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Second overtone mode (0001)/(000-1) ScAlN multilayer FBARs fabricated by anode RF bias deposition
陽極 RF バイアス成膜法による 2 次モード極性反転 ScAlN 多層 FBAR

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1. Introduction

AlN has high sound velocity, heat conductivity and low acoustic attenuation. Therefore, AlN film acoustic wave resonators (FBARs) have been used commercially for the GHz filter of mobile communications [1]. However, its low electromechanical coupling coefficient k is a serious problem in the filter applications because the bandwidth of the filter is determined by the k value of the resonators. Recently, Akiyama et al. reported the enhancement of piezoelectricity in Sc doped AlN film [2]. The ScAlN film is expected to have a high k value and a low acoustic attenuation, and therefore has attracted attention as a potential material for FBAR applications.

c-axis oriented AlN film can be classified as either an (000-1) N-polarity or an (0001) Al-polarity. The control of the polarity makes it possible to obtain high-performance FBAR. Polarity-inverted multilayer FBAR excites high overtone mode resonance, enabling high frequency or high power operation. The insertion of a buffer layer is one of the techniques to obtaining polarity inversion in AlN films [3-5]. However, the polarity-inverted multilayer structure has not been obtained by these polarity inversion techniques because the polarity of the second and subsequent layers cannot be controlled. Polarity inversion, which does not depend on the properties of the under-layer surface, makes it possible to obtain polarity-inverted multilayer structure. We previously investigated the development of c-axis parallel AlN films by ion beam irradiation during film growth [6]. We explained that this was caused by the ion beam tolerant anisotropy of AlN crystal. Similarly, we assumed that the polarity inversion of AlN films is induced by ion beam tolerant anisotropy between (0001) and (000-1) planes.

In this study, the effect of the ion beam irradiation on the polarity of c-axis oriented ScAlN films was investigated [7]. In addition, second overtone mode polarity-inverted (000-1)/(0001) ScAlN FBAR was prepared.

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2. ScAlN film growth

To investigate the effect of the ion beam irradiation during ScAlN film growth on the polarity, c-axis oriented ScAlN films were grown by anode RF bias deposition [7]. To enhance ion beam irradiation during the film growth, the substrate was set on an anode with magnetron circuit, and 14 MHz RF bias at 0－2 W was applied to the substrate. The RF bias power was monitored by an RF power meter with 3W full-range. Twenty Sc ingots (1.0 g in total, Kojundo chemical laboratory Co., Ltd.) were placed at the 2-inch Al target, and c-axis oriented ScAlN film was grown on the substrate. (0001) oriented Ti bottom electrode (100－120 nm, FWHM of rocking curves = 4.0－4.8°) / silica glass (0.5 mm thick) was used as the substrate. Ti bottom electrode was grown by a DC sputtering deposition. The RF power to the target, the total gas pressure and N_2/Ar gas ratio were set to be 200 W, 0.75 Pa and 1/2, respectively. The film thickness of all samples was adjusted to approximately1.5 μm.

For comparison, additional ScAlN film was grown using the condition which is close to the commonly-used AlN film growth condition. For this film growth, the enhancement of the ion beam irradiation by the magnetic fields of magnetron circuit was suppressed by covering the anode with an iron plate.

3. Polarity of ScAlN films

The polarity of the ScAlN films was determined by a press test [7]. A c-plane ZnO single crystal (Tokyo Denpa Co., Ltd., 10×10×0.5 mm3, >10^{10} Ω*m) was prepared as a reference sample for the press test. When the compressive stress was applied, a negative or a positive amplitude response appeared in the Zn-polar or O-polar ZnO single crystal, respectively, as shown in **Fig. 1 (b)**.

As shown in **Fig. 1 (a)**, a negative response, indicating Al-polarity, were observed in the ScAlN film grown using the condition which is close to the commonly-used AlN film growth condition, and in the films grown with an RF bias of 1.00－2.00 W. In contrast, a positive response, indicating N-polarity, were observed in the film grown with an

RF bias of 0−0.75 W. These results demonstrate that the polarity of the ScAlN film is inverted from Al-polarity to N-polarity by enhancing ion beam irradiation during the film growth [7]. As previously assumed, the polarity inversion by ion beam irradiation may result from ion beam tolerant anisotropy between N-polar (000-1) and Al-polar (0001) crystal planes. We deduced that Al-polar (0001) oriented crystal growth is inhibited by ion beam irradiation, and relatively damage tolerant N-polar (000-1) oriented crystals develop preferentially.

