Texture growth of AlN films deposited on Si(100) and (111) by DC reactive magnetron sputtering (dcMS) and by high power impulse magnetron sputtering (HiPIMS)

***A. Riah*[1], *A. Ayad*[1, 2], *J.Camus*[3], *M.A. Djouadi*[3] *and N. Rouag*[1]**

[1]Laboratoire Microstructures et Défauts dans les Matériaux, Université Frères Mentouri Constantine 1, Route Ain EL Bey, Constantine 25017, Algeria.
[2]Département de pharmacie, Faculté de Médecine, Université Constantine 3, Algeria.
[3]Institut des Matériaux Jean Rouxel IMN UMR 6502, Université de Nantes, 2 rue de la Houssinière BP 32229, 44322 Nantes Cedex France.

Abstact

We have studied the texture evolution of Aluminum nitride (AlN) thin. AlN thin films were deposited on Si (100) substrate by dc magnetron sputtering (dcMS) and High Power Impulse Magnetron Sputtering (HiPIMS) technics.We consider the influence of the deposition parameters (thickness, orientation of the substrate) on the anisotropy of the films. These films are aimed for many applications in electronics and photonics. They are used for acousto-optical filters type SAW (Surface acoustic wave) and UV emitting diodes. They are particularly useful in photonics (filter, Bragg mirror, LED, UV). Control of the anisotropy can improve the mechanical use properties of thin films. The most research works concerning AlN films have been focused on the wurtzite crystal phase,However the cubic AlN has many interesting properties, which are very different from those of the hexagonal phase. For example, is attracting more interest for its higher crystal- lographic symmetry, and it is expected to exhibit higher thermal conductivity, electrical resistivity, and acoustic velocity than h-AlN. Anyway this phaseis stilldifficult tocharacterize.

Keywords: AlN thin films, DC-PVD, Fiber texture, Dispersion, Orientation, Asymmetry.

Introduction

Aluminum nitride (AlN) is a material with remarkable properties, a large optical band gap of about 5.9–6.02 eV [1], high hardness [2], chemical stability, large acoustic velocity Moreover, AlN is fully compatible with conventional silicon technology [2,3] and has a good thermal conductivity [4]. AlN thin films are one of the most interesting materials in microelectronic and optoelectronic devices such as ultraviolet detector, light emitting diodes [5], thermal interface materials [6] , dielectric layers in integrated circuits [7] and piezoelectric materials in surface acoustic wave devices [4]. The aim of this work is to investigate the effect of thichness thin and the substrate orientation on the texture evolution of AlN films deposited by dc magnetron sputtering (dcMS) and HiPIMS. Texture describes the statistical distribution of crystal grain orientations in thin films. The distribution is an important characteristic of the microstructure in thin films, and it determines various electrical, magnetic, and mechanical properties [8]

Results and discussion

Part I- Texture growth of AlN on Si (100)

1- Textures growth of AlN_H films deposided on Si (100),Si(111) substrates by dcMS:

For AlN films grown on Si (111), the fiber (0001)<uviw>can be considered as perfect (fig.1) with low dispersion less than 7.5° (fig.2) for plan (0001) and the texture is particularly marked. For AlN with Si (001) substrate, the fiber texture isless pronounced andmore dispersed (≈ 12°) and also presents preferred orientations. The observed asymmetry increases
with thickness and could be connected to the differences angular between the AlN (0001)and Si (100) which lead toafull distortion.

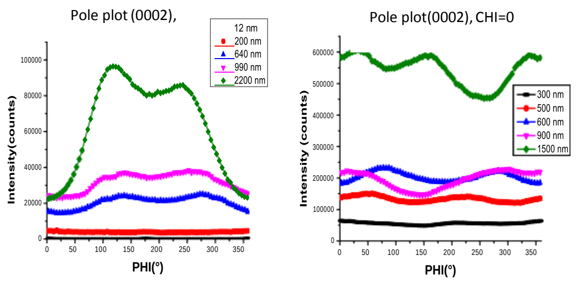


Figure. 1. Intensity evolution report to the azimuth angle PHI.

