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FERRIMAGNETIC IRON GARNET HAVING LARGE FARADAY EFFECT

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ABSTRACT OF THE DISCLOSURE

A ferrimagnetic iron garnet having the general formula

$$\{Bi_{3-2x-y}Ln_yCa_{2x}\}[Fe_2](Fe_{3-x}V_x)O_{12}$$

where Ln is a trivalent rare earth element and x and y are selected to provide both a large Faraday rotation and a thermally induced magnetic compensation point. The garnet is particularly applicable to magneto-optical memories in which both the read-in and read-out processes are optically controlled.

BACKGROUND OF THE INVENTION

This invention relates to a ferrimagnetic iron garnet containing in combination a trivalent bismuth ion and a magnetic rare earth ion. The new garnet has a large Faraday effect and a thermally sensitive magnetic compensation point making it particularly useful as a component in magneto-optical variable memories.

Magneto-optical memories have been devised which make use of the optical Faraday effect and temperature compensation properties of certain rare earth iron garnets to achieve a memory in which both the read-in and read-out processes are optically controlled. Such materials have magnetic sublattice magnetizations with different temperature characteristics and each becomes magnetically compensated only at a specific temperature. For example, $Gd_3Fe_5O_{12}$, $Tb_3Fe_5O_{12}$, $Dy_3Fe_5O_{12}$ and several of the heavier rare earth iron garnets become magnetically compensated at approximately 290° K., 250° K., 220° K. and lower temperatures respectively.

In these materials there are three magnetic sublattices containing two octahedral Fe^{3+} ions with a moment of 10 Bohr magnetons, three tetrahedral Fe^{3+} ions with a moment of 15 Bohr magnetons and three rare earth ions per formula unit. The net iron moment of 5 Bohr magnetons is opposed by the rare earth moments in the case of Gd^{3+}, Tb^{3+} and Dy^{3+} and, at a sufficiently low temperature, these rare earth moments reach the net iron moment and the material becomes compensated. A crystal maintained at the compensation temperature requires a relatively large coercive magnetic field to reverse the magnetization directions of the rare earth and iron sublattices; however, a small temperature excursion (about 3° C. for gadolinium iron garnet) from the compensation temperature results in a large reduction in the magnitude of the required coercive field.

When a beam of linearly polarized light is transmitted through a thin section of a rare earth iron garnet in the same direction as an applied magnetic field, it undergoes a Faraday rotation in a first direction. The sense of rotation reverses when the direction of magnetization of the iron sublattice is reversed. The rotation depends essentially on the magnetization of the iron sublattice and therefore the rotation occurs over a range of temperatures including the compensation point where the net magnetization of the crystal is zero.

A typical magneto-optical memory consists of a closely packed mosaic of small thin rare earth iron garnet crystals mounted on a transparent, high thermal conductivity, substrate maintained at the compensation temperature. Each crystal comprises a single domain in which the net magnetization is zero, the zero magnetization resulting from the rare earth and iron sublattices being in either of the two remanent opposing magnetization directions normal to the crystal surface. When a low-intensity beam of linearly polarized light is incident on a selected crystal, its axis of polarization is rotated clockwise or counter-clockwise depending on which of the two remanent iron sublattice magnetization directions was previously established in the crystal. A polarization analyzer samples the light emerging from the crystal and, by sensing the direction of the Faraday rotation, produces an output corresponding to the specific magnetization direction of the iron sublattice in the selected crystal. In gadolinium iron garnet, for example, this rotation is about 1000 degrees per centimeter for a beam of linearly polarized light having a wavelength of 6328 angstroms. A substantially monochromatic beam at this wavelength may be obtained for a commercially available helium-neon gas laser.

Information is read-in to a selected crystal of the mosaic by focusing a pulsed high-intensity beam on the crystal thereby raising its temperature locally by a few degrees. This produces a large temporary reduction of its coercivity relative to the remainder of the crystals in the mosaic. Consequently, a magnetic field of appropriate direction applied to the entire array can be used to reverse the magnetization of the addressed crystal without disturbing the other crystals in the mosaic which are maintained at the compensation temperature. The magnetic field is turned off once the crystal has cooled to a point where demagnetization cannot occur. Magneto-optical memories of this type are described in the paper "Magneto-Optical Variable Memory Based Upon the Properties of a Transparent Ferrimagnetic Garnet at Its Compensation Temperature," Chang et al., Journal of Applied Physics, volume 36, No. 3, March 1965.

