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Anomalous phase change characteristics in Fe-Te materials

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Phase change materials have become significantly attractive due to its unique characteristics for its extensive applications. In this paper, a kind of phase change material, which consists of Fe and Te components, is developed. The crystallization temperature of the Fe-Te materials is 180 °C for Fe_{1.19}Te and can be adjusted by the Fe/Te ratio. High-speed phase change in the Fe-Te materials has been demonstrated by nanosecond laser irradiation. Comparing to conventional phase change materials, the Fe-Te materials exhibit an anomalous optical property that has higher reflectivity at amorphous than crystalline state, which is useful for data storage design. © 2012 American Institute of Physics. [<http://dx.doi.org/10.1063/1.4719074>]

Current operation of data storage has applied phase change materials for the extensive applications in optical data storage and solid state memory.¹ The processes of the phase change materials depend on the significant difference of optical and electronic properties, which are based on their atomic arrangement at amorphous or crystalline state. Among the current phase change memory applications, several materials have been used, which do show promising phase change properties, such as Ge-Sb-Te (GST).² However, for the conventional phase change materials, high current requirement is observed to induce phase switching between amorphous and crystalline states. They have disadvantages on energy saving and phase change temperature distinction from working environment. Therefore, the phase change performance needs to be further enhanced. It is the need to either improve these phase change materials or explore new phase change materials as alternatives.

Despite the studies of their crystal structures, superconducting and magnetic properties have been carried out in Fe-Sb-Te, Fe-Te-Se, FeTe₂, Fe₂Te₃, Fe_{1.125}Te, and FeTe materials,^{3–11} there is no report on the phase change properties of these materials. Therefore, phase change properties in these Fe-Te materials remain uncertain. In this paper, Fe-Te materials (FeTe and Fe_{1.19}Te) are investigated as a potential replacement of traditional phase change materials. In order to develop its phase change characteristics, different phase change tests are carried out to study switching state between amorphous and crystalline. A phase change property, being able to be reverse to the traditional phase change materials, is observed in the Fe-Te materials.

One-layer structure of the phase change material (FeTe/Fe_{1.19}Te) was deposited on Si substrates (orientation <100>) in room temperature and 220 °C, respectively, to make amorphous and crystalline phase change materials. Laser molecular beam epitaxy (MBE) (pulse energy: 250 mJ, chamber pressure: 1.5 × 10⁻⁸ Torr) was applied to de-

posit the thin films of a thickness of ~50 nm. The samples were characterized by x-ray photoelectron spectroscopy (XPS) and x-ray diffraction (XRD) measurements to determine their compositions and crystal structures. The thin film reflectivity was measured at both amorphous and crystalline states by a Shimadzu's ultraviolet-visible spectrophotometer. The amorphous thin films were proceeded for phase change temperature tests to switch the samples from amorphous to crystalline state. During the process, a pulsed laser beam was used to detect the reflectivity change of the phase change materials versus temperature at an increase rate of 50 °C/min, so as to obtain the crystallization temperature.

XPS measurements were conducted first and indicate that the compositions of the Fe-Te materials are FeTe and Fe_{1.19}Te. Figs. 1(a) and 1(b) show the XRD patterns obtained for both FeTe and Fe_{1.19}Te materials synthesized at the amorphous and crystalline states. The spectrum with the diffraction peaks (101), (002), (110), (003), and (004) for FeTe thin films and (002), (003), and (004) for Fe_{1.19}Te thin films can be clearly observed at the crystalline state. The peaks have been identified as the tetragonal structure with a lattice parameter of $a = 0.384$ nm and $c = 0.628$ nm for the FeTe thin films and $c = 0.630$ nm for the Fe_{1.19}Te thin film. Both lattice parameters are close to Fe_{1.125}Te. It shows that the FeTe and Fe_{1.19}Te thin films have the same crystal structure as Fe_{1.125}Te.⁶

The crystallization temperature of both the materials FeTe and Fe_{1.19}Te was measured by a phase change temperature tester, which consists of a diode laser, a photodiode detector, a heater system, and a vacuum system. The reflected light was collected from the surface of the heated thin films, which was irradiated by a diode laser (1 mW, 635 nm).¹² Figs. 2(a) and 2(b) exhibit the reflectivity (R) and its derivative with respect to temperature (dR/dT) versus temperature (T) curves for both FeTe and Fe_{1.19}Te thin films deposited at room temperature. It can be seen that a step phase switch exists in both FeTe and Fe_{1.19}Te thin films. As-deposited FeTe and Fe_{1.19}Te thin films have high reflectivity at amorphous state, which is different from the conventional phase

