

Fig.3 Response of the prototype detector with picosecond pulsed laser with applied bias. The inset shows the repetitive signal pulses with 8kHz frequency.

In conclusion, in the absence of sufficient signal deposition by single α or β particles in the thin detector layer, charged particle generation by a fast laser pulse at a wavelength above the semiconductor bandgap as demonstrated can be used to detect the fast response of the device.

Future work

Unlike the point-like incidence of an isolated charge particle at a single location on the detector, the beam spot size of the incident UV pulse is ultimately diffraction limited. Therefore, the generation of electron/hole signal pairs over an extended area and the obtained signal response is a convolution of the collective motion of a 'cloud' of electron/hole pairs in the bias field. This leads to a slight broadening of the signal pulse in time domain. Based on the fact that focused spot size of the laser in our setup covers nearly the entire active area of the detector, this technique enables us to do a quick check of the detector functionality in the absence of an intense radiation source. Further work in collimating the beam spot using a lithographically patterned micron-scale pinhole can allow us to accurately localize the region of charge production in the semiconductor and hence do a systematic scan of the entire detector active area.

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