Title of Project : Crystalline polymorphic-change memory technology

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【Purpose and Background of the Research】

In Society 5.0, the amount of information will dramatically increase. Therefore, there is a strong demand for innovation in memory devices that store information. In particular, addition to the increase in the memory capacity, the saving of operation energy and the speeding up of operation are strongly expected. One of the post-Si memory technologies is phase-change memory technology. Generally, a phase-change material (PCM) showing reversible and non-volatile phase-change between high-resistance amorphous (A) and low-resistance crystalline (C) phase is used for phase-change memory devices. Currently, Ge-Sb-Te compound (GST) is put into practical use as a PCM, and realizes good memory performance that surpasses that of flash memory. However, GST has three major challenges that impede innovation in phase-change memory technology: (1) Heating above the melting point to obtain A-phase, causing high operating power, (2) Low crystallization temperature, leading difficulty in further miniaturization, and (3) Large volume-change due to phase-change, making it difficult to extend the endurance. In other words, although it is common sense to use A-phase in phase-change memory, the phase-change to A-phase is the bottleneck for the innovation. In this study, we propose a crystalline polymorphic semiconductor compound as a new type of PCM. We will challenge to elucidate the phase-change mechanism and to control the polymorphic-transition by various external field and then, we will try to develop crystalline polymorphic-change memory technology.

【Research Methods】

Recently, we found that MnTe shows a large change in resistance due to a crystalline polymorphic transition, and the MnTe device shows non-volatile memory characteristics due to the polymorphic transition by Joule heating. It is noteworthy that the transition is a displacive transition without random diffusion of atoms. Such new findings motivate us to investigate what kind of external field can induce the polymorphic transition, and to explore other materials showing the polymorphic transition. In this study, to establish polymorphic memory technology, we organized a team with experts in numerical and theoretical calculation, integration technology, optics and magnetics. For crystalline polymorphic transition semiconductors such as MnTe, we will (i) reveal the effect of thermal strain on the polymorphic transition behavior and investigate electrical properties of each polymorph, (ii) evaluate three-terminal structure device characteristics, (iii) investigate the photo-induced transition behavior using time-resolved photoelectron spectroscopy, and (iv) measure the magnetic properties of each polymorph and evaluate the magnetic-induced transition. In addition, through (v) synchrotron radiation experiments and first-principles calculations, we will discuss the electronic state, chemical bonding state and phase stability of each polymorph, and elucidate the polymorphic transition mechanism.

【Expected Research Achievements and Scientific Significance】

Unlike conventional PCMs showing A/C phase-change that requires large diffusion of atoms, MnTe showing the crystalline polymorphic change through the displacive transition, i.e., diffusionless transition can be expected to be a new type of crystalline polymorphic-change memory that realizes low operating energy, high-speed operation, and long endurance. Furthermore, next-generation optical devices using phase-change memory technology has been actively studied all over the world, but A/C transition by photoexcitation is difficult in conventional PCMs. On the other hand, since MnTe shows diffusionless transition, it may realize an optical memory enabling ultra-high speed and ultra-low energy by photoexcitation. In addition, MnTe is also a magnetic semiconductor, and therefore, a new memory that utilizes the degree of freedom of magnetic properties can be expected. Furthermore, MnTe films can be fabricated by conventional sputtering deposition technique, which is a good merit for practical application. This is very significant study not only academically but also industrially to support the advanced information society of the future.

【Publications Relevant to the Project】

- S. Mori, S. Hatayama, Y. Shuang, D. Ando, Y. Sutou, Reversible displacive transformation in MnTe polymorphic semiconductor, Nat. Commun. 11, article 85 (2020).
- S. Mori, D. Ando, Y. Sutou, Sequential two-stage displacive transformation from β to α via β’ phase in polymorphic MnTe film, Mater. Des. 196, 109141-1-8 (2020).
- S. Mori, S. Hatayama, D. Ando, Y. Sutou, Thermal stability and polymorphic transformation kinetics in β-MnTe films deposited via radiofrequency magnetron sputtering, Jpn. J. Appl. Phys. 60, 045504-1-5 (2021).

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