Study of Gd-Y Alloys for Use in Cycle of Active Magnetic Regeneration

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ABSTRACT

Until now, gadolinium (Gd) has been used as a magnetic refrigerant in room temperature magnetic refrigeration studies based on the Active Magnetic Regeneration (AMR) cycle. However, with this material, the working temperature region is restricted by the value of magnetic entropy change (ΔS_m), which shows a sharp peak near the Curie temperature (T_C). In order to expand the working temperature region of Gd, it may be possible to use layered structures of magnetic refrigerants with different T_C so as to achieve a broader region of magnetic entropy change.

In this study, we analyzed the T_C and ΔS_m of Gd-Y alloys to identify suitable magnetic refrigerants for use in a layered structure. Details are presented which show that the T_C of Gd-Y alloys is easily controllable, and that the refrigerating capacity of Gd-Y alloys is almost equivalent to that of Gd.

INTRODUCTION

In recent years, magnetic refrigeration based on the magnetocaloric effect has attracted attention as a candidate technology for minimizing impact to the Earth environment and minimizing global warming. A key advantage of magnetic refrigeration is that it does not use chlorofluorocarbons that can negatively influence ozone layer depletion.

Operation near room temperature places new demands on magnetic refrigeration that may be fulfilled by the AMR cycle, as this cycle is expected to be able to expand the working temperature region from low temperature to room temperature. Over the past few years there have been many studies of magnetic refrigeration using superconducting magnets or permanent magnets in the AMR cycle in the room temperature region.[1-7]

In these studies, ferromagnetic materials, such as Gd, have been used as the magnetic refrigerant. The value of ΔS_m of ferromagnetic materials shows a peak near T_C, and the ΔS_m decreases as the temperature separates away from the T_C temperature. This is one of the reasons that the working temperature region of the AMR cycle with ferromagnetic materials has been restricted. In order to apply room-temperature magnetic refrigeration techniques to practical use, the working temperature region must be greater than 30 K. One possible means of expanding the working temperature region of Gd, is to use layered structures of magnetic refrigerants with different T_C.

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The purpose of this study was to investigate the magnetocaloric effects and the working temperature region of Gd-Y alloys as possible candidates for use in layered-structure magnetic refrigerants.

EXPERIMENTAL METHOD

Gd and Y of 99.9 % purity were used for the production of the Gd-Y alloys. The composition ratios of Gd-Y alloy samples, as a ratio of atoms, were Gd98-Y2, Gd96-Y4, Gd94-Y6, Gd92-Y8 and Gd90-Y10. After weighing the bits of metal of Gd and Y, they were melted using arc-melting equipment. In order to increase the homogeneity of the alloys, the melting was performed four times. After the melting, we achieved alloys in the shape of a button about 3 cm in diameter.

To accurately perform the magnetization measurements it was necessary to make the alloys the shape of a slender rod so that a demagnetizing field would not influence the alloys. The alloys of the shape of a button were cut into the shape of a rod with an aspect ratio of 1 : 8. The mass of the rod-like samples was about 4.5 mg. The temperature dependence and magnetic field dependence of magnetization of these rodlike samples were measured using a Superconducting Quantum Interference Device (SQUID) magnetometer.

RESULTS AND DISCUSSION

Figure 1 shows the temperature dependence of magnetization of the Gd and Gd-Y alloys. The Curie temperature T_C corresponds to the inflection point of magnetization. Each magnetization is normalized with the value at 150 K so that T_C may become intelligible. The T_C of Gd90-Y10 is estimated to be 273 K from the graph, while the T_C of Gd is 294 K, as is generally known. In the range from 273 K to 294 K, it turns out that T_C gradually moves to lower temperatures as the Y content increases. The T_C of all Gd-Y alloys were estimated from Figure 1 and are listed in Table 1.

Referring to Table 1, Figure 2 shows the Y content dependence of the T_C of Gd-Y alloys. Depending on the Y content, the T_C drops in temperature almost linearly: for each 1 at% of Y that is compounded, the T_C falls 2 K.

Next, we discuss the value of ΔS_m of Gd and Gd-Y alloys. The value of ΔS_m of ferromagnetic

Table 1. The Curie temperature of Gd-Y alloys.

Y content (at %)	0	2	4	6	8	10
T_C (K)	294	290	286	282	278	273

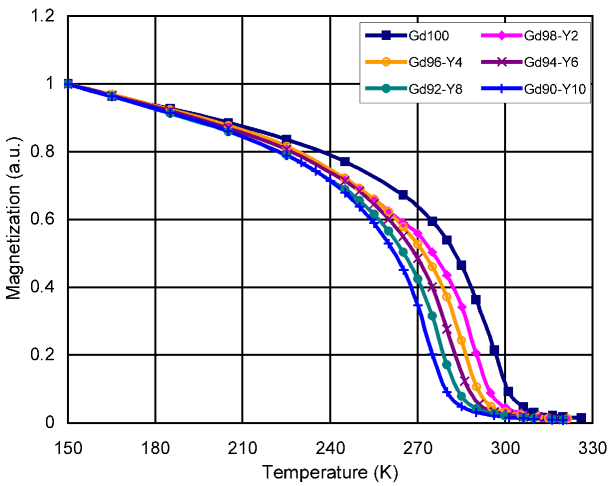

Figure 1. Temperature dependence of magnetization of Gd-Y alloys; each magnetization curve is normalized to unity at 150 K.

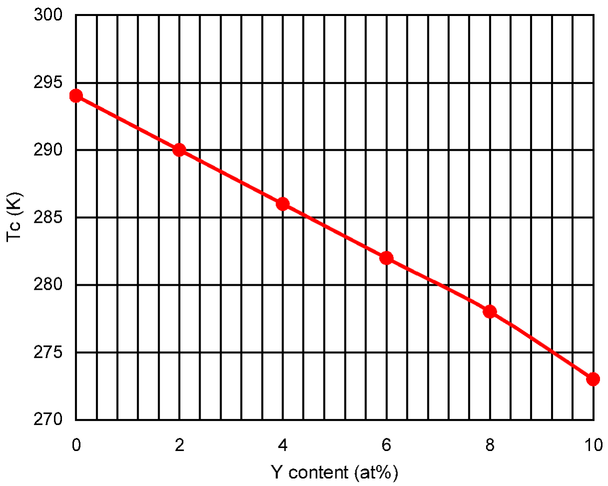

Figure 2. Dependence of T_C on Y content in Gd-Y alloys.

substances can be derived using Maxwell's relation. Maxwell's relation is shown below as Equation (1).

$$\left(\frac{\partial S(T,H)}{\partial H}\right)_T = \left(\frac{\partial M(T,H)}{\partial T}\right)_H \tag{1}$$

$$\Delta S_M(T,H) = \int_0^{\Delta H} \left(\frac{\partial M(T,H)}{\partial T}\right)_H dH \tag{2}$$

The value of $\Delta S_m(T, \Delta H)$ of Gd and Gd-Y alloys can be estimated from Equation (2) using magnetization measurement results and the temperature dependence and magnetic field dependence of the magnetization.

Figure 3 shows the temperature dependence of ΔS_m of Gd and Gd-Y alloys with changing magnetic field strength from 0 to 0.8 T (ΔH=0.8 T). The peak value of ΔS_m of Gd with ΔH=0.8 T is about 2.8J/kg·K. The magnetic field strength of 0.8 T can be obtained with ordinary permanent

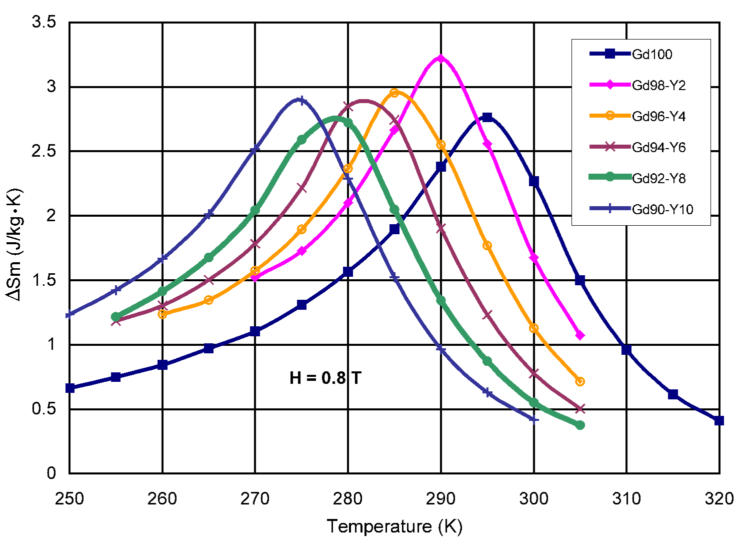

Figure 3. Temperature dependence of ΔS_m for Gd and Gd-Y alloys.

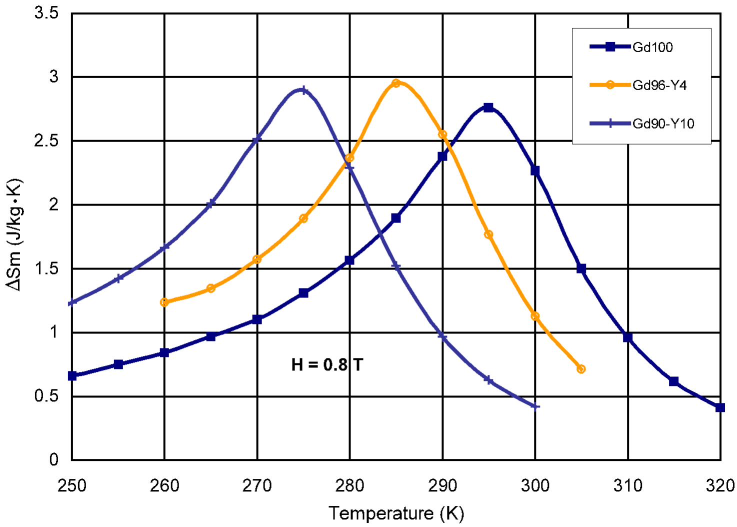

Figure 4. Temperature dependence of ΔS_m for Gd and Gd-Y alloys.

magnets. The value of ΔS_m of each Gd-Y alloy achieves a peak around the T_C, and the peak temperature shifts to the lower temperature side gradually. It is also observed that the peak values of ΔS_m of the Gd-Y alloys are almost equivalent to that of Gd.

CONCLUSIONS

We have confirmed that the T_C of Gd-Y alloys is easily controllable in the range from 273 K to 294 K; in fact, the T_C of Gd-Y alloys drops in temperature almost linearly with the Y content. We also have determined that the refrigerating capacity of Gd-Y alloys is almost equivalent to that of Gd, because the peak value of ΔS_m of Gd-Y alloys and that of Gd are practically equal. Thus, we conclude that Gd-Y alloys will be suitable for use in layered structures of magnetic refrigerants.

Figure 4 shows the temperature dependence of ΔS_m of Gd100, Gd96-Y4 and Gd90-Y10. This is representative of a 3-layered-structure magnetic refrigerant where the working temperature region or each of the three components has been shifted by 10 K. Such a magnetic refrigerant has the potential of maintaining a high value of ΔS_m over the indicated temperature region. In the future, we will investigate the appropriate interval of the working temperature region.

Figure 5 shows the spherical particles of the Gd-Y alloy; the diameter is about 1 mm. We will try and use the Gd-Y spherical particles for a layered structure.

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Figure 5. Spherical particles of Gd-Y alloy.

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