GROWTH OF HIGHLY C-AXIS ORIENTED ALUMINUM NITRIDE THIN FILMS ON SiO_2/Si(100)

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Abstract

Highly c-axis oriented aluminum nitride (AlN) thin films have been successfully deposited on SiO_2 coated Si (100) substrates by reactive RF magnetron sputtering. The structural characterizations determined by X-ray diffraction (XRD) measurement are found to be sensitive to the deposition conditions. A strong AlN (002) preferred orientation perpendicular to the substrate surface can be identified at a substrate temperature of less than 450 °C. Meanwhile, the crystallization of AlN thin film with (002) preferred orientation tends to be improved with increased RF power and/or nitrogen concentration. Besides, an optimal sputtering pressure of 7.5 ~ 15 mTorr exists for the growth of (002) preferred orientation.

Keywords: c-axis oriented, aluminum nitride, reactive RF magnetron sputtering, X-ray diffraction, preferred orientation

1. Introduction

Aluminum nitride (AlN) thin films have been widespread applied because they have some excellent properties such as chemical stability, high thermal conductivity, electrical isolation, a wide bandgap (6.2eV) [1], a thermal expansion coefficient similar to that of GaAs [2], higher acoustic velocity and larger electromechanical coupling coefficient [3]. Therefore, AlN thin films have been applied not only to surface passivation of semiconductors and insulators, but also to optical devices in the ultraviolet spectral region, acoustooptic (AO) devices and surface acoustic wave (SAW) devices.

C-axis oriented or single-crystal AlN thin films have been grown by various methods such as chemical vapor deposition (CVD) [4-7], molecular beam epitaxy (MBE) [8], reactive evaporation [9], and reactive sputtering [10-14]. The CVD technique has become the commonly used method for the growth of Ⅲ-V compounds because of its excellent controllability and suitability for mass production. However, the substrate temperature adopted in conventional CVD method is very high (>1000 °C) and a smooth surface morphology of AlN thin films cannot be obtained by this method owing to its high grain growth rate. This phenomenon will result in the increased propagation loss at high frequency when used as AO or SAW devices because of the rough surface.

on the other hand, the AlN thin films with a smooth surface have been grown by reactive sputtering method to prevent AlN grain growth [13]. Meanwhile, there exists some advantages of reactive sputtering method over CVD method, e.g., low-temperature operation and ease of fabrication. Besides, low-temperature growth of AlN thin films on silicon (Si) substrates is very important for the development of new hybrid optical integrated circuit (OIC). Therefore, it is desired to prepare AlN thin films on Si substrates at low substrate temperature by reactive RF magnetron sputtering.

The purpose of this work is to investigate the growth of c-axis oriented AlN thin films on SiO_2/Si (100) substrates by reactive RF magnetron sputtering. The crystal orientation of AlN thin films are examined by X-ray diffraction (XRD). The dependence of c-axis preferred orientation on various sputtering conditions, such as sputtering pressure, RF power, substrate temperature and nitrogen concentration ($N_2/Ar+N_2$) is investigated and discussed.

2. Experimental

The RF sputtering system employs a simple chamber with a water-cooled 99.999 % pure aluminum targe disk of 3-inch diameter. A 5-inch-diameter p type Si (100) wafer with a 350 Å SiO_2 layer on the surface is used as the substrate. After the chamber is evacuated to below 8×10^{-6} Torr, high-purity argon gas (Ar, 99.999%) controlled by a mass flow controller (MFC) is introduced into the chamber. The RF power and chamber pressure are kept at about 100 W and 30 mTorr for presputtering of about 1 h. After presputtering, a fixed total gas flow of 12 sccm with various ratios of argon gas to nitrogen gas (N_2, 99.999%) controlled by MFCs is introduced into the chamber, and the substrate is heated to the desired temperature. Then, the RF power and the sputtering pressure are adjusted to the desired values for sputtering. A typical growth condition is shown in Table 1. The deposition rate is found to be proportional to the RF power with a typical value of about 1.30 μm/h at 300 W. XRD, carried out on a Siemens D500 diffractometer with CuKα radiation, is adopted to identify the crystal structure and crystalline orientation of AlN thin films.

