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# Effects of radio-frequency power on structural properties and morphology of AlGaN thin film prepared by co-sputtering technique

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**Abstract:** To date, the deposition of AlGaN thin film using the co-sputtering technique at room temperature has not been reported yet. The use of AlGaN for electronic devices has been widely known because of its ultra-wide bandgap. However, to deposit the AlGaN thin film and achieved high quality of AlGaN films, higher temperature or extra time deposition are needed, which is not compatible with industrial fabrication process. Here, a co-sputtering technique between two power supplies of magnetron sputtering (which are RF and HiPIMS) is introduced to deposit the AlGaN thin films. The AlGaN thin films were deposited at various RF power to study their effect on structural properties and morphology of the thin films. AlGaN films were sputtered simultaneously on silicon (111) substrate for short time and at room temperature using GaN and Al target. Then, the films were characterized by X-ray diffraction (XRD), atomic force microscopy (AFM), and surface profiler to study their properties. XRD shows the GaN (101) and (013) plane for the AlGaN deposited at RF power of 30 W. Also there only GaN (101) for the AlGaN with 50 W RF power. Yet, the 70 W RF power shows the amorphous structure of AlGaN. The roughness and the grain size of AlGaN film from AFM analysis showed the trend of decreasing and increasing respectively. The roughness of the AlGaN films with 30 W power was 0.82 nm, 0.85 nm for 50 W, and 0.46 nm for 70 W RF power. The grain size of the AlGaN films was 30.06 nm, 32.10 nm, and 37.65 nm for RF power of 30 W, 50 W, and 70 W respectively. The profilometer found that the thickness of the AlGaN films was decreasing with increasing of RF power. This paper can demonstrate a successful co-sputtering technique of AlGaN. Despite AlGaN crystal structure was not able to found out in the XRD analysis, the effect of RF power has been studied to give significant effects on AlGaN thin film deposition.

**Keywords:** AlGaN thin film, co-sputtering technique, RF power,thin film deposition



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## 1. INTRODUCTION

AlGaN alloys were the ternary alloy of GaN and AlN. AlGaN, also known as ultra-wide bandgap materials, has a bandgap greater than GaN ($E_G$ = 3.4 eV), allowing for the next step in power electronics output [1]. AlGaN alloys are extremely appealing for the manufacture of ultraviolet UV and deep UV emitters, detectors, and other optoelectronic equipment due to their ability to control the direct bandgap in the broad energy range 3.4–6.1 eV. Aside from that, AlGaN has a high mechanical hardness, thermal conductivity, dielectric constant, and resistance to harsh environments [2]. Furthermore, the majority of alloy research to date has focused on epitaxial films deposited by metal-organic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE) which applied substrate temperature more than 900 °C to produce high quality of III-nitride materials [3]–[5]. The growth of Al-rich AlGaN using solely thermal atomic layer deposition was recently completed successfully at 342°C [6]. Therefore, we introduce two techniques of sputtering to deposit AlGaN simultaneously at room temperature.

RF magnetron sputtering (RFMS) has been used widely to fabricate thin films such as AlN and GaN [7]–[10].

RFMS deposition methods have several benefits for fabrication systems, including the ability to deposit thin films at lower substrate temperatures and the ability to manufacture uniform thin films over wide areas [11]. Simanullang et al. [8] used the RFMS technique to successfully obtain a high crystal structure of GaN thin film at a low temperature (≤200 °C). High power impulse magnetron sputtering (HiPIMS) also a part of the magnetron sputtering power supply that has been used to fabricate thin films [12]–[14]. HiPIMs have a significant fraction of ionized sputtered to create a high-performance thick coating, which has improved the thin film consistency even further [15]. HiPIMS deposition generates a substantial number of metal ions (up to 40–80%), HiPIMS films are generally thick and smooth, and plasma density is more than $10^{-13}$ $cm^3$. As a result, its stoichiometry and structural strength can be easily measured at lower deposition temperatures as compared to other approaches [16]. In this paper, we want to study morphology and structural properties of AlGaN thin film deposited by the both technique of RFMS and HiPIMS simultaneously at room temperature. As we know that, there is not much paper reported regarding the fabrication of AlGaN and its properties. The wide bandgap of AlGaN increases the interest to study further the behavior of AlGaN for semiconductor devices.

## 2. EXPERIMENTAL DETAILS

### 2.1 Substrates preparation

Before the silicon wafer (111) acts as substrate enters the sputtering chamber, the substrate was cleaned to remove the native oxide layer that exists on the surface of the silicon wafer. Silicon was cleaned by dipping the Si into the diluted hydrofluoric acid (HF) for 1 minute. After that, deionized water was used to rinse the Si wafer and nitrogen gas was used to dry the Si wafer after the cleaning process. Once the cleaning process was done, the Si wafer was immediately put into the sputtering chamber.

### 2.2 Deposition process

The deposition process takes place in the chamber of magnetron sputtering. A 3-inch diameter of GaN and Al target (purity 99.999%) was used and connected directly to the RF and HiPIMS power supply, respectively. By using a turbo molecular pump, the base pressure of the sputtering chamber was achieved at $8.0 \times 10^{-6}$ Torr and the sputtering pressure was set at 10 mTorr. RF power with 13.65 MHz (Advance Energy, Cesar RF Power), meanwhile the HiPIMS power consisted of DC power supply (PsPlasma, SDC 1024) and impulse power supply (Starfire Industries, SF-Impulse-SH) was used to supply the power to the magnetron sputtering. The Ar/N2 flow rate was maintained at 100/25 sccm using the mass flow controller for 1 hour at room temperature. The distance between target and substrate was 10 cm and the substrate rotation was set at 5 rpm. The HiPIMS power was maintained at 10 W, in the meantime, the RF power was varied at 30 W, 50 W, and 70 W. The experimental setup is shown in Figure 1 and the sputtering parameter details is shown in Table 1.

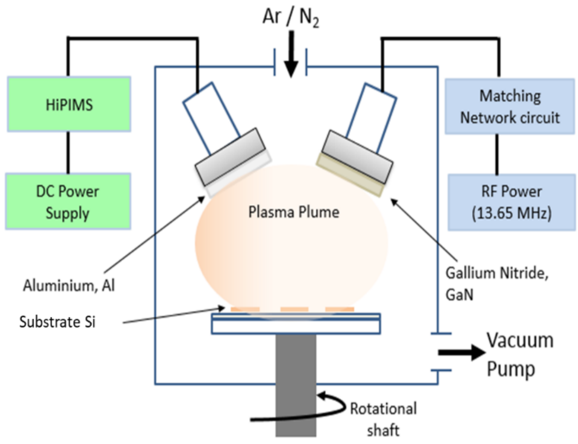


Figure 1. Experimental setup of AlGaN using the co-sputtering technique

Table 1. Parameter of the AlGaN deposition

| **Power Supply** | HiPIMS | RF |
|---|---|---|
| **Frequency** | 1500 Hz | 13.65 MHz |
| **Pulse Width** | 300 | - |
| **Working pressure** | $10 \times 10^{-3}$ Torr | |
| **Base Pressure** | $8 \times 10^{-4}$ Torr | |
| **Ar/N2 flow rate** | 100/25 sccm | |
| **Power (W)** | 10 | 30,50,70 |
| **Distance target to the substrate (cm)** | 10 | |

### 2.3 Characterization of AlGaN thin films

The structural properties of the AlGaN thin films were investigated by analyzing the result from the x-ray diffraction (XRD) PANalytical X-Pert Powder scan at 2 thetas of 20° - 80° with ½ divergence slit and the incident angle "omega" at 0.5 degrees. The surface morphology of the AlGaN film was observed using atomic force microscopy (AFM5100N-DFM) from Hitachi using contact mode AFM. The scan size was taken at 1 × 1 µm. In addition, the thickness of the AlGaN films was identified using the surface profilometer (DektakXT) from Bruker.

## 3. RESULTS AND DISCUSSIONS

The XRD pattern of AlGaN films in Figure 2 shows the (101) and (013) plane of hexagonal GaN with PDF code: ICSD 98-018-1358 was exist at a degree of 36.5° and 62.7° respectively for RF power at 30 W. However the peak of GaN (013) disappeared when the RF power increase to 50 W and both of the GaN peak missing which show amorphous structure up to 70 W of RF power. According to Hwang et al. [17], the films deposited at higher RF power have a higher deposition rate resulting in better crystallinity than lower RF power. However, the crystallinity can become worse when the RF power increases further. Therefore, for our AlGaN thin film when the RF power increases up to 70 W, the films show low crystallinity. Nonetheless, based on Mantarci et and Kundakci [18] the RF power under 50 W was the best crystallizing of GaN films on Si substrate. Figure 3 shows the thickness of the AlGaN depends on the RF power from the profilometer. The trend shows that the thickness of the AlGaN film decreasing with increasing RF power.

