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Study On the Uniformity Aluminum Nitrate Thin Film On 2-Inch Silicon Substrate Prepared by RF Magnetron Sputtering

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Abstract: Aluminum nitrate (AlN) has attracted the researcher's interest due to its unique properties in the semiconductor material and other high-performance devices. This results in numerous techniques to investigate the uniformity of AlN thin film. The deposition in this study is carried out on an AlN on a 2-inch silicon substrate using a magnetron sputtering technique. The RF magnetron sputtering can also produce better film quality and deposit a wide variety of insulators, metals, alloys and composites. In this study, the AlN film was deposited using the RF magnetron sputtering by using three different parameters for the growth of the AlN on the 2-inch Si substrate for uniformity analysis. The uniformity of AlN thin film includes analyses of the structural, thickness, topology and surface morphology by using the characterization of X-ray diffraction (XRD), atomic force microscopy (AFM), surface profiler and field emission scanning electron microscopy (FE-SEM). Based on the result from three parameters that have been done, parameter one shows the best results. For the crystalline structure results, the peak (100) AlN indicates the highly textured phases similar to a single crystal, and the cross-section result in FE-SEM shows the homogenous thickness.

Keywords: RF magnetron sputtering, uniformity, AlN films, Silicon

1. Introduction

Aluminum nitride (AlN) is a semiconductor material with a large 6.2 eV band-gap, which has attracted attention of the scientific community due to various advantages that AlN. AlN thin film with a hexagonal wurtzite crystalline structure is used in various applications like optical hard coatings, wear resistant, high temperature microelectronics, chemical and thermal stability [1]. AlN have high thermal conductivity (320W K-1m-1) [2].

Different methods are used to deposit AlN thin films, although chemical vapor deposition (CVD), molecular beam epitaxy (MBE), and pulsed laser deposition (PLD) are preferred [1]. During the deposition process, these approaches mostly required high temperatures [3]. There are already numerous articles on physical vapor deposition (PVD)

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techniques for high-quality AlN film deposition at low temperatures [1]. Sputtering is the typical deposition method used in the PVD process. This is due to the benefits of its simplicity [4], low thermal temperature, low cost, and ability to manufacture high-quality films with the appropriate qualities in comparison to the high temperature processes that are conventionally utilized . magnetron sputtering also has benefit in develop the uniformity on large-area substrate [5].

In this investigation, the AlN thin film were deposited by using RF magnetron sputtering. The deposited AlN thin film were characterized the crystal structure, topology and thickness properties by using X-ray diffraction (XRD), atomic force microscope (AFM), surface profiler and the field emission scanning electron microscope (FE-SEM).

