# Design, fabrication and characterization of high-performance AlGaN UV photodetectors

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AlGaN based photodetectors have emerged as an alternative to conventional ultraviolet (UV) sensors with the advent of metal organic chemical vapor deposition (MOCVD) systems [1-2-3]. Many workers have demonstrated metal-semiconductor-metal (MSM) [4- 5], Schottky [6], p-i-n [7] and avalanche type [8] AlGaN UV photodetectors successfully. Ultraviolet detectors have a wide range of applications in flame, fire and missile detection, chemical and biological analysis, short distance non-line- of-sight optical communications, as well as emitter calibration. The existing fire warning systems utilize infrared (IR)/IR [9], UV/IR, or UV/visible/IR channels. Multiband narrow-spectrum UV detectors would in turn increase the fire source and range recognition capabilities of such systems and help to eliminate false alarms. One method of narrow spectral-band detection is to employ absorptive epitaxial filter-layers [10].

The AlGaN p-i-n structures were grown on double-side polished c-plane sapphire ($Al_2O_3$) substrates by low-pressure metal organic chemical vapor deposition (MOCVD) system, which is located at the Bilkent University Nanotechnology Research Center. First, the wafer surface was cleaned by desorption in an $H_2$ environment at 1,080ºC. Then, a ~100 Å AlN nucleation layer was grown at 550ºC by trimethylaluminum (TMAl) and ammonia ($NH_3$) under 50mbar pressure. Subsequently, a high temperature (1,135ºC) $Al_{0.4}Ga_{0.6}N$ buffer layer of 1,600 Å was grown with trimethylgallium (TMGa) and a high flow NH3 at 1,160ºC. An N-layer with a thickness of 5,000 Å was grown with silane (SiH4), in turn resulting in a carrier concentration of $10^{18}$ $cm^{-3}$. The growth continued with a 6,000 Å $Al_{0.4}Ga_{0.6}N$ i-layer at 1,130ºC. In the last step, a 1,000 Å $Al_{0.4}Ga_{0.6}N$ p-layer with Mg doping by biscyclopentadienylmagnesium ($Cp_2Mg$) was grown at 1,050ºC. In all of the steps, the carrier gas was $H_2$ and the chamber pressure was kept at 50mbar.

The samples were fabricated via a six-step microwave-compatible fabrication process in a class-100 clean room environment[11-12]. The dry etching was accomplished by reactive ion etching (RIE) under $CCl_2F_2$ plasma, 20 sccm gas flow rate, and 200 W RF power conditions. Mesa structures of the devices were formed via the RIE process, by etching all of the layers (> 1.2 µm) down to the nucleation layer for mesa isolation. After an ohmic etch of ~ 0.7 µm, Ti/Al/Ti/Au (100 Å/1,000 Å/100 Å /2,000 Å) metal contacts and Ni/Au (100 Å/1,000 Å) metal contacts were deposited by thermal evaporation and left in acetone for the lift-off process for N+ and P+ ohmic contacts, respectively. The ohmic contacts were annealed at 750°C for 60 s. Thereafter, a 240 nm thick $SiO_2$ was deposited via plasma enhanced chemical vapor deposition (PECVD) for passivation. Finally, a ~0.3 µm thick Ti/Au interconnect metal was deposited and lifted-off in order to connect the n-type and p-type ohmic contact layers to the coplanar waveguide transmission line pads (Fig. 1).

Spectral transmission, current-voltage (I-V), and quantum efficiency (QE) measurements were performed. I-V characterization of the fabricated photodetectors was carried out by using a 4142B electrometer and Keithley 6517A high resistance electrometer with low noise triax cables. QE measurements were performed using a Xenon arc lamp, monochromator, UV-enhanced fiber, and SRS lock-in amplifier. Solar blindness is guaranteed by the cut off wavelength, which is 276nm. The I-V measurement results in Figure 2 show that the 5V bias dark current of a 200 µm diameter photodetector was 5 fA. This current level corresponds to the background noise floor of the electrometer that was used for the experiments, i.e. the minimum value that the electrometer can measure. The corresponding dark current density was $1.6 \times 10^{-11} A/cm^2$. The dark current at 120V was 1.6nA. The breakdown voltage of the photodetectors was measured as approximately 250 V. To our knowledge in terms of breakdown voltage and dark current density at 5V, these values correspond to the best results for AlGaN based solar-blind p-i-n type photodetectors.

Besides these solar-blind AlGaN detectors, an eight element array of wavelength sensitive back-illuminated ultraviolet metal-semiconductor-metal photodetectors was demonstrated on an $Al_xGa_{1-x}N$ heterostructure. The average of the full-width at half-maximum (FWHM) of the responsivity peaks was 10 nm. Relative response function of consecutive photodetector elements is proposed to determine the wavelength of monochromatic illumination in the 250 nm to 335 nm wavelength range. By comparing the measured cut-off wavelengths to published data, the molecular composition of each layer shown in Fig. 3 is determined. The thicknesses of each layer were determined to be in accordance with the design value of 500 nm, within a 5% error associated with the thickness measurement. The responsivity of each element of the wavelength-sensitive photodetector array is plotted in Fig. 4 for the 250 nm - 350 nm spectral range.

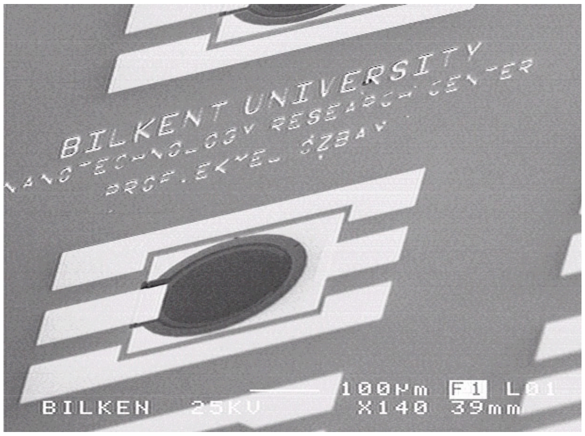


Fig. 1. SEM image of 200 micron diameter f abricated device

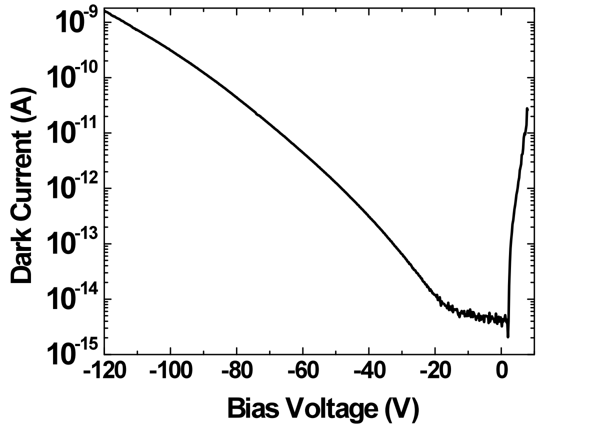


Fig. 2. Dark current of a 200 µm diameter AlGaN p -i-n photodetector.

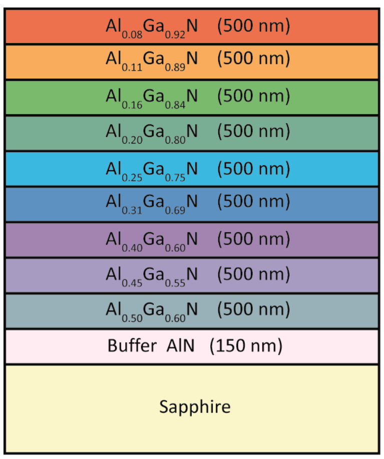


Fig. 3. Epi -layer structure used to study wavelen gth sensitive UV photodetectors.

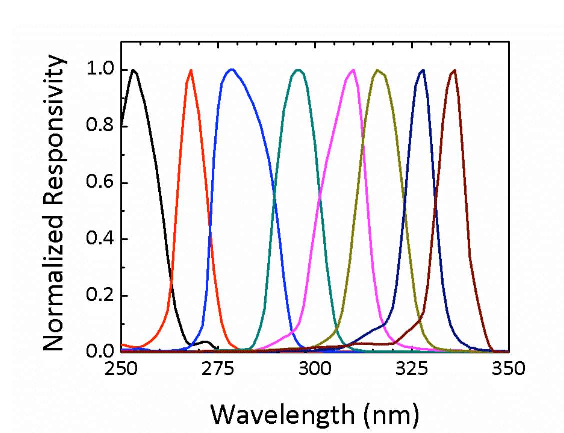


Fig. 4 . Normalized responsivity of wavelength sensitive monolithic stack of MSM photodetectors.

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