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Phase-change non-volatile memory equipped with topological insulating properties - Fusion of PCRAM and spintronics -

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Abstract

Ge-Sb-Te ternary alloy is a typical recording material used in PCRAM. It is usually non-magnetic except for doping a magnetic element. However, once it is fabricated as a layered structure with GeTe/Sb_2Te_3 in crystal, the film is magnetized when an external electrical field is applied. We introduce the experimental evidences, and propose the mechanism using *ab-initio* computer simulation based on topological insulating.

1. Introduction

Phase-change memory (PCM) was first commercialized as optical memory (PD, CD-RW, DVD-RAM, DVD-RW) in the 1990s, and was taken over to Blu-ray disc. In optical PCM the data was stored as the optical contrast (reflection) between amorphous and crystal in chalcigenides based on Ge-Sb-Te ternary alloys, while in electrical PCM (PCRAM) the data is stored as the electrical resistance change (two to three order of magnitudes). Although these two systems are different in the mechanisms at glance, they are switched on the same mechanism. The only difference is a method to melt-quench: laser melting or electrical current melting [1]. The energy required for the melting and the entropy energy loss accompanied with, however, steal more than 95% of the input energy to the PCRAM device[2].

The switching mechanism of PCRAM has long been thought to be the change of the phases: crystal or amorphous until recently. However, due to the detailed analysis using XAFS since 2004, it was revealed that the optical contrast and large electrical resistance between the two phases mainly relay on the bonding state of Ge atoms: tetrahedral (high resistance) or octahedral (low resistance) [3]. Based on the fundamental principle, it is no longer to melt a Ge-Sb-Te alloy for the solidification of the amorphous state. Interfacial phase change memory (iPCM) was designed to realize a coherent Ge-switch without melting and to reduce the input energy drastically [4].

2. Interfacial Phase Change Memory, iPCM

IPCM has a multilayered structure of GeTe and Sb_2Te_3 sub-layers as shown in Figure 1. Unlike the conventional PCRAM fabrication, the sub-layers are both deposited in crystal at a high temperature. A Sb_2Te_3 crystal layer (*P3-m*) is highly oriented with c-axis normal to the surface. Interestingly, although a GeTe crystal layer has a *fcc* structure, it is likely to orient to [111] direction normal to the surface on the Sb_2Te_3 layer. The lattice matching in both parameters is less than 5%. Therefore, in some condition, these alternatively deposited layers construct a superlattice with a block of $[(GeTe)_x(Sb_2Te_3)_y]_z$. Hence, x. y and z are integers, respectively.

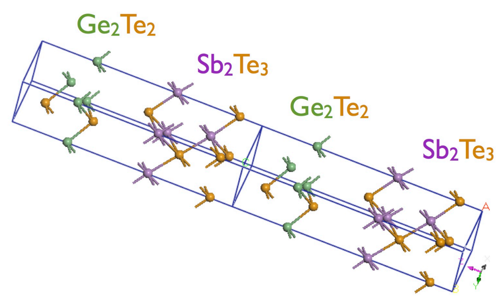

Figure 1 $[(GeTe)_2(Sb_2Te_3)_1]_n$型 iPCM structure composing of alternative GeTe and Sb_2Te_3 crystal blocks.

Using the iPCM structure, we first demonstrated a new PCRAM operated at a small input energy as small as 10% in the conventional one with the same composition alloy in 2011. Soon after the demonstration, in addition, we noticed that iPCM has a giant magnetoresistance, which has never been observed in Ge-Sb-Te phase-change alloys so far [5]. Remember that optical PCM without Kerr rotation detection using quite expensive pair of polarizers and a magnet completely extruded magneto-optical (MO) disk out of the storage market in the late 1990s. If the phase-change film had the magnetic property, MO media would have still dominated the optical storage market. Why does iPCM show the magnetic property without any magnetic dopant?

3. Topological insulating in iPCM

Sb_2Te_3 sub-layers consisting of iPCM is known as a 3D topological insulator (TI) [6]. Up to now, TI has usually been studied as an interface with vacuum. In iPCM on the other hand GeTe sub-layers play a role in vacuum instead. GeTe is a narrow gap semiconductor. TI layers (Sb_2Te_3) are stacked with the insulating spacer layers (GeTe). At each interface therefore two different topological states must be linked with a gapless edge because a TI phase has inverted band structures due to a large spin-orbit coupling. However, depending on the insulator layer thickness, the two interfaces are interacted, resulting in three states: 3D topological insulator, Dirac semimetal as a bulk, or insulator. Figure 2 shows the band structure of $[(GeTe)_2(Sb_2Te_3)_1]_z$. It has a single Dirac cone at Γ point in bulk coincidently [7]. This is the specific feature of iPCM devices.

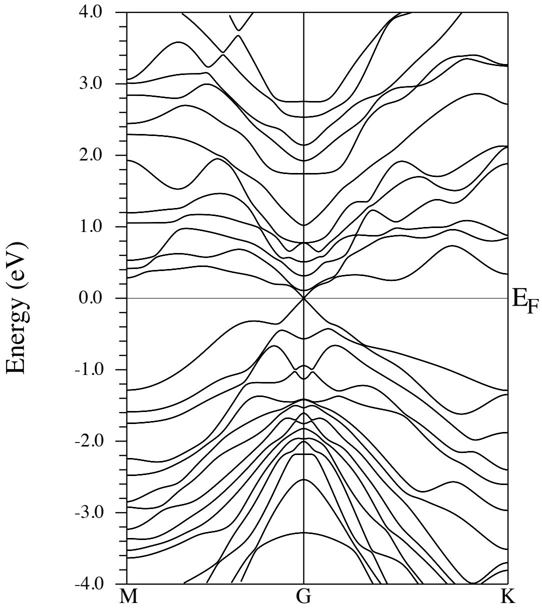

Figure 1. The band structure of $[(GeTe)_2(Sb_2Te_3)_1]_z$.

The topological strength depends on the thickness of the Sb_2Te_3 blocks (Te-Sb-Te-Sb-Te) (we call quintuple layer, QL) and of the GeTe layer. Each QL is connected each other through van-der-Waals force between Te atoms located the outside of QL. In the Reset phase in the iPCM, as the layer has a Te-Ge-Ge-Te layer sequence and has a spatial inversion symmetry, the iPCM device cannot display a net magnetic moment if a magnetic moment is generated by some reasons. This is reasonable because a TI is usually diamagnetic. However, once electrical field is applied, the situation may be changed because Ge atoms are slightly e positively while Te atoms are slightly negative in the GeTe layers in the layer. As the electrical field is increased, Ge and Te atoms are shifted oppositely, and the spatial inversion symmetry may be broken. In such a case, it is possible that the net magnetic moment is induced due to lifting off the Dirac gapless edge into two spin bands like a Rashba split. However, the magnetic moment is eliminated by turning off the electrical field. It is speculated that the electrical-field-induced giant magnetoresistance observed in iPCM devices is attributed to the mechanism.

4. Conclusions

IPCM is the first device which enables to realize topological insulating accompanied with Rashba effect at room temperature. Using the characteristics, the future spintronics will be replaced by all non-magnetic phase-change functional devices.

Acknowledgements

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