METHOD FOR PRODUCING BUBBLE DOMAINS IN MAGNETIC FILM-SUBSTRATE STRUCTURES

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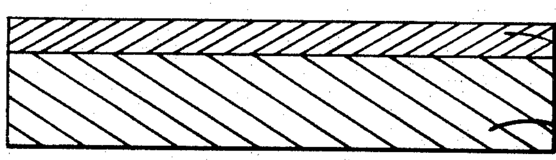

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METHOD FOR PRODUCING BUBBLE DOMAINS IN MAGNETIC FILM-SUBSTRATE STRUCTURES

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ABSTRACT OF THE DISCLOSURE

A method for producing a bubble domain in a magnetic single crystal garnet film-substrate structure is disclosed. The method involves the epitaxial deposition of an iron garnet film of the proper crystallographic orientation and having a negative magnetostriction constant on a garnet substrate in which the room temperature lattice consant of the substrate is larger than the room temperaure lattice constant of the film, preferably by an amount less than 0.016 angstrom.

BACKGROUND OF THE INVENTION

(1) Field of the invention

This invention relates to bubble domains and more particularly to a method of forming a craze-free film having bubble domains therein.

(2) Description of prior art

Magnetic bubble domains in a sheet of magnetic medium, such as yttrium orthoferrite, are well known in the art and are described in U.S. Pat. No. 3,460,116 and others. Magnetic bubble domains in composite structures having a thin film of a single crystal iron garnet on an oxide substrate are disclosed in the copending patent applications to Mee et al., U.S. Ser. Nos. 16,446 and now U.S. Pat. No. 3,645,788 and 16,447, filed Mar. 4, 1970. These copending patent applications are incorporated herewith.

Some of the bubble domain composite single crystal film-substrate structures reported in the prior art have had crazing, that is cracking, of the film, making them unsuitable for certain types of bubble domain device applications. Other iron garnet film-substrate structures were observed to have domains whose magnetization directions are in the plane of the film in contrast to the desired bubble domains whose magnetization directions are perpendicular to the plane of the film.

SUMMARY OF THE INVENTION

It is a primary object of this invention to provide an improved method of forming a single crystal iron garnet film-substrate structure having bubble domains therein.

It is another object of this invention to provide a method of forming a bubble domain film-substrate structure having a craze-free film surface.

These and other objects of this invention are accomplished by a method in which the uniaxial anisotropy necessary for bubble domain formation in a craze-free film-substrate structure is affected by proper control of the mechanical stress present in the film at room temperature. A specific step in the method involves depositing a single crystal iron garnet film of the proper crystallographic and having a negative magnetostriction constant on a substrate in which the room temperature lattice constant of the substrate is larger than the room temperature lattice constant of the film preferably by an amount less han 0.016 angstrom.

An example of a preferred embodiment in accordance with this invention is to chemically vapor deposit a gallium substituted yttrium iron garnet, $Y_3Ga_{1.2}Fe_{3.8}O_{12}$, film of the proper orientation and having a negative magnetostriction constant on a mixed yttrium-gadolinium gallium garnet, $Gd_{2.7}Y_{0.3}Ga_5O_{12}$, substrate. The lattice constant of the substrate is 12.367 angstroms which is 0.010 angstrom larger than the 12.357 angstroms lattice constant of the film.

Other objects and advantages of this invention will be apparent from the following detailed description wherein a preferd embodiment of the present invention is clearly shown.

BRIEF DESCRIPTION OF THE DRAWING

The drawing shows a magnetic bubble domain film-substrate structure made in accordance with the method of this invention.

DETAILED DESCRIPTION OF THE INVENTION

This invention involves a process in which a single crystal iron garnet material is chemically vapor deposited to form a film on a substrate. It is necessary that the single crystal material have the proper crystallographic orientation to take advantage of the negative magnetostriction. In addition the room lattice constant of the substrate is larger than the room lattice constant of the deposited film, preferably by an amount less than 0.016 angstrom. The resultant film-substrate structure has a craze-free film with bubble domains therein.

In general, the normal source of uniaxial anisotropy observed in magnetic materials is the crystal structure of the material. When single crystal platelets with negative magnetostriction constants (λ_{100}, $\lambda_{111}<0$) are under stress, the magnetostriction contribution tends to make the normal to the plane of the platelet an easy axis of magnetization if the platelet is in tension ($\sigma>0$) and a hard axis if the platelet is in compression ($\sigma<0$)λ_{100} and λ_{111} are the saturation values of the linear magnetostriction constants along the <100> and <111> directions, respectively, and σ is the stress in the plane of the material.

The room temperature magnetostriction constants of selected iron garnet$_0$ are listed in the following table.