3. Results and Discussion

Figure 1 shows the XRD patterns of AlN thin films deposited at the RF power of 150 ~ 350 W with a substrate temperature of 350 °C, sputtering pressure of 7.5 mTorr and N_2 concentration of 75%. The AlN thin film, deposited at 150 W, does not exhibit any crystalline orientation of AlN. However, when the RF power increases up to 200 W, the AlN thin film reveals a mixture of AlN (002) and (100) planes. Further increasinig of RF power of more than 250 W, a strong AlN (002) preferred orientation perpendicular to the substrate surface can be obtained. The results also show that the AlN (002) peak tends to be improved with increased RF power within the experimental range.

Figure 2 shows the XRD patterns of AlN thin films deposited at the N_2 concentration of 25 ~ 75% with a substrate temperature of 350 °C, RF power of 300 W, sputtering pressure of 7.5 mTorr. The film deposited at 25% reveals a AlN (101) peak. When the N_2 concentration increases up to 37.5%, a mixture of AlN (101), (002) and (100) peaks exists. Further increasing of N_2 concentration of more than 50%, the AlN (101) peak decreases and the AlN (002) peak becomes dominant. When the N_2 concentration increases up to 75%, a pure and strong AlN (002) preferred orientation can be improved gradually with increased N_2 concentration in this study.

The XRD patterns of AlN thin films deposited at the sputtering pressure of 0.75 ~ 37.5 mTorr with a substrate temperature of 350 °C, RF power of 300 W and N_2 concentration of 75% are shown in Fig.3. The films deposited at 0.75 ~ 15 mTorr reveal a hexagonal AlN (002) plane. However, the FWHM results show that the AlN thin films deposited at 7.5 ~ 15 mTorr exhibit a minimum value, which indicates a better crystallization exists. Increasing of sputtering pressure of more than 22.5 mTorr, the AlN (002) peak disappears. This disappearance of XRD peaks may be due to the scattering effect [15], that is, when the sputtering pressure increases, the probabilities of collision between sputtered species will increase before they arrive at the substrate. Thus, the scattering effect will result in the energy loss in each collision and reduce the momentum and mobility of adatoms on the substrate. Therefore, the formation of crystalline structure of AlN thin film becomes more difficult. Further increasing of sputtering pressure, the energy loss will be more serious, and finally, these adatoms will not have sufficient energy to form the crystalline structure. The above results show that the qualities of these films are critically dependent on the sputtering pressure ranged from 0.75 ~ 37.5 mTorr. The optimal sputtering pressure for the growth of strong c-axis oriented AlN thin films is about 7.5 ~ 15 mTorr in this study.

Figure 4 shows the XRD patterns of AlN thin films deposited at the substrate temperature of 150 ~ 450 °C with a sputtering pressure of 7.5 mTorr, RF power of 300 W and N_2 concentration of 75%. The film deposited at 150 °C shows a mixture of AlN (100), (002) and (101) planes. Increasing of substrate temperature of more than 250 °C, the AlN (100) and (101) peaks decrease and the AlN (002) peak increases. Further increasing of substrate temperature up to 450 °C, a strong c-axis oriented AlN thin films can be obtained at a substrate temperature of less than 450 °C by reactive RF magnetron sputtering method.

4. Conclusions

We have fabricated the c-axis oriented AlN thin films on SiO_2/Si (100) substrates at a substrate temperature of less than 450 °C by reactive RF magnetron sputtering. The structural characterizations determined by XRD show that the AlN (002) peak tends to be improved with increased RF power and/or N_2 concentration. Besides, an optimal sputtering pressure of 7.5 ~ 15 mTorr exists for the growth of AlN (002) preferred orientation. Therefore, it can be estimated that the optimal conditions in this study for the growth of the strong c-axis oriented AlN thin films on SiO_2/Si (100) are the RF power of 250 ~ 350 W, N_2 concentration of 75%, sputtering pressure of 7.5 ~ 15 mTorr and substrate temperature of 250~450 °C. The fabrication and characteristic investigation of SAW devices on the AlN thin films are in progress.

