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1. Introduction

Piezoelectric and ferroelectric materials such as LiNbO\textsubscript{3}, LiTaO\textsubscript{3}, PZT, ZnO and AlN, etc. are widely used in ultrasonic applications, especially in surface acoustic wave filters and sensors, bulk acoustic wave transducers and so on. In these devices, polarity-inverted structure is useful to improve the device performance.

Recently, it has been reported that polarity of ZnO and AlN piezoelectric thin film fabricated by radio frequency (RF) magnetron sputtering method can be switched by growth condition, and polarity-inverted structure can be obtained \cite{1}. That technique must be very important for high performance piezoelectric device applications, because it is applicable to fabricate multi-layered structures. In order to develop polarity-inverted films as well as devices, non-destructive measurement method of the layered polarity-inverted structure is required.

It is known that scanning nonlinear dielectric microscopy (SNDM) is a purely electrical method for measuring the polarization distribution without being influenced by the shielding effect with free charge \cite{2, 3}. It has been reported that SNDM has high spatial resolution in ferroelectric domain measurement on the surface theoretically and experimentally. It is also reported that the measurable depth of SNDM depends on the radius of probe tip and dielectric constant of specimen \cite{4}. Therefore, by considering the tip radius, SNDM can detect the information of polarization about depth direction in layered polarity-inverted thin films. The method for obtaining a depth profile of polarity inverted structure in a layered ferroelectric and/or piezoelectric thin film has been reported in reference \cite{5}.

In this paper, improve the reported work, quantitative thickness measurement in the layered polarity-inverted piezoelectric and/or ferroelectric thin films using scanning nonlinear dielectric microscopy is proposed. It is performed by surface measurement non-destructively.

2. Concept of the measurement

Figure 1 shows a concept of the measurement. Figure 1(a) shows that the tip radius is small relative to the film thickness. In this case, SNDM measure only the property of the top layer. On the other hand, figure 1(b) shows that the tip radius is relatively large. In this case, SDNM measure the average of the property of second layer and top layer, and the output signal depends on the thickness of the top layer as shown in Fig. 2 \cite{5}.

The relation between the SNDM output, tip radius and the dielectric constant has already been investigated precisely in ref. \cite{4}. Applying this investigation to layered structure, and considering these properties, it is expected to obtain the depth profile of the polarity in layered polarity-inverted structure.
3. Quantitative measurement

SNDM signal depends not only on nonlinear dielectric constant $\varepsilon_{333}$ of the sample but also stray capacitance $C_0$ of probe. In case $\varepsilon_{333}$ and $C_0$ are unknown, we need to use 2 probe tip which have different radius.

Vertical axis in Fig. 2 corresponds to equation (1).

$$\frac{\Delta C_{S2}}{\Delta C_{S1}} = \frac{f_{s1}^{st} f_{s1}^{ui} \Delta f_{d1}^{ui}}{f_{s1}^{st} f_{s2}^{ui} \Delta f_{d1}^{ui}}$$

where $\Delta C_{S1}$ shows capacitance variation in SNDM measurement using sufficiently small probe tip (tip 1), that is, the tip detect the signal obtained from only upper layer, and $\Delta C_{S2}$ shows capacitance variation in SNDM measurement using probe tip (tip2) having appropriate tip radius which corresponds to the measureable ragion in Fig. 2. $f_{s1}^{st}$ and $f_{s2}^{st}$ show oscillation frequency in measuring a standard sample with tip1 and tip2, respectively. $f_{s1}^{ui}$ and $f_{s2}^{ui}$ show oscillation frequency in measuring the polarity inverted sample with tip1 and tip2, respectively. $\Delta f_{d1}^{ui}$ and $\Delta f_{d2}^{ui}$ show frequency variation under applying electric field in measuring the polarity inverted ample with tip1 and tip2, respectively.

Fig. 3 shows a measurement result of Sc-AlN fabricated by RF magnetron sputtering method. The thickness is obtained by equation (1).

5. Summary

In this paper, the method for obtaining thickness of polarity inverted structure in a layered ferroelectric and/or piezoelectric thin film using SNDM is proposed. It showed that layer thickness can be estimated from the output signal of SNDM by choosing an appropriate tip radius. Also, we showed an experimental result in AlN films which have polarity-inverted layer fabricated by RF magnetron sputtering. This method can be applied to multi layered structure by measuring with various probe tips having different tip radius and by analyzing the results.

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References