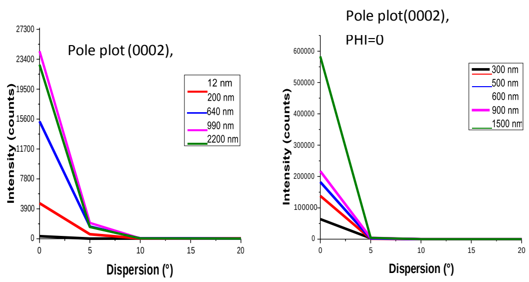


Figure 2.Dispersion angle of (0001) fiber.

The (10-11) and (10-12) pole figure confirm the presence of reinforcements on the (0001) fiber (Fig3). The angles betweenthese reinforcementsare about60° and 120° in the case of AlN on Si (100).

(a) (b)

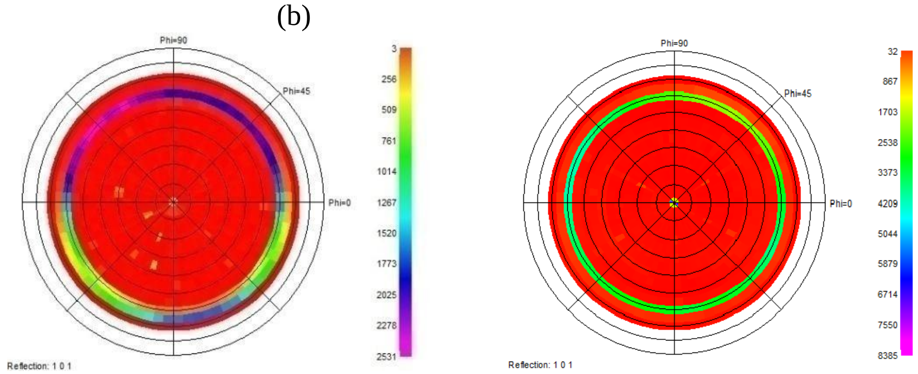


Figure .3. Experimental (10-11) (2θ= 37.89°) pole figure of AlN_H on:
(a) AlN(2200nm)/Si(100), (b) AlN(1500nm)/Si(111)

2- Textured growth of AlN_H films deposided on Si(100) by dcMS and HiPIMS

Figure 3 and 4 shows the intensity evolution report to azimuth angle PHI, at tilt angle CHI=0, for AlN_H films deposited by dcMS and HiPIMS. For AlN_H films grown by HiPMS, the texture is particularly marked and the fiber (0001)<uviw> can be considered as perfect. Nevertheless, for AlN_H thin films deposited by dcMS, the fiber (0001) is less homogenous.

(0002) Pole plot

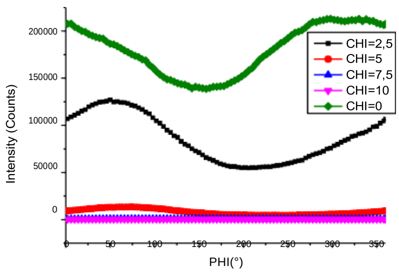


Figure 3. Intensity evolution report to azimuth angle PHIfor CHI=0 to 10°

(0002) Pole plot

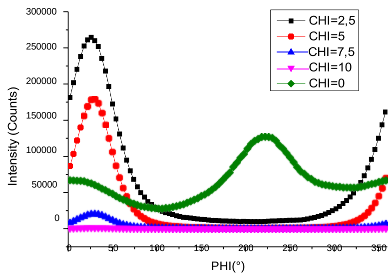
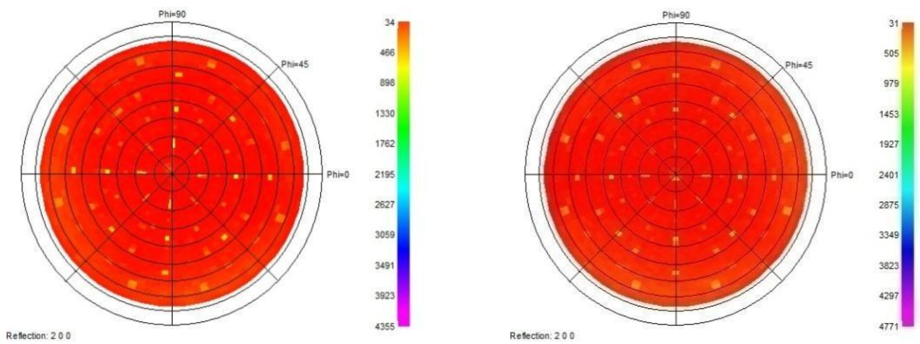