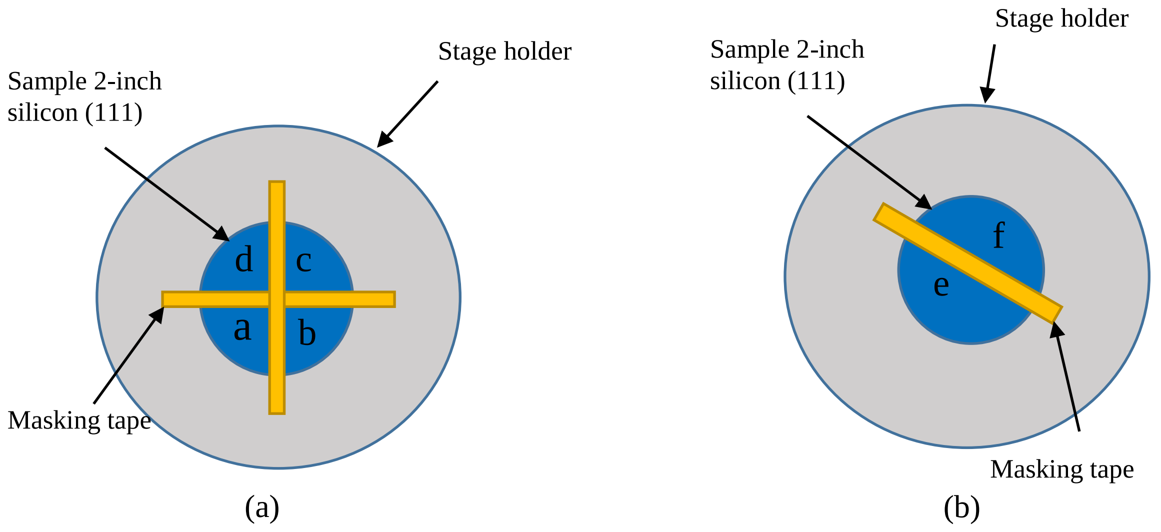
2. Methods

Aluminum nitride films were deposited on 2-inch Si (111) substrate by using the RF magnetron sputtering. The silicon substrate was cleaned using the ultrasonically for 3 minutes with deionized water. The substrate was immersed in diluted hydrofluoric acid (HF) to deionized water to eliminate the native oxide layer. After the substrate immerse the substrate for short time rinse with deionized water then blow it using the nitrogen gas to drying the substrate. The cleaned substrate will place into the chamber for vacuum. There are three deposition processes that are carried out using three different parameters for study the uniformity AlN thin film. All deposition process used the 99.999% pure Al target with the distance 12.7 cm from the substrate. The parameter used in the deposition process was listed in Table 1. Four characterizations are used for study the uniformity AlN thin film on a 2-inch Si substrate: structural properties using X-ray diffraction (XRD) to assess the quality of crystalline AlN films [6], surface topology analysis using atomic force microscopy (AFM) to measure surface roughness and grain size [7], thickness analysis using a surface profiler, and surface morphology cross-section analysis using field emission scanning electron microscope (FE-SEM).

This study used three parameters with different sample positions in the stage holder. There are four positions on the 2-inch sample used in parameter 1. The sample was divided into four positions labelled a, b, c and d using adhesive tape. Parameter 2 uses two positions, e and f, on a 2-inch sample at the center position on the stage holder. It is also divided into two positions using adhesive tape, as shown in Fig. 1. Finally, for parameter 3, there are two different positions on the stage holder: the center and the outer. The center position was labelled as g, and the outer position was labelled as h. The various positions used in this study are to investigate the uniform AlN film by using different parameters.

Table 1 - Parameter of AlN thin film deposited by RF magnetron sputtering

Parameter	1	2	3
Ar / N_2 flow	100 / 50 sccm	100 / 50 sccm	100 / 50 sccm
Work pressure	3.3 mTorr	3.3 mTorr	3.3 mTorr
RF power	200 W	200 W	300 W
Duration	2 hours	1 hours	1 hours
Rotation	5 rpm	10 rpm	10 rpm
z-position	Top	Top	Top
Temperature	Room temperature	Room temperature	Room temperature
Base pressure	8 x 10^{-6} Torr	8 x 10^{-6} Torr	8 x 10^{-6} Torr



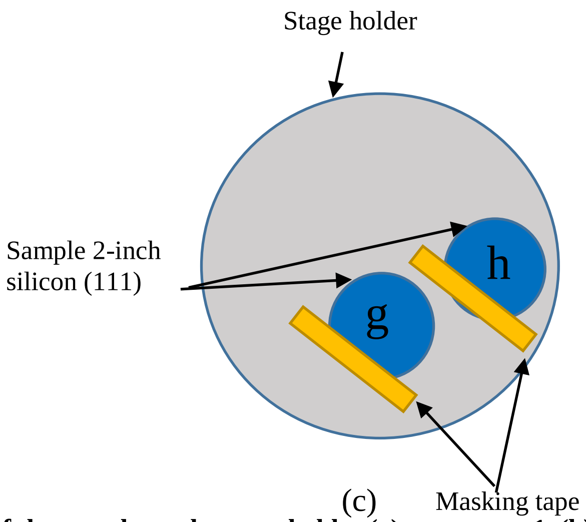


Fig. 1 - The position of the sample on the stage holder (a) parameter 1, (b) parameter 2 and (c) parameter 3

