Characterization of AlN Thin Films for Applications in Bulk Acoustic Filters

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Abstract:

This paper describes the characterization of aluminum nitride (AlN) thin films, deposited using reactive magnetron sputtering, for applications in bulk acoustic filters. Argon (Ar) and nitrous oxide (N_2, reactive gas) flow and direct current (DC) bias were controlled to optimize film properties. Increasing gas flow rates resulted in reduced compressive stress. Increasing the Ar flow improved crystal orientation quality while increasing the N_2 flow degraded crystal orientation. A higher DC bias led to a more uniform film. Acoustically coupled monolithic filters were fabricated after the conditions for the best quality films were determined.

Introduction:

The objective of this study was to optimize AlN films for use in filter devices such as thickness-mode thin-film piezoelectric-on-substrate (TPoS) filters [1]. The AlN layer influences device properties such as center frequency, bandwidth and insertion loss. AlN is a material of choice for use in complementary metal oxide semiconductor (CMOS)-compatible electro-acoustic devices as it can be deposited at low temperatures (below 400°C). For low loss filters, AlN was chosen as the transduction material because it has low dielectric loss, high resistivity, and a reasonably large piezoelectric coupling [1]. Reactive sputtering of AlN was characterized on molybdenum (Mo) electrodes with a titanium (Ti) seed layer on a silicon (Si) wafer since previous studies have shown that Mo and Ti are optimal materials for deposition of highly c-axis oriented AlN films [2].

Deposition parameters of AlN were optimized for film stress, crystal orientation, and uniformity. Sputtered AlN films are polycrystalline in nature and the effective piezoelectric coupling is a vector summation of grain orientation. Thus, good c-axis crystalline orientation is important to achieve low loss devices. The piezoelectric properties of the film have a strong correlation with the full-width at half maximum (FWHM) value of the x-ray diffraction (XRD) rocking curve [3], and they can be controlled by adjusting gas flow rates. Large film stress leads to complications in releasing suspended structures.

A released device with high stress could have large device bow or film cracking. While reducing device size can help alleviate these problems, the motional impedance increases with reducing device area. As a result, control of film stress is important in order to achieve good device yield. Changing gas flow rates causes thickness uniformity degradation, which can then be independently tuned by applying a DC bias to the substrate.

Experimental Methods:

The 1 μm thick AlN characterization films were deposited on patterned bottom electrodes (100 nm Mo on a 20 nm Ti seed layer) on a clean 4-inch <100> Si wafer. AlN films were deposited using the Tegal AMS 2004 dual cathode reactive magnetron sputtering system. Post film characterization, TPoS filters were fabricated on silicon-on-insulator (SOI) wafers using published fabrication methods [1].

In order to characterize the effect of gas flow variation, N_2 flow was held constant at 28 standard cubic centimeters per minute (sccm) while varying Ar flow. Ar flow was held constant at 35 and 45 sccm in two separate experiments while varying the N_2 flow (Figures 1-3). DC bias was varied from 0.1 to 0.7 kW to tailor the uniformity (Figure 4). AlN film crystal orientation was characterized by taking XRD measurements with a Rigaku Ultima IV system.

Results and Conclusions:

Increasing the gas flow rate reduced compressive stress (Figures 1 and 2). At higher flow rates, further increasing the flow rates had a smaller impact on the stress of the films. When the Ar flow rate was constant at 45 sccm, the
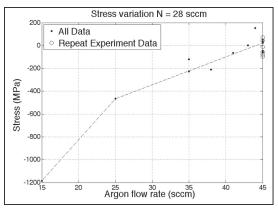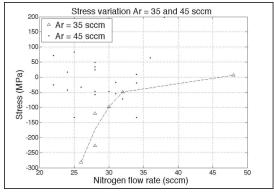
Figure 1: Stress variation with Ar flow rate.

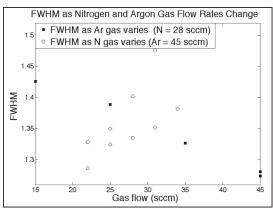*Figure 2: Stress variation with N_2 flow rate.*

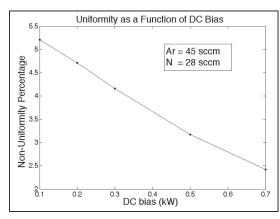
Figure 3: FWHM variation with gas flow rate.

Figure 4: Uniformity variation with DC bias.

total gas flow appeared high enough that increasing N_2 flow had little effect on stress. At lower flow rates, species in the sputtering chamber transfer more energy to the substrate due to fewer collisions in the sputtering chamber. This allows atoms in the substrate to relocate more easily, enabling the removal of vacant sites and an increase in compressive stress [4]. The ion bombardment energy is reduced with increased flow rates and may not exceed the activation energy, thereby causing further increases in flow rate to have a smaller impact on the stress.

A peak at 35.8° on a θ-2θ scan verified that the AlN films had a c-axis orientation. Rocking curves indicated FWHM measurements from 1.25° to 1.54°. Increasing N_2 flow led to an increase in FWHM, implying worse film orientation, while increasing Ar flow led to a decrease in FWHM (Figure 3). At lower flow rates, we expected a better FWHM because species colliding with the substrate transfer more energy to the ad-atoms of the substrate, allowing for better crystal formation. Ar ions have been shown to affect crystal orientation more than N species in the chamber due to a larger energy transfer to the ad-atoms of the substrate [5]. Despite higher flow rates, it is possible that FWHM improved with increased Ar because of the greater role of Ar ions in energy transfer.

Film uniformity varied linearly between 2.4% to 5.2% with DC bias (Figure 4). At a lower Ar flow of 35 sccm, film uniformities better than 1.8% were achieved.

Acknowledgements:

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