Figure 4. Intensity evolution report to azimuth angle PHIfor CHI=0 to 10°

The difference of texture in the case of dcMS and HiPIMS (Figure 3 and 4) can be explained on the existence of an amorphous region with a thickness of a few nano-meters between the AlN layer and the silicon (100) substrate in the case of dcMS. Such amorphous layer may be derived from the native SiO2 layer but in the cae of HiPIMS method, the interface between the film and the Si substrate is sharp, which indicates a local epitaxial growth of AlN on the Si substrate. The local absence of the amorphous SiO2 layer in the case a deposited film by HIPIMS could be due to high ion bombardment, which likely leads to cathodic re-sputtering of the substrate and cleans the surface of the substrate at the start of film deposition. The ion bombardment may be enough to remove the SiO2 layer and thus results in a kind of continuous growth AlN preferentially oriented along c-axis on the Si substrate [9].

3- Textured growth of AlN_C films deposided on Si(100) by dcMS and HiPIMS

For AlN_C, the characterization is more confused than the hexagonal phase because the peaks of AlN_C are less pronounced than those of AlN_H. On the other hand, very few references exist for sake of comparison. The presence of AlN_C phase was showed on the experimental (200) pole figure for AlN_C (Figure 5) and also on (0001) AlN_H (Figure 6), which is coinciding with (111) pole figure AlN_C (2θ= 37.78°). The high intensity of (0001) fiber hides the AlN_C response (Figure 4a), we observe (111) pole figure by removing the pole figure center (Figure 4b). Noted, the (0001) fiber for AlN_H is more marked in the case of HiPIMS compared to the dcMS, while the scales of intensity are almost identical for AlN_C, in both dcMS and HiPIMS.



(a) (b)

Figure 5. Experimental {200} pole figure (2θ= 43.91°) of AlN_C : (a) dcMS, (b) HiPIMS.

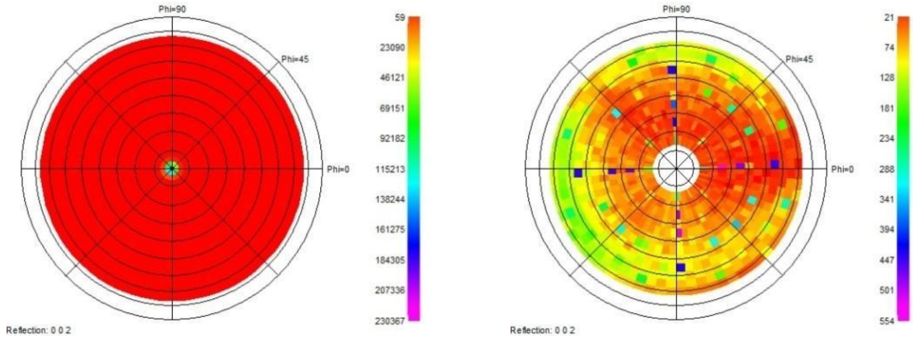


Figure 6.Experimental (0002) pole figure (2θ=36.04°) of AlN_H for HiPIMS method: (a) CHI=0 to 75° (b) CHI=15 to CHI=70°.

Part II- The different possibility of growth of AlN on Si (100)

The most research works concerning AlN films have been focused on the wurtzite crystal phase,However the cubic AlN has many interesting properties, which are very different from those of the hexagonal phase. For example, is attracting more interest for its higher crystal- lographic symmetry, and it is expected to exhibit higher thermal conductivity, electrical resistivity, and acoustic velocity than h-AlN. Anyway this phaseis stilldifficult tocharacterize [10]. In other III-V compounds, cubic films of GaN and InN have been epitaxially grown on various substrates. Atomic radius and ionization energy of Al are almost same as those of Ga. Thus, it is expected that politype of AlN films is controllable by selecting suitable growth conditions such as substrate crystal structure, substrate orientation, and lattice matching between the film and the substrate. However, there have been few reports which suggested the epitaxial growth of c-AlN on TiN and Si substrates.
In this part, we report the different possibility on the growth of AlN films on Si (100). The atomique arrangements are shown in figure 7.