Iron garnet	Magnetostriction constant	
	λ100 (×10⁶)	λ111 (×10⁶)
$Sm_3Fe_5O_{12}$	+21	−8.5
$Eu_3Fe_5O_{12}$	+21	+1.8
$Gd_3Fe_5O_{12}$	0	−3.1
$Tb_3Fe_5O_{12}$	−3.3	+12
$Dy_3Fe_5O_{12}$	−12.5	−5.9
$Ho_3Fe_5O_{12}$	−3.4	−4.0
$Er_3Fe_5O_{12}$	+2.0	−4.9
$Tm_3Fe_5O_{12}$	+1.4	−5.2
$Yb_3Fe_5O_{12}$	+1.4	−4.5
$Y_3Fe_5O_{12}$	−1.4	−2.4
$Y_3Ga_{0.64}Fe_{4.36}O_{12}$	−1.4	−1.7
$Lu_3Fe_5O_{12}$	−1.4	−2.4

Some of these iron garnet materials, for example

$$Tb_3Fe_5O_{12}$$

and $Yb_3Fe_5O_{12}$, have both a negative and a positive magnetostriction constant. In the practice of this invention the crystallographic orientation of the garnet film must be chosen to take advantage of the negative magnetostriction constant. In the case with $Tb_3Fe_5O_{12}$ material, the orientation would be {100}. With the $Yb_3Fe_5O_{12}$ material, the orientation would be {111}.

The values of the magnetostriction constants of the iron garnet material, as well as its magnetization, can be varied by depositing a film containing a mixture of two or more pure iron garnets and/or by substituting other cations for iron ions.

It is understood that whether there is mixing and/or substitution or not, the condition for bubble domain formation in the iron garnet material, $H_A/4\pi M_s > 1$, has to be satisfied, where H_A is the uniaxial anistotropy field and $4\pi M_s$ is the magnetization.

In magnetic oxide film-substrate structures formed by chemical vapor deposition, the dominant source of uniaxial anistotropy is the magnetostrictive effect resulting from the stress existing in the film. This stress is due to the difference between the lattice constants and the thermal expansion coefficients of the film and substrate and may be in the form of tension or compression.

This invention specifically covers a method of forming a bubble domain structure by depositing a magnetic single crystal garnet film of the proper orientation and having a negative magnetrostriction constant on a substrate in which the film is in tension.

A copending application to Mee et al., Ser. No. 101,785, filed Dec. 28, 1970, covers a method of forming a bubble domain structure by depositing a magnetic single crystal garnet film of the proper orientation and having a positive magnetostriction constant on a substrate in which the film is in compression.

A copending application to Mee el al., Ser. No. 101.787, filed Dec. 28, 1970, covers a second method of forming a bubble domain structure by depositing a magnetic single crystal garnet film of the proper orientation and having a negative magnetostriction constant on a substrate in which the film is in tension.

As shown in the drawing, an oxide substrate **10** is subjected preferably to a chemical vapor deposition step to provide a thin film of magnetic bubble domain material, film **12**. The deposition step is carried out in accordance with the copending application, Ser. No. 833,268, filed June 16, 1969, and assigned to the assignees of the present invention. This pending patent application is incorporated herewith by reference hereto. The film **12** may be deposited by sputtering techniques or by a liquid phase epitaxial process.

The substrate **10** is monocrystalline garnet having a $J_3Q_5O_{12}$ formulation wherein the J constituent of the wafer formulation is at least one element selected from the group consisting of cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium dysprosium, holmium, erbium, thulium, yetterbium, lutetium, lanthanum, yttrium, calcium, bismuth; and the Q constituent of the wafer formulation is at least one element selected from the group consisting of indium, gallium, scandium, titanium, vanadium, chromium, manganese, rhodium, zirconium, hafnium, niobium, tantalum, aluminum, phosphorous, arsenic and antimony.

Examples of substrate materials are mixed yttrium-gadolinium gallium garnet, gadolinium gallium garnet, aluminum substituted gadolinium gallium garnet, terbium gallium garnet, and dysprosium gallium garnet.

The film of the bubble domain material is a single crystal garnet film having a $J_3Q_5O_{12}$ formulation wherein the J constituent of the film formulation has at least one element selected from the group of cerium, praseodymium, neodymium, promethium, samarium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, lanthanum and yttrium; the Q constituent of the film formulation is taken from the group consisting of iron, iron and aluminum, iron and gallium, iron and indium, iron and scandium, iron and titanium, iron and vanadium, iron and chromium, and iron and manganese.

A preferred substrate material is mixed yttrium-gadolinium gallium garnet when the film material is gallium substituted yttrium iron garnet.

In accordance with this invention, an iron garnet film of the proper orientation and having a negative magnetostriction constant is deposited on a garnet substrate in which the room temperature lattice constant of the substrate is larger than the room temperature lattice constant of the film, preferably by an amount less than 0.016 angstrom. When the substrate lattice constant exceeds the film lattice constant, the film is in tension and bubble domains are present therein. The preferred differences between the lattice constants is of the order of 0.005 to 0.010 angstrom. When the lattice constant difference is 0.016 angstrom or more, the tension or stress is so great that there is crazing or cracking of the film. When the substrate lattice constant is smaller than the film lattice constant by an amount less than about 0.035 angstrom, the film is in compression and there are no bubble domains since the normal to plane of the film is the hard magnetization axis and the domain magnetizations lie in the plane.

