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Development of an AlN Deep UV Detector for Space Application

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ABSTRACT

AlN is a very promising deep UV sensing material suitable for space application such as exoatomospheric solar blind detectors due to its large band gap (6.2 eV), excellent radiation and thermal stability. In this paper, a deep UV detector based on AlN photoconductor was successfully grown and characterized. High quality AlN thin films on Sapphire have been confirmed by *in-stu* RHEED and X-ray diffraction measurements. The film has an optical E_g of 5.96 eV. The detector has extremely low dark current. Different electrodes were investigated as contact materials. Al and Pt are more suitable electrode contacts for AlN photoconductor compared to Ti. The DC responsivity of the detector starts to rise for photon energies of about 255 nm (4.9eV) and reaches its maximum 7×10^{-5} A/W at 195 nm (6.5eV).

INTRODUCTION

AlN is a very promising deep UV sensing material suitable for space application due to its large band gap (6.2 eV), excellent radiation and thermal stability. Recently, many researchers have developed UV detectors based on GaN and AlGaN alloy [1,2]. These detectors are visible or even solar blind detectors due to the wide band gap of III nitrides. There is also great interest in detectors for space applications operating in the deep UV to soft X-ray (250-100 nm) region of the spectra. However, It has been shown [3, 6] that the responsivity of detectors decreases dramatically with the increase of Al composition in the AlGaN alloy, which corresponds to the deep UV region. So far there is no report on AlN based UV detector. In this paper we report the preliminary result of a deep UV detector based on AlN photoconductor.

EXPERIMENT

AlN photoconductors were grown at the Wayne State University Center for Smart Sensors and Integrated Microsystems by Plasma Source Molecular Beam Epitaxy (PSMBE).). PSMBE uses a unique hollow cathode plasma source lined with MBE grade aluminum. High quality AlN epitaxial layers have been grown by using this system [4, 5]. The base pressure of the system is maintained in the range of 10^{-9}-10^{-10} Torr. Radio Frequency (RF) power is supplied to generate plasma inside the hollow cathode. The dynamic pressure during deposition is maintained at 1×10^{-3} Torr. Negative acceleration bias is applied to the substrate. The growth temperature, acceleration bias, N_2 flow and RF power level can be adjusted to get optimum thin films.

The growth was conducted on C-plane Sapphire. Prior to the growth the Sapphire substrates were ultrasonically cleaned and etched to get atomic smooth surface. A thin (~500 Å) low temperature (400 °C) buffer layer was deposited first. The final growth was performed at 650 °C. RF source power was 200 W. The N_2 and Ar flow ratio was kept at 10/40 sccm. The thickness of films ranged from 0.2 – 1 μm.

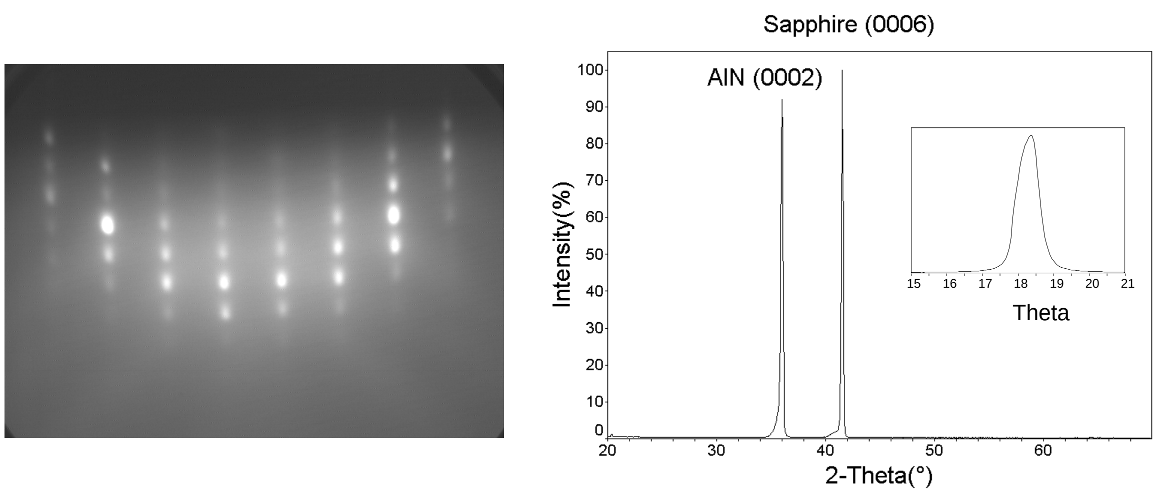
The testing device has a structure of a simple interlaced metal electrode pattern with an approximate area of 6×1 mm interelectrode space on the surface of AlN thin films. Three different metals (Ti, Al and Pt) were studied as electrode contacts.