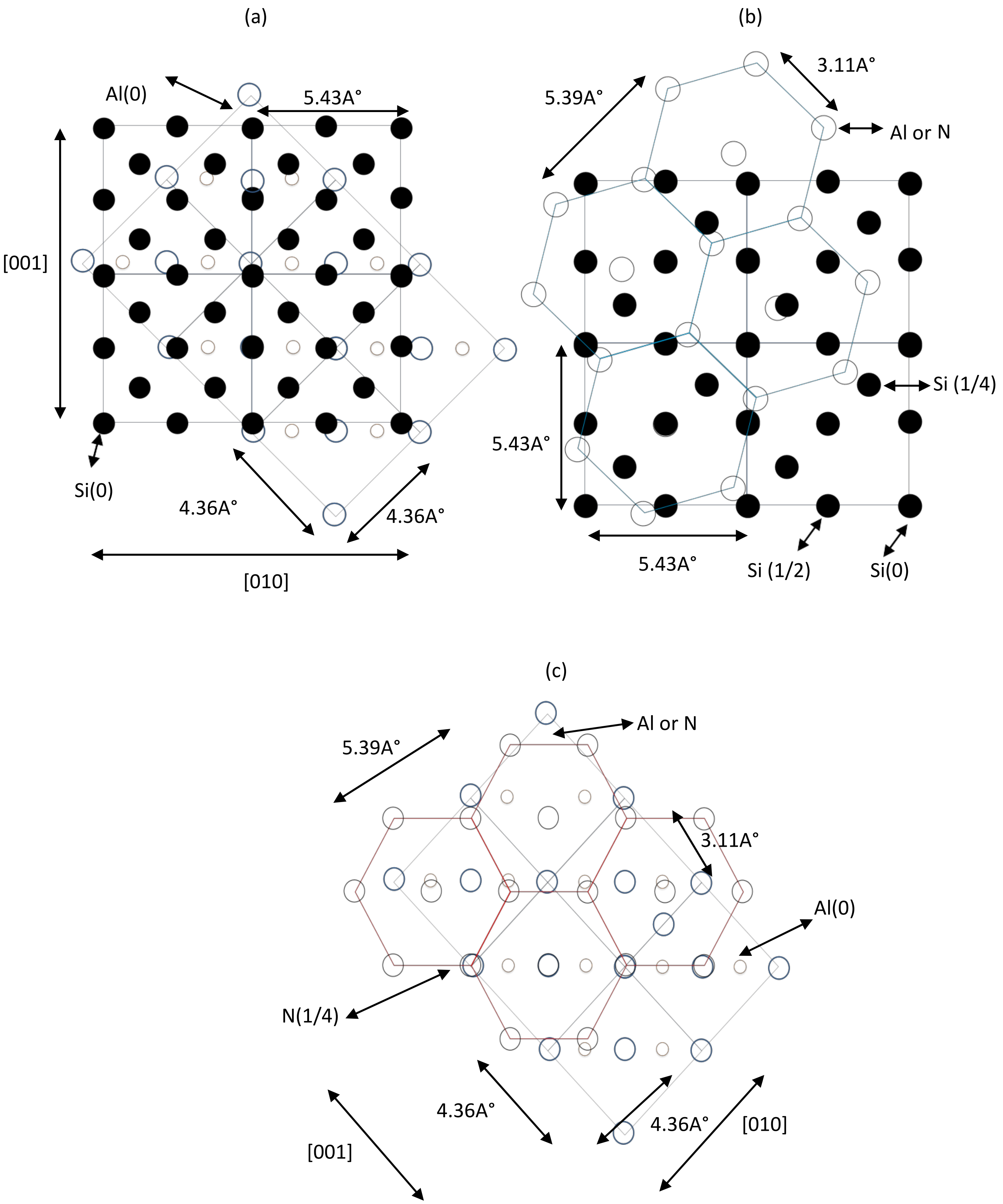


Figure.7. The atomic arrangements of (a) the epitaxial (100)AlN_C/(100) Si interface, (b) the epitaxial (0001) AlN_H/(100)Si interface and (c) AlN_H(0001)/AlN_C(100). ●Si, ○, N ○