As previously discussed, the difference in the coefficients of thermal expansion between the film and the substrate contributes to the total stress present in the film. The thermal expansion stress contribution is within acceptable limits as long as the coefficient of thermal expansion of the substrate is the same as or lower than that of the film by an amount not more than $1 \times 10^{-6}/°$ C. between 25° C. and 1200° C. A certain amount of mismatch between film-substrate room temperature lattice constants and/or thermal expansion characteristics is required in order to provide the stress which produces the uniaxial anisotropy necessary for bubble domain formation. If film and substrate are too closely matched in both lattice constant and thermal expansion, the proper stress necessary for bubble domain formation will not be achieved.

EXAMPLE I

A {111} gallium substituted yttrium iron garnet,

$$Y_3Ga_{1.2}Fe_{3.8}O_{12}$$

having a lattice constant of 12.357 angstroms was deposited on a mixed yttrium-gadolinium gallium garnet, $Gd_{2.7}Y_{0.3}Ga_5O_{12}$, by chemical vapor deposition techniques. The lattice constant of the mixed yttrium-gadolinium gallium garnet was 12,367, which exceeded that of the film by 0.010 angstrom. The resultant structure had a craze-free film which had bubble domains therein.

EXAMPLES II–V

Examples I–V are listed below in the following able. In Example II, a gallium substituted yttrium iron garnet film was deposited in accordance with this invention on a gadolinium gallium garnet in which the substrate lattice constant exceeded the film lattice constant at room temperature by 0.019. This structure had bubble domains in the film and also had crazing on the film surface making it less useful for certain applications. Examples III, IV and V were the gallium substituted yttrium iron garnet films on different substrates in which the film lattice constant exceeded the substrate lattice constant by less than 0.035 angstrom. As a result, these films were in compression and there were no bubble domains, only domains whose magnetization lies in the plane.

TABLE

Example No.	Film		Subtrate		Substrate lattice constant-film lattice constant,[a] A.	Bubble domain	In-Plane vector domains	Crazing on film surface	Stress
	Material [b]	Lattice constant,[a] A.	Substrate material [c]	Lattice constant,[a] A.					
I	$Y_3Ga_{1.2}Fe_{3.8}O_{12}$	12.357	$Gd_{2.7}Y_{0.3}Ga_5O_{12}$	12.367	0.010	Yes	No	None	Tension.
II	$Y_3Ga_{1.2}Fe_{3.8}O_{12}$	12.357	$Gd_3Ga_5O_{12}$	12.367	0.019	Yes	No	Yes	Do.
III	$Y_3Ga_{1.2}Fe_{3.8}O_{12}$	12.357	$Gd_3Al_{0.6}Ga_{4.4}O_{12}$	12.355	−0.002	No	Yes	None	Compression.
IV	$Y_3Ga_{1.2}Fe_{3.8}O_{12}$	12.357	$Tb_3Ga_5O_{12}$	12.347	−0.010	No	Yes	do	Do.
V	$Y_3Ga_{1.2}Fe_{3.8}O_{12}$	12.357	$Dy_3Ga_5O_{12}$	12.341	−0.016	No	Yes	do	Do.

[a] At room temperature.
[b] 111 orientation, negative magnetostriction constant;
[c] 111 orientation.

What is claimed is:

1. A method of producing a bubble domain containing single crystal iron garnet film-substrate structure comprising the step of depositing an iron garnet film of the proper crystallographic orientation and having a negative magnetostriction constant on a substrate in which the substrate has a room temperature lattice constant which exceeds the room temperature lattice constant of the iron garnet film, by an amount less than .016 angstrom.

2. A method as described in claim 1 whereby the room temperature lattice constant oft he substrate exceeds the room temperature lattice constant of the film by an amount between 0.005 and 0.010 angstrom.

3. A method as described in claim 1 whereby said film is deposited by a chemical vapor deposition technique.

4. A method of producing a bubble domain containing film-substrate structure comprising the steps of depositing a yttrium iron garnet film of the proper crystallographic orientation and having a negative magnetostriction constant on a substrate in which the substrate has a room temperature lattice constant which exceeds the room temperature lattice constant of said film by an amount less than 0.016 angstrom.

5. A method as described in claim 4 whereby said substrate is a mixed yttrium-gadolinium gallium garnet.

References Cited

UNITED STATES PATENTS

3,525,638	8/1970	Archey	117—107.1 X
3,486,937	12/1969	Linares	117—235 X
3,429,740	2/1969	Mee	117—235 X
3,131,082	4/1964	Gambino	117—235
3,573,099	3/1971	Moore et al.	117—235 X
3,645,787	2/1972	Mee et al.	117—239
3,645,788	2/1972	Mee et al.	117—235
3,617,381	11/1971	Hanak	117—235

OTHER REFERENCES

Giess et al.: IBM Tech. Dis. Bull., p. 517, 117-235, vol. 13, No. 2, July 1970.

WILLIAM D. MARTIN, Primary Examiner

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U.S. Cl. X.R.

117—106 R

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,728,152 Dated April 17, 1973

Inventor(s) Jack E. Mee et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 42, "garnet$_o$" should read -- garnets --.

Column 3, line 22, "101.787" should read -- 101,787 --.

Column 5, claim 2, line 11, "oft he" should read -- of the --.

Signed and sealed this 21st day of May 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents