Fabrication and characterisation of solar-blind $Al_{0.6}Ga_{0.4}N$ MSM photodetectors

N. Biyikli, I. Kimukin, T. Tut, O. Aytur and E. Ozbay

Solar-blind metal–semiconductor–metal (MSM) photodiodes based on MOCVD-grown $Al_{0.6}Ga_{0.4}N$ template have been fabricated and tested. AlGaN detector samples were fabricated using a microwave compatible fabrication process. Optical transmission, current–voltage, spectral responsivity, and temporal pulse response measurements were carried out. The fabricated devices had very low leakage current and displayed true solar-blind response with ~255 nm cutoff wavelength.

Introduction: Since the first demonstration of solar-blind $Al_xGa_{1-x}N$ photoconductors [1, 2], AlGaN-based ultraviolet (UV) photodetectors with cutoff wavelengths smaller than 280 nm have proved their potential for solar-blind detection [3]. Different types of solar-blind AlGaN detectors have been demonstrated with high performance in all aspects [4–6]. Metal–semiconductor–metal photodiodes are particularly attractive for this wide-bandgap material system: high-quality Schottky contacts on AlGaN layers can be achieved easily. Recently we have reported solar-blind MSM photodetectors on $Al_{0.38}Ga_{0.62}N$ epilayers [7]. In this Letter, we report the fabrication and characterisation of solar-blind MSM photodiodes using $Al_{0.6}Ga_{0.4}N$ templates.

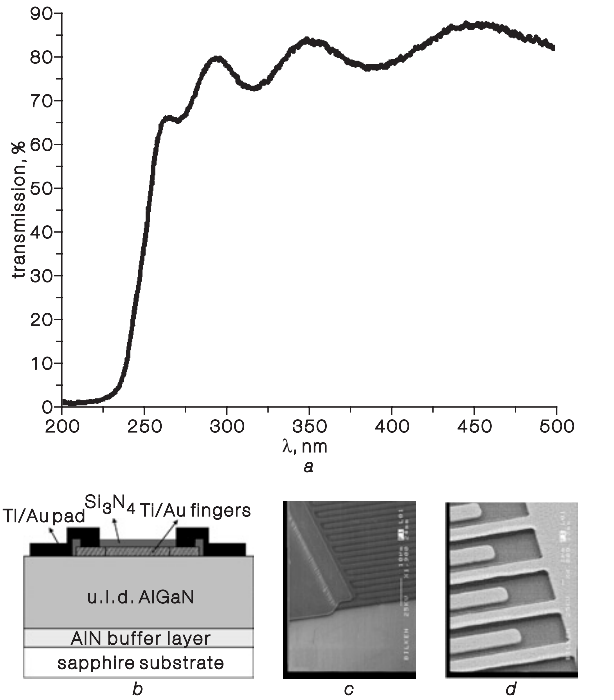

Fig. 1 *Transmission spectrum of AlGaN wafer; cross-sectional diagram of completed AlGaN MSM photodetector; scanning electron microscope pictures of fabricated MSM devices*

a Transmission spectrum
b Cross-sectional diagram
c, *d* SEM pictures

Design and fabrication: The high Al-content AlGaN wafer was grown by MOCVD on double-side polished sapphire substrate. The wafer structure consisted of a ~2 μm-thick unintentionally doped $Al_{0.6}Ga_{0.4}N$ layer on top of a thin AlN nucleation layer. To measure the cutoff wavelength of our samples, optical transmission measurements were performed before device fabrication. The measured spectral transmission curve of the $Al_{0.6}Ga_{0.4}N$ wafer is shown in Fig. 1*a*. A sharp cutoff at ~250 nm was observed. This ensured the true solar-blind operation of our detectors. Fabrication process started with the formation of interdigitated metal (Ti/Au) fingers. This was followed by mesa isolation etch, which was accomplished with a CCl_2F_2-based reactive ion etching process. Device mesas with 100 × 100 μm active area were defined. In the third step, the sample surface was passivated using plasma-enhanced chemical vapour deposition of ~100 nm-thick Si_3N_4 layer. Fabrication was completed with the deposition of thick interconnect metal pads. Cross-sectional schematic and scanning electron microscope pictures of completed AlGaN MSM photodiodes are shown in Figs. 1*b*–*d*.

Results: Current–voltage (I–V) characteristics were measured using a high-resistance electrometer with low-noise DC probes and triax cables. I–V measurements of the fabricated solar-blind AlGaN devices resulted in extremely low dark currents, even at high voltages. Fig. 2*a* shows the dark current of an MSM detector with 10 μm finger width/spacing. The dark current was less than 100 fA up to ±200 V bias voltage. The inset shows the dark current measurement between 0–300 V. No sign of breakdown was observed for applied voltages up to 300 V. Leakage current is smaller than 10 fA in the (−50 V, +100 V) range. Low leakage current and >300 V breakdown voltage indicate the layer and contact quality for these devices.

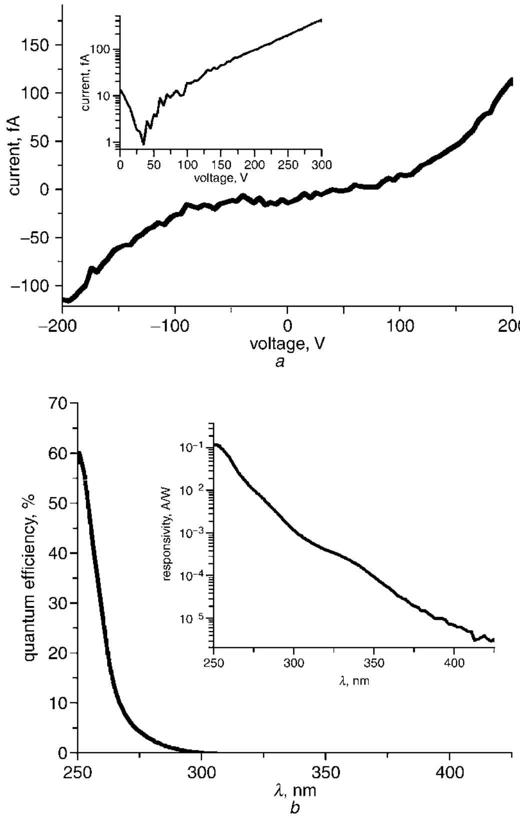

Fig. 2 *I–V measurement of an $Al_{0.6}Ga_{0.4}N$ MSM photodiode*

a I–V measurement of $Al_{0.6}Ga_{0.4}N$ MSM photodiode
Inset: Dark current up to 300 V bias in logarithmic scale
b Spectral quantum efficiency of solar-blind MSM photodiode
Inset: Corresponding responsivity curve

The spectral photoresponse measurements were carried out in the 250–420 nm range, where we were limited by the 250 nm cutoff of the calibrated Si photodetector. The detectors were illuminated with a 100 μm-diameter UV-fibre carrying the monochromated Xe-lamp output. The resulting photocurrent was recorded via a lock-in amplifier. Device responsivity increased with bias application. Fig. 2*b* shows the measured spectral quantum efficiency of a typical solar-blind MSM detector under 10 V bias. The quantum efficiency reached a maximum of 60% at 250 nm, corresponding to a device responsivity of 0.12 A/W. The cutoff was around 255 nm, which is in good agreement with the transmission spectrum. The inset in Fig. 2*b* shows the corresponding responsivity curve of the device. Although the cutoff looks sharp in the linear scale, we observe a rather gradual decrease in device responsivity. The visible rejection reached 8×10^4 at 420 nm.

High-speed temporal pulse response measurements were carried out at 260 nm using a modelocked femtosecond Ti:sapphire laser setup with two nonlinear crystals. Sub-picose UV pulses were focused onto the samples using UV-grade mirrors and lenses. The measurements were performed on a microwave probe station with 40 GHz probes. The electrical response pulses were observed on a 20 GHz scope. Faster pulses were obtained with higher bias voltages and smaller finger spacings. Fig. 3 shows the pulse response of a detector with 3 μm finger spacing under 50 V reverse bias. The pulse response had a fast rise time of 25 ps, but a slowly decaying fall time of 1.30 ns. FWHM of the pulse was measured as 122 ps. The corresponding FFT curve of the temporal data is shown in the inset. A 3 dB bandwidth of 150 MHz was achieved.

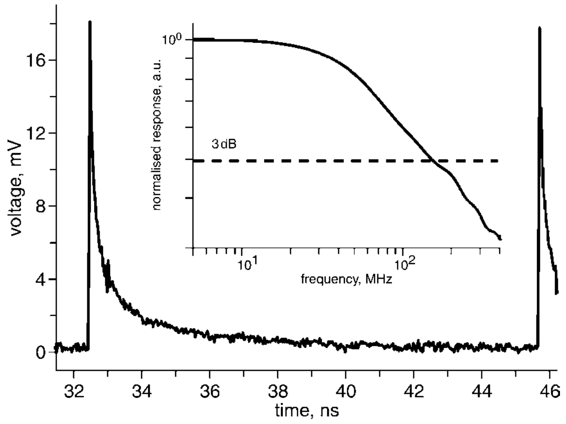

Fig. 3 *Measured pulse response of 3 μm finger width/spacing $Al_{0.6}Ga_{0.4}N$ MSM device*

Inset: Corresponding calculated FFT curve

Conclusion: We have fabricated and tested true solar-blind MSM photodetectors on high (60%) Al-content AlGaN templates. The fabricated $Al_{0.6}Ga_{0.4}N$ MSM photodiodes exhibited low leakage current, high breakdown voltage and low cutoff wavelength. The cutoff wavelength of 255 nm corresponds to the lowest cutoff wavelength reported with AlGaN-based MSM photodiodes.

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