Interdigitated Electrode Geometry Variation and External Quantum Efficiency of GaN/AlGaN-Based Metal–Semiconductor–Metal Ultraviolet Photodetectors

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Efficient and ultrafast $Al_xGa_{1-x}N$-based ultraviolet (UV) photodiodes are suitable candidates for UV photodetection because of their highly mobile carriers. The characteristics of $Al_xGa_{1-x}N$, a group III–V compound that has endeared it to the optoelectronics community, consist of a tunable direct band gap, superior electrical stability, elevated thermal resistivity, and robust performance in hazardous environments like inertial confinement chambers and space environments. $Al_xGa_{1-x}N$-based photodiodes (PD's) offer an important feature that permits the selection of a desired spectral window by simply altering the percentage composition of Al in the $Al_xGa_{1-x}N$ compound.[1,2]

AlGaN-based PD's produce the best response speed in the metal–semiconductor–metal (MSM) configuration because in this design, the response time is limited by the carrier transit time between the interdigitated fingers. Furthermore, in the MSM setup, the capacitance due to the interdigitated fingers is extremely small, of the order of 20×10^{-15} F, which leads to an ~1-ps resistor capacitor time constant for a 50-Ω external coupling circuit.[3]

Here, we discuss the successful design and fabrication of $Al_xGa_{1-x}N$-based photodetectors with rectangular and circular asymmetric, interdigitated electrode geometries GaN/AlGaN semiconductors. The thin films were grown on commercially available sapphire substrates via metal-organic chemical vapor deposition by KYMA Technologies.[4] The best-performing devices yielded a scope-limited pulse duration of 62 ps with a 29-ps rise time. The bias-independent external quantum efficiency of the devices was >70% for intrinsic devices at 60 V and >400% at 10 V. The main goal of this investigation was to establish the bias voltage that saturates the external quantum efficiency (EQE) of these devices.

Figure 1 depicts the device's epitaxial structure for both metals that were employed in the detectors. The experimental setup is shown in Fig. 2. UV light was produced by Astrella and an optical parametric amplifier (OPA) by a fourth-harmonic–generation technique. Astrella is an 800-nm Coherent laser operating at 1 kHz and possessing a 30-fs pulse duration. The 800-nm visible

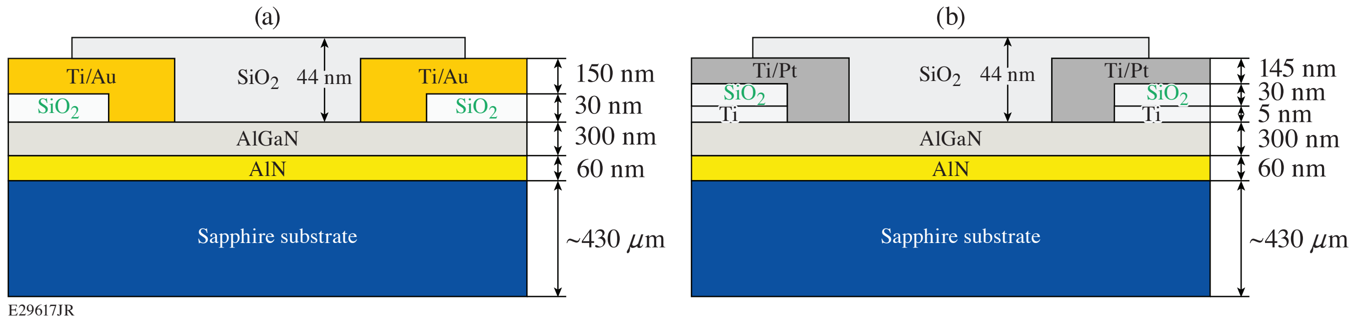

Figure 1
Epitaxial stack of the fabricated (a) Au and (b) Pt AlGaN-based MSM UV PD's for efficient and ultrafast UV detection.

