Growth of GaN thin film by pulsed laser deposition and its application on ultraviolet detectors

D.Rusdiana[1,2] , A.Suhandi[1,2], S. Karim[1], Sukirno[2], M. Budiman[2], M. Barmawi[2]

[1] Department of Physics, Indonesia University of Education, Jl. DR.Setia Budi 229 Bandung
[2]Laboratory of Electronic Material Physics, Department of Physics, Bandung Institute of Technology, Jl. Ganesha 10 Bandung, Indonesia. E-mail: *dadi_rusdiana@upi.edu*

ABSTRACT

Crystalline GaN films were grown on (0001) sapphire substrates in atmospheres of nitrogen by pulsed laser deposition. The properties of GaN thin films were improved by increasing the growth temperature to 680° C and the nitrogen flow rate during growth to 150 sccm. The GaN film grown at 680° C in 100 sccm of nitrogen had a wurtzite structure with (0002) and (0004) orientations. The GaN film had an n-type carrier concentration of 1.5 x 10^{19} cm^{-3} and the electron mobility of 19.05 cm^2/V.sec. The ultraviolet detector based on GaN grown on (0001) sapphire were fabricated and characterized. The current responsivity increase at λ >310 nm and remain reasonably flat for photons with wavelength from 347 nm to 366 nm.

Keywords: Pulsed Laser Deposition (PLD), Gallium Nitride (GaN), Ultraviolet (UV) detector.

1. INTRODUCTION

The group III-nitride materials, such as aluminum nitride, gallium nitride, and their alloys are currently under intense investigation due to their unique properties. A wide energy gap makes it the most promising material for semiconductor optoelectronic devices in the blue and ultraviolet (UV) spectral regions. The superior radiation hardness and high temperature resistance of the group III-nitride materials allow the fabrication of devices suitable for working in extreme conditions. Applications range from space communications to ozone layer monitoring, flame detection or missile guidance systems.

Gallium nitride (GaN) is a promising semiconductor with enormous applications in both electronic devices operating under high temperature and high power conditions and optoelectronic devices with a room-temperature band-gap of 3.41 eV (365 nm) makes it possible to develop ultraviolet (UV) sensors. The advent of such devices paves the way to satellite communication bands inaccessible to earth surveillance, full color light emitting diode (LED) displays, and optical data storage units with densities much higher than currently possible. In addition, transistors based on the group III-nitrides should operate at higher temperatures and under more adverse conditions than similar devices based on silicon, II-VI materials, or other III-V materials such as GaAs, due to the high band gap, the strong chemical bond, and the relative chemical inertness of the nitrides. High quality GaN films have mostly been prepared by metal-organic chemical vapor deposition (MOCVD) [7,8,12], molecular beam epitaxy (MBE) [1,3,11] and vapour phase epitaxy (VPE) [9]. Most studies have been devoted to understanding the growth kinetics and the properties of the GaN films grown by these techniques.

Compared to the MOCVD and MBE techniques, pulsed laser deposition (PLD) [4] is a relatively new growth technique used widely for the growth of III-V semiconductor, such as GaN thin film. Several advantages of PLD for depositing high-quality thin films make it worthy of study as a method of growing nitride. The congruent ablation achieved with short ultraviolet (UV)-laser pulses allows deposition of a multicomponent material by employing a single target. A useful feature of the PLD method is that multiple targets can be loaded inside the chamber on a rotating holder, which can be used to sequentially expose different targets to the laser beam, thereby enabling the in situ growth of heterostructures and the rapid investigation of material integration strategies. The growth rate achieved by PLD can be varied through adjusting the repetition rate of the laser, which is useful for both atomic level investigations and thick layer growth.

Because of these attractive features of the PLD technique, there has been a growing interest in the deposition of GaN by PLD. Huang et al.[10] and Feiler et al.[6] have demonstrated the epitaxial growth of GaN films on sapphire. The effects of the nitrogen flow rate during growth on the properties of GaN films have not been well investigated. In this paper, we discuss the influence of the deposition parameters, the substrate temperature and the nitrogen flow rate during growth, on the electrical and the structural properties of GaN films. Results from the optical properties and the responsivity measurement of GaN ultraviolet detector are presented.

