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Phase-change materials for low-energy operation PCRAM

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Abstract

Ge-Sb-Te (GST) has been used in practical PCRAM showing high operation speed and long endurance, but it has some issues to be solved for future devices, such as poor high-temperature data retention and high operating energy compared to other next generation memories. To solve those issues, we have proposed PCRAM materials such as $Cr_2Ge_2Te_6$ which shows an inverse resistance change; low-resistance amorphous and high-resistance crystalline phases, and MnTe which shows a large resistance change due to crystalline polymorphic transition. In this presentation, we will introduce phase change characteristics of those phase-change materials (conduction mechanism in each phase and phase change mechanism etc.), and the energy-saving performance of those phase-change materials.

1. Introduction

Phase change random access memory, called PCRAM has been attracting attention. The recording layer of PCRAM is composed of phase-change materials which are capable of a reversible phase change between amorphous and crystalline phases, and the information can be recorded using the large change in resistance associated with the phase change (generally, the amorphous phase shows higher resistance). Because of the simple memory cell structure, a high density integration can be expected compared to other emerging memories. Practical phase-change material is Ge-Sb-Te compound (GST) which exhibits large change in electrical resistance (over two-order of magnitude) and very fast phase change speed (nanoseconds order). Therefore, GST-based PCRAM can realize high speed memory operation. In addition, the phase-change between amorphous and crystalline phases is highly reversible, which enables a long endurance. However, the crystallization temperature of GST is low (about 160°C), which means that the amorphous phase has a poor heat resistance and poor data retention at high-temperature environments. In addition, GST has a high operation energy consumption compared to other emerging memories. For next-generation PCRAM, new phase-change materials are expected to be developed to improve data retention at a high temperature and to reduce the operation energy of PCRAM.

In this paper, we introduce our recent studies on chalcogenide materials including transition metals; $Cr_2Ge_2Te_6$ and MnTe which can realize better data retention at high temperature and low energy operation, and discuss on the phase transition mechanism (conduction mechanism, crystal structure and so on) and the effect of contact resistance between phase-change material and electrode on the memory operation.

2. Results and Discussion

$Cr_2Ge_2Te_6$ phase-change material

Our group has proposed TM-Ge-Te compounds including transition metals (TMs) such as Cu_2GeTe_3 [1] and $Cr_2Ge_2Te_6$ (CrGT) [2] as new phase-change materials with a high crystallization temperature above 200 °C. In particular, CrGT shows p-type semiconductor properties in both the amorphous and crystalline phases. More interestingly, CrGT exhibits a higher electrical resistivity in the crystalline phase than in the amorphous phase (Fig. 1). This inverse resistance change of CrGT-based PCRAM, which is opposite to the conventional one, makes it possible to drastically reduce the operation energy to 1/10 or less compared to conventional GST-based PCRAM. In addition, although a selector layer is essential to prevent snake current in a 3D cross-point memory cell structure, we proposed a PCRAM device with selector/memory function using a pn diode with p-type phase-change material and n-type oxide stacking, taking advantage of the fact that both amorphous and crystalline phases are semiconductors [3].

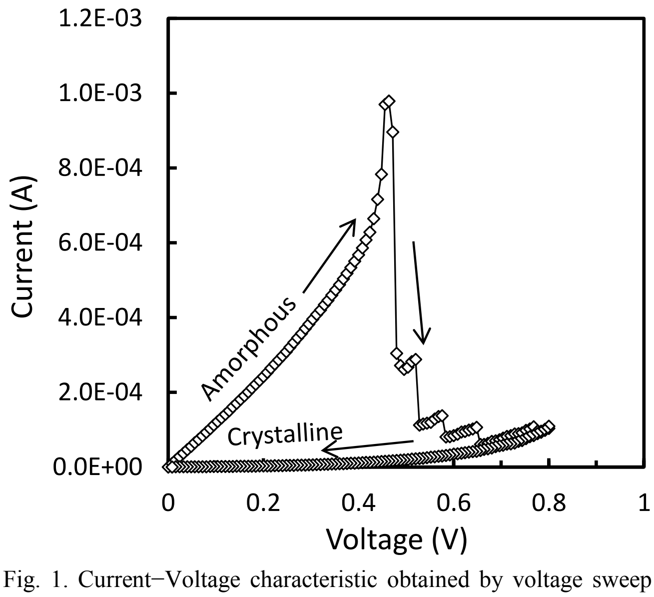

Fig. 1. Current−Voltage characteristic obtained by voltage sweep measurements of the CrGT-based memory device, where the initial state was a low resistance amorphous state. The current increases with increasing sweep voltage and then drastically drops at around 0.45 V, indicating the phase transition from low resistance amorphous to high-resistance crystalline state.

MnTe phase-change material

We have recently found that MnTe compound shows a large resistance change due to a reversible crystalline polymorphic transition instead of the conventional amorphous/crystalline phase transition (Fig. 2) [4]. Since this polymorphic transition between NiAs-type structure and Wurtzite -type structure is caused by a displacive phase transition without a long range atomic diffusion, its operation energy is very low. In addition, the phase-change can be occurred using an electrical pulse with a width of 10-ns. These results also imply that MnTe polymorphic compound is a promising phase-change material for next-generation PCRAM material enabling low-operation energy and fast operation.

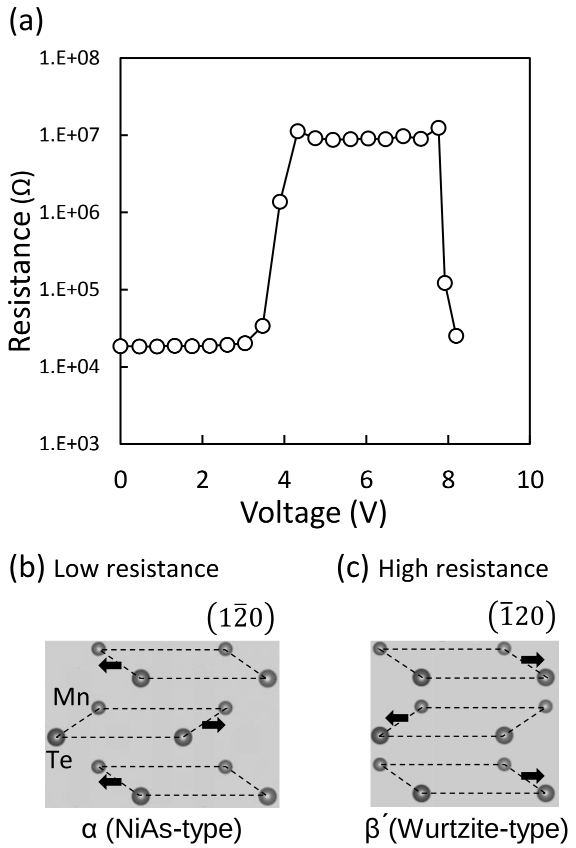

Fig. 2 (a) Resistance vs. voltage curve for MnTe-based memory device, where the read voltage was 0.1 V. (b), (c) Polymorphic-change mechanism between the α (NiAs-type) and β′ (Wurtzite-type) structures through alternate atomic-plane shuffling, where (b) and (c) shows a projection of atoms of the crystal structure of the α- and β′-phases. The arrows indicate the shuffling direction of each atomic-plane for the polymorphic-change between the α and β′ phases.

3. Conclusions

Emerging non-volatile memories such as STT-MRAM, ReRAM, PCRAM are key semiconductor devices for advanced information society. Among them, PCRAM is a promising next generation non-volatile memory because of its simple data storage principle and cell-structure. A large reduction of operation energy of PCRAM is a very important issue for the next generation society. Inverse resistance-change $Cr_2Ge_2Te_6$ and polymorphic MnTe which can realize a large reduction of resistive switching operation energy are promising candidates for next generation PCRAM.

Acknowledgements

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