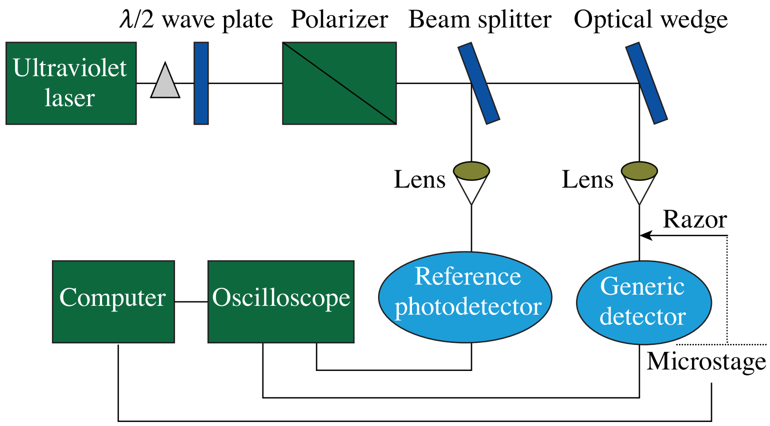

Figure 2
Experimental setup for ultrafast testing of AlGaN PD's at 262 nm (Ref. 1).

light output of Astrella served as the input pump laser to the OPA, which changes it to 262 nm of UV light using fourth-harmonic generation. The output energy per pulse from the OPA at 262 nm is 40×10^{-6} J, but only 0.749×10^{-9} J reached the detector under test. The reference detector was a 200- to 1100-nm Thorlab Det10 Si-biased detector.

Figure 3(a) posits the photocurrent of Pt intrinsic $Al_{0.2}Ga_{0.8}N$ with the circular asymmetric contact device as a function of bias voltage. The Schottky contact blocks current from –3.5 V to +3.5 V.

Figure 3(b) depicts the ultrafast impulse response function of Au $Al_{0.1}Ga_{0.9}N$ and Pt $Al_{0.2}Ga_{0.8}N$ intrinsic MSM UV photodiodes at 20-V bias voltage. The Au PD recorded a 29-ps rise time with 62-ps pulse duration, while the Pt PD showed a 34-ps rise time and 72-ps pulse width. The Au device exhibited the best response characteristics with a 29-ps rise time with 62-ps full width at half maximum; this response is not the intrinsic response time of the device due to the bandwidth limitation of the oscilloscope.

$$\mathrm{QE}(\eta) = \frac{I_{\mathrm{ph}}/e}{P/h\nu}. \tag{1}$$

The efficiency of the devices was computed using Eq. (1) and the results for Pt $Al_{0.1}Ga_{0.9}N$ n-doped circular asymmetric (CA) and Pt $Al_{0.2}Ga_{0.8}N$ intrinsic rectangular asymmetric (RA) detectors are plotted in Figs. 3(c) and 3(d), respectively.

The interdigitated electrode geometries of $Al_xGa_{1-x}N$ MSM UV photodiodes were redesigned as rectangular asymmetric and circular asymmetric fingers. These were successfully implemented and tested to establish their UV response profiles. Investigations were done to obtain the bias voltage that saturates these devices to find the detector's bias-independent EQE. The alterations of electrode geometry in addition to fewer electrodes on the devices reduced the effects of electrode shadowing and allowed about 34% more UV light to be absorbed. A combination of these factors resulted in the recorded bias-voltage–independent EQE of our devices. Establishment of the efficiency of these detectors will improve the quest for semiconductor-driven ultrafast laser pulse characterization and plasma diagnostics.

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1. S. Nwabunwanne and W. Donaldson, Proc. SPIE **12001**, 120010F (2022).
2. E. Monroy *et al.*, Appl. Phys. Lett. **74**, 3401 (1999).
3. Y. Zhao and W. R. Donaldson, IEEE J. Quantum Electron. **56**, 4000607 (2020).
4. AlGaN Templates, Kyma Technologies Inc., Raleigh, NC 27617, accessed 10 June 2022, https://kymatech.com/products-services/materials/gan-related-iii-n-materials/499-algan-templates.