2. EXPERIMENT

Thin films of GaN were grown in a vacuum chamber equipped with a leak valve to introduce nitrogen into the chamber during deposition. The nitrogen flow rate was varied from 50 to 150 sccm. All films were deposited on (0001) Al_2O_3 at substrate temperatures from 600° C to 680° C. These surfaces were cleaned ex situ in a 1:1 mixture of acetone and isopropanol. Target pellets were prepared by pressing GaN (99.99%) powder at $7x10^4$ $N.cm^{-2}$ followed by sintering at 650° C in atmosphere of nitrogen to improve the mechanical strength of the target [5]. A neodymium-yttrium aluminum garnet (Nd:YAG) laser (λ=355 nm) was used for ablation of GaN target at energy 250 mJ with a laser repetition rate of 10 Hz, and a target- substrate distance of approximately 2.5 cm. Thickness measurements were made using a Dektak IIA profilometer. The growth parameters for the various films are listed in the Table 1.

Table 1.

The growth parameters for the various GaN thin films

Sample	Growth pressure (mbar)	N_2 Flow rate (sccm)	T_{sub} (°C)	Growth Time (min)	Thickness (nm)
#1	0.15	50	680	120	114
#2	0.25	100	680	120	171
#3	0.35	150	680	120	201
#4	0.25	100	600	120	54.8
#5	0.25	100	650	120	106

3. RESULTS AND DISCUSSION

3.1 Crystallinity and Orientation

X-ray diffraction (XRD) experiments were performed on the films to determine their crystallinity and orientation. Fig.1 and Fig.2 shows the XRD pattern for the GaN film. It shows the GaN and sapphire basal planes to be parallel, i.e. GaN(0001)// sapphire(0001). The deposition condition can change drastically the crystalline quality of GaN thin film. After increasing the nitrogen flow rate to 100 sccm and 150 sccm, respectively (fig.1) and after increasing the deposition temperature to 650° C and 680° C, respectively (fig.2), these (0002) and (0004) peaks orientation was spring up. The crystalline quality degrade after the nitrogen flow increases to 150 sccm, respectively with followed by appearance of $(10\underline{1}1)$ peaks orientation.

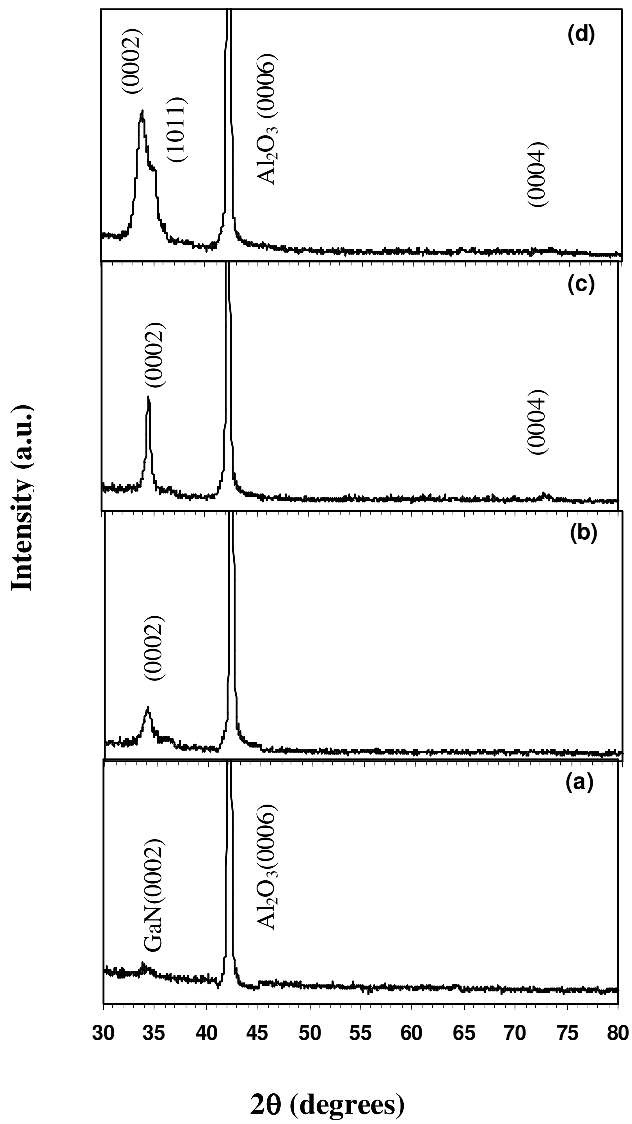

Figure 1. The XRD pattern for the GaN film grown with various the N_2 flow rate: a) without N_2, b) 50 sccm, c) 100 sccm, d) 150 sccm.

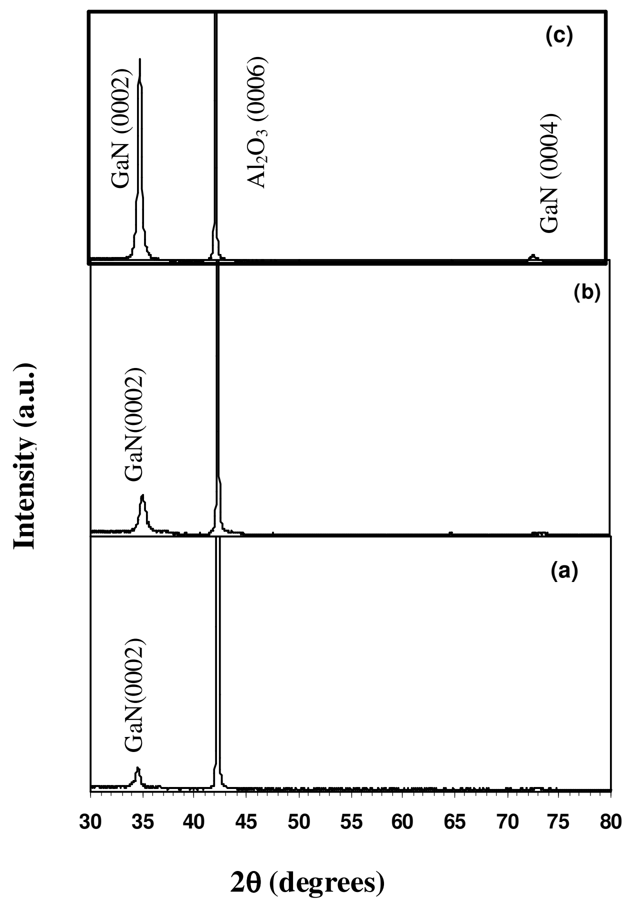

Figure 2. The XRD pattern for the GaN film grown on sapphire at :
a) 600^{o} C, b) 650^{o} C, c) 680^{o} C.

3.2 Electrical and Optical Properties

The electrical properties of our semiconducting sample were determined by Van der Pauw-Hall measurements at room temperature. Figure 3 shows the room temperature Van der Pauw-Hall measurement for the GaN thin films grown at 680^{o} C as a function of the nitrogen flow rate. It shows that the carrier density of GaN film is 3.13 x 10^{19} cm^{-3} and the electron mobility is 12.5 cm^2/V.sec at the nitrogen flow rate 50 sccm. As the nitrogen flow rate increase to 100 sccm, the carrier densities decrease to 1.51 x 10^{19} cm^{-3} and the electron mobility increase to 19.05 cm^2/V.sec and then the carrier densities increase to 2.53 x 10^{19} cm^{-3} and the electron mobility decrease to 15.45 cm^2/V.sec at the nitrogen flow rate 150 sccm. The GaN film grown in 0.15 – 0.35 mbar of nitrogen (table 1) was found to have n-type conduction. Feiler et al.[6] reported the GaN film grown in 10^{-2} mbar of nitrogen had a p-type conduction with a hole concentration of 7.5 x 10^{18} cm^{-3} and a mobility of 150 cm^2/V.sec.