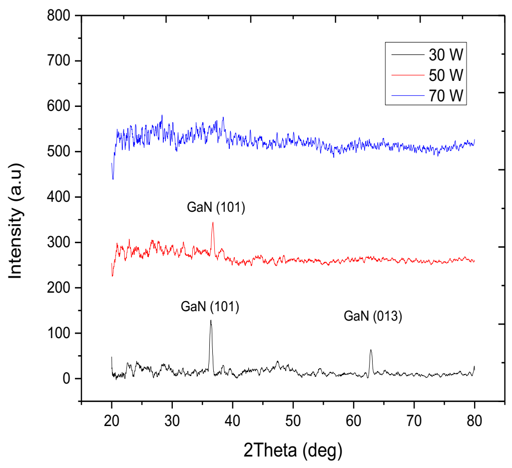


Figure 2. XRD pattern of prepared thin film at differences RF powers

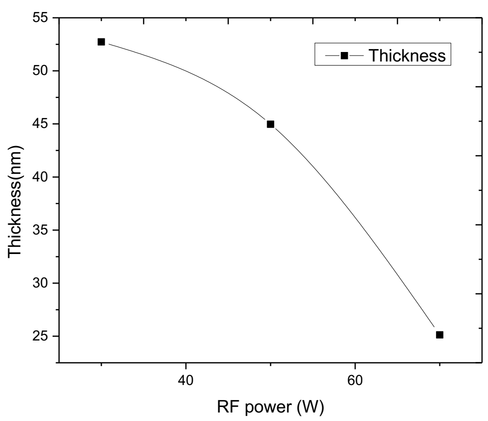


Figure 3. The thickness of AlGaN thin films depends on RF power

An increase in RF power from 30 to 50 W resulted in a 0.03 nm rougher surface. However, increasing the RF power from 50 to 70 W resulted in a 0.39 nm smoother surface. The roughness of the AlGaN thin films ranged from 0.46 to 0.85 nm on average. Based on Figure 4, the highest roughness was 0.85 corresponding to the 50 W RF power growth condition, whereas the lowest roughness was 0.46 nm corresponding to the 70 W RF power growth condition. Increasing the RF power from 50 to 70 W resulted in a considerable reduction in the average roughness of the thin film, resulting in a small improvement in the surface morphology of the thin film. However, raising the RF power from 30 to 50W increased the average roughness of the thin film, resulting in deterioration of the thin film's surface morphology. Thin films with minimal roughness are frequently sought for optoelectronic device applications because it impacts another layer or ohmic contact that is produced over the roughened surface. As we know, increasing the RF power may lead to higher surface roughness due to an increased rate of deposition [19]. Nevertheless, in our cases, the results show vice versa with the literature, which may be due to both techniques RF and HiPIMS was sputtered simultaneously that to contribute to the smoother surface of the thin film. Meanwhile, Figure 5 shows the grain sizes of AlGaN thin films increase proportionally with RF power. The grain sizes give an effect to the strength of the AlGaN material. AlGaN with 30W RF power has a smaller grain size of 30.06 nm, while AlGaN with 50W and 70W RF power has grain sizes of 32.10 nm and 37.65 nm, respectively. A fine grain size would undoubtedly increase the finished product's yield strength and stress relief tolerance. Smaller grains can also increase a material's formability in general [20].

## 4. CONCLUSION

The effect of RF power on the structural properties and morphology of AlGaN has been investigated systematically. The AlGaN film was co-sputtered on clean silicon (111) substrates with varied RF power from 30 to 70 W under pure Ar and $N_2$ plasma. The film thickness was found to decrease with the increase of RF power. The XRD shows only the GaN structure (101) and (013) plane for AlGaN deposited with 30 W RF power and only GaN (101) for AlGaN with 50 W RF power. The XRD pattern found the amorphous structure of AlGaN when deposited with 70 W of RF power. It was found that the grain size grew up with the increase of RF power. Vice versa, the surface roughness of the AlGaN decreases with the increase of the RF power. However, in the future, the deposition of the AlGaN can be carried out with varied other parameters that can affect the properties of the AlGaN and enhance the quality of the films.

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Figure 4. Surface roughness of AlGaN thin films at differences RF power from AFM analysis

Figure 5. Grain sizes of AlGaN thin films at differences RF power from AFM analysis

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