Solar-blind AlGaN-based p-i-n photodetectors with high breakdown voltage and detectivity

Turgut Tut, Tolga Yelboga, Erkin Ulker, and Ekmel Ozbay

Citation: Appl. Phys. Lett. 92, 103502 (2008); doi: 10.1063/1.2895643
View online: http://dx.doi.org/10.1063/1.2895643
View Table of Contents: http://apl.aip.org/resource/1/APPLAB/v92/i10
Published by the American Institute of Physics.

Related Articles
Effects of annealing temperature on the characteristics of Ga-doped ZnO film metal-semiconductor-metal ultraviolet photodetectors
Conditions for a carrier multiplication in amorphous-selenium based photodetector
Appl. Phys. Lett. 102, 073506 (2013)
Photoresponses of manganese-doped gallium nitride grown by metalorganic vapor-phase epitaxy
Appl. Phys. Lett. 102, 071107 (2013)
A polychromator-type near-infrared spectrometer with a high-sensitivity and high-resolution photodiode array detector for pharmaceutical process monitoring on the millisecond time scale
Transparent ion trap with integrated photodetector
Appl. Phys. Lett. 102, 054106 (2013)

Additional information on Appl. Phys. Lett.
Journal Homepage: http://apl.aip.org/
Journal Information: http://apl.aip.org/about/about_the_journal
Top downloads: http://apl.aip.org/features/most_downloaded
Information for Authors: http://apl.aip.org/authors
Solar-blind AlGaN-based \( p-i-n \) photodetectors with high breakdown voltage and detectivity

Turgut Tut, a) Tolga Yelboga, Erkin Ulker, and Ekmel Ozbay

Nanotechnology Research Center, Department of Physics, and Department of Electrical and Electronics Engineering, Bilkent University, Bilkent, 06800 Ankara, Turkey

(Received 1 February 2008; accepted 12 February 2008; published online 10 March 2008)

We report on the high performance solar-blind AlGaN-based \( p-i-n \) photodetectors that are grown by metal-organic chemical vapor deposition on \( c \)-plane sapphire substrates. The dark current of the 200 \( \mu \text{m} \) diameter devices was measured to be on the order of 5 fA for bias voltages up to 10 V. The breakdown voltages were higher than 200 V. The responsivities of the photodetectors were 0.052 and 0.093 A/W at 280 nm under 0 and 40 V reverse biases, respectively. We achieved a detectivity of \( 7.5 \times 10^{14} \text{ cm Hz}^{1/2} / \text{W} \) for 200 \( \mu \text{m} \) diameter AlGaN \( p-i-n \) detectors.

\[ \text{© 2008 American Institute of Physics. [DOI: 10.1063/1.2895643]} \]

The recent developments in high quality GaN/AlGaN material growth technology have led to the realization of high performance solar/visible-blind photodetectors operating in the ultraviolet (UV) spectral region. Diverse applications wherein GaN/AlGaN-based photodetectors are utilized include engine/flare monitoring and detection, plant/vegetation growth monitoring, oxygen layer monitoring, UV astronomy, gas detection, water purification, submarine communication, and medical applications.\(^1\)^\(^5\) These photodetectors are also chemically inert and suitable for harsh environments.\(^1\)^\(^3\) These photodetectors include engine/flare monitoring and detection, plant/vegetation growth monitoring, oxygen layer monitoring, UV astronomy, gas detection, water purification, submarine communication, and medical applications.\(^1\)^\(^5\) These photodetectors are also chemically inert and suitable for harsh environments. GaN-based solid-state photodetectors with breakdown voltages \( \sim 100 \text{ V} \), \(^6\)^\(^8\) responsivities of 0.18 A/W at 360 nm (Ref. 9) (for Schottky-type photodetectors), and 0.2 A/W at 355 nm (for backilluminated GaN-based \( p-i-n \) photodetectors) that corresponds to 70% quantum efficiency (QE) at zero bias,\(^10\) 3 dB bandwidth of 16 GHz (for metal-semiconductor-metal (MSM)-type photodetectors),\(^11\) 2.6 GHz (for GaN-based Schottky-type photodetectors with indium tin oxide),\(^12\) and 1.6 GHz (for \( p-i-n \)-type photodetectors)\(^13\) have all been previously reported. AlGaN-based solar-blind photodetectors with breakdown voltages larger than 100 V, 136 mA/W responsivity under 0 V bias at 282 nm, and 72% QE under 5 V reverse bias for backilluminated AlGaN \( p-i-n \) photodiodes,\(^14\) solar-blind focal plane arrays that possess 60% QE at 280 nm under 0 V bias,\(^15\) dark current density of \( 8.2 \times 10^{-11} \text{ A/cm}^2 \) under 5 V reverse bias,\(^16\) and thermally limited detectivity of \( 4.9 \times 10^{14} \text{ cm Hz}^{1/2} / \text{W} \) (Ref. 17) at 267 nm have also been reported. In the present paper, we present our experimental results on high performance AlGaN-based solar-blind \( p-i-n \) photodetectors. Our solar-blind AlGaN photodetectors possess higher breakdown voltage, higher detectivity, and lower dark current density compared to the previously published AlGaN-based solar-blind \( p-i-n \) photodetector results in the literature.

