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Growth of inclined c-axis AlN films in planar system for BAW devices

A. Fardeheb-Mammeri[1,2], M. B. Assouar[1*], O. Elmazria[1], J-J. Fundenberger[3], B. Benyoucef[2]

[1]Laboratoire de Physique des Milieux Ionisés et Applications, UMR 7040 CNRS, Université de Nancy, Boulevard des Aiguilletes -BP 239, F-54506 Vandoeuvre-lès-Nancy Cédex (France)
[2]Unité de Recherche sur les Matériaux et les Energies Renouvelables(URMER), université Abou-bekr Belkaïd B.P.119, 13000 Tlemcen (Algérie).
[3]Laboratoire d'Etude de texture et Application aux Matériaux, UMR CNRS 7078, Université Paul Verlaine, Metz, France

[*]badreddine.assouar@lpmi.uhp-nancy.*fr*

Abstract

Piezoelectric AlN films are of continued interest for the excitation of acoustic waves for surface acoustic wave (SAW) and bulk acoustic wave (BAW) devices. This paper reports on the growth and the characterisation of AlN thin films with inclined c-axis. These films are of significant interest for shear waves generation in view of realisation of film bulk acoustic wave resonators (FBAR) operating as liquid sensor. AlN films were deposited on silicon wafers by RF magnetron sputtering planar system under various deposition parameters including pulverisation pressure and nitrogen concentration, without any additional modification of the equipment. The crystalline orientation and inclination of c-axis of obtained AlN thin films were investigated using X-ray diffraction and field emission scanning electronic microscopy (FESEM).

After the characterisation of deposited AlN films at different experimental parameters, we describe the realisation of BAW device. In fact, we present the realisation of over mode FBAR which made to point out the excitation of shear waves and the determination of shear velocity and effective coupling versus c-axis inclination. Then, AlN films were deposited between two electrodes on doubles polished faces silicon substrate and the realised device was characterised in terms of frequency response to point out the longitudinal and shear over modes.

1. Introduction

Piezoelectric AlN thin films are of continued interest for the excitation of acoustic waves for surface acoustic wave (SAW) and bulk acoustic wave (BAW) devices [1, 2, 3]. Many growth methods such as MO-CVD [4, 5], plasma CVD [6], magnetron sputtering [7, 8] have been used to deposit these films in order to generate specific modes of surface or bulk waves. In the most of these techniques, the grown films show a strong tendency to grow with their c-axis perpendicular to the film plane. The purpose of this study is to obtain AlN thin films with inclined c-axis suitable for shear wave excitation using a planar deposition system. Reactive sputtering is a commonly used method for the deposition of thin films, since it is compatible with the planar technology in addition to being a low temperature technique with excellent thickness uniformity [9, 10]. The obtaining of c-axis inclined AlN films allows the realisation of film bulk acoustic resonators (FBAR) based on shear excitation for liquid sensors applications. In fact, the shear waves are more sensitive in liquid media than longitudinal ones. Shear acoustic waves do not produce any compressional motion into the liquid and thereby no energy leakage [11]. In this paper, we report on the growth and the characterisation of c-axis inclined AlN films deposited using a planar sputtering system without any additional hardware modification. The advantage of this system is that we can achieve relatively good thickness uniformity of AlN films on the 3 inch (100) silicon wafer which we have used in this study. We can also obtain a good growth rate than the others methods based on adding hardware modification on system or based on deposition on tilted substrates, even if in the last case a higher inclination of c-axis can be obtained. We present in this study, the results obtained on our planar deposition system and we demonstrate that we can obtain a c-axis inclined AlN thin film without hardware modification and at low temperature.

Experimental methods used for growth AlN films show a strong tendency to grow with their c-axis perpendicular to the film plane. The purpose of this study is to obtain c-axis inclined AlN films in order to excite shear acoustic waves in bulk acoustic wave (BAW) resonators. Figure 1 shows the cross section of an over moded resonator (HBAR) dedicated to liquid sensors.

