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GaN UV detectors for synchrotron-based protein structure studies

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Abstract

AlGaN and GaN have been investigated as UV detector materials for applications in protein structure studies. I-V characteristics performed on the material using concentric contacts showed 4 orders of magnitude greater dark current for the $Al_{0.1}Ga_{0.9}N$ than for the GaN. Subsequently, interdigitated metal-semiconductor-metal (MSM) photodetectors were successfully fabricated on GaN. No changes in levels of dark surrent were recorded using varying metal electrodes with similar work functions (Pd and Au). The unbiased diodes showed a difference of 3 orders of magnitude between dark and photocurrent levels on exposure to UV. The responsivity for diodes with 25 and 100μm finger separation operated in unbiased mode was around 100mA/W and was flat over the bandgap. These results show a responsivity in agreement with those from previous measurements for biased GaN photodetectors [1]. Using these results, a design for an unbiased GaN detector to be used for protein structure studies is proposed

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1 Introduction

Due to advances in growth technologies GaN has recently been the focus of intense interest. It works well in aggressive environments, due to its thermal stability and radiation hardness [2], and its direct wide energy bandgap (3.4eV) makes it a highly promising material for photon detection in the UV range. The addition of Al can lower the cutoff wavelength from 365 to 200nm. Consequently, no short pass filter is necessary for selective UV detection.

Potential uses for GaN UV detectors [3] range from spaced-based, military and environmental applications to proteomics - the study of proteins. One such example of protein structure studies is that of Circular Dichrosim (CD) [4]. In CD, an optically active molecule preferentially absorbs one specific direction of circularly polarised light. It is known that each secondary structure of a protein has its own characteristic CD spectrum. To study how a protein folds into its specific compact structure, CD measurements must be performed below 260nm. At present, complications arise from the need to make measurements where the samples absorb strongly below 200nm, a range of UV not easily accessible using conventional CD instrumentation. A CD experiment is therefore to be performed at the Daresbury SRS, utilising the higher intensity and range of electromagnetic radiation in the hard UV range offered by a synchrotron source (<∼160nm) [5]. Additionally, to reduce the time of data acquisition and levels of protein, a 46-channel array of UV diodes is proposed to measure the wavelengths 160-260nm simultaneously through use of a diffraction grating.

This work details the fabrication and characterisation of UV detectors using (Al)GaN. The effects of varying parameters such as the material composition, diode geometry and Schottky metals are presented, with the optimised parameters subsequently implemented in the design for a 46-channel diode array to be operated unbiased for use in CD measurements using synchrotron radiation.

2 Material Fabrication

The material used was $\sim 2\mu m$ thick, metal organic chemical vapour deposition (MOCVD) grown GaN and $Al_{0.1}Ga_{0.9}N$ on basal plane sapphire. Two shapes of diodes were used in this work. For the material characterisation, a pad of $300\mu m$ diameter, with a ring of $200\mu m$ separated by a $100\mu m$ gap was used (Fig 1a). For the UV tests interleaving finger diodes were employed. Finger diodes are ideal for UV detection in GaN since;

1. Collection time is reduced as the incident photon will be nearer to an electrode
2. Active area (area between the fingers) is not compromised

Diodes were fabricated with 25, 50 and $100\mu m$ as the finger pitch and width (Fig 1b). All samples were prepared using standard photolithographic techniques.

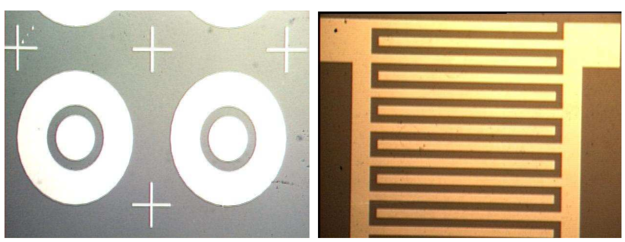

Figure 1: Fabricated diodes on (Al)GaN: a - concentric contacts, b - $100\mu m$ finger diodes

3 Characterisation & Optimisation

Concentric Contacts

I-V characteristics were measured using a Keithley 237 unit controlled by LabView software. Samples were characterised in a light tight probe station. Fig 2 shows the I-V characteristics for the GaN and AlGaN pad/circle structures. Due to the thinness of the epilayer, the contact potential was able to deplete the diode fully at 0V bias.