3. Results and Discussion

The Fig. 2 shows the XRD pattern using parameter 1. From those results, all the AlN films exhibited the preferred (100) orientation and also it is indicating highly textured phases similar to the single crystal. By using the parameter 2 and 3, it shows the XRD pattern in Fig. 3 and 4 are amorphous. There is no peak at (100) plane that correspond to the a-axis perpendicular to the surface that the preferred orientation of the hexagonal wurtzite-type structure. This may be due to the thickness shown in thickness analysis for parameter 2 and 3 is lower and higher thickness respectively [8][9]. From the XRD pattern, we can observe that the AlN film that only the peak at (100) and (113) plane is appear with the peak of 2θ at 33º and 59º respectively. From the observed, the parameter 1 is optimum parameter for the develop uniform AlN films compare with the others parameter. For the Full Width at Half Maximum (FWHM) of AlN (100) peaks that measured by software have resulted in 0.4723º, 0.8640º, 0.4723º and 0.5904º for the sample at position a, b, c and d respectively. The XRD patterns show the AlN (100) peaks for 2θ is 33.4207º (sample a), 33.4592º (sample b), 33.4382º (sample c) and 33.3889º (sample d).

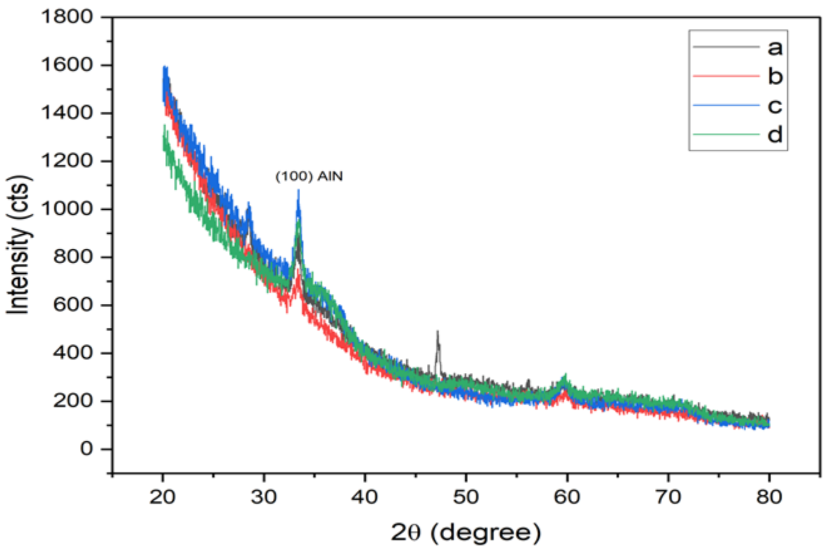


Fig. 2 - XRD pattern for position a, b, c and d using parameter 1

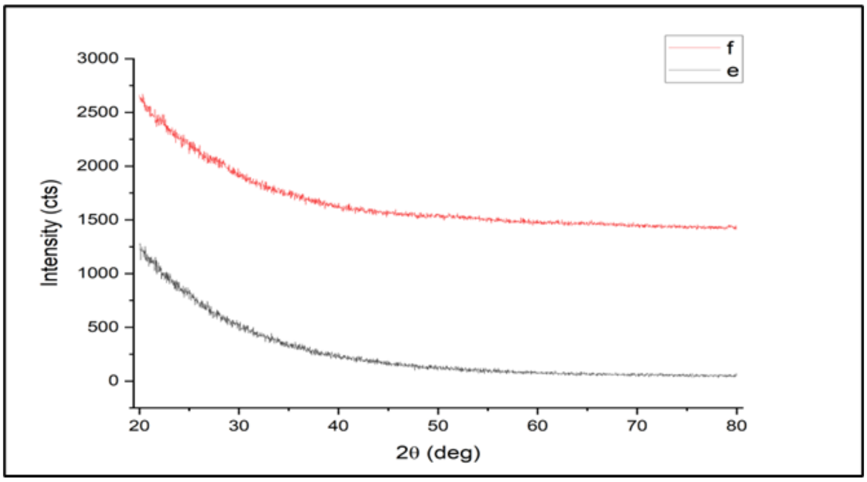


Fig. 3 - XRD pattern for position e and f using parameter 2

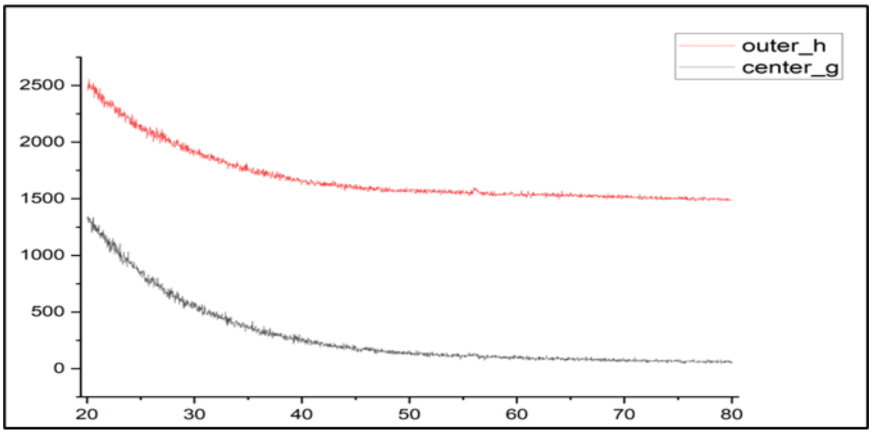


Fig. 4 - XRD pattern for position g and outer h using parameter 3

3.1 Surface Topology

The surface roughness of AlN thin film has impacted the uniformity and quality of the thin film. The surface roughness was analyzed using atomic force microscopy (AFM), which enables the characterization of the film surface topology evolution with the growth AlN in this study. The non-contact mode of the AFM was employed to characterize the surface topography of each