InGaN thin film deposition on Si(100) and glass substrates by termionic vacuum arc

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Abstract. Group-III nitride semiconductors covering infrared, visible and ultraviolet spectral range has direct band gaps changing from 0.7 eV (InN) to 3.4 eV (GaN). LEDs emit red, blue, green light, ultraviolet (UV) laser diodes (LD). UV light detectors and high power electronic devices are obtained and commercialized based on group-III nitride materials. InGaN semiconductor can be deposited by different techniques such as molecular beam epitaxy (MBE), metal organic chemical vapor deposition (MOCVD). In this study, InGaN thin films were prepared on Si and glass substrates as well as on GaN layer by termionic vacuum arc (TVA) which is a plasma assisted thin film deposition technique. The film was deposited at 10⁻⁶ torr working pressure, 18 A filament current. Plasma was produced at 200 V with 0.6 A plasma current. The purpose of this research is to investigate the properties of InGaN thin films. X-ray diffraction (XRD) spectrophotometer was used to analyze microstructure of the deposited films. Scanning electron microscopy (SEM) were used for surface morphology characterizations. Compositional analysis was done by energy dispersive X-ray spectroscopy (EDAX).

1. Introduction
Semiconductors underlies the today’s technology due to their tunable energy band gaps [1]. Elemental semiconductors are formed by same type of atoms, such as; silicon and germanium. Silicon technology has used in the construction of electronic circuits as the substrate for 20 years [2]. These conventional semiconductors are not suitable for fabrication of devices working on short wavelength optoelectronics. Devices based on these classical semiconductors are not tolerant on high temperatures.

III-V group semiconductors, including GaN(Gallium nitride), InN(Indium nitride), and AlN (Aluminum nitride) are quite attracted attention and were examined separately. Group-III nitride semiconductors cover spectral range of infrared, visible and ultraviolet and they have direct band gap, ranging from 0.7 eV (InN) to 6.2 eV (AlN) [3]. Figure 1. shows the band gap versus lattice parameter of the group-III nitrides [4]. III-Nitrides have been used for a wide range of applications. Light emitting devices (LED), laser diodes, photovoltaics and high power electronic devices have been achieved based on III-Nitrides material systems [5,6]. There are two types of crystal structures of group III-Nitrides: cubic zincblende and hexagonal wurtzite. Both can coexist under various parameters for crysyal growth. Wurtzite structure is thermodinamically stable. InGaN material formed by GaN and InN has also wurtzite structure [7]. Lattice parameters of InGaN compound are given by the linear relationship between the lattice constant of the two compounds (GaN and InN).
Figure 1. Band gap versus lattice constant of group III- Nitride material systems

In this study, InGaN thin films were prepared and deposited on Si and glass substrates as well as on GaN layer. The purpose of this research is to investigate the properties of InGaN thin films. X-ray diffraction (XRD) spectrophotometer was used to analyze microstructure of the deposited films. Scanning electron microscopy (SEM) were used for surface morphology characterizations. Compositional analysis was done by energy dispersive X-ray spectroscopy (EDAX).

2. Experimental
InGaN semiconductor can be deposited by different techniques such as molecular beam epitaxy (MBE) [8,9], metal organic chemical vapor deposition (MOCVD) [10-12], sputtering deposition [13-15]. Thermionic Vacuum Arc (TVA) is a thin film deposition technique which generates anodic plasma with fast deposition and within short times [16].

Figure 2. Schematic view of the TVA system [16]
Figure 2. represents a schematic view of the deposition technique. The film was deposited at $10^6$ torr working pressure; hence there is no need to buffer gas for deposition at this high vacuum level. Plasma is established between the anode and cathode. The filament current is applied as 18 A to heat the cathode and the voltage is applied to move the electrons from the cathode to the anode in order to melt the anode material. In this voltage value, the plasma current is established and is about 0.6 A. Then, melting material will be evaporated in the vacuum chamber. The ions in the chamber are combined with each other. Therefore, detected layers on substrate will be occurred [17].