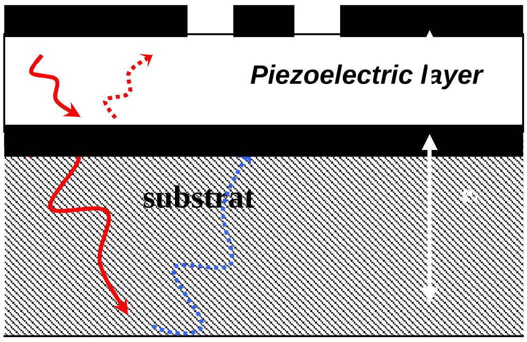

Figure 1: Cross view of an over moded resonator (HBAR)

2. Experiments

500nm AlN thin films were deposited reactively from an 99,99% pure aluminium target and 99,999% pure nitrogen and argon gas mixture with a conventional RF magnetron sputtering planar system (figure 2). The heater temperature was varied from 100°C to 300°C. Pressure ranged from 4.10^{-3} to 2.10^{-2}mbar. The RF power applied to the cathode was fixed to 200W. The distance between target and substrate was around 80mm.

The AlN films deposition was carried out on an amorphous SiO_2 dielectric layer deposited firstly on the silicon substrate. The role of this amorphous layer (buffer layer) is to induce no particular preferred orientation on the surface, rather than all orientations are possible.

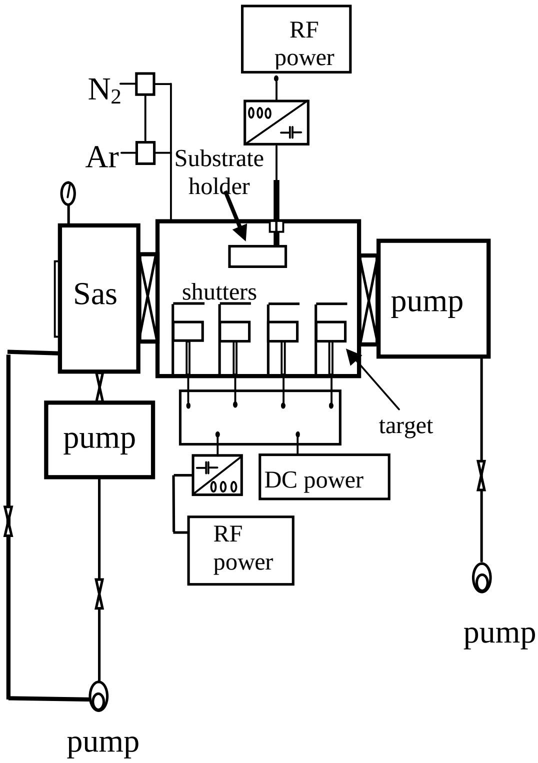

Figure 2: Schematic of magnetron system without any additional hardware modification

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X-ray diffraction using Cu-kα cathode has been used to determine the crystalline properties of the AlN thin films in terms of preferred orientation and of c axis inclination by θ/2θ and χ scan measurements respectively as function of experimental growth parameters. The degree of orientation, which is quantified by the full width half maximum (FWHM) value of the rocking curve corresponding to (002) X-ray diffraction peak was determined. Cross sections of the films were observed using a field emission scanning electron microscopy (FESEM) in order to characterise the thickness morphology and to determine the columns size of AlN thin films.

3. Results and discussion

First of all, the X-ray diffraction in θ/2θ scan mode was carried out on synthesised AlN samples deposited on 3” silicon wafer in various growth conditions. We present in this study only the effect of the pressure on c-axis inclination of AlN films. The other experimental parameters are: 200W RF power, 70%N_2 in Ar/N_2 gas mixture and a temperature of 200°C. The morphological and structural analyses were done on all the parts of the wafer. Two parts of the 3″ wafer used in experiments are considered as shown in figure 3. The part (1) represents the central part of the wafer estimated at 2 cm diameter and the part (2) is concerned the rest of the wafer (figure3).

