MAGNETICALLY REFRIGERATING MAGNETIC MATERIAL, MAGNETIC REFRIGERATION APPARATUS, AND MAGNETIC REFRIGERATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from Japanese Patent Applications No. 2008-227035, filed on Sep. 4, 2008, the entire contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to a magnetic material having a magnetocaloric effect, a magnetic refrigeration apparatus using the magnetic material and a magnetic refrigeration system.

BACKGROUND OF THE INVENTION

At present, almost all refrigeration technologies in a room temperature region, which closely relates to a human daily life, for example, a refrigerator, a freezing chamber, a room heating/cooling system, and the like, mostly employ gas compression/expansion cycle. However, the refrigeration technologies based on the gas compression/expansion cycle have a serious problem of an environmental destruction due to specific freon gas discharged into the environment. Further, as to alternative freon gas, its adverse affects on the environment are also concerned. From the above background, practically use of a safe, clean, and effective refrigeration technology which does not cause a problem of the environmental destruction even if a working gas is discarded is required, as found in an examination of natural refrigerants such as CO_2, ammonia, and the like, and isobutene which have a smaller risk to the environment.

Thus expectations are raised for a magnetic refrigeration as one of environment-conscious and effective refrigeration technologies. Then, research and development of a magnetic refrigeration technology aiming at a room temperature range are accelerated. The magnetic refrigeration technology uses a magnetocaloric effect that Warburg discovered on iron (Fe) in 1881. The magnetocaloric effect is a phenomenon that the temperature of magnetic material changes according to changing of external magnetic field in an adiabatic state. In early 1900's, the refrigeration system using paramagnetic salts and compounds represented by $Gd_2(SO_4)_3.8H_2O$ or $Gd_3Ga_5O_{12}$, which show the magnetocaloric effect, was developed. However that system was mainly used in an ultra-cold temperature region around 20 K or less, and needed a high magnetic field around 10 T which is created by a superconducting magnet.

Researches for making use of a magnetic transition between a paramagnetic state and a ferromagnetic state have been vigorously carried out from the 1970s' up to now to realize a magnetic refrigeration in a high temperature region. As a result of these researches, some magnetic materials are proposed. For example, a simple substance of rare earth (Pr, Nd, Dy, Er, Tm, Gd and the like), rare earth alloys which include at least two kinds of rare earth element, such as Gd—Y, Gd—Dy, and intermetallic compounds such as RAl_2 and RNi_2 (R represents rare earth elements), GdPd, and the like.

In 1982, Barclay proposed an AMR ("Active Magnetic Regenerative Refrigeration") system as a magnetic refrigeration system for a room temperature region in the United States. The key feature of this system is to use the two effects, a magnetocaloric effect and a heat accumulation, of magnetic materials (refer to U.S. Pat. No. 4,332,135). That is, this system actively uses the lattice entropy which was conventionally considered as a disincentive.

In United States in 1998, Zimm, Gschneidner, Pecharsky et al succeeded in a continuous operation of a magnetic refrigeration cycle by using AMR systems with Gd (gadolinium) under the high magnetic field (5 T) generated by a superconducting magnet.

Magnetic refrigeration is carried out by the AMR system using the following steps:

(1) A magnetic field is applied to a magnetic refrigeration working material;

(2) The magnetic refrigeration working material heat up at step (1) and this heat energy is transported to one side by a heat transfer fluid;

(3) The magnetic field removed; and

(4) The magnetic refrigeration working materials cool down at step (3) and this coldness is transported to the other side by a heat transfer fluid.

Repeating the cycle from (1) to (4), the heat energy generated by magnetic refrigeration material is transported to one direction and then the temperature gradient is created in AMR bed. As a result, a refrigeration work is carried out by generating a large temperature difference.

However, a magnetocaloric effect of the magnetic refrigeration material is maximized in the vicinity of a magnetic transition temperature and reduced as a temperature is away from the magnetic transition temperature. Accordingly, there is a problem in that a job efficiency is deteriorated. To cope with the above problem, there is proposed to increase a working temperature region by filling an AMR bed with magnetic materials having a different magnetic transition temperature in a layered state in agreement with a temperature difference generated in the AMR bed (refer to JP-A H04-186802 (KOKAI)

SUMMARY OF THE INVENTION

A magnetic material for magnetic refrigeration of an embodiment of the present invention has a magnetic material shown by a composition formula of $Gd_{100-x-y}Zr_xY_y$, wherein 0 (at %)<x<3.4 (at %) and 0 (at %)≤y≤13.5 (at %).

A magnetic refrigeration apparatus of an embodiment of the present invention using a heat transfer fluid has an AMR bed filled with a magnetic material, a magnetic field generation device configured to apply and remove a magnetic field to and from the magnetic material, a low temperature side heat exchanging unit configured to receive coldness from the AMR bed, a high temperature side heat exchanging unit configured to receive heat from the AMR bed, and a heat transfer fluid path formed by connecting the AMR bed, the low temperature side heat exchanging unit, and the high temperature side heat exchanging unit for circulating a heat transfer fluid, wherein at least a part of the magnetic material is formed of a magnetic material shown by a composition formula of $Gd_{100-x-y}Zr_xY_y$, wherein 0<x<3.4 and 0≤y≤13.5.

A magnetic refrigeration system of an embodiment of the present invention has a magnetic refrigeration apparatus having an AMR bed filled with a magnetic material, a magnetic field generation device configured to apply and remove a magnetic field to and from the magnetic material, a low temperature side heat exchanging unit, a high temperature side heat exchanging unit, and a heat transfer fluid path formed by connecting the AMR bed, the low temperature side heat