

- [54] **METHOD OF FORMING MULTIPLE LAYER STRUCTURES INCLUDING MAGNETIC DOMAINS**
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- [51] Int. Cl. **H01f 10/06**
- [58] Field of Search..... **117/235, 239, 212, 215, 217, 117/236, 240**

3,511,702 5/1970 Jackson et al.117/212
 2,919,432 12/1959 Broadbent.....340/174

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[57] **ABSTRACT**

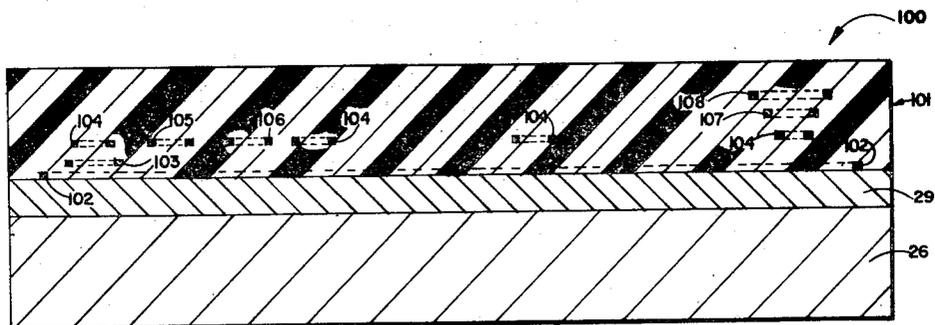
A composite consisting of multiple layer structures, the basic structure of which is a chemically vapor deposited film on a substrate wafer, disclosed herein. The film is of such material appropriate for creating therein single wall magnetic domains which are capable of being moved about in predetermined directions within the thickness of the film and in the plane of the film. Devices are adapted to the film for sensing the motion of these domains thereby enabling application of these structures toward circuits which may be particularly utilized in memory or logic applications. A complete family of film on substrate materials are fabricated through a unique process, one of the steps of the process relates to establishment of the exact location of the substrate within the reactor at which deposition of the film upon the substrate is to be made in order to obtain the desired film characteristics. Included, are provisions for making multiple film layers to result in a matrix of films and hence a multitude of such circuits.

[56] **References Cited**

UNITED STATES PATENTS

3,460,116	8/1969	Bobbeck et al.....	340/174 M
3,429,740	2/1969	Mee	117/235 X
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6 Claims, 4 Drawing Figures



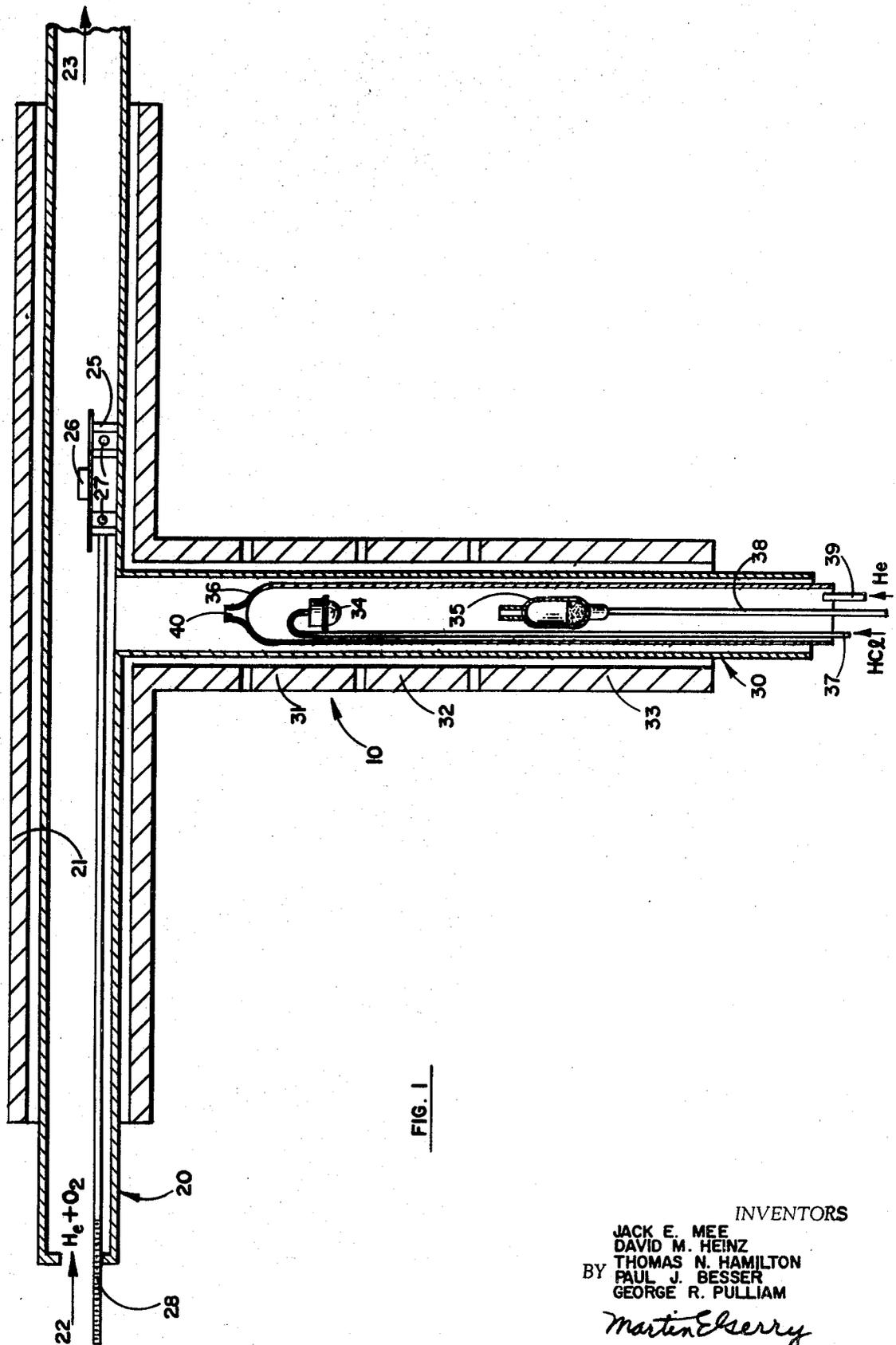


FIG. 1

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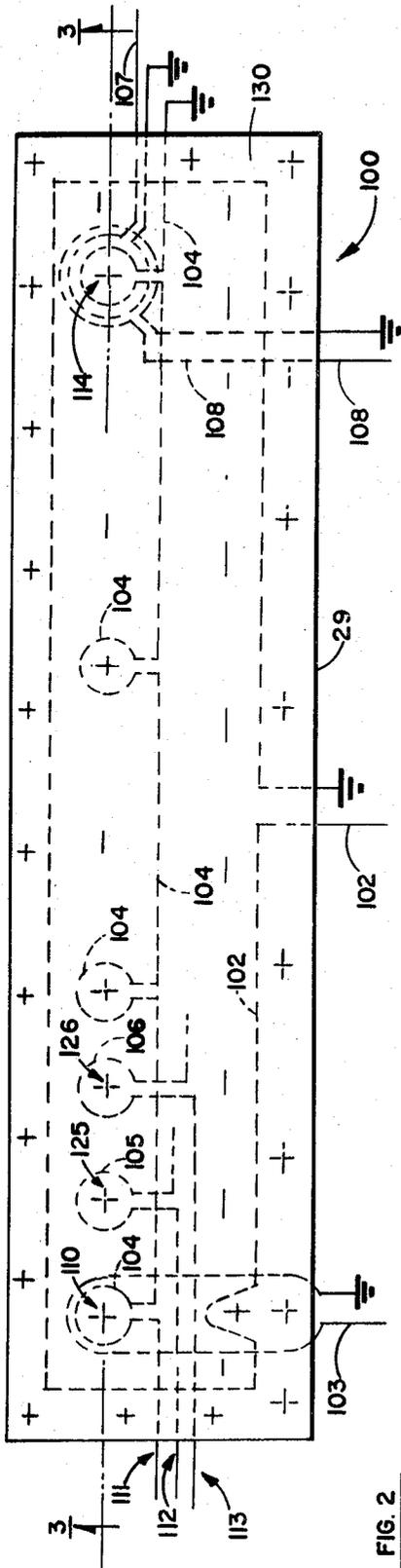