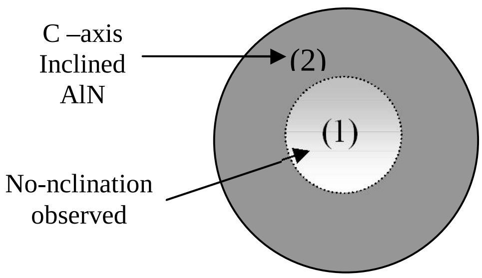

Figure 3: Schematisation of different parts of Si (100) 3″ wafer

In figure 4, the XRD patterns show the preferred orientations of the deposited AlN thin films in different pulverisation pressure. One can observe also the peaks corresponding to the (100) orientation which means that the c-axis of AlN films could be inclined from the normal of the surface.

The XRD spectra of figure 4 were obtained on all wafer parts except the central part of the wafer estimated at 2 cm diameter (part 1). In this central part, we obtain a pure (002) preferred orientation. Cross section FESEM observation in this part shows very perpendicular AlN columns. Concerning the rest of the wafer (part 2) which not include the central part, the evolution of the intensities of these peaks is not very clear even if the decreasing of the pulverisation pressure induces significant increasing of (002) peak intensity. We can also observe a slight shift of XRD spectrum concerning the AlN sample deposited at the lower pressure.

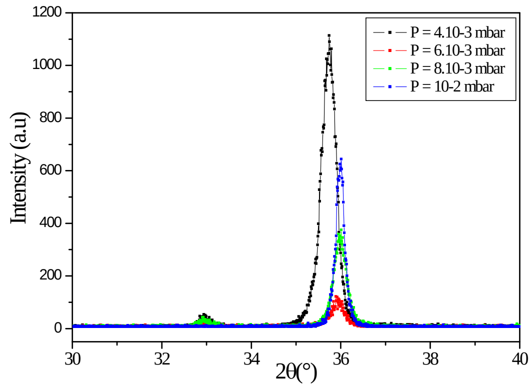

Figure 4: XRD spectra of AlN thin films deposited at different pressures

In order to investigate this aspect and to determine the morphology of the AlN films elaborated in different pressures, FESEM analysis was used. In the next, all the presented results will concern only the part 2 of the wafer which presents c-axis inclination. Figure 5 shows four cross section FESEM images for samples synthesised at 4.10^{-3}mbar, 6.10^{-3}mbar, 8.10^{-3}mbar and 10^{-2}mbar. One can observe clearly that the AlN columns are inclined from the normal to the surface. The columns size is estimated of about 20nm. From these characterisations using FESEM and XRD in θ/2θ scan mode, we can affirm that we have obtained a c-axis inclined AlN films. We can also observe from this figure that the c-axis inclination increases with the pressure.

However, we can not by these analyses quantify the degree of this c-axis inclination. Then, we have to measure directly this inclination in order to determine the shear coupling coefficient of our AlN thin films. In fact, the coupling coefficient of the shear mode which we would like to generate in these films, exists only in inclined AlN films and increases with the inclination until 35° which represents the maximum of this coupling [12].

To have a maximum coupling, we have to obtain a maximum inclination of AlN c-axis. XRD characterisation using χ mode was used in order to determine directly the inclination of c-axis (figure 6-a and 6-b).

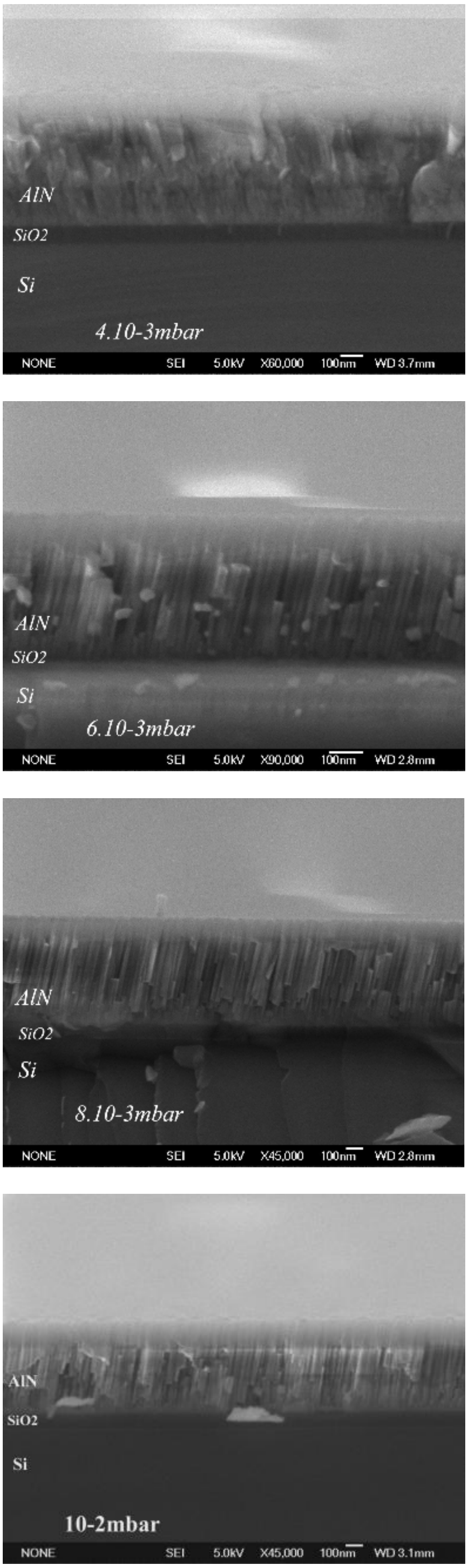

Figure 5: Cross sectional FESEM images of the AlN films synthesised under different pulverisation pressure.

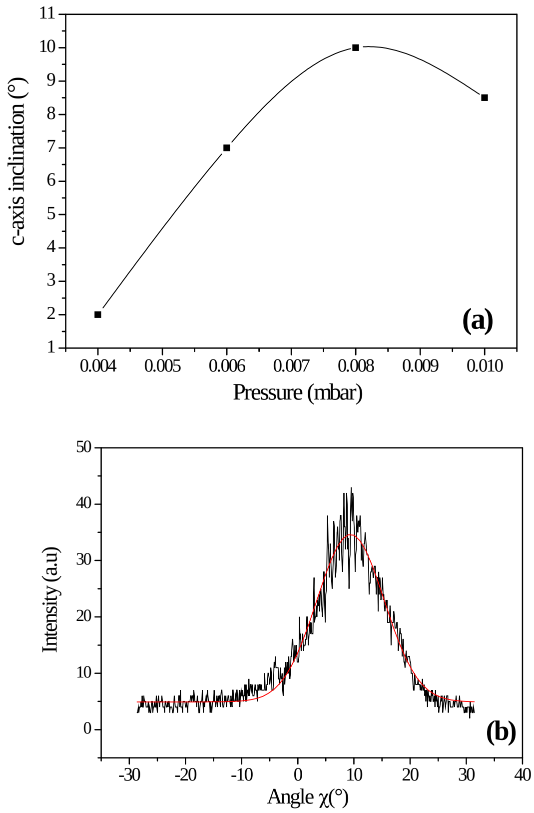

Figure 6: a- The evolution of the c-axis inclination with the pressure.
b- Typical χ scan mode measurement showing an inclination of about 10° of c-axis

One can observe that the c-axis inclination increases with the pressure. In fact, at low pressure, films deposited shows grains staying quasi vertical to the film (inclination of 1° to 2°). This observation confirms the fact that θ/2θ XRD spectrum of the AlN film synthesised at 4.10^{-3}mbar exhibits a high (002) orientation as shown in figure 7.