3. Results and Discussion

3.1 Structural analysis
Figure 3. XRD spectras of deposited thin films (a) deposited InGaN on Si, (b) deposited GaN and InGaN on Si, (c) deposited GaN and InGaN on glass substrates

Figure 3. exhibits X-ray diffraction patterns of the produced films. It can be seen from Figure 3. (a), the diffraction peaks at 68.75 and 32.5 degrees for silicon and InGaN thin film, respectively. It is also seen from Figure 3. (b), diffraction peaks of deposited GaN and InGaN on silicon substrate are at 28.98 and 32.99 degrees, respectively. Deposited films of GaN and InGaN on glass substrate are also observed from the XRD spectra. It is apparent from Figure. 3 (c), GaN peak was observed at 32.75 degree, while InGaN peak was observed at 36.12 degree. In addition, the glass has a peak, eich are between the 20-25 degress. The GaN and InGaN peaks deposited on glass substrate are shifted to right on the XRD spectra, compared to that of the GaN and InGaN peaks deposited on silicon substrate. The observed diffraction peaks are sharp, indicating good crystalline quality.

3.2 Surface Morphological Analysis

It is very important to investigate surface morphology of the films. For studying surface morphology, scanning electron microscopy (SEM, JEOL-JSM5600) was used. SEM images are shown in Figure 4. It is observed that the films are crystalline with uniform dimension of crystals. Figure 4. (a) and (b) indicates the SEM images of the deposited InGaN on silicon substrate for different magnitudes. Also, Figure 4. (c) shows the SEM image of the GaN and InGaN films on silicon substrate. As seen in image, InGaN thin film has a granular structure. Deposited films are dense, smooth, well adhered to the substrate and continue without any holes and cracks.
Figure 4. SEM images of deposited films spectra of deposited thin films (a) and (b) deposited InGaN on Si for different magnitudes, (c) deposited GaN and InGaN on Si substrates

3.3 Chemical Microanalysis

Table 1. EDX analysis results of the GaN and InGaN deposited films on Glass

| Element    | Weight ratio % | Atomic ratio % |
|------------|----------------|----------------|
| Nitrogen   | 1.22           | 1.91           |
| Oxygen     | 42.58          | 58.29          |
| Silicon    | 48.90          | 38.13          |
| Indium     | 5.07           | 0.97           |
| Gallium    | 2.23           | 0.70           |
Energy dispersive X-ray spectroscopy (EDX) is a chemical microanalysis technique. Table-1 shows the weight and atomic ratio of elements which found in the films and substrates for deposited GaN and InGaN films on glass.

Figure 5. EDX spectrum of the deposited GaN and InGaN films on glass substrate

Figure 5. shows the EDX spectrum of GaN and InGaN thin films grown on glass substrate. The elemental analysis results confirmed the presence of the Si, Ga, In, N and O in the film.

Figure 6. EDX spectrum of the deposited InGaN film on silicon substrate

Figure 6. indicates the EDX spectrum ogf the InGaN thin film on silicon substrate. As can be seen from Figure 6, presence of the Si, Ga, N and In atoms were detected by the EDX analysis.
4. Conclusion
InGaN thin films were successfully deposited on silicon substrate and also deposited on glass substrate with GaN film using TVA technique. The main advantage of this deposition technique is its high deposition rate without any loss in the quality of the thin film. The material properties of the produced thin film were investigated. XRD peaks have been observed that the films have sharp diffraction peaks and good crystalline quality. SEM analysis of the produced films show that the thin films have granular structure and they are dense, homogeneous and continue without any cracks and holes. EDX analysis are also investigated. From the EDX spectrum, presence of the atoms in the film is confirmed. The results show that TVA is suitable for deposition of thin films on silicon and glass substrates.

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