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Proceedings of Symposium on Ultrasonic Electronics, Vol. 36 (2015)
5-7 November, 2015

Quantitative Thickness Measurement in Layered Polarity-Inverted Piezoelectric Thin Films Using Scanning Nonlinear Dielectric Microscopy

走査型非線形誘電率顕微法による層状極性反転圧電膜の層厚の定量測定

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1. Introduction

Piezoelectric and ferroelectric materials such as $LiNbO_3$, $LiTaO_3$, 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 usefull 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 [1]. That technique must be very important for high performance piezoelectric device applications, because it is apricable 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 measureing the polarization distribution without being influenced by the shielding effect with free charge [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 [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 [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 [5].

The relation between the SNDM output, tip radius and the dielectric constant has already been investigated precisely in ref. [4]. Appling this investigation to layerd structure, and considering these properties, it is expected to obtain the depth profile of the polarity in layered polarity-inverted structure.

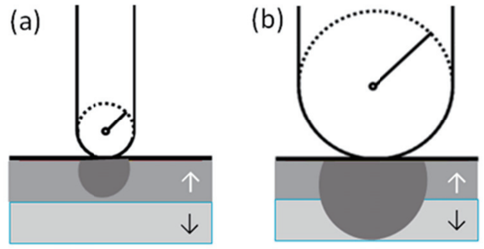

Fig. 1 Schematic drawings of concept of the measurement.
(a): tip radius is small relative to the film thickness,
(b): tip radius is relatively large.

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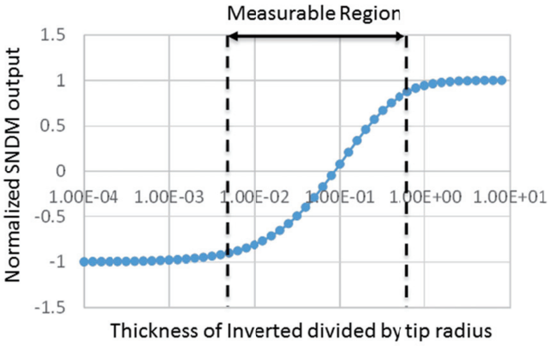

Fig. 2 Relation between normalized SNDM output and inverted layer thickness divided by tip radius. ($\varepsilon_3 = 8$)

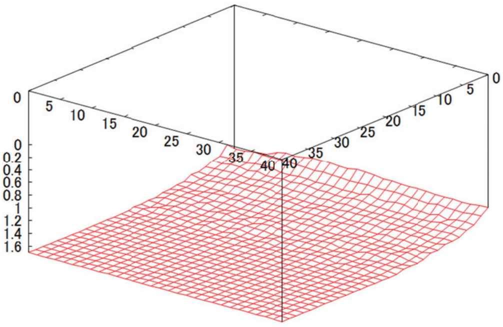

Fig. 3 Thickness profile of inversion layer. Measured area is 3mm square.

3. Quantitative measurement

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

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

$$\frac{\Delta C_{S2}}{\Delta C_{S1}} = \frac{f_{s2}^{st}}{f_{s1}^{st}} \frac{f_{s1}^{ui}}{f_{s2}^{ui}} \frac{\Delta f_{d2}^{ui}}{\Delta f_{d1}^{ui}} \qquad (1)$$

where ΔC_{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 ΔC_{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. Δf_{d1}^{ui} and Δf_{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.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 15K04725. Part of this work was carried out under the Cooperative Research Project Program of the Research Institute of Electrical Communication, Tohoku University.

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