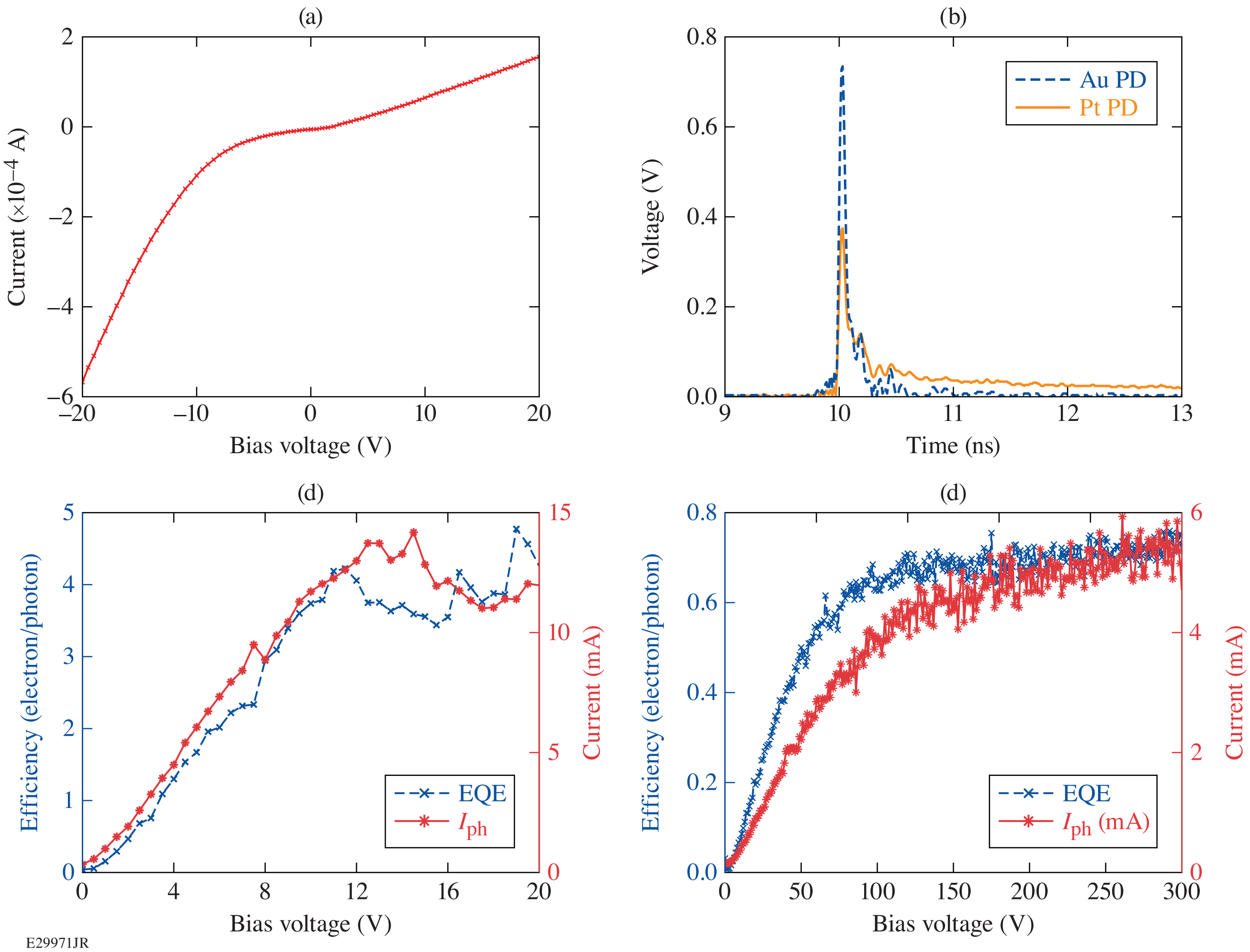

Figure 3
(a) Pt intrinsic $Al_{0.2}Ga_{0.8}N$ MSM UV photodiode I–V curve under dark conditions. (b) Au $Al_{0.1}Ga_{0.9}N$ and Pt $Al_{0.2}Ga_{0.8}N$ intrinsic MSM UV photodiodes' impulse response function at 20-V bias voltage. The Au PD yielded a 29-ps rise time with 62-ps pulse duration, while the Pt PD produced a 34-ps rise time and 72-ps pulse width. External quantum efficiency and photocurrent as a function of bias voltage. (c) Pt $Al_{0.1}Ga_{0.9}N$ *n*-doped CA device (saturation began at 10 V). (d) Pt $Al_{0.2}Ga_{0.8}N$ intrinsic RA device (saturation began at 60 V).