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Table 1. Sputtering conditions

Substrate	SiO_2/Si(100)
Substrate temperature	150 ~ 450 °C
Substrate to target distance	6.5 cm
Target	Aluminum (3-inch-diam. 99.999%)
Residual pressure	$<8 \times 10^{-6}$ Torr
RF power	150 ~ 350 W
Sputtering pressure	0.75 ~ 37.5 mTorr
Ar gas flow rate	0 ~ 12 sccm
N_2 gas flow rate	0 ~ 12 sccm
Total gas flow rate	12 sccm

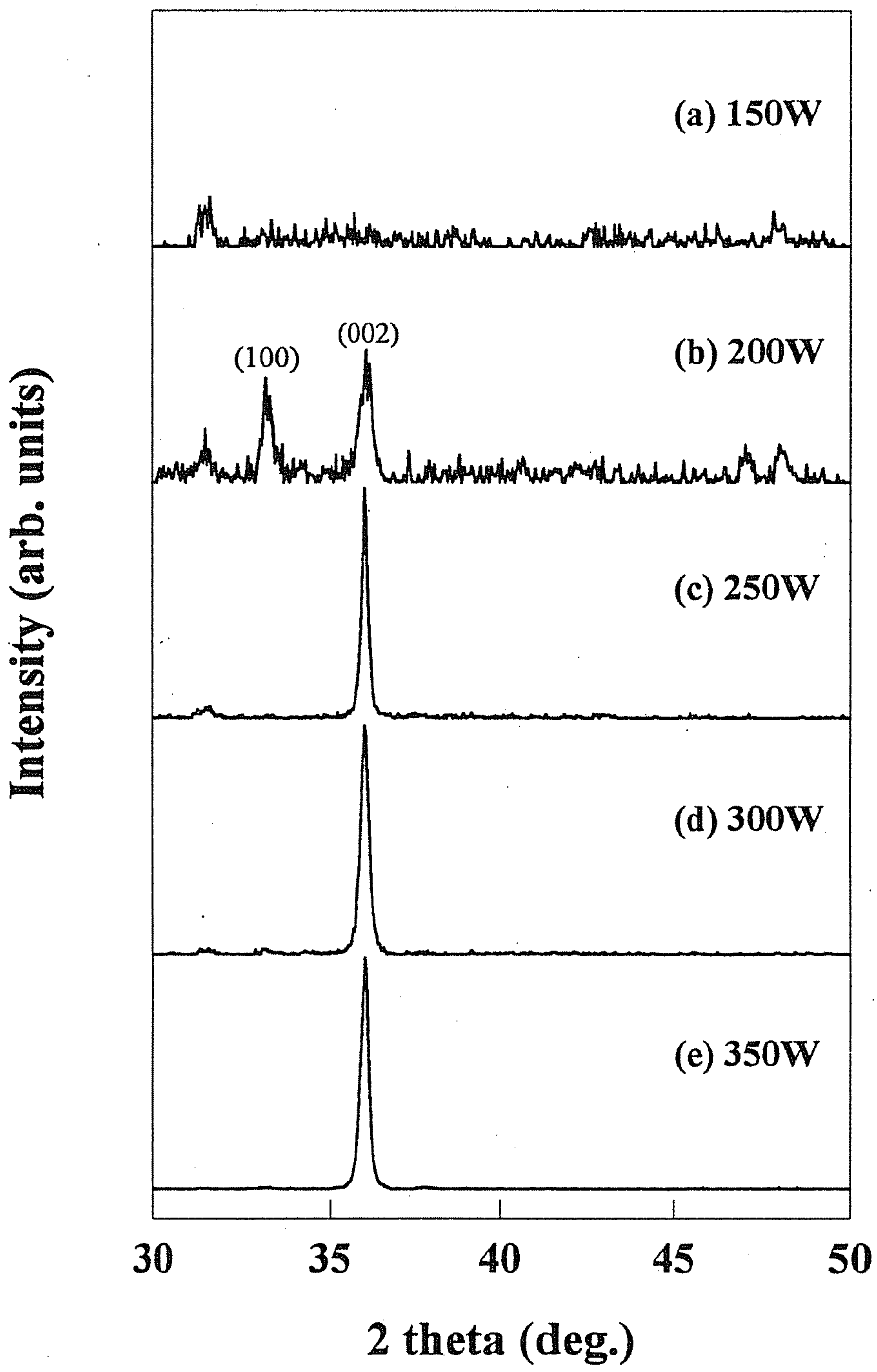

Figure. 1. The XRD patterns of AlN thin films deposited at various RF power with a sputtering pressure of 7.5 mTorr, substrate tempertaure of 350 ℃ and N_2 concentration of 75%