sample. Table 2 presented the detail of the AFM analysis. The average roughness in parameter 1 is 1.469nm. The data analysis shows that the sample values of c and d are close to the average roughness of 7% and 4%, respectively. Compared, the samples at positions a and b show highly different values with an average roughness of 28% and 15%, respectively. A highly diverse average range is displayed on each sample. The surface roughness in parameter 1 is non-homogeneous. It should have a surface roughness approaching the average range to obtain a smooth or uniform film. Tables 2 and 3 show the data analysis of surface topology in parameters 2 and 3. The total average of each parameter was 0.519nm and 1.6455nm, respectively. It does not achieve the uniformity of AlN thin film because those differ highly from the range of average roughness by 20% and 37%, respectively. The surface roughness and high surface roughness values will increase the grain size and thickness. (Jiao et al.) reported that AlN thin films average roughness decreased as thickness and grain size decreased [10]. It should have a low surface roughness to get a smooth or uniform film. The film exhibited more homogenous when the grain size is small or shrunk [10].

Table 2 - The AFM image, average roughness and grain size of AlN films using parameter 1

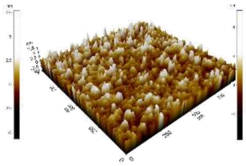
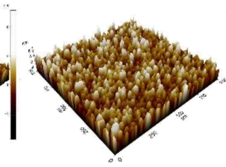
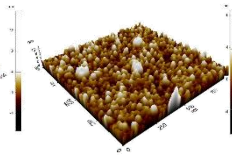
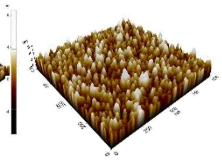
Sample position	a	b	c	d
AFM image				
Average roughness (nm)	1.067	1.700	1.577	1.533
Grain size (nm)	28.00	29.89	35.52	34.42

Table 3 - The AFM image, average roughness and grain size of AlN films using parameter 2

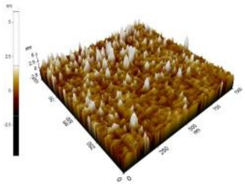
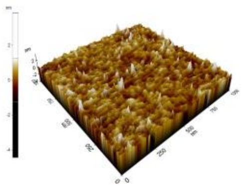
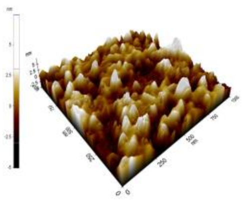
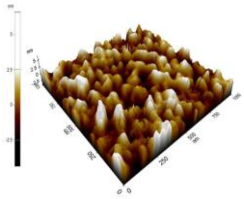
Sample	e	f
AFM image		
Average roughness(nm)	0.626	0.412
Grain size (nm)	25.00	30.00

Table 4 - The AFM image, average roughness and grain size of AlN films using parameter 3

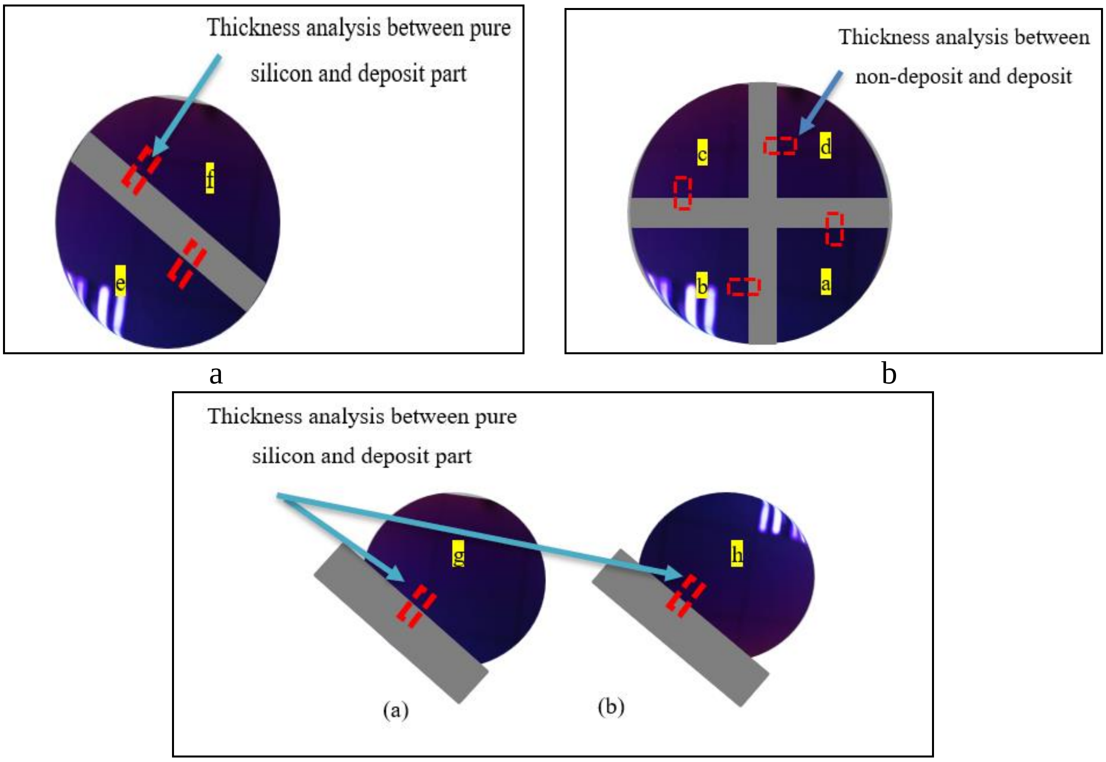
Sample position	center_g	outer_h
AFM image		
Average roughness(nm)	2.265	1.026
Grain size (nm)	27.869	58.000

3.2 Thickness Properties

The thickness of the samples was determined with the surface profiler. Measured samples are to carry out the AlN layer thickness that known of optical film properties. Surface profiler is a method that using optical interference. Table 5 shows the thickness of four samples that had analysis using parameter 1 by the surface profiler. The different thickness of the four samples indicates that it is almost uniform thin film because the range of thickness samples is between 9% - 11% with the total average thickness. Parameters 2 and 3 also show the different thickness values in Tables 6 and 7, respectively. The range average thickness for parameter 2 is close to parameter 1, which is 13%. The thickness range in parameter 3 is not uniform because it differs highly from parameters 1 and 2, which is 39%. This is because it is related to the surface roughness and grain size. For verify the good uniformity of the sample, it can be measured by using the average thickness equation below

$$\eta = \frac{d(\max) - d(\min)}{2d(\text{average})} \quad (1)$$

where η and *d* are non-uniformity and the thickness of the thin film respectively [8].



(c) Two different positions in the stage holder (a) center and (b) outer

Fig. 5 - AlN film deposited by using RF magnetron sputtering with (a) parameter 1; (b) parameter 2 and; (c) parameter 3

Table 5 - Thickness analysis data from parameter 1

Sample	**Thickness (nm)**
a	258.46
b	210.33
c	209.49
d	262.93
Total average of thickness:	235.30

Table 6 - Thickness analysis data from parameter 2

Sample	**Thickness (nm)**
e	85.26
f	110.381
Total average of thickness:	98.03

Table 7 - Thickness analysis data from parameter 3

Sample	Thickness (nm)
g	298.14
h	376.48
Total average of thickness:	337.31

3.3 Surface Morphology

For analysis of the surface morphology and cross-section, it used the FE-SEM. It can observe the surface to see any defects or damaged surfaces [11]. Good surface morphology has a smooth surface without any particles [8]. The image FE-SEM in Fig. 6 shows the image at higher magnification (100 000x) that observes the surface morphology of AlN films and can relate with the thickness of the samples to cross-section analysis. Fig. 7 presents the thickness analysis for parameter 1 from the cross-section using the FE-SEM. The results show the thickness on each sample is a consistent value. The thickness analysis data from the cross-section in parameters 2 and 3 showed the non-consistent value of thickness based on the range of values shown in Fig. 8 and 9, respectively. The cross-section results for thickness analysis with the morphology surface are used to verify the uniform AlN by analysing the surface and the thickness. The observation in this investigation shows that the thickness analysis by cross-section FE-SEM is more accurate than the surface profiler because it measures the actual layer of AlN films.

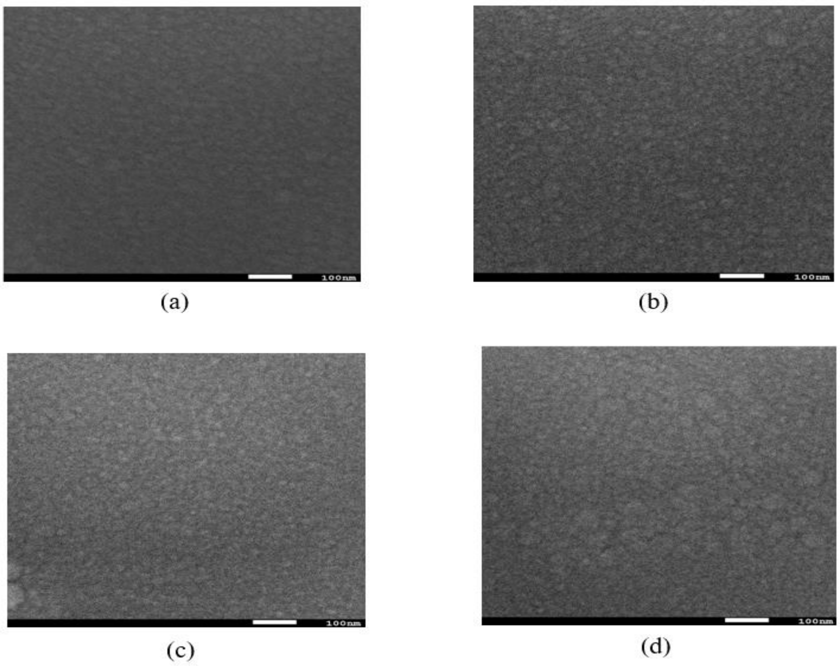


Fig. 6 - Surface morphology of AlN thin film for position a, b, c and d using parameter 1

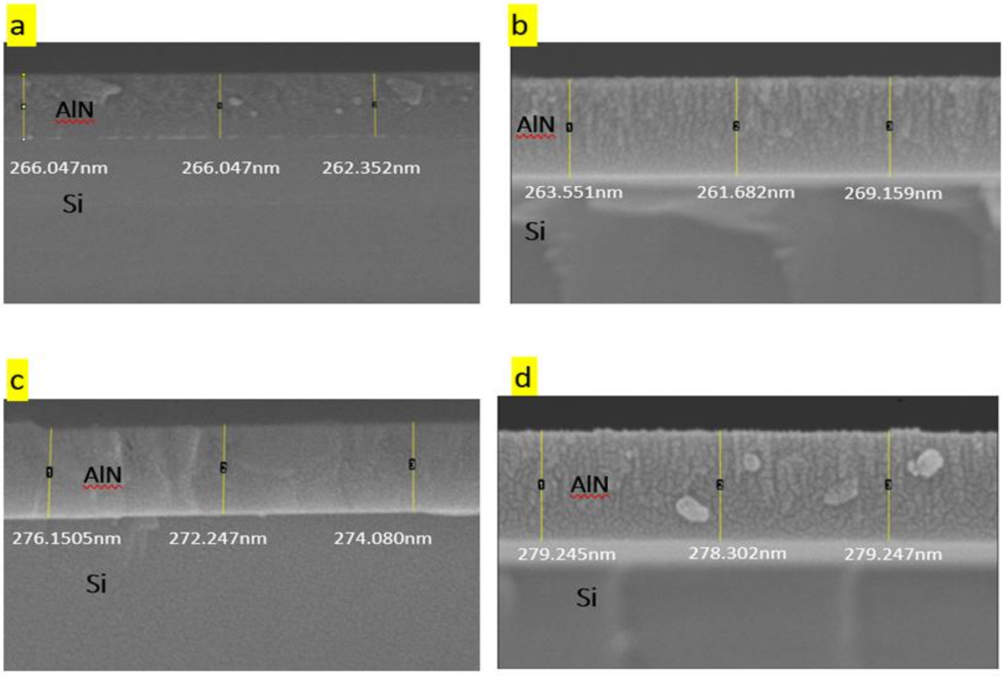


Fig. 7 - Cross-section by using FE-SEM in parameter 1

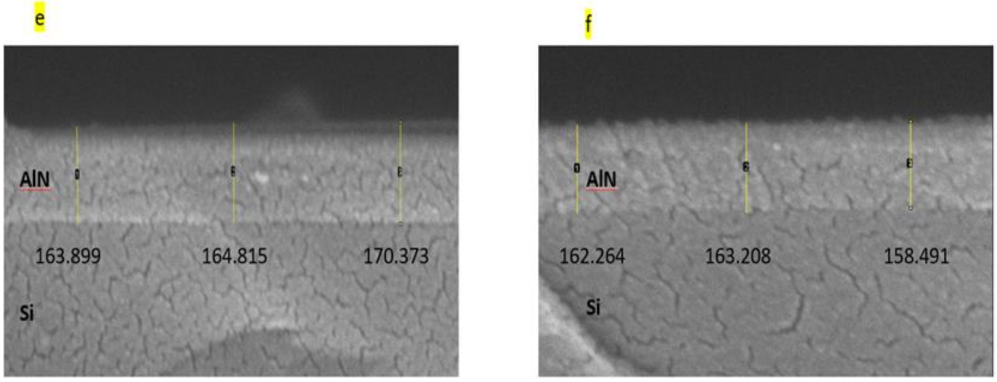


Fig. 8 - Cross-section by using FE-SEM in parameter 2

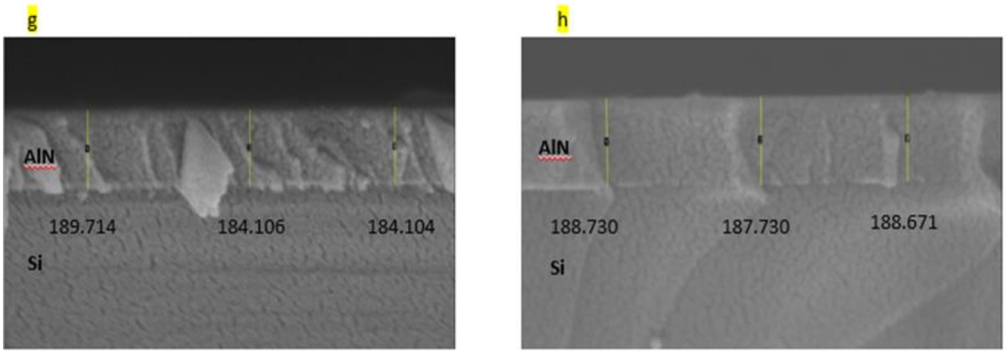


Fig. 9 - Cross-section by using FE-SEM in parameter 3

4. Conclusion

In this study, The AlN thin film is successfully deposited by the technique of RF magnetron sputtering that uses the Al as the single target to achieve the objectives of this study, which are to carry out the deposition of AlN on a 2-inch silicon substrate using the RF magnetron sputtering technique and to characterization the AlN films Si (111) substrate using XRD, surface profiler, AFM, FE-SEM for develop the uniform AlN thin film on 2-inch Si substrate. Based on the result from three parameters that have been done, parameter 1 shows the best results. The peak (100) AlN in Fig. 1 indicates the highly textured phases similar to a single crystal for the crystalline structure results. The thickness is an essential characterization to investigate the uniformity of AlN film. The cross-section result in FE-SEM in Fig. 5 shows the homogenous thickness of four samples from the 2-inch substrate in the center position in the stage holder with the parameter shown in Table 1.

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References

[1] Kumari N., Singh A. K., and Barhai P. K., "Study of Properties of AlN Thin Films Deposited by Reactive Magnetron Sputtering," *Int. J. Thin Film. Sci. Technol.*, vol. 3, no. 2, pp. 43–49, May 2014, doi: 10.12785/ijtfst/030203.

[2] Ait Aissa K. *et al.*, "Plasma functionalization of carbon nanowalls and its effect on attachment of fibroblast-like cells Achieving high thermal conductivity from AlN films deposited by high-power impulse magnetron sputtering," 2014.