The transformation from quasi-vertical to tilted growth (inclination up to 10° of c-axis) could be induced by the decreasing of ad-atom mobility and by shadowing effect due to higher pressure [13, 14]. In the other hand, the obtaining of c-axis inclination only in the part 2 of the wafer is due to the oblique incidence. In fact, oblique incidence is due to the cosine distribution of sputtered particles, and explains also the fact that we haven't obtained c-axis inclination in the centre of the wafer.
Furthermore, the SiO_2 buffer layer plays a very crucial role in the deposition mechanism. In fact, the buffer amorphous layer has no particular preferred nuclei orientations, rather

than all orientations are possible, and then the atoms arriving on the substrate with oblique incidence have more ability to induce inclined orientation deposition. This means that the cones aligned with the inclined net flux direction grow fastest than the other ones (competitive growth regime) inducing the obtaining of c-axis inclined films. The deposition mechanism of c axis inclined AlN films is illustrated on figure 7.

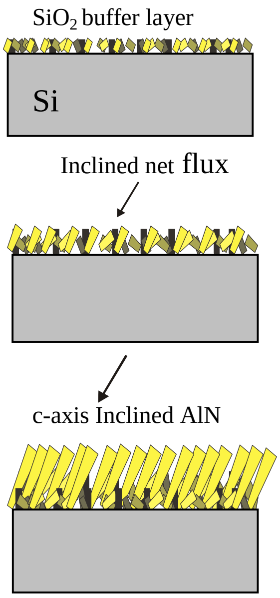

Figure 7: Schematic of growth mechanism of c axis inclined AlN films

To investigate the degree of the orientation of inclined c-axis, rocking curve measurement was done. Figure 8 shows the measurement carried out the AlN film exhibiting a 10° c-axis inclination. The FWHM of rocking curve is about of 5.7°, which demonstrates that the inclined AlN film is well oriented on the tilted c-axis.

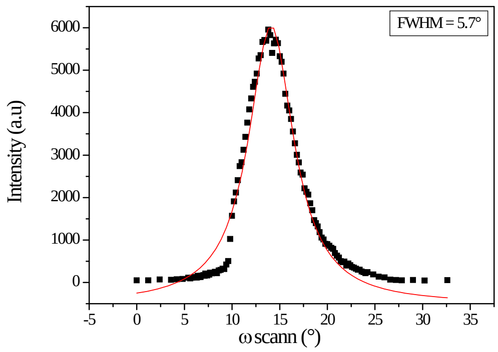

Figure 8: Rocking curve on (002) orientation of c-axis inclined AlN thin film

In this work, the c-axis inclination was obtained on 3 inch substrate except for the central part estimated at 2 cm diameter. Thus, about of 74% of 3″ substrate presents c-axis inclination with uniform thickness.

4. Conclusion

The interest of this study is the deposition of c-axis inclined AlN thin films by magnetron sputtering at low temperature in planar system without any hardware modification and without the inclination of substrate. We have shown that we can obtain c-axis inclined AlN thin film with inclination of 10° on about of 74% of 3” (100) silicon wafer. The structural and morphological characterisations were pointed out the columnar aspect of deposited AlN films and the well oriented of c-axis on tilted orientation revealed by XRD rocking curve. We have shown that the obtaining of c-axis inclined films depends on the pulverisation pressure and on the oblique incidence, which explains also the no observed inclination in the centre of wafer. The growth mechanism was discussed and explained. The low temperature deposition of inclined c-axis AlN films is very important in regard to the next technological steps to achieve the FBAR device. Further work is needed to improve the inclination of deposited AlN films in order to increase the shear mode coupling.

5. References

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