ALUMINIUM NITRIDE (AlN) AS BUFFER LAYER FOR DEPOSITION OF GALLIUM NITRIDE (GaN) THIN FILMS ON SILICON SUBSTRATES USING MAGNETRON SPUTTERING TECHNIQUE

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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In the name of Allah, Most Gracious, The most Merciful

All Praised to Allah

To my beloved father and mother,
Alias bin Candeng and Saharyati Binti Harun.

My beloved sibling,
Nurlisa binti Alias, Husain bin Alias and Ahmad Safwan bin Tahan.

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ABSTRACT

Group III-nitrides semiconductors composed of gallium nitride (GaN), Indium nitride (InN), and aluminium nitride (AlN) had found use in broad technologies especially in optoelectronic and power devices. The main issues that limit the performance of GaN-based ultraviolet light-emitting diodes (UV-LEDs) are difficult to achieve highly crystalline GaN because lack of suitable substrates available and needed for high-temperature deposition process. Hence, the present research is focused on the enhancement of AlN as a buffer layer for the deposition of GaN thin films on Si substrate at low-temperature process using radio frequency RF magnetron sputtering. The function of AlN buffer layer is to reduces the lattice mismatch between the heterostructure of the thin films and its substrate. Firstly, the parameters such as type of sputtering used, target to substrate distance, deposition time, discharged power, and argon flow rate were varied to obtain high crystalline structure on AlN thin films. After AlN preferred crystal orientation structure obtains, GaN will be deposited on the top of it. The effect of thick and thin buffer layer to the GaN will be studied to see which will provide the lowest resistivity and high n-type carrier concentration for the GaN thin films. The parameter to obtain AlN high crystallinity structure is 200 W of discharged power, 120 min deposition time, 5 mTorr working pressure, and 100: 50 sccm of Ar to N flow rate. This is because, this parameter yield AlN (002) preferred orientation with full width at half maximum (FWHM) of 0.3838 and crystallite size 21.7712 nm, 186.73 nm thickness, and lowest surface roughness of 5.825 x10^{1} nm. The deposition of GaN using 40 W on thick AlN buffer layer revealed that the electrical properties obtain are N-type carrier, low resistivity which is 1.025x10^{-5} Ω·m, and high carrier concentration, 2.330x1024 m^{-3}. These properties are comparable with previous literature to be suitable for realization of UV-LED even though using low-temperature processes and unconventional substrate.

ABSTRAK

Semikonduktor kumpulan III-nitrida terdiri daripada gallium nitrida (GaN), indium nitrida (InN) dan aluminium nitrida (AlN) telah digunakan dalam pelbagai teknologi terutamanya dalam peranti optoelektronik dan kuasa. Isu utama yang menghadkan prestasi diod pemancar cahaya berasaskan ultraviolet (UV-LED) adalah kesukaran untuk mendapatkan kristalan yang tinggi kerana kurangnya tapak yang sesuai dan memerlukan prosess pemendapan dalam suhu yang tinggi. Oleh itu, penyelidikan ini memfokuskan penambahbaikan AlN sebagai penyangga untuk pemendapan GaN filem nipis diatas tapak Si pada suhu rendah menggunakan pemercitan magnetron frekuensi radio (RF). Fungsi penyangga AlN adalah untuk mengurangkan ketidaksepadanan kekisi diantara heterostuktur filem nipis dan tapaknya. Pertamanya, parameter seperti jenis pemercitan, jarak diantara sasaran ke tapak, masa pemendapan, kuasa yang dilepaskan dan kadar aliran gas argon telah di boleh ubah untuk mendapatkan struktur kristalan yang tinggi pada AlN filem nipis. Setelah AlN struktur orientasi kristal pilihan diperoleh, GaN akan dimendapkan di atasnya. Kesan lapisan penyangga yang tebal dan nipis akan dikaji untuk dinilai yang mana memberikan kerintangan yang paling rendah dan pembawa kepekatan jenis-N yang tinggi untuk pemendapan GaN filem nipis. Parameter untuk mendapatkan struktur kristalan yang tinggi adalah 200 W pelepasan kuasa, 120 min masa pemendapan, 5 mTorr tekanan pembinaan dan 100:50 sccm kadar aliran gas argon. Hal ini kerana parameter tersebut menghasilkan orentasi AlN (002) bersama dengan ‘full width at half maximum’ (FWHM) 0.3838, saiz kristal 21.7712 nm, ketebalan 186.73 nm dan permukaan kasar yang paling rendah iaitu 5.825 x10^1 nm. Pemendapan GaN menggunakan 40 W di atas lapisan penyangga yang tebal menunjukkan bahawa sifat elektrik yang diperoleh ialah pembawa jenis-N, kerintangan yang rendah iaitu 1.025x10-5 Ω·m dan pembawa kepekatan jenis-N yang tinggi iaitu 2.330x1024 m^{-3}. Ciri-ciri ini sesuai untuk merialisasikan UV-LED walaupun menggunakan proses suhu yang rendah dan bukan pada tapak kebiasaannya.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

