

Spintronics using interfacial phase change memory, iPCM

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1. INTRODUCTION

Nobody including the present authors had believed so far that spintronics was related to phase change memory (PCM). Interfacial phase change memory (iPCM) however may open a new era and become one of the powerful tools for spintronics. Because of its unique characteristics excluding magnetic elements, it is expected that completely different magnetic devices will be realized using phase change materials besides Fe- or Co-based magnetic device and memory.

The present PCM and the materials whatever works optically or electrically are usually non-magnetic because Ge, Sb and Te are non-magnetic. It was already confirmed [1]. However, the invention of iPCM and the discovery of a room-temperature giant magnetoresistance broke the common sense [2-4]. iPCM is a kind of PCMs, which switches between one *crystalline* phase and another *crystalline* phase, while a typical PCM is operated between *amorphous* and *crystalline* phases. In order to realize the crystal-crystal phase transition in iPCM, a Ge-Sb-Te alloy film is built up using crystalline sub-layers of GeTe and Sb₂Te₃, which share a crystalline growth axis: [111] in *rhomboidal* GeTe and [111] of *A-7-type rhomboidal* Sb₂Te₃. The switching mechanism and the device performance were already reported [5]. Of course, iPCM does not include any magnetic element. Why does iPCM show the giant magnetoresistance? Since the discovery, we have engaged in making clear the mechanism.

2. MODELS

iPCM is a crystalline superlattice built up from heterocrystalline layers of GeTe and Sb₂Te₃: [(GeTe)_l(Sb₂Te₃)_m]_n block, where *l*, *m* and *n* are integers. For example, a [(GeTe)₂(Sb₂Te₃)₁]_n block has the same composition as Ge₂Sb₂Te₅. The former has the atomic layer structure, while the latter has a NaCl-type fcc lattice with a random occupation of Ge or Sb at cation sites. Sb₂Te₃ has a feature to grow the crystal phase on a Si wafer orientating the [111] axis normal to the surface at a high temperature [8]. On the other hand, fcc-GeTe has a feature to grow the crystal phase orientating the [111] axis normal to the Sb₂Te₃ (111) surface at 200~250°C [6]. Therefore, a highly anisotropic film is formed by controlling the formation temperature. Figure 1 shows the film structure of a typical GeSbTe superlattice [(GeTe)₂(Sb₂Te₃)₁]_n with *a*=4.22 Å and *c*=18.71 Å. It is recently noticed that the Sb₂Te₃ sub-layer (quintuple layer QL) is a 3D-topological insulator. On the other hand, the GeTe layer is known to be a ferroelectric material [7]. The models shown in Fig. 1 are two of the atomic sequence orders in the GeTe sub-layer. Although the other sequence besides the models, Ge-Te-Te-Ge (Petrov) is possible, we found that the Petrov sequence is unstable at the film deposition temperature (~250°C) than the other two sequences using *ab-initio* molecular dynamics simulations. It is easily understood that phase transition between the two models in Figure 1 occurs by Ge-

flip-flop transition through the Te plane in the GeTe sub-layers. In addition, the transition process breaks the spatial inversion symmetry of the Te-Ge-Ge-Te sequence.

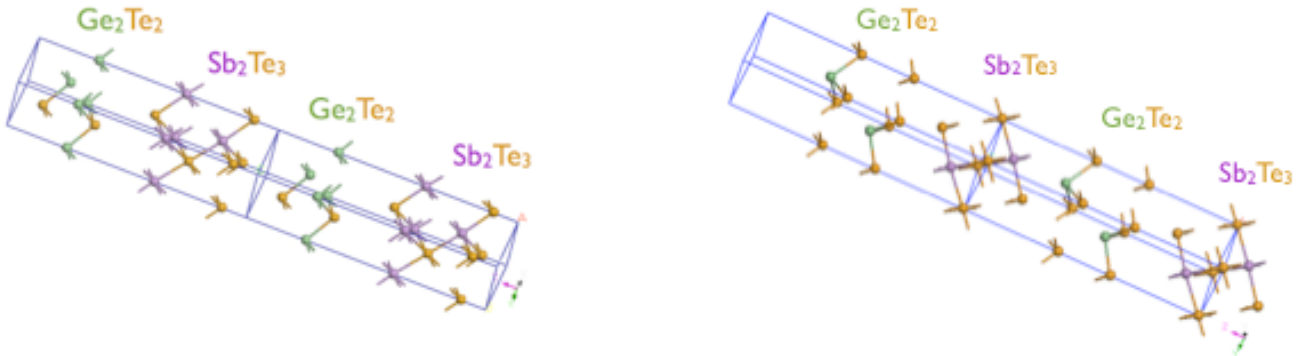


Figure 1 Basic cell models of iPCM with $[(\text{GeTe})_2(\text{Sb}_2\text{Te}_3)_1]_n$. Two Ge atoms are installed in the GeTe layer, and the Sb_2Te_3 layer is composed of a Te-Sb-Te-Sb-Te stacking sequence (QL). Te-Ge-Ge-Te sequence (left: RESET) and Ge-Te-Ge-Te sequence (right: SET).

It is noticed that Te-Ge-Ge-Te sub-layer is dielectric due to holding the spatial inversion symmetry (RESET state) while the Ge-Te-Ge-Te sub-layer is ferroelectric due to the break of the inversion symmetry (SET state). Each sub-layers are weakly bonded by *van der Waals* force. Due to the feature, Sb_2Te_3 QLs may play a role in a 3D-topological insulator independently in some extent. As increasing the QL blocks ($l \geq 1$) in the superlattice $[(\text{GeTe})_2(\text{Sb}_2\text{Te}_3)_m]_n$, the surface bands are generated at the top and bottom surfaces play independently. On the other hand, when the GeTe sub-layer is thicker or thinner than a critical thickness, the iPCMs have a band gap, due to the hybridization of the bottom edgeless band and the top edgeless band in the adjacent Sb_2Te_3 sub-layers [8]. In the former case, the iPCM becomes a 3D-TI, while the latter becomes a bulk insulator. But, the top and bottom surfaces of the film hold the 2D-TI features if the number of the QL is ≥ 1 . It is noticed that a Dirac cone is formed in the bulk band structure when the hybridization is balanced. The structure of $[(\text{GeTe})_l(\text{Sb}_2\text{Te}_3)_m]_n$ iPCM films may take the critical condition, depending on each block thickness.

3. MAGNETIZATION OF IPCM

Figure 2 shows the bulk band structure of $[(\text{GeTe})_2(\text{Sb}_2\text{Te}_3)_2]$ iPCM film. It is found that band gap is negligibly small and p_z -orbitals in Ge, Sb and Te invade into the conduction bottom band. A material with such a special condition is called *Dirac semimetal*. In the model (left) in Figure 1, the band structures of the spin-up and spin-down are degenerated, while the degeneration is lifted into split bands corresponding to each spin-state in the model (right). When an external electrical field is applied, there may generate a difference in between the spin densities of the state. This is called *Rashba* effect. Recently, it was reported that GeTe has a large *Rashba* effect [7]. If the iPCMs are Dirac semimetals, a band gap may easily open when a voltage is applied to an iPCM device, resulting in a *non-ohmic* resistance change. In addition, in an external magnetic field, the spin-density of the state may be no longer equal in between spin-up and spin-down electrons, resulting in an electrical-field-induced magnetization.

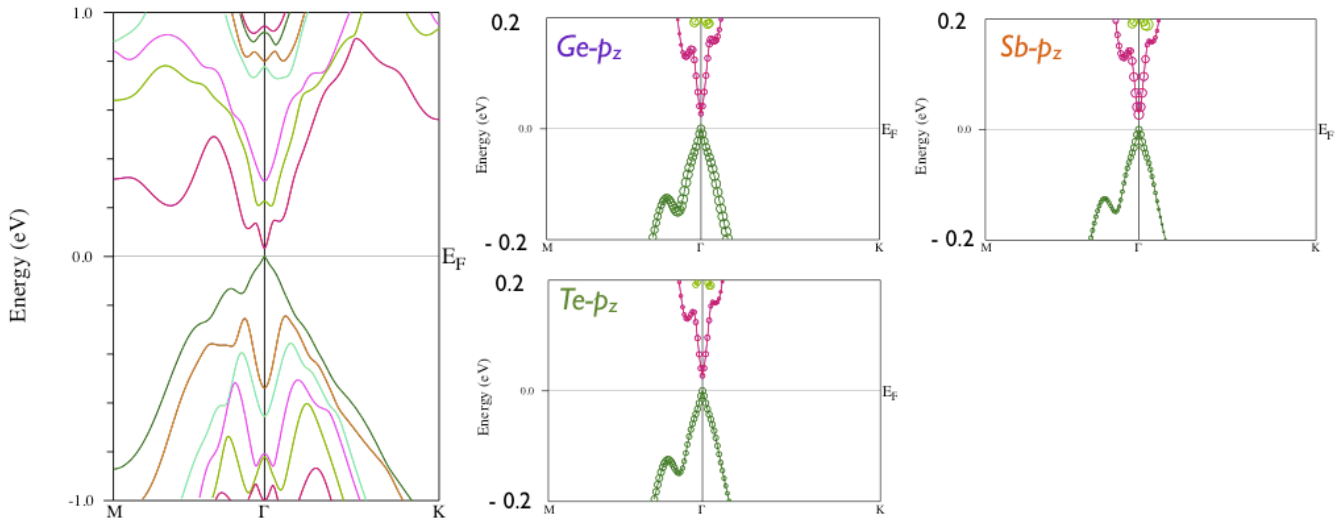


Figure 2 Bulk band structure of $[(\text{GeTe})_2(\text{Sb}_2\text{Te}_3)_2]$ iPCM (left). Three zoom images are of $\text{Ge-}p_z$, $\text{Sb-}p_z$ and $\text{Te-}p_z$ contributions (the size of the circles on the lines). The p_z orbitals in Ge, Sb and Te invade from the valence top to the conduction bottom.

4. SUMMARY

Electrical-field-induced magnetic properties in iPCMs may be generated by the break of the Dirac cone in the bulk state due to the combination between the ferroelectric & antiferroelectric GeTe layers and the topological insulating Sb_2Te_3 layers. iPCM is the first engineering material to probe topological insulating properties.

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