Fig 2 shows that the dark current (and hence the conductivity) of the GaN is lower than that of the $Al_{0.1}Ga_{0.9}N$ by 3 orders of magnitude (10^{-4}A and 10^{-7}A respectively at 6V). Also, the dark current for each diode fabricated on GaN and AlGaN varied with position on the wafer. This implies inhomogeneities in the

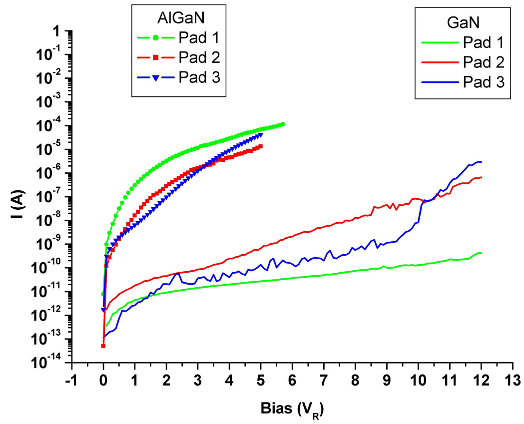

Figure 2: I-V characteristics for AlGaN & GaN concentric ring diodes

material, possibly due to varying trap densities introduced at the growth stage [6]. Due to the low resistivity of the $Al_{0.1}Ga_{0.9}N$ material, only GaN was used for the fabrication of the subsequent UV devices.

Interdigitated Fingers

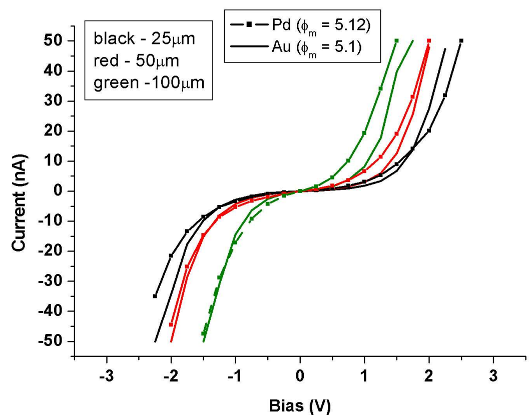

Figure 3: I-V characteristics for Pd & Au interleaving finger contacts on GaN

To investigate the suitability of different metals for Schottky contacts, Au (Φ_m=5.1eV) and Pd (Φ_m=5.12eV) contacts were realised using 400nm Au or 200nm Pd/ 200nm Au. Fig 3 shows a similarity in the levels of leakage current among diodes fabricated using Pd and Au. However, it was found that Pd was more successful at the lift-off stage of fabrication than Au. Also, as Pd is more transparent than Au in the UV region [7], thin layers of Pd can be used for the creation of semi-transparent contacts, used for increasing the active area of the detector. Initial UV characterisation of GaN finger diodes was performed using a Penray UV source. An I-V characteristic was measured whilst illuminated by the source.

Fig 4 shows an increase in current by 3 orders of magnitude for the unbiased sample. A detailed examination of spectral response was carried out using a deuterium source coupled to an automated monochromator. The 25 and 100μm interdigitated GaN detectors were connected in series with a trans-impedance amplifier. The detectors were operated unbiased. The optical power, P_{opt}, of the source was measured using a Hamamatsu UV power meter. Responsivity levels were calculated using the expression

$$\Re = \frac{I_p}{P_{opt}} \tag{1}$$

The responsivity of these detectors (Fig 5) is relatively flat over the bandgap at $\sim$ 100mA/W. The detectors show a response in the $\sim$ 190nm wavelength region, essential for use in synchrotron applications. The low quantum efficiency is thought to be caused by a combination of trapping [8] and the short diffusion length of