FIG. 2

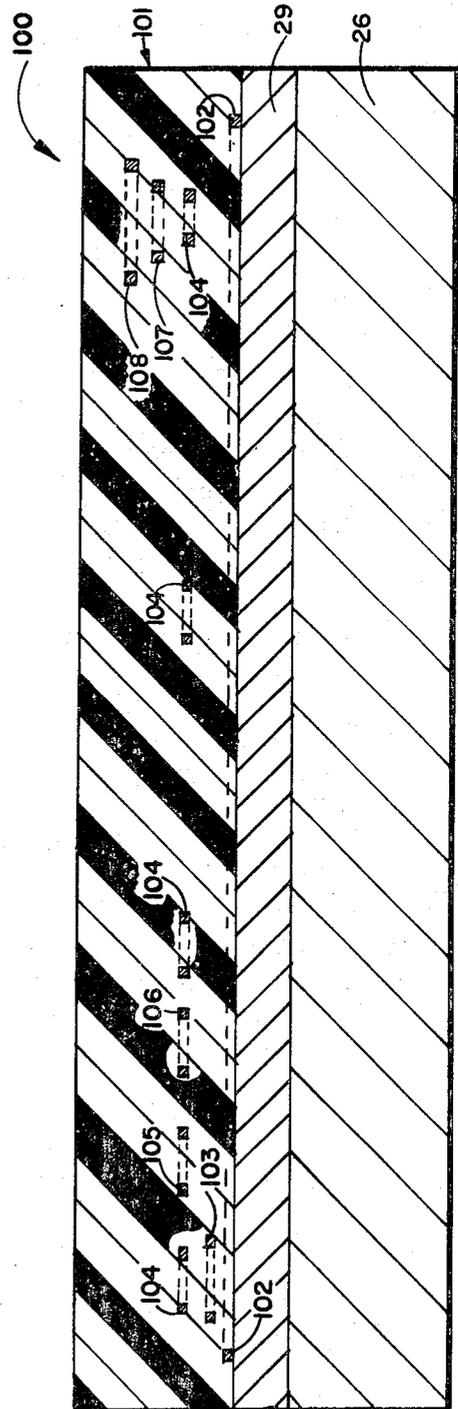


FIG. 3

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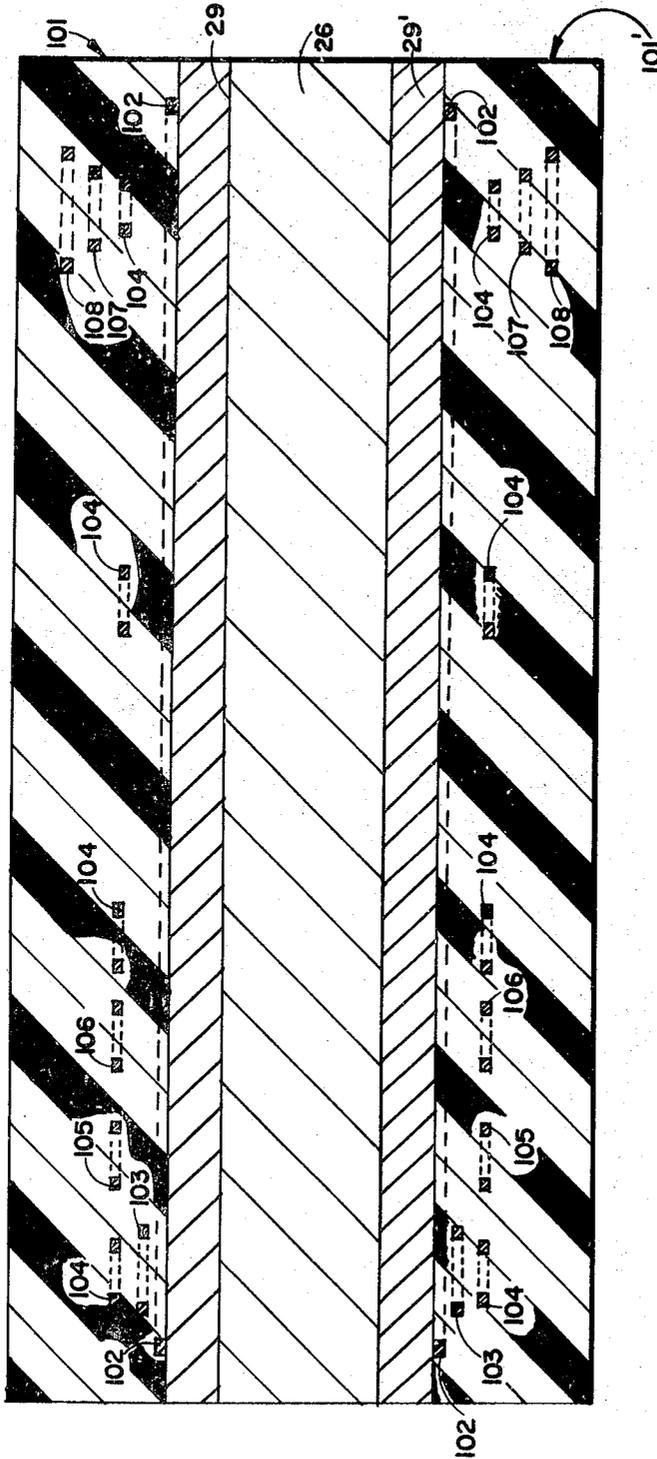


FIG. 4

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METHOD OF FORMING MULTIPLE LAYER STRUCTURES INCLUDING MAGNETIC DOMAINS

BACKGROUND OF THE INVENTION

1. Field of Invention

The invention relates to a chemical vapor deposition process and product resulting therefrom for epitaxially growing oxygen compound films of yttrium, lanthanum or any of the lanthanide group of elements mixed with certain metals or other elements and deposited on a substrate wafer comprising a variety of compounds for obtaining a composite of a multiple layer structure. This composite structure has utility in magnetic devices as well as is particularly useful in logic devices or circuits due to the capability of creation of single wall magnetic domains in the films thereof.

2. Prior Art

The current interest in orthoferrite single crystals has been aroused by the ability to produce mobile single domain wall or bubble magnetic domains in thin plates of proper crystallographic orientation as described in a paper by A. H. Bobeck entitled "Properties and Device Applications of Magnetic Domains in Orthoferrites," published in the "Bell System Technical Journal," Volume 46, page 1901 (1967). These domains can be manipulated by magnetic fields to perform logic and memory functions as demonstrated in a patent to A. H. Bobeck et al. U.S. Pat. No. 3,460,116, issued Aug. 5, 1969.