[3] Wang J. *et al.*, "Effect of substrate temperature and bias voltage on the properties in DC magnetron sputtered AlN films on glass substrates," *J. Mater. Sci. Mater. Electron.*, vol. 27, no. 3, pp. 3026–3032, 2016, doi: 10.1007/s10854-015-4125-6.

[4] Alrashdan M. H. S., Hamzah A. A., Majlis B. Y., and Aziz M. F., "Aluminum nitride thin film deposition using DC sputtering," in *IEEE International Conference on Semiconductor Electronics, Proceedings, ICSE*, Oct. 2014, pp. 72–75. doi: 10.1109/SMELEC.2014.6920798.

[5] "Magnetron sputtering." [Online]. Available: http://iopscience.iop.org/0305-4624/19/2/304

[6] "What is X-Ray Diffraction Analysis (XRD) and How Does it Work? - TWI." https://www.twi-global.com/technical-knowledge/faqs/x-ray-diffraction (accessed Feb. 05, 2023).

[7] Hiesgen R. and Friedrich K. A., "Atomic force microscopy," *PEM Fuel Cell Diagnostic Tools*, no. March, pp. 395–421, 2011, doi: 10.4011/shikizai.93.321.

[8] Liu S., Peng M., Hou C., He Y., Li M., and Zheng X., "PEALD-Grown Crystalline AlN Films on Si (100) with Sharp Interface and Good Uniformity," *Nanoscale Res. Lett.*, vol. 12, no. 1, Dec. 2017, doi: 10.1186/s11671-017-2049-1.

[9] Khan S. *et al.*, "Texture of the nano-crystalline AlN thin films and the growth conditions in DC magnetron sputtering," *Prog. Nat. Sci. Mater. Int.*, vol. 25, no. 4, pp. 282–290, 2015, doi: 10.1016/j.pnsc.2015.08.006.

[10] Oliveira I. C., Grigorov K. G., Maciel H. S., Massi M., and Otani C., "High textured AlN thin films grown by RF magnetron sputtering; Composition, structure, morphology and hardness," *Vacuum*, vol. 75, no. 4, pp. 331–338, 2004, doi: 10.1016/j.vacuum.2004.04.001.

[11] Fischer P. and Roy S., "Characterizing magnetic skyrmions at their fundamental length and time scales," *Magn. Skyrmions Their Appl.*, pp. 55–97, Jan. 2021, doi: 10.1016/B978-0-12-820815-1.00005-5.