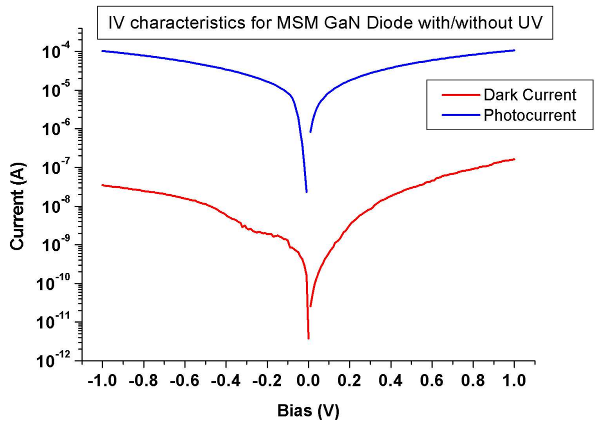

Figure 4: I-V characteristic for interdigitated GaN detectors with/without exposure to UV

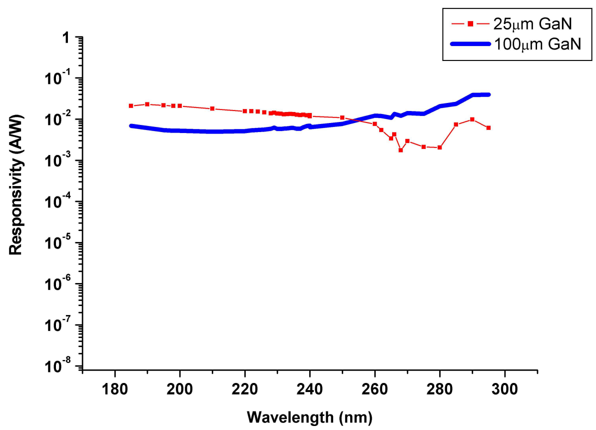

Figure 5: Responsivity measurements for 25 and 100μm finger diodes operated unbiased

minority carriers [9]. These measurements are in agreement with the simulation shown by Monroy et al [10], where it is proposed that the quantum efficiency of interdigitated diodes is strongly influenced by the finger pitch.

4 Conclusions & Future Work

In summary, interleaving finger diodes have been successfully fabricated on GaN. Metals used for the realisation of Schottky contacts were varied, but no major difference in dark currents was observed between Au and Pd. A ratio of 10^3:1 is seen for levels of photocurrent against dark current. Full UV characterisation of the diodes shows good performance in the 190nm region when unbiased, with the responsivity relativley flat over the bandgap. Although the level of responsivity is low, unlike UV silicon, there is still no need for filters for the visible range. Also unlike diamond (where the cut-off wavelength is ~225nm), all wavlengths under 365nm are detectable.

Using these results, the following 46 channel array diode design has been proposed for use in CD measurements to be performed at the Daresbury Synchrotron Radiation Source (Fig 6). The design is for a 46 channel array on GaN. The dimensions are chosen so the diode can be easily wire bonded to a commercially available DIP socket. The array of interleaving finger diodes with 10μm finger width and pitch are arranged so that each set shares a common ground. The design's main feature is that the diodes can be separated by distances of millimeters, whilst the detectable quantum efficiency will be determined by the pitch of the fingers. Semi-transparent contacts are to be made using Pd metal to optimise the active area. The detector can also operate unbiased.

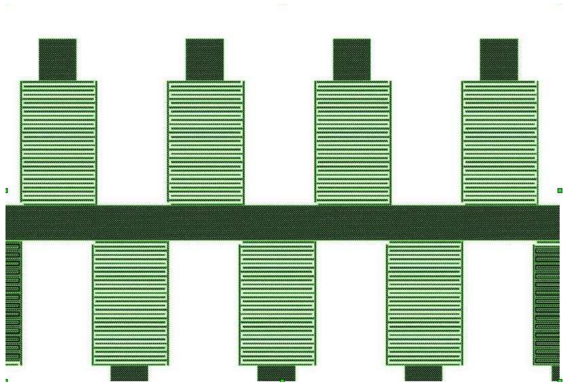

Figure 6: Proposed 46 channel array on GaN for protein structure studies at Daresbury

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