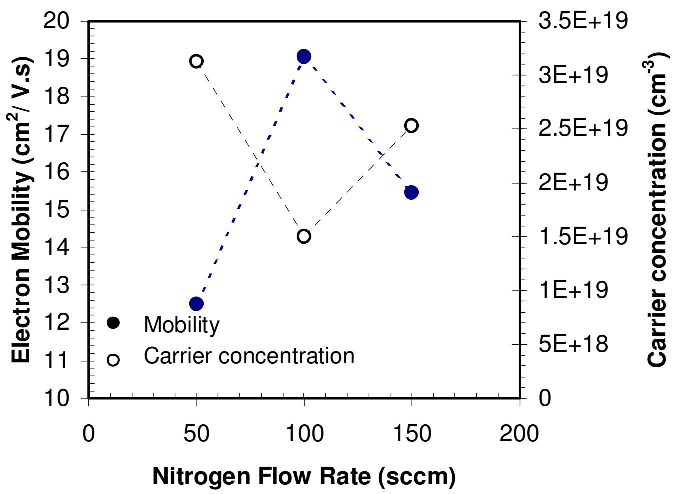

Fig. 3. The carrier mobility and carrier concentration as a function of the N_2 flow rate

For the film grown at higher and lower nitrogen flow rate, the electrical properties and the crystal quality degrades. This phenomenon can be related to the kinetic energy of the arriving species at the substrate. At low nitrogen flow rate the ablated species go through few collisions before they arrive at the surface of the substrate. With sufficient kinetic energy, arriving species can produce lattice displacement damage to the growing films. Such damage can be reduced by increasing the nitrogen flow rate in the chamber to promote the collisions between ablated species and ambient gas. However, increasing the nitrogen flow rate beyond 100 sccm degrades the film properties. Significant collisions occurring at high nitrogen flow rate can reduce the energy of the ablated species below what is necessary to grow epitaxial films.

Figure 4 shows the room temperature optical transmission spectra for the GaN thin films grown at 680° C in the nitrogen flow rate 100 sccm. Optical absorption measurement was performed at room temperature. It is well known that the absorption coefficient of semiconductor with direct band-gap obeys the following relationship near the absorption edge [2]:

$$\alpha \propto (E-E_g)^{1/2} \qquad (1)$$

Where E is the photon energy and E_g is energy of band-gap. The band-gap was found to be 3.4 eV for the high quality film as determined by a linear fit of the absorption coefficient as a function of the photon energy near band gap (equation 1).

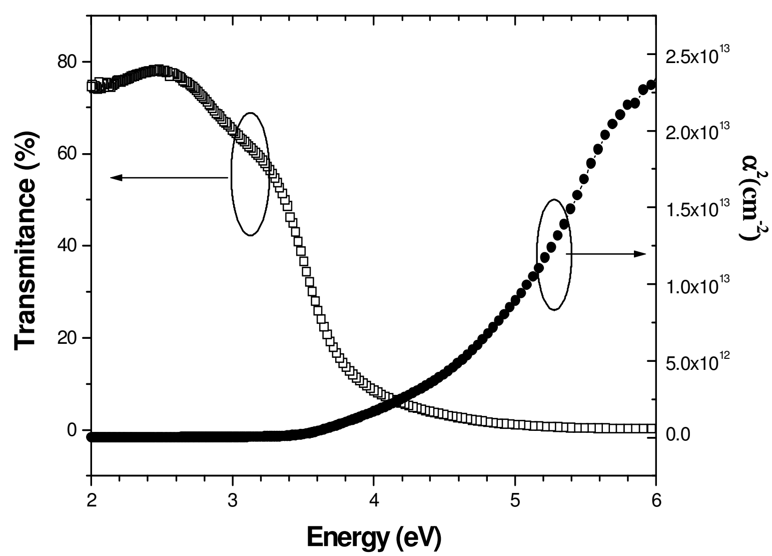

Figure 4. Transmission spectrum and the deduced spectral absorption coefficient of the GaN epilayer

3.3 The Current Responsivity of GaN Sample

The Responsivity measurement setups are shown in fig.5. A van der Pauw-type cloverleaf pattern was realized onto the GaN sample and four indium contacts were attached on the periphery. A bias was applied onto two adjacent contacts with a load resistor of 30 kΩ. The other two contacts were used for photoresponse measurements. The sample and the biasing were enclosed in a metallic box to minimize electromagnetic interferences. Spectral responsivity studies were performed by using a 150 W xenon arc lamp as the optical excitation source and a spex 1681 monochromator. The source was chopped at 500 Hz and synchronous detection scheme was used. Photosignal current was measured as a function of wavelength with a bias applied at 0.5, 1, 1.5 and 2 V. A Keithley 2000 current meter with a built-in preamplifier was used for the photocurrent measurements.

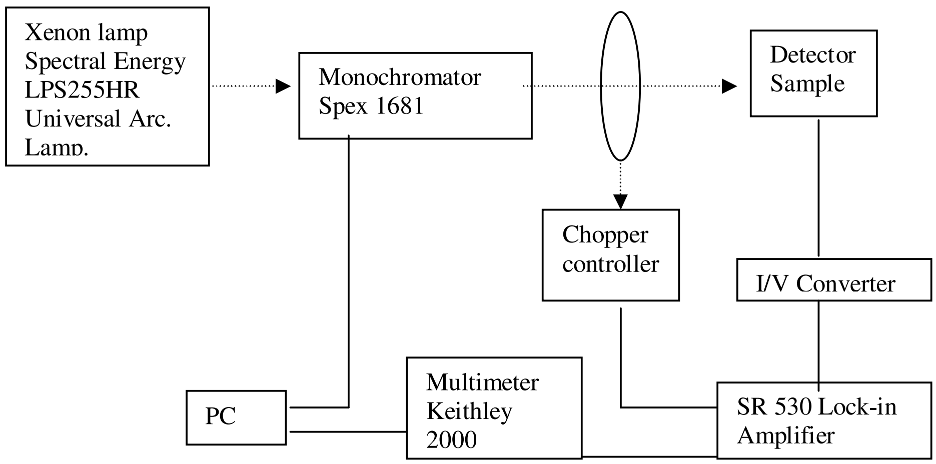

Figure 5. The Responsivity measurement setup of ultraviolet photodetector

Figure 6 depicts the spectral responses of ultraviolet detector biased at 0.5, 1, 1.5 and 2 V. It was found that the responsivity show a linear dependence on bias voltage (inset of Fig.6). Such behavior indicates the presence of internal gain in the devices. As seen, the current responsivity increase at λ >310 nm and remain reasonably flat for photons with wavelength from 347 nm to 366 nm. As seen, for wavelength in excess of 370 nm, the spectral responsivity is below the signal detection limit of our system. It reaches its peak value at 366 nm (band-gap energy as seen in Fig.4). In this experiment, the influence of the thickness of GaN film on the responsibility is not been studied.

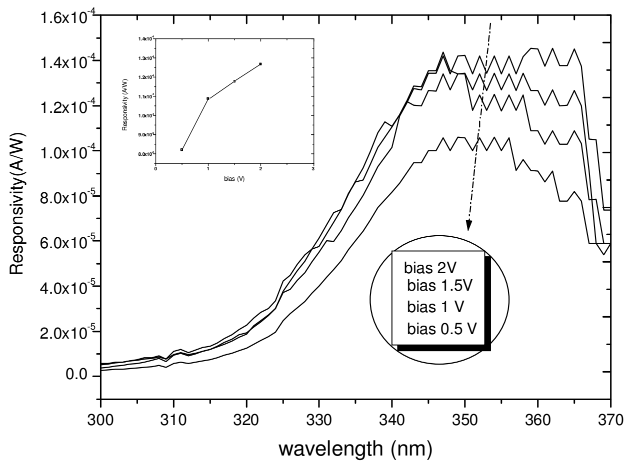

Figure 6. Depicts the spectral responses of ultraviolet detector biased at 0.5, 1, 1.5 and 2 V. The inset shows the bias dependence of responsivity

4 CONCLUSION

In summary, we report on the growth of high crystalline quality GaN films by PLD. The GaN film grown at 680°C in the nitrogen flow rate 100 sccm was found to have n-type conduction with a electron concentration of 1.5 x 10^{19} cm^{-3} and the mobility 19.05 cm^2/V.sec. The Energy of band-gap for the high quality films was 3.4 eV. The spectral responses of ultraviolet detector biased at 0.5, 1, 1.5 and 2 V. It shows that the current responsivity increase at λ >310 nm and remain reasonably flat for photons with wavelength from 347 nm to 366 nm.

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Profile

Dadi Rusdiana was born in Tasikmalaya, Indonesia at October 15,1968. He has worked at Department of physics, Indonesia University of Education (UPI), Bandung, Indonesia from which he received his B.Sc. Recently, he has been pursuing a Ph.D program at Department of Physics, Bandung Institute of Technology (ITB), Bandung, Indonesia.