AFM	-	Atomic force microscope
AlN	-	Aluminum nitride
Ar	-	Argon
Al_2O_3	-	Sapphire
AlN/Si	-	Aluminum nitride over silicon
AlGaN	-	Aluminum gallium nitride
D	-	Crystallite size
DC	-	Direct current
EDS	-	Energy dispersive x-ray spectroscopy
FESEM	-	Field emission scanning electron microscope
GaAs	-	Galium Arsenide
GaN	-	Gallium nitride
HCl	-	Hydrogen chloride
HF	-	Hydro-fluoric
HVPE	-	Hydride vapour phase epitaxy
InN	-	Indium nitride
IQE	-	Internal quantum efficiency
LPE	-	Liquid phase epitaxy
MBE	-	Molecular beam epitaxy
MiNT-SRC	-	Microelectronic and Nanotechnology Shamsudin Research Centre

MOCVD - Metal organic chemical vapour deposition

N_2 - Nitrogen gas

NH_3 - Ammonia

PLD - Pulse laser deposition

RF - Radio frequency

SAW - Surface acoustic wave

Si - Silicon

SiC - Silicon carbide

TMGa - Tri-methyl-gallium

UV- LED - Ultra violet light emitting diode

XRD - X-ray diffraction

k - Dimensionless shape factor

λ - Wavelength

β - Full width at half maximum intensity of the peak

θ - Performance of BPGD on measuring criteria

BPGD - Backpropagation gradient descent adaptive gain

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Group III-nitride semiconductors are composed of gallium nitride (GaN), indium nitride (InN) and aluminium nitride (AlN). They are an excellent choice for modern electronic and optoelectronic applications because of their direct band gap properties. GaN-based light-emitting diodes (LEDs) have attracted a great deal of attention because of their wide applications, such as in solid-state lighting [1], biomedical research [2], agriculture, aquaculture, biomass production, phototherapy and environmental applications [3]. Remarkable breakthroughs for GaN-based LEDs have been achieved since 1996 when Nichia Chemical Corporation developed the first white LEDs, which were successfully commercialised around the world [4]. This achievement gave new motivations to researchers and scientists to explore, modify and enhance the knowledge on GaN-based materials. One of the trending innovations of LEDs which have a high demand from customers in the marketplace nowadays is GaN-based UV-LEDs for purification and disinfection of water or air [5], [6].

Recently, researchers are competing with each other to create new ideas to improve the efficiency and reduce the production cost of GaN-based UV-LEDs. This is done to facilitate daily human life with new and environmentally friendly technologies. One of the recent new innovations for GaN-based UV-LEDs which have not been studied extensively yet is the epitaxial growth of GaN on silicon (Si) substrates [7], [8]. Si is known to be widely used in many applications, such as electronics, building materials, health device and daily products. This is because silicon is notable with its low cost, good thermal property and availability in various sizes in the market [9]. Hence, commercialised GaN-based UV-LEDs using the typical sapphire substrate can be replaced in the future with silicon substrates, which have the same quality but with a lower cost of materials.

In order to realise low-cost GaN-based UV-LEDs on silicon substrates, choosing the right method for the growth of the thin film is very crucial. The common methods to grow III-nitrides, such as hydride vapour-phase epitaxy (HVPE), metal-organic chemical vapour deposition (MOCVD) and molecular-beam epitaxy (MBE), require high cost and use a high-temperature process. Thus, to reduce the production cost, a low-temperature process method can be applied using a less expensive machine. Sputtering can be an alternative way to prepare thin films since it can perform rapid deposition, and hence the production of low-cost and large-scale thin films is possible. Sputtering also can grow thin films without using high temperature, unlike other growth methods [10], [11].