Since there is probably no epitaxial relationship between AlN_H and Si (100) similar to the case between AlN_H and TiN(100) and MgO(100), there are actually two epitaxial relationship between AlN_H and (001) silicon, a type of terrace following the orientation of the silicon dimers (0001) AlN // (001) Si and [-2110] AlN1 // [01-10] AlN2 // [110] Si. The AlN epitaxial layer is composed of two fields which are rotated 30 ° relative to each other. The presence of two fields generates a high density of defects and it is particularly difficult to optimize the growth parameters to get a smooth growth front [11]. The interfacial energy at AlN_C/Si (100) and AlN_H/AlN_C should be relatively small than the energy at AlN_H on Si (100). In the case of GaN, it has been demonstrated that epitaxial growth of GaN_C and GaN_H was controlled only by changing the growth conditions [12]. In our case, we hypothesize that very thin sphalerite-type AlN_C layer was formed on Si(100) by PVD methods, this thin layer favors the grown of AlN_H similar to the case of AlN on MgO (100)[13].

Conclusions

We have made a comparative study of the texture evolution of AlN films (3µm thick) deposited by conventional dcMS and HiPIMS. For AlN_H, the texture is particularly marked in the case of HiPIMS and the fiber (0001)<uviw> can be considered as perfect, with low dispersion. HiPIMS method gives a more perfect fiber with low dispersion (5°) while the dcMS gives an asymmetric fiber, with preferred orientations. Moreover, for AlN_C, our first results show its presence in all samples, suggesting that it is reoriented under stress effect and does not appear as a metastable phase, as generally admitted.

References

1. A. Shah, A. Mahmood, Phys. B Condens, ―Effect of Cr implantation on structural and optical properties of AlN thin films,‖ *Matter*,407 (2012), 3991.
2. C. Caliendo, P. Imperatori, and G. Scavia, ―Quasi-epitaxial growth of crystalline wurtzite AlN thin films on Si(001) by RF magnetron sputtering,‖ (Proc. IEEE Ultrason Symp. 2009),1614.
3. T. Aubert, M. B. Assouar, O. Legrani, O. Elmazria, C. Tiusan, and S. Robert, ―Highly textured growth of AlN films on sapphire by magnetron sputtering for high temperature surface acoustic wave applications,‖ *Journal of Vacuum Science & TechnologyA*, 29 (021010) (2011).
4. K. Ait Aissa, A. Achour , J. Camus, L. Le Brizoual, P.-Y. Jouan, M.-A. Djouadi, ―Comparison of the structural properties and residual stress of AlN films deposited by dc magnetron sputtering and high power impulse magnetron sputtering at different working pressures,‖ *Thin Solide Films*, 550 (2014), 264-267
5. S. Joblot, E. Feltin, E. Beraudo, P. Vennéguès, M. Leroux, F. Omnès, M. Laügt, Y.Cordier,
―Hexagonal c-axis GaN layers grown by metallorganic vapor-phase epitaxy on Si (001),‖ *J. Cryst. Growth*, 280 (2005), 53.
6. C. Duquenne, M.P. Besland, P.Y. Tessier, E. Gautron, Y. Scudeller, D. Averty, ―Thermal conductivity of aluminium nitride thin films prepared by reactive magnetron sputtering,‖ *J. Phys. D.Appl. Phys.*, 45 (2012), 015301.
7. Toshihiro Kamohara, Morito Akiyama, Naohiro Ueno, Kazuhiro Nonaka, and Noriyuki Kuwano,
―Local epitaxial growth of aluminum nitride and molybdenum thin films in fiber texture using aluminum nitride interlayer,‖ *Applied Physics Letters*, 89 (071919) (2006).