The structural and optical characteristics of the epitaxial AlN thin films on Sapphire were analyzed using several techniques. *In-stu* RHEED was performed using a STAIB Instrument RHEED operating at 30KV. X-ray diffraction was conducted using a RIGAKU powder diffractometer. The optical and detector spectral responsivity measurements were done using a Perkin Elmer Lambda 900 spectrometer.

Photoconductivity has been performed by using a 30 W AS240 Deuterium lamp as optical power source. Photocurrent was measured by a Keithley 6517A electrometer. For spectral responsivity studies the sample was illuminated inside the Perkin Elmer Lambda 900 UV/VIS/NIR Spectrometer. The wavelength-dependent power output of the spectrometer was calibrated using a Newport 818-UV Si photodetector in the wavelength of 190-280 nm. The photocurrent induced in the film was measured using a HP4140B pA Meter/DC voltage source at room temperature. The bias voltage was held at 99V. The measured photocurrent was divided by the energy of reference beam to obtain the spectral responsivity.

RESULTS

Materials characterization

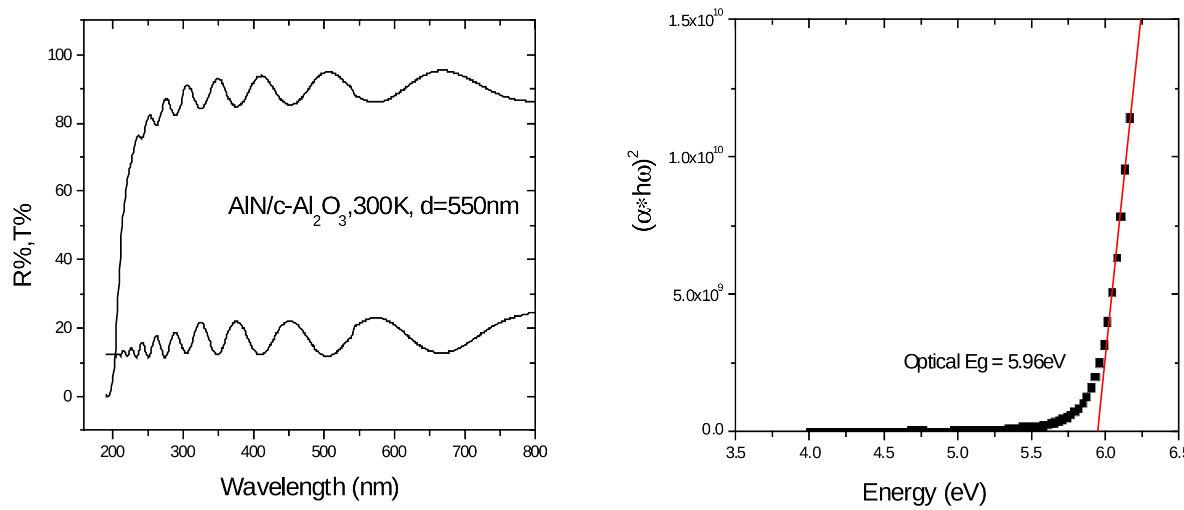


(a) **(b)**

Figure 1. RHEED pattern (a) and XRD spectra (b) of AlN/Sapphire

Figure 1a shows the *in-stu* RHEED image of as grown AlN/Sapphire C plane. The sharp, distinguish pattern suggests that the film is crystalline. The spectrum of X-ray diffraction, which is shown on Figure 1b, also confirmed that the film is highly C-axis oriented. The insert of the spectrum is the rocking curve of AlN (0002), which shows the FWHM is about 37 arcmin.