It can be seen that the magnitude of the Faraday effect governs the reliability of the read-out process and therefore it is desirable to use magneto-optic materials having Faraday rotations which are as large as possible. Accordingly, I have invented a material which yields a significantly larger Faraday effect than previously known rare earth iron garnets and which has a thermally sensitive magnetic compensation.

SUMMARY OF THE INVENTION

In accordance with the present invention I have discovered a series of compositions of matter which have thermally induced magnetic compensation points together with unusually large Faraday effects. These compositions consist essentially of a ternary system having the general formula $\{Bi_{3-2x-y}Ln_yCa_{2x}\}[Fe_2](Fe_{3-x}V_x)O_{12}$ where the rare earth Ln is selected from a first group consisting of Gd, Tb, Dy, Ho, and Er or a second group consisting of Pr and Nd. In this formula $0 \leq x < 1.4$ and $0.05 < y < 2.9$.

For the rare earths of the first group, a thermally induced magnetic compensation point exists only at one specific temperature below the Curie temperature for values of x equal to and greater than zero and less than unity, and for rare earths of the second group the compensation point exists for values of x greater than unity and less than approximately 1.4. In the case of the rare earths of the first group, the magnetic moments of the heavier rare earth couple opposite that of the tetrahedral iron sublattice which remains dominant. In the case of the second group, Pr and Nd, thermally compensated compositions can be obtained for the specified values of x because for these values the rare earth moment orders parallel to the tetrahedral iron moments.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The specific values of x and y in the general formula determine several factors including (1) the magnitude of the Faraday effect, (2) the compensation temperature, (3) the rate of change of magnetization with temperature at the compensation point, and (4) the phase stability. A preferred composition was synthesized by mixing the following compounds in the indicated proportions:

Compound:	Parts by weight
$CaCO_3$	12.8
Fe_2O_3	20.5
V_2O_5	6.2
Bi_2O_3	49.7
Gd_2O_3	10.8

The mixture was heated in a covered platinum crucible to 1200° C. to form a melt and then allowed to slowly cool at a rate of about 4 degrees per hour to 950° C. to form crystals of a garnet having the approximate formula

$$Bi_{0.6}Gd_{0.8}Ca_{1.6}Fe_{4.2}V_{0.8}O_{12}$$

These crystals were then separated by washing the mixture in dilute nitric acid which dissolve the solidified flux leaving the desired crystals relatively unaffected.

The crystals grown in this way had a magnetic compensation temperature of 237° K. and exhibited a Faraday rotation of 7000 to 8000 degrees per centimeter when exposed to a linearly polarized light beam at 6328 angstroms. This rotation occurred in the temperature range 200 to 300° K. with the sign of the Faraday effect changing from positive above the compensation temperature to negative below this temperature. The Faraday effect for the preferred material is several times larger than and has an opposite sign from that found in gadolinium iron garnet.

Other compositions can be obtained by a similar flux growth method, as is well known in the art, and other rare earth oxides can be substituted for Gd_2O_3. Also, additional flux forming compounds, such as PbO, PbF_2 and B_2O_3 can be added to achieve optimum compositions.

What is claimed is:

1. A ferrimagnetic iron garnet having the general formula

$$(Bi_{3-2x-y}Ln_yCa_{2x})(Fe_2)(Fe_{3-x}V_x)O_{12}$$

wherein y is greater than 0.05 and less than 2.9 and x is equal to or greater than 0 and less than 1.4 but not equal to 1 and wherein Ln is selected from the group consisting of Gd, Tb, Dy, Ho and Er when x is equal to or greater than 0 and less than 1 and Ln is selected from the group consisting of Pr and Nd when x is greater than 1 and less than 1.4, said garnet having a thermally induced magnetic compensation point and a Faraday rotation larger than the corresponding rotation of $Ln_3Fe_5O_{12}$.

2. A ferrimagnetic iron garnet as defined by claim **1** and wherein Ln is selected from the group consisting of Gd, Tb, Dy, Ho, and Er.

3. A ferrimagnetic iron garnet as defined by claim **1** and wherein Ln is selected from the group consisting of Pr and Nd.

4. A ferrimagnetic iron garnet as defined by claim **1** wherein Ln is Gd.

5. A ferrimagnetic iron garnet as defined by claim **4** wherein x and y are each approximately 0.8.

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