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Overview and Future Challenges of Advanced Materials for FeRAM

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1. Introduction

Ferroelectric random access memory (FeRAM) has been commercialized from low density products. For the future advance of the FeRAM, there are a lot of requirements not only for the device integration and the logic but also for the ferroelectric material itself because the FeRAM basically uses the function of the materials itself, i.e. ferroelectricity, for memory storage. In this review, we try to summarize the state of the art and the feature aspect of the ferroelectric materials for FeRAM based on the results of our groups.

2. Thin film preparation for low voltage operation

Low voltage operation is one of the critical issues for power consumption because it is one of the big advantages of the FeRAM compared to other novel memories. Low voltage operation is realized by decreasing film thickness. We succeeded in 1 V operation with 35nm-thick $Pb(Zr,Ti)O_3$ films by grain-to-grain local epitaxial growth between $Pb(Zr,Ti)O_3$ and the bottom electrode, $SrRuO_3$ [1]. The remanent polarization (*Pr*) value was beyond 40 μC/cm^2 and showed almost no degradation with decreasing film thickness down to 35 nm.

3. Materials with large remanent polarization

Large *Pr* value is also critical issue for the realization of the high density FeRAM consisting of the cell capacitances with small footprint. Otherwise, three dimensional ferroelectric capacitor must be realized having homogeneous film thickness inside the trench together with the homogeneity of the multi composition, which is not perfectly achieved [2]. *Pr* value is determined by the spontaneous polarization (*Ps*), determined by the material itself, and the film orientation. In the following, we discuss the material selection for *Pr* value.

3-1 $Pb(Zr,Ti)O_3$ vs BLSF

Commercialized FeRAM mainly uses $Pb(Zr,Ti)O_3$ or bismuth layer-structured ferroelectrics (BLSF). $(Bi, Nd)_4(Ti, V)_3O_{12}$ is reported to have largest *Ps* value of 58 μC/cm^2 in BLSF family [3]. Taking account of the achieved orientation of the films deposited on Si substrate, the expected maximum *Pr* value on Si is almost the same to be about 54-58 μC/cm^2 for both of $Pb(Zr_{0.4}Ti_{0.6})O_3$ and $(Bi, Nd)_4(Ti,V)_3O_{12}$, meaning that maximum *Pr* value is almost compatible for both materials.

3-2 $BiFeO_3$-based materials

To achieve larger *Pr* value than the present materials, $BiFeO_3$ is a novel candidate because its

Pr value is reported to be beyond 100 μC/cm^2 which is different from the previous data of 4 μC/cm^2 [4]. Figure 1 shows the relationship between the Curie temperature and *Ps*. It is clear that the ferroelectric material having large *Ps* value shows high Curie temperature. The large *Ps* value of $BiFeO_3$ can be explained by high *Tc*, which also lets us imagine large coercive field (*Ec*) because *Ec* is also a function of *Tc*. Large *Ec* value requires the decrease of the film thickness for the low voltage operation mentioned in section 1. This was improved by the substitution and/or solid solution formation of $BiFeO_3$, which also resulted in the decrease of the large leakage current [5, 6].

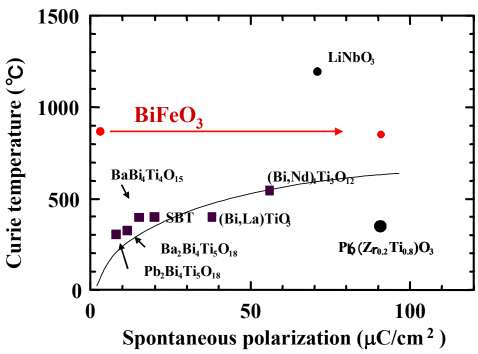

Fig.1 Relationships between Curie temperature and the spontaneous polarization.

3-3 Novel materials

Recently, giant *Ps* values have been estimated for some novel materials, such as $PbVO_3$ and $BiCoO_3$ from the crystal structure analysis [7]. These are mainly high pressure form and are unstable at atmospheric pressure, but are possibly stabilized in film form [8]. However, large *Ec* related to the high *Tc* must be also taken into account as well as the fact that the estimated band gap is very narrow, suggesting the possibility of relatively large leakage current density. Film preparation is under investigation.

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