Bulk orthoferrite crystals have been grown from solution, either by a molten flux technique as described in a patent to J. P. Remeika, U.S. Pat. No. 3,079,240, issued Feb. 26, 1963, or a hydrothermal technique as described in a paper by E. D. Kolb, D. L. Wood, and R. A. Laudise entitled "The Hydrothermal Growth of Rare Earth Orthoferrite," published in the "Journal of Applied Physics," Volume 39, page 1362 (1968). Both growth methods as stated by the authors of these publications are prone to produce crystals with solvent inclusions or voids, and solvent chemical substitution in the crystal is described for example in a paper by J. P. Remeika and T. Y. Kometoni entitled "Lead Substitution in Flux Grown Single Crystal Rare Earth Orthoferrites," published in "Material Research Bulletin," Volume 3, page 895 (1968) and the above listed paper on hydrothermal growth by E. D. Kolb, D. L. Wood and R. A. Laudise. Single crystals resulting from either of these growth processes must be sliced and polished down to thin wafers of proper crystallographic orientation. Although very thin orthoferrite layers are desired, the limit of mechanical polishing is a few thousandths of an inch beyond which breakage becomes excessive. In addition, polishing scratches must be eliminated for they impede magnetic domain motion.

Techniques are known for obtaining magnetic oxide films on crystalline substrates include spraying a suspension of reactants on heated substrates, vacuum depositing metal alloys with subsequent oxidation, and chemically depositing on a substrate from mixed nitrate solutions followed by a firing of the material. More recently, certain films have been prepared by electron beam evaporation and by RF sputtering.

Cech and Alessandrini in a paper entitled "Preparation of FeO, NiO, and CoO Crystals by Halide Decomposition," published in "Transaction of the American Society of Metals," Volume 50, page 150 (1959), reported the epitaxial growth of certain materials by a chemical vapor deposition method. Others independently extended the techniques reported and showed that complex metal oxides could also be grown epitaxially by the chemical vapor deposition method. In general, chemical vapor deposition methods have produced films with desirable properties but the films have been difficult to reproduce.

As has been reported by A. H. Bobeck, R. F. Fischer, A. J. Perneski, J. P. Remeika and L. G. Van Uiter in a paper "Application of Orthoferrites to Domain Wall Devices," published in the "IEEE Transactions on Magnetics," Volume MAG-5 (1969), there is a minimum domain diameter for each orthoferrite which is characteristic of that material at room

temperature and for which a specific sample thickness is required. One way of reducing the characteristic domain diameter that has been described in the literature by V. F. Giandola, D. H. Smith, A. A. Thiele and L. G. Van Uiter in a paper "Material Requirements for Circular Magnetic Domain Devices," published in the "IEEE Transactions on Magnetics," Volume MAG-5 (1969), is for example to form solid solutions with samarium orthoferrite which has properties that depress the minimum domain diameter.

Sheets or films of polycrystalline magnetizable metals which may be subjected to magnetic influences for the purpose of creating magnetic domains have been shown in a patent to K. D. Broadbent, U.S. Pat. No. 2,919,432, issued Dec. 29, 1959. That patent specifically describes a thin sheet domain wall shift register in which a reverse magnetized domain, bounded by leading and trailing domain walls, is nucleated at an input position in the sheet and propagated along a first axis in the sheet by a step-along multiphase propagation field. Such a domain wall device usually requires or is characterized by anisotropic magnetic sheet where propagation of a reverse domain is either along the easy or the hard axis and the domain walls bounding that reverse domain extend to the edge of the sheet in the direction orthogonal to the axis of propagation. Inasmuch as the walls of the domain are bounded by the edge of the sheet, propagation of those domains is constrained to one of the axis along a transverse direction of the sheet.

In a patent to A. H. Bobeck et al. U.S. Pat. No. 3,460,116, issued Aug. 5, 1969, it is shown that a reverse magnetized domain may be bounded by a single wall domain. Such a domain differs from the reverse domain propagated in the Broadbent patent in that the single wall domain, encompassing the former, has a cross-sectional shape independent of the breadth of the sheet, or in other words is not bounded by the edge of the sheet. These domains are referred to as single wall domains.