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FIG. 1. XRD of (a) FeTe and (b) Fe_{1.19}Te samples at amorphous and crystalline state.

change material at the amorphous state. From $dR/dT \sim T$ curve, on-set temperature of crystallization and crystallization temperature T_C can be obtained. Upon heating by laser up to on-set temperature of crystallization, atoms in the films start to obtain enough energy to rearrange and phase change takes place from amorphous to crystalline state. At a temperature of T_C , dR/dT reaches to the maximum value, which is identified as the temperature of maximum¹³ crystallization rate or crystallization temperature. The reflectivity decreases until its full crystallization. Fig. 2 shows a crystallization temperature of $\sim 180^\circ\text{C}$ for Fe_{1.19}Te and $\sim 214^\circ\text{C}$ for FeTe. Comparing the difference between T_C of Fe_{1.19}Te and FeTe, it was found that crystallization temperature changes with Fe and Te content. As a result, the phase change temperature of the Fe-Te materials can be modified accordingly to the requirement of the applications.

In order to further study the optical properties of Fe-Te materials at amorphous and crystalline states, the reflective spectrum was measured, as shown in Figs. 3(a) and 3(b) for FeTe and Fe_{1.19}Te at amorphous and crystalline states, respectively. It is observed that the Fe-Te materials have higher reflectivity at the amorphous states. When the Fe-Te materials are deposited at crystalline state, the reflectivity is

FIG. 2. Reflectivity versus temperature curve and derivative of reflectivity with respect to temperature for (a) FeTe and (b) Fe_{1.19}Te films deposited at room temperature.

tested to be smaller. It is confirmed by Fig. 2 that the reflectivity of both the materials drops abruptly from amorphous to crystalline state.

In Figs. 4(a) and 4(b), the reflective spectrums were presented for the FeTe and Fe_{1.19}Te thin films deposited at room temperature before and after the thermal annealing, respectively. During the annealing in vacuum, both materials FeTe and Fe_{1.19}Te are phase changed from amorphous to crystalline, and their reflectivities are measured at either states. As shown in Fig. 4, the reflectivity of the Fe-Te materials drops from a higher value at the amorphous state to smaller value when switching to the crystalline phase. This unique optical property of the Fe-Te phase change materials, which is reverse to the optical property of conventional phase change materials, fits the results indicated in Fig. 3.

To study the crystallization speed of Fe-Te materials, an experiment on laser-induced phase change was carried out. An excimer laser (wavelength: 248 nm, pulse duration: 30 ns) at the fluences of 52.5 and 42.5 mJ/cm² were applied to induce local phase change of Fe_{1.19}Te thin films.¹² Figs. 5(a) and 5(b) show typical optical micrographs of Fe_{1.19}Te films with and without the laser irradiation. In Fig. 5(a), the left part gives the original surface of Fe_{1.19}Te films at amorphous state and the color is brighter than the right part, which is irradiated by the excimer laser at a laser fluence of 42.5 mJ/cm² for 2 pulses. The color changed from bright to dark

FIG. 3. Reflectivity versus wavelength for (a) FeTe and (b) Fe_{1.19}Te at amorphous and crystalline state.

FIG. 4. Reflectivity versus wavelength for (a) FeTe and (b) Fe_{1.19}Te before and after annealing.

FIG. 5. Typical optical micrograph of Fe-Te material at (a) amorphous state and (b) crystalline state with and without laser irradiation.

relatively. In Fig. 5(b), the left part gives the original surface of Fe_{1.19}Te films at crystalline state and the color is darker than the right part, which was irradiated by excimer laser at a fluence of 52.5 mJ/cm² for 5 pulses. The color changed from dark to bright relatively. Both Figs. 5(a) and 5(b) infer that the phase switches of the Fe_{1.19}Te thin film between amorphous and crystalline states happen during the laser pulse duration of 30 ns. The FeTe thin film (not shown) has the similar behavior when laser irradiation is applied. These findings demonstrated that Fe-Te materials have a high phase change speed. Furthermore, the color changes of the Fe-Te materials between amorphous and crystalline states confirm the corresponding reflectivity at each state in Figs. 2–4. The reflectivity of the Fe-Te materials at either amorphous or crystalline state can also explain why the colors or brightness of the thin films appear.

In conclusion, the Fe-Te materials were prepared by the laser MBE process. Both FeTe and Fe_{1.19}Te material show tetragonal structure. An obvious phase change is observed in both FeTe and Fe_{1.19}Te. Meanwhile, the Fe-Te materials have a higher reflectivity at amorphous state, which drops abruptly when being switched to crystalline state as a high speed. Furthermore, with the change of content of Fe and Te in Fe-Te phase change materials, the phase change temperatures become adjustable.

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