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Bismuth ferrite Thin Films for Advanced FeRAM Devices

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1. Introduction:

The desirable properties of ferroelectric random access memory (FeRAM) device are (1) large remanent polarization so that a large polarization reversal current can be derived from a small area capacitor, (2) low dielectric constant because a high dielectric constant produce a large displacement current and (3) low coercive field for low voltage operation. Presently three materials satisfy these properties; they are $PbZr_xTi_{1-x}O_3$, $SrBi_2Ta_2O_9$, and $(BiLa)_4Ti_3O_{12}$ and shows remanent polarization of 30, 10 and 20 $\mu C/cm^2$ respectively.

We have reported remanent polarization of $90\mu C/cm^2$ in $BiFeO_3$ (BFO) thin film fabricated by chemical solution deposition [1]. This large Pr value is advantageous for the fabrication of advanced high-density FeRAMs. The crystallization temperature of BFO films is lower than 550ºC, which is suitable for implementing BFO capacitors on CMOS logic circuits. $BiFeO_3$ is a multiferroic material because it exhibits ferroelectric and ferromagnetic properties simultaneously. One of the major problems of BFO thin films is low electrical resistivity, which affects the measurement of ferroelectric/ferromagnetic properties at room temperature. Here, we will measure electrical properties in BFO thin films on (100) Si and (0001)- sapphire substrate and discuss the origin of the large polarization .

2. Experimental:

The BFO films were fabricated by a sol-gel method on $Pt/Ti/SiO_2$/(100)Si and Pt/(0001)-sapphire structures. In case of sapphire substrates, we deposited 100-nm-thick Pt bottom electrode films at 500^oC using a sputtering system. The $BiFeO_3$ precursor was spin-coated at 3000 rpm for 30 s and dried on a hot plate in air. This process was repeated several times to obtain the films of desired thickness and then the films were annealed at different temperatures in various gases. The crystalline structure of the film was investigated with a multipurpose x-ray diffractometer (X,Pert-Pro MPD, Philips). The electrical properties of the film capacitors were measured using a standardized ferroelectric test system (Radiant Technologies, RT66a) and an HP4156A precision semiconductor parameter analyzer (Hewlett-Packard). x-ray photoemission spectroscopy (XPS) measurement was also conducted to discuss the electrical properties.

3. Results:

We optimized the growth parameter to fabricated $Pt/BiFeO_3/Pt$ thin film capacitors. The orientation of the film depended upon growth parameters such as annealing temperature, duration, and annealing atmosphere. We found that 5-min annealing at 550^oC in N_2 atmosphere was sufficient to obtained crystallization structure in $BiFeO_3$ thin films as shown in Fig. 1. A small amount of $Bi_2Fe_4O_9$ which presented in the film on Si substrate was reduced by use of the sapphire substrate.

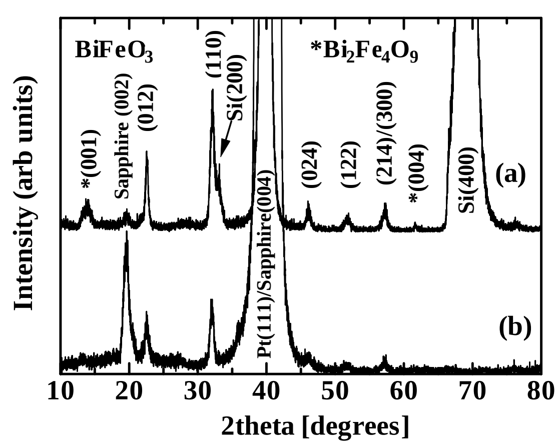

Figure 1 XRD patterns of $BiFeO_3$ thin films on (a) (100)-Si and (b) (0001)-sapphire substrate

For the first time, we measured current density in the range of $10^{-8} A/cm^2$ (Fig. 2) in $BiFeO_3$ thin films at room temperature.

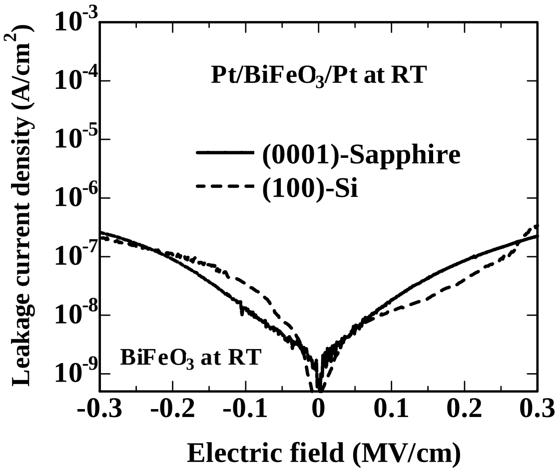

Fig. 2 I-V characteristics of $BiFeO_3$ thin film on (100)-Si and (0001)-sapphire substrates

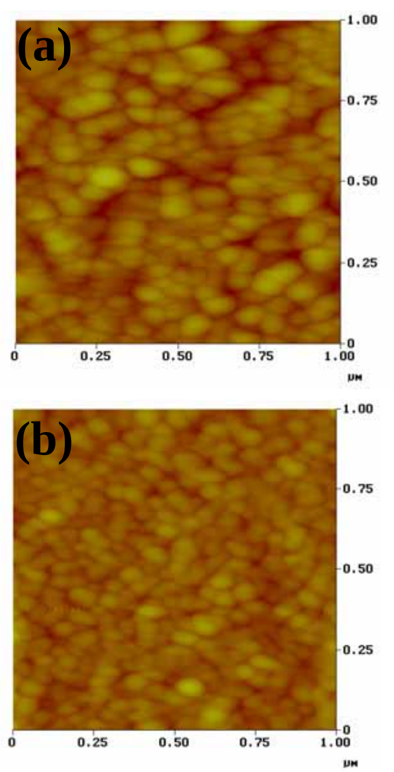

Figure 3 AFM image of $BiFeO_3$ thin film on (a) (100)-Si and (b) (0001)- sapphire substrates

Annealing temperature, atmosphere and substrate were found to play crucial role to control the orientation and microstructure as well as electrical properties of the $BiFeO_3$ films. We observed small grains of 0.1 μm in size in the $BiFeO_3$ film on $Pt/TiO_2/SiO_2/Si$ substrates, which reduced to 0.05 μm in size on sapphire substrate as shown in Fig. 3.

We acquired the well saturated polarization in our $BiFeO_3$ films at 80K. Figure 4 shows the P-V hysteresis loop of $BiFeO_3$ thin film capacitor at 80K with the largest remnant polarization around 100 $\mu C/cm^2$ observed in a $BiFeO_3$ thin film deposited by chemical solution method on sapphire substrate. Finally, in order to investigate the origin of the low leakage current, XPS measurement was conducted. The spectra for Fe2p showed two peaks located at 711and 724.6 eV, which indicate that the valence state of iron is Fe^{3+} [2]. We conclude that the existence of Fe^{3+} is the main reason of the excellent leakage characteristics.

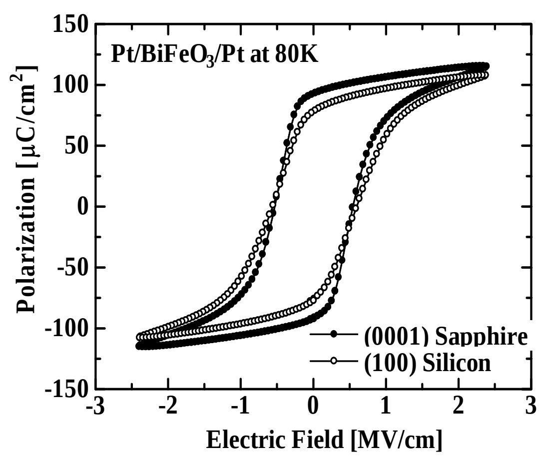

Fig. 4 P-V hysteresis loop of $BiFeO_3$ thin film capacitor at 80K.

References:

[1] S. K. Singh and H. Ishiwara, Jap. J. Appl. Phys.(Express Letter) , in press, May (2005).

[2] K. Y. Yun, M. Noda and M. Okuyama, Appl. Phys. Lett. 83, 3981 (2003).

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