The fabrication of GaN-based UV-LEDs on Si substrates is very challenging work. The key parameters for high-performance GaNs are high internal quantum efficiency (IQE), high-output optical power of deep UV-LED (DUV-LED) [12], excellent hole injection efficiency, excellent electron capture rate of the near-UV active region [13] and high density of dislocation of materials. In order to produce high-performance devices, such as GaN-based DUV-LEDs on silicon which radiate an electromagnetic spectrum wavelength of 200–365 nm, there are problems caused by the thermal expansion coefficient mismatch (57%) and the large lattice mismatch (16.9%) in the lattice constant between GaN and Si [14]. These lead to cracking, high-density threading dislocations and cloudy surface morphology [15], which can reduce the performance quality of emission in AlGaN-based devices. The recent progress of growing high-quality AlGaN on Si substrate by Li et al. [7] overcame the issues by deploying an AlN buffer layer using MOCVD. In their study, the crystalline quality of GaN film will worsen at temperatures above 1000 °C, and so it is possible to replace MOCVD with sputtering (which has a far lower cost than MOCVD) to obtain high-quality GaNs on Si. However, the sputtering method for GaN growth is not fully understood yet. Hence, the present research focused on the fabrication of GaN on AlN/Si substrates using a low-temperature method by sputtering for low-cost GaN-based UV-LEDs.

1.2 Problem statement

According to a 2017 report by the World Health Organization and UNICEF, 2.1 billion people worldwide do not have access to safe drinking water and 4.5 billion lack access to basic sanitation, especially in rural areas. As a result, the transmission of diseases such as diarrhoea, cholera, hepatitis A, dysentery, typhoid and all water-related diseases are difficult to prevent. To overcome this problem, low-cost water disinfection systems are needed so that all people from urban to rural areas can have access to safe drinking water. Traditionally, mercury lamps are used as the primary source of UV radiation for conventional water treatment and purification [3] but mercury contains hazardous substances which are dangerous for human and the environment. Furthermore, mercury vapour lamps also require high operating power and have a short lifetime of about 10,000 h [3]. Therefore, it is necessary to develop an alternative solid-state UV light source to replace the traditional mercury lamps. One of the candidates that show promise as an alternative UV light source is GaN-based UV-LEDs. GaN possesses very high electron saturation velocity, high temperature resistance, high adjustability, high radiative resistance and low dielectric constant [16].

The main issue that limits the performance of GaN-based UV-LEDs is the difficulty of growing highly crystalline AlGaN due to the lack of suitable substrates for fabricating UV-LEDs because of large lattice mismatch such as for Si with GaN is 16.9% [14]. Thus, to overcome this limitation, an AlN buffer layer is introduced prior to the deposition of the GaN layer on the Si substrate. Other than that, the current LED fabrication are using very high temperature up to 400 ^{o}C [17] . This led to this research, which was to fabricate GaN and AlN thin films on Si substrate using the magnetron sputtering technique.

1.3 Objectives of the study

The objectives of this research are as listed below:

(i) To deposit highly crystalline AlN buffer layer using rf magnetron sputtering on Si substrates at various parameter.

(ii) To characterize AlN thin films using XRD, FESEM, EDS, AFM and ellipsometry.

(iii) To deposit GaN thin films on AlN buffer layer and study its electrical properties using Hall effect measurements.

1.4 Scopes of study

The scope of this research is as listed below:

(i) AlN and GaN thin films were deposited using pulsed magnetron sputtering with shorter times at 60 min and 120 min.

(ii) Applying low power (100–200 W), low working pressure (5 mTorr) and low frequency (1–5 Hz) in the experiment.

(iii) Using only room temperature for the deposition of the thin films using magnetron sputtering to create the preferred AlN crystal orientation.

(iv) Si (100) n-type was used as a substrate.

(v) The characterisation of the structural, composition, morphological and electrical properties of the AlN and GaN thin films deposited on silicon substrate by using ellipsometry, FESEM, AFM, XRD, EDS and Hall effect.

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