The major disadvantages of both the Broadbent and Bobeck patents are that the former resorts to the use of an anisotropic film or sheet of material which results in striped or fingerlike domains substantially across the entire width or length of the sheet, while the latter patent does not utilize a substrate wafer for providing structural support of the sheet of material, thereby preventing the formation of very thin sheets of material for example thicknesses below 25 microns which offer advantages in high domain density applications.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a chemical vapor deposition process for epitaxially producing at least one film, containing oxide compounds having a pseudoperovskite-type structure comprised of at least one element selected from the group consisting of the lanthanides, lanthanum or yttrium and having at least another element selected from the group consisting of aluminum, gallium, indium, scandium, titanium, vanadium, chromium, manganese and iron. The pseudoperovskite for perovskitelike type of crystal structure is one having atoms with the symmetrical relationship of those in a perovskite lattice, but which has been distorted from cubic symmetry. This film is deposited by the process stated below on an oxide substrate compound wafer having at least one element selected from the group consisting of the lanthanides, lanthanum, yttrium, magnesium, calcium, strontium, barium, lead, cadmium, lithium, sodium or potassium, and having at least another element which is selected from the group consisting of gallium, indium, scandium, titanium, vanadium, chromium, manganese, iron, rhodium, zirconium, hafnium, molybdenum, tungsten, niobium, tantalum or aluminum.

It is a further object of the invention to provide the stated film on the substrate so as to enable extremely thin films to be chemically deposited and structurally supported thereon.

It is still a further object to provide a film compound attached to the substrate wafer wherein the film may be suitable for producing single wall magnetic domains therein, the single

wall magnetic domains behaving in a manner attributable to a single wall domain within a virtually isotropic medium. The behavior of the single wall magnetic domain and an exemplary device showing utility of said domain is described in detail in the invention to A. H. Bobeck et al., U.S. Pat. No. 3,460,116, issued Aug. 5, 1969, and for the purpose of describing the theory of operation of the device set forth therein, and the principles of creating, propagating and sensing single wall magnetic domains in virtually isotropic films, this patent is incorporated herein by reference.

It is therefore also an object of this invention to provide a process and a film-on-substrate structure wherein the film and substrate provided will be single crystalline in character and where said at least one film will have virtually isotropic magnetic characteristics in the plane of the film, and alternatively have embedded or attached thereto means for providing at least one single wall domain in the film at predetermined locations in the film, means for propagating said single wall domains in any direction parallel to and within the plane or thickness of the film, and sensing means which are responsive to propagation of the single wall domain so as to determine the shift or presence of the single wall domain within said film.

It is yet a further object to utilize the properties of the film once deposited on the substrate and the single wall magnetic domains therein as may be created, for a multitude of purposes, one of which is addressed to logic circuitry applications.

It is a further objective to provide a plurality of such films as hereinabove stated inclusive of the several means for creating, propagating and sensing single wall domains therein on the same substrate for providing integrated logic devices.

Briefly in accordance with the invention, a plurality of films and substrates as hereinabove stated have been determined usable for the purpose of creating magnetic domains in predetermined locations, propagation thereof in substantially all directions in the plane of said at least one film with virtually equal degree of energy applied to move said domain and with means for sensing the shift in position of any of said magnetic domains for logic circuit applications. The structure of a shift register, illustrated and completely described in the Bobeck patent, are therefore described hereinbelow with respect to such component portions as are adapted to or are in magnetic communication with the film itself for execution of the creation, propagation and sensing functions of the magnetic domains. The equipment external to the film per se is not illustrated, as exemplary equipment used in connection with devices having single wall magnetic domains and propagation thereof are completely explained in the Bobeck patent. The instant invention, however, utilizes specific compounds for both the film and the substrate wafer which provide the desired results with added advantages of providing structural support for the film so that very thin film of less than 25 microns thick, formed by the inventive process to provide advantages of very small domain areas and hence higher densities of single wall magnetic domains.

In films of single crystalline rare earth orthoferrites, it is possible to establish cylindrical magnetic domains. The net magnetization direction of these domains in most orthoferrites is perpendicular to the (001) plane at room temperature. With application of an increasing magnetic field to oppose the domain magnetization, