DOPED GD5GE2SI2 COMPOUNDS AND METHODS FOR REDUCING HYSTERESIS LOSSES IN GD5GE2SI2 COMPOUND

REFERENCE TO RELATED APPLICATIONS

[0001] This patent application is a divisional application of U.S. patent application Ser. No. 11/262,270, entitled "Doped $Gd_5Ge_2Si_2$ compounds and methods for reducing hysteresis losses in $Gd_5Ge_2Si_2$ compound", to Robert D. Shull, which was filed on, Oct. 27 2005, the disclosure of which is incorporated herein by reference. U.S. patent application Ser. No. 11/262,270 in turn claims priority under 35 U.S.C. §119(e) to U.S. Provisional Patent Application Ser. No. 60/641,168 entitled "Near-Elimination of Large Hysteresis Losses in the $Gd_5Ge_2Si_2$ Alloy by Small Iron Addition Resulting in a Much Improved Magnetic Refrigerant Material" which was filed on Jan. 4, 2005, the disclosure of which is also incorporated herein by reference.

TECHNICAL FIELD

[0002] 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

[0003] 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.

[0004] 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 $Gd_5Si_2Ge_2$", 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).

[0005] 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".

[0006] 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 $Gd_5(Si_2Ge_2)$ ", Phys. Rev. Lett. 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 Comp. 260, 98-106 (1997); and Pecharsky, V. K., Pecharsky, A. O., and Gschneidner, K. A., Jr., "Uncovering the structure-property relationships in $R_5(Si_xGe_{4-x})$ intermetallic phases", J. Alloys and Comp. 344, 362-368 (2002)).

[0007] 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 hysteresis 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 $G_5(Si_{1.5}Ge_{2.5})$ and $Gd_5(Si_2Ge_2)$", Phys. Rev. B 62, R14625-R14628 (2000); Giguere, A. et al., "Direct Measurement of the 'Giant' Adiabatic Temperature Change in $Gd_5Si_2Ge_2$", Phys. Rev. Left. 83, 2262-2265 (1999)).

[0008] There is a need to greatly reduce or eliminate the large hysteresis losses in the $Gd_5Ge_2Si_2$ 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.

[0009] 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

[0010] 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.

[0011] It is, therefore, one aspect of the present invention to provide for an improved magnetic refrigerant material.

[0012] 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.

[0013] It is a further aspect of the present invention to provide for a method of preparing a doped $Gd_5Ge_2Si_2$ alloy.

[0014] It is yet an additional aspect of the present invention to provide for a method of reducing large hysteresis losses in the $Gd_5Ge_2Si_2$ containing alloy.

[0015] The aforementioned aspects of the invention and other objectives and advantages can now be achieved as described herein.

[0016] In one aspect, a method of reducing hysteresis 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