DOPED $GD_5GE_2SI_2$ COMPOUNDS AND METHODS FOR REDUCING HYSTERESIS LOSSES IN $GD_5GE_2SI_2$ COMPOUND

REFERENCE TO RELATED APPLICATION

This patent application claims priority under 35 U.S.C. §119(e) to provisional patent application Ser. No. 60/641,168 entitled "Near-Elimination of Large Hysteresis Losses in the $Gd_5Ge_2Si_2$ Alloy by Small Silicide Forming Metal Addition Resulting in a Much Improved Magnetic Refrigerant Material" which was filed on Jan. 4, 2005, the disclosure of which is incorporated herein by reference provisional patent application.

TECHNICAL FIELD

Embodiments are generally related to magnetic refrigerant compounds and, in particular, to Gd—Ge—Si containing compounds. Embodiments are also related to methods of preparing $Gd_5Ge_2Si_2$ doped alloys. Embodiments are additionally related to methods of reducing hysteresis losses in the $Gd_5Ge_2Si_2$ compound.

BACKGROUND OF THE INVENTION

Magnetic refrigeration is in principle a much more efficient technology than conventional vapor compression refrigeration technology as it is a reversible process and, moreover, it does not use environmentally unfriendly ozone-depleting chlorofluorocarbon refrigerants (CFCs). Magnetic refrigeration depends on the magnetocaloric effect (MCE), utilizing the entropy of magnetic spin alignment for the transfer of heat between reservoirs.

Since the late nineties, the use of a $Gd_5Ge_2Si_2$ compound in near-room temperature magnetic refrigeration applications has attracted attention owing to its potential as a suitable refrigerant material for near room temperature magnetic refrigeration. A large magnetocaloric effect in the $Gd_5Ge_2Si_2$ compound in the 270-300 K temperature range has been reported by Gschneidner, Pecharsky and their coworkers in the following published references: Pecharsky, V. K. & Gschneidner, K. A., Jr., "The Giant Magnetocaloric Effect in $Gd_5(Ge_2Si_2)$", *Phys. Rev. Lett.* 78, 4494-4497 (1997), Pecharsky, A. O., Gschneidner, K. A., Jr., "The Giant Magnetocaloric Effect of Optimally Prepared $Gd_5Ge_2Si_2$", *J. Appl. Phys.* 93, 4722-4728 (2003), and Pecharsky, V. K. & Gschneidner, K. A., Jr "The Giant Magnetocaloric Effect in $Gd_5(Si_xGe_{1-x})_4$ Materials for Magnetic Refrigeration", *Advances in Cryogenic Engineering,* 43, edited by P. Kittel, Plenum Press, New York, 1729-1736 (1998).

The aforementioned references disclosed that the large magnetocaloric effect observed in the $Gd_5Ge_2Si_2$ compound, in the 270-320 K temperature range, is the result of a magnetic field-induced crystallographic phase change from the high-temperature paramagnetic monoclinic phase to the low-temperature ferromagnetic orthorhombic phase. Unfortunately, large hysteresis losses were also observed in the $Gd_5Ge_2Si_2$ magnetic refrigerant compound in the 270-320 K temperature range. These large hysteretic losses occurred at the same temperature range where the compound exhibits a pronounced magnetocaloric effect, referred as "The giant magnetocaloric effect".

Choe, W. et al, and other researchers have proposed that the large magnetocaloric effect is the result of a field-induced crystallographic phase change from the high temperature paramagnetic monoclinic phase to the low-temperature ferromagnetic orthorhombic phase (see Choe, W. et al, "Making and Breaking Covalent Bonds across the Magnetic Transition in the Giant Magnetocaloric Material $Gd_5(Ge_2Si_2)$", *Phys. Rev. Left.* 84, 4617-4620 (2000), Pecharsky, V. K. & Gschneidner, K. A., Jr., "Phase relationship and crystallography in pseudobinary system Gd_5Si_4—Gd_5Ge_4", *J. Alloys and Compd.* 260, 98-106 (1997), and Pecharsky, V. K., Pecharsky, A. O., and Gschneidner, K. A., Jr., "Uncovering the structure-property in $R_s(Si_xGe_{4-x})$ intermetallics phases", *J. Alloys and Compd.* 344, 362-368 (2002).)

Other studies by Pecharsky et al and by other researchers have also observed the magnetocaloric effect of the $Gd_5Ge_2Si_2$ magnetic refrigerant compound and the hysterisis losses behavior (See Pecharsky, V. K. & Gschneidner, K. A., Jr. "Tunable magnetic regenerator alloys with a giant magnetocaloric effect for magnetic refrigeration from 20 to 290 K", *Appl. Phys. Lett.* 70, 3299-3301 (1997), Levin, E. M., Pecharsky, V. K., and Gschneidner, K. A., Jr. "Unusual magnetic behavior in $G_5(Ge_{1.5}Si_{2.5})$ and $G_5Ge_2Si_2$", *Phys. Rev.* B 62, RI4 625-R14 628 (2000), Giguere, A. et ai. Direct Measurements of the 'Giant' Adiabatic Temperature, Change in $G_5Ge_2Si_2$", *Phys. Rev. Left.* 83, 2262-2265 (1999).

There is a need to greatly reduce or eliminate the large hysteresis losses in the $G_5Ge_2Si_2$ compound so that the potential of the compound as an efficient and attractive refrigerant material for near-room temperature magnetic refrigeration can be fully realized.

The embodiments disclosed herein therefore directly address the shortcomings of present $Gd_5Ge_2Si_2$ magnetic refrigerant compounds, providing an alloy that is suitable for near-room temperature magnetic refrigeration applications.

BRIEF SUMMARY

The following summary of the invention is provided to facilitate an understanding of some of the innovative features unique to the present invention and is not intended to be a full description. A full appreciation of the various aspects of the invention can be gained by taking the entire specification, claims, drawings, and abstract as a whole.

It is, therefore, one aspect of the present invention to provide for an improved magnetic refrigerant material.

It is another aspect of the present invention to provide for a Gd—Ge—Si containing alloy suitable for near-room temperature magnetic refrigeration applications.

It is a further aspect of the present invention to provide for a method of preparing a doped $Gd_5Ge_2Si_2$ alloy.

It is yet an additional aspect of the present invention to provide for a method of reducing large hysterisis losses in the $Gd_5Ge_2Si_2$ containing alloy.

The aforementioned aspects of the invention and other objectives and advantages can now be achieved as described herein.

In one aspect, a method of reducing hysterisis in a $Gd_5Ge_2Si_2$ refrigerant compound is provided. The $Gd_5Ge_2Si_2$ compound is doped or alloyed with an effective amount of a silicide-forming metal element such that the magnetization hysterisis losses in the doped $Gd_5Ge_2Si_2$ compound are substantially reduced in comparison to the hysterisis losses of the undoped $Gd_5Ge_2Si_2$ compound. By adding a silicide-forming metal to the $Gd_5Ge_2Si_2$ compound in this manner, a magnetic refrigerant material highly suitable for near-room temperature applications is provided.

About one atomic percent of said silicide-forming metal can be added to the $Gd_5Ge_2Si_2$ compound in order to reduce hysteresis losses by more than 90 percent compared to the undoped $Gd_5Ge_2Si_2$ compound. Additionally, the resulting