The AlGaN \( p-i-n \) structure that was used in the present study was grown on double-side polished \( c \)-plane sapphire (Al\(_2\)O\(_3\)) 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 a H\(_2\) environment at 1080 °C. Then, an \( \sim 100 \, \text{Å} \) AlN nucelation layer was grown at 550 °C by trimethylaluminum and ammonia (NH\(_3\)) under 50 mbar pressure. Subsequently, a high temperature (1135 °C) Al\(_{0.4}\)Ga\(_{0.6}\)N buffer layer of 1600 Å was grown with trimethylgallium and a high flow NH\(_3\) at 1160 °C. A N layer with a thickness of 5000 Å was grown with silane (SiH\(_4\)), in turn resulting in a carrier concentration of \( 10^{18} \text{ cm}^{-3} \). The growth continued with a 6000 Å Al\(_{0.4}\)Ga\(_{0.1}\)N i-layer at 1130 °C. In the last step, a 1000 Å Al\(_{0.4}\)Ga\(_{0.1}\)N p-layer with Mg doping by bicyclopentadienylmagnesium was grown at 1050 °C. In all of the steps, the carrier gas was H\(_2\) and the chamber pressure was kept at 50 mbar.

The samples were fabricated via a six-step microwave-compatible fabrication process in a class-100 clean room environment. The dry etching was accomplished by reactive ion etching (RIE) under CCl\(_2\)F\(_2\) plasma, 20 SCCM (SCCM denotes cubic centimeter per minute at STP) 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 nucelation layer for mesa isolation. After an Ohmic etch of \( \sim 0.7 \, \text{μm} \), Ti:Al/Ti:Au (100 Å:1000 Å:100 Å:2000 Å) metal contacts and Ni:Au (100 Å:1000 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 for passivation. Finally, an \( \sim 0.3 \, \text{μm} \) 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).

For the present study, spectral transmission, current-voltage (I-V), and 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 cutoff wavelength, which is 276 nm (Fig. 1(a)). The I-V measurement results in Fig. 2 show that the 5 V bias dark current of a 200 μm diameter photodetector was 5 fA. This current level corre-
sponds 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 120 V was 1.6 nA. The breakdown voltage of the photodetectors was measured as approximately 250 V. In terms of the breakdown voltage and dark current density at 5 V, these values correspond to the best results for AlGaN-based solar-blind $p$-$i$-$n$-type photodetectors.

A maximum 42% QE corresponding to 0.093 A/W responsivity at 280 nm under 40 V reverse bias and a 22% QE corresponding to 0.049 A/W under 0 V bias were achieved. The dark current of a 200 μm diameter circular diode was measured to be approximately 5 fA for voltages up to 10 V reverse bias, along with a breakdown voltage that was approximately 250 V. The solar-blind spectrum detectivity is calculated as $D^* = 7.5 \times 10^{14}$ cm Hz$^{1/2}$/W at 280 nm. In terms of the breakdown voltage and detectivity, the reported results are better than the previously published AlGaN-based $p$-$i$-$n$ photodetector results in the literature.

This work is supported by the European Union under the projects EU-NoE-METAMORPHOSE, EU-NoE-PHOREMOST, EU-ECONAM, and TU-BITAK under Project Nos. 105E066, 105A005, 106E198, 106A017, and 107A012. One of the authors (E.O.) also acknowledges partial support from the Turkish Academy of Sciences.

4J. C. Campbell, S. Demiguel, F. Ma, A. Beck, X. Guo, S. Wang, X. Zheng,