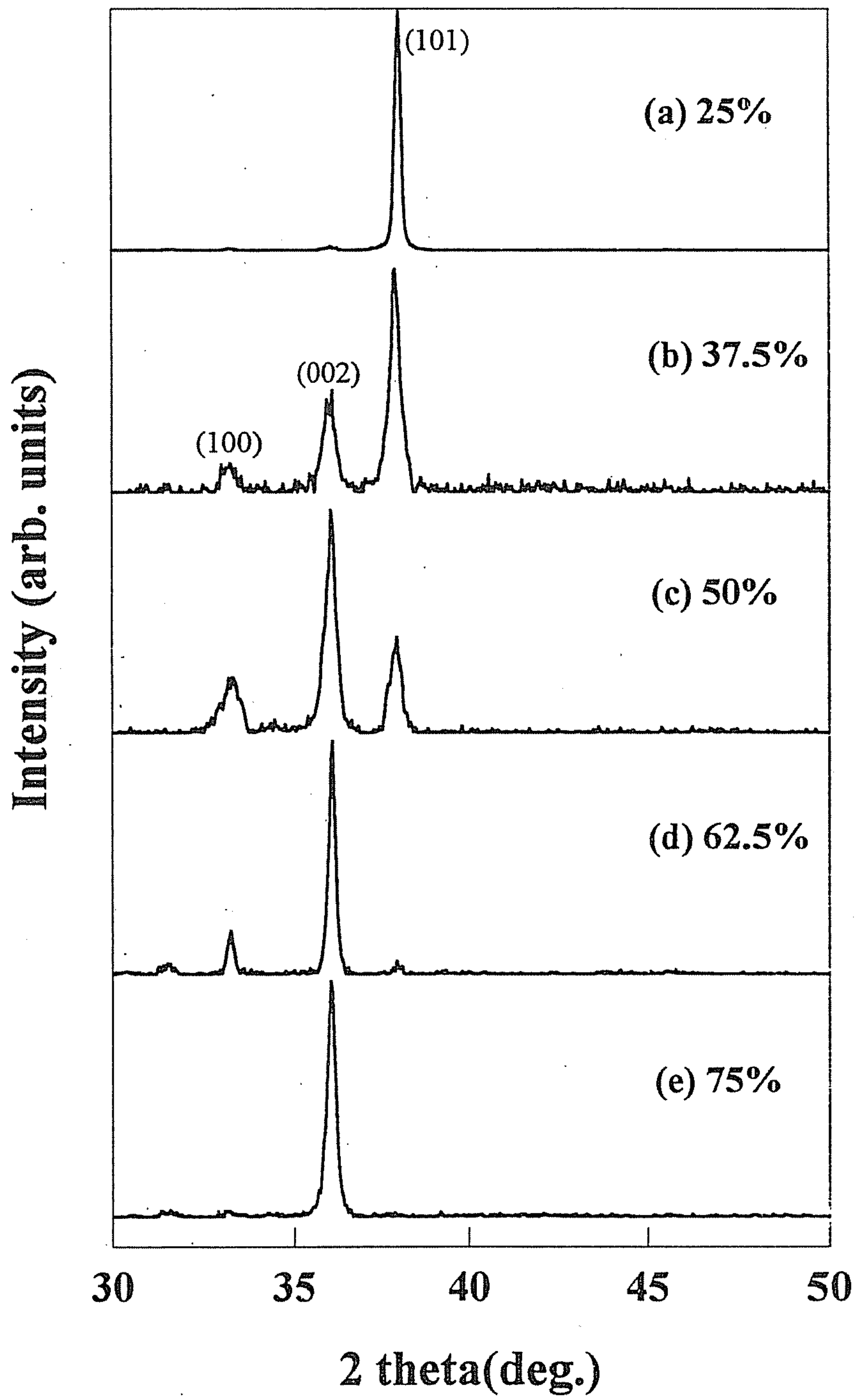

Figure. 2. The XRD patterns of AlN thin films deposited at various N_2 concentration with a sputtering pressure of 7.5 mTorr, substrate temperature of 350 °C and RF power of 300 W.