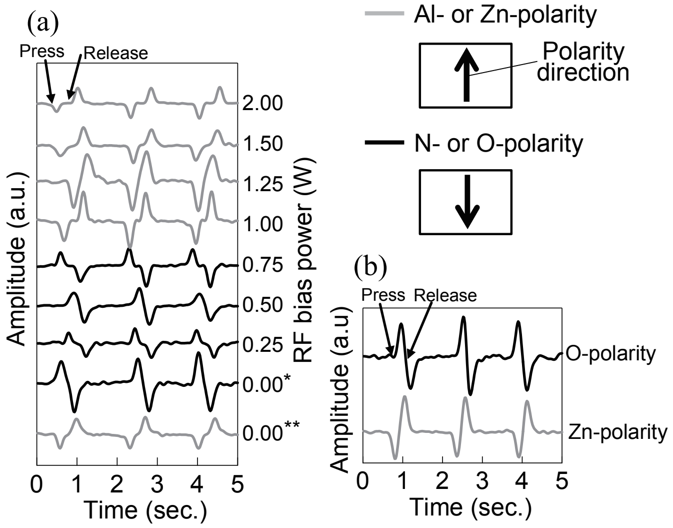

Fig. 1 Piezoelectric response of (a) ScAlN films grown with an RF bias to the substrate and (b) ZnO single crystal plate

* ScAlN film grown on the substrate which was set on the anode with magnetron circuit.

** ScAlN film grown on the substrate which was set on the anode where the effect of magnetron circuit was excluded by covering the anode with an iron plate.

4. Polarity inverted ScAlN FBAR

Next, we tried to fabricate the bilayer polarity-inverted ScAlN FBAR. The Al-polar (0001) ScAlN first layer (1.7 μm) was grown on the substrate (Ti bottom electrode/silica glass substrate) using commonly-used AlN film growth condition. The N-polar (000-1) ScAlN second layer (2.0 μm) was grown on the first layer by an RF bias deposition. The RF bias of 0.5 W was applied to the substrate during the second layer growth. Al top electrode was deposited on the film. The FBAR structure, consisting of Al top electrode / (000-1) ScAlN film /(0001) ScAlN film / Ti bottom electrode, was obtained by peeling off the layers from the silica glass substrate. For comparison, a monolayer (0001) ScAlN FBAR was also prepared. The thickness of the monolayer ScAlN film was 4.2 μm.

Fig. 2 shows the frequency characteristic of the admittance of the FBARs. The fundamental (1st) and 3rd mode resonance was excited around 1.0 GHz and 3.4 GHz in the monolayer (0001) ScAlN FBAR. On the other hand, the fundamental and 3rd mode resonance around 1.0 GHz and 3.2 GHz was suppressed, whereas the 2nd mode resonance was excited around 2.3 GHz in the bilayer ScAlN FBAR whose total thickness is approximately equal to that of monolayer FBAR. These results show that the polarity of first and second layers in the bilayer film were completely inverted with each other, regardless of the polarity of the under-layer.

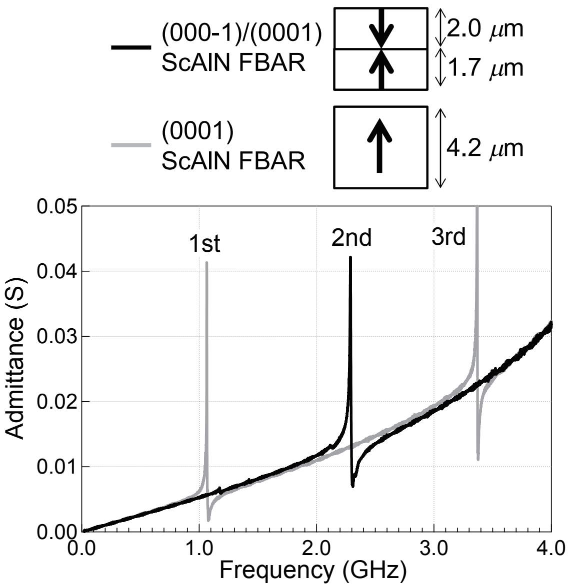

Fig. 2 The frequency characteristic of the admittance in (000-1)/(0001) ScAlN FBAR and (0001) ScAlN FBAR.

5. Conclusion

The polarity of a c-axis oriented ScAlN film was inverted from Al-polarity to N-polarity by enhancing ion beam irradiation during film growth. Second overtone mode resonance excitation demonstrated that the polarity was inverted without depending on the polarity of the under-layer.

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