Optical measurements



(a) (b)

Figure 2. (a) Optical transmittance and reflectance and (b) optical absorption data from AlN thin film on Sapphire

Figure 2a shows the Optical transmittance and reflectance spectra for AlN on C-plane Sapphire at room temperature. The film thickness is 550 nm. The optical absorption data is shown in Figure 2b. For direct band gap semiconductors the optical absorption coefficient α is expected to obey the dependence on the photon energy $\hbar\omega$ and the band gap energy E_g:

$$\alpha \sim \frac{(\hbar\omega - E_g)^{1/2}}{\hbar\omega}$$

The sample clearly exhibits a linear dependence of $(\alpha\hbar\omega)^2$ *vs*. photon energy. The linear regression analysis of the data points is used to determine E_g. The absorption edge (AE) or optical E_g is defined as the value at the intersection of the extrapolated best fitted line with the x-axis, as shown in Figure 2b. The optical E_g is 5.96 eV, which is smaller than the theoretical value 6.2 eV. The optical E_g shift towards a lower photon energy region is due to the stress in our thin films.

Electrical measurement

Table I. Comparison of photoconductivity of different electrode materials on AlN the UV detector, the bias voltage is held at 100V

Electrode Material	Dark Current (A)	Photo Current (A)
Al	2.8×10^{-12}	4.4×10^{-11}
Pt	4×10^{-14}	1.3×10^{-11}
Ti	5×10^{-14}	7.7×10^{-13}

Table I shows our detector has extremely low dark current for all electrodes even at 100V bias. Al electrodes give the highest net photocurrent, while Pt electrodes yield highest signal-noise ratio. It is found that Ti is not suitable electrode material for the detector.

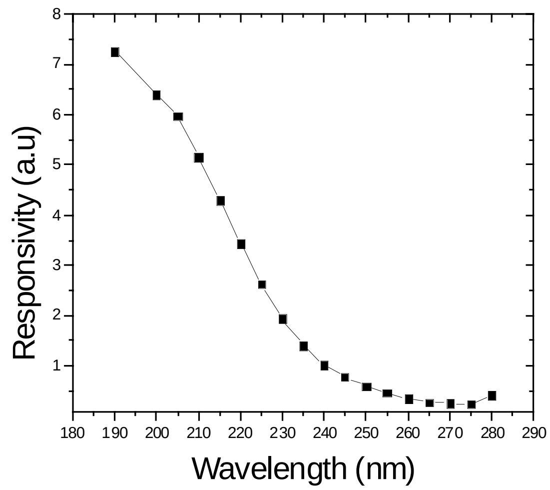


Figure 3. Spectral responsivity of the AlN UV detector.

The DC responsivity of the detector starts to rise for photon energies of about 255 nm (4.9eV) and reaches its maximum at 195 nm (6.5eV). The absolute maximum value for responsivity is 7.2×10^{-5}A/W. This value is much greater than the result reported by Walker [6], who reported maximum current responsivity of 2.8×10^{-6} A/W for $Al_xGa_{1-x}N$ photodetector with x=0.5. These results are also comparable to the transmittance spectrum in Figure 2.

CONCLUSION

In conclusion, a deep UV detector based on AlN photoconductor was successfully grown and characterized. High quality AlN thin films on Sapphire have been confirmed by *in-stu* RHEED and X-ray diffraction measurements. The film has an optical E_g of 5.96 eV. The detector has extremely low dark current. Different electrodes were investigated as contact materials. Al and Pt are more suitable electrode contacts for AlN photoconductor compared to Ti. The DC responsivity of the detector starts to rise for photon energies of about 255 nm (4.9eV) and reaches its maximum 7×10^{-5} A/W at 195 nm (6.5eV).

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