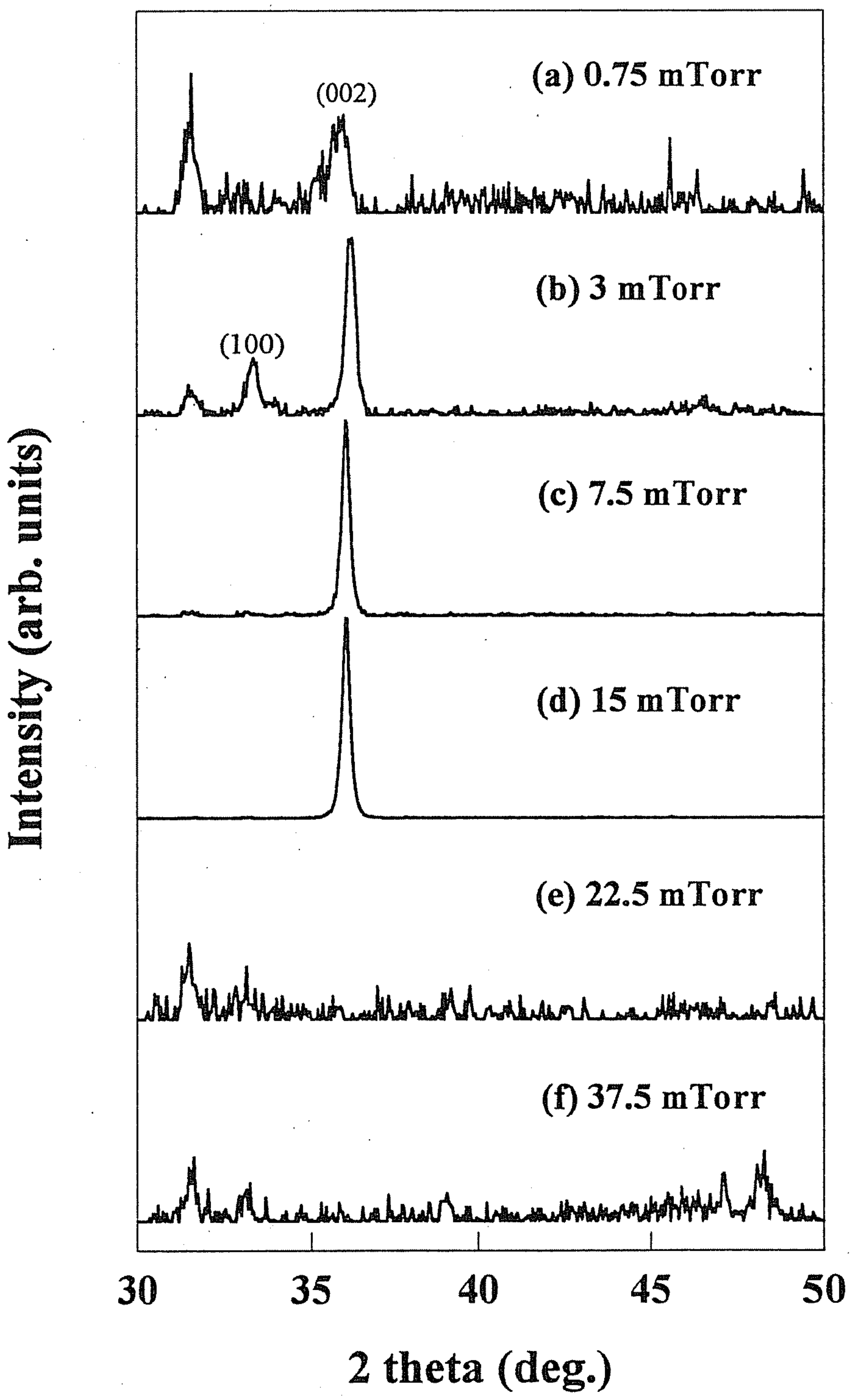

Figure. 3. The XRD patterns of AlN thin films deposited at various sputtering pressure with a substrate temperature of 350 °C, RF power of 300 W and N_2 concentration of 75%.

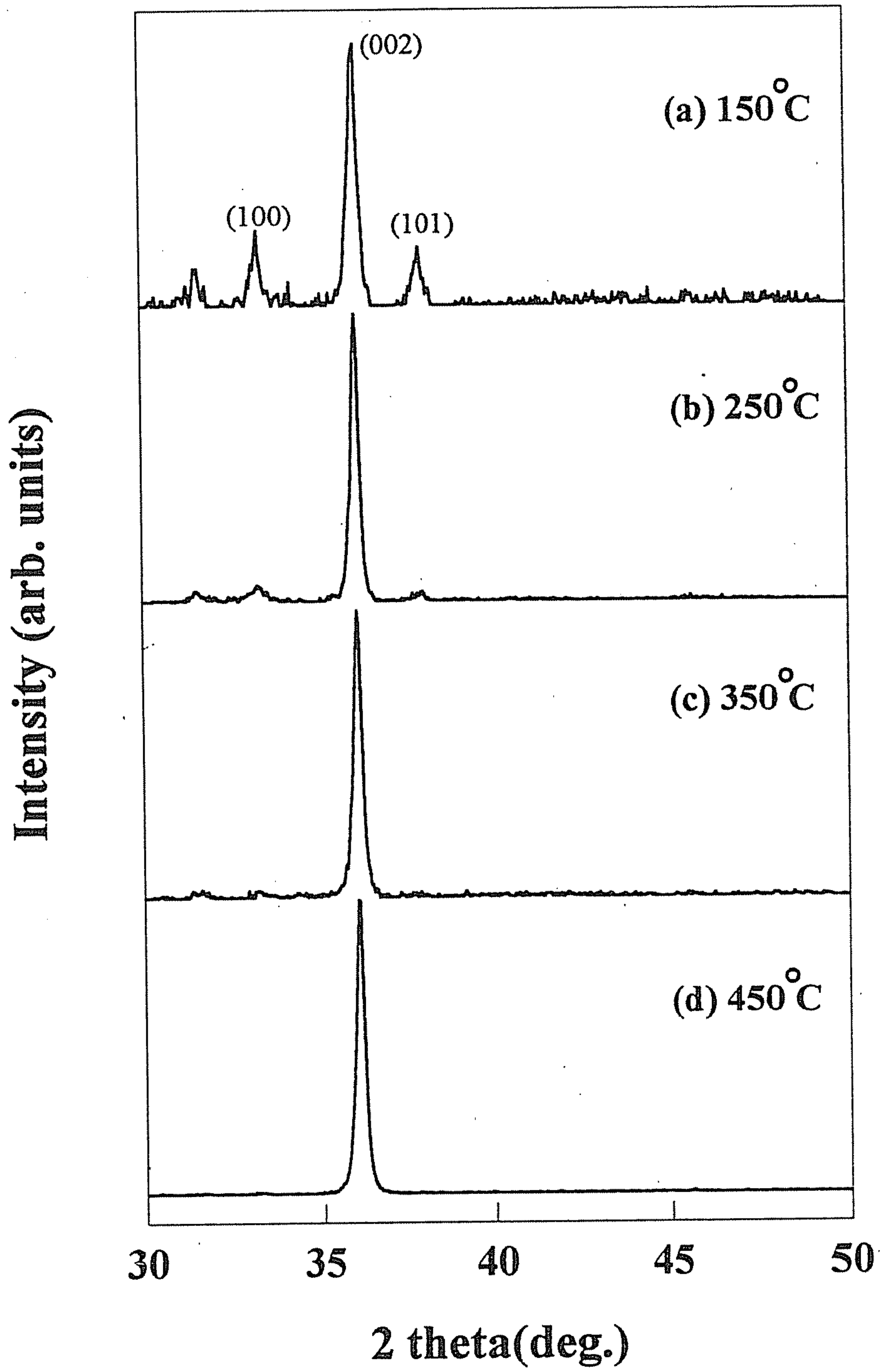

Figure. 4. The dependence of the XRD patterns for AlN thin films on various substrate tempertaure at a sputtering pressure of 7.5 mTorr, RF power of 300 W and N_2 concentration of 75%.

在 SiO_2/Si(100) 基板上成長高 C 軸排向氮化鋁薄膜

鄭建銓*

摘 要

使用磁控射頻濺鍍法成功的在二氧化矽覆膜之矽基板上沈積高 C 軸排向氮化鋁薄膜；薄膜結構的特性取決於 X 光繞射儀，同時與沈積條件有密切的關係。實驗的結果顯示，在基板溫度低於 450 ℃時，優先取向之氮化鋁（ 002 ）峰值可被獲得；同時，此優先取向之氮化鋁（ 002 ）峰值傾向於隨著 RF 功率或氮氣濃度之增加而增強；除此之外，對於濺鍍壓力而言，存在一個較適佳的範圍約 7.5 ～ 15m Torr ，可得到高 C 軸排向之氮化鋁薄膜。

關鍵字： C 軸排向，氮化鋁，磁控射頻濺鍍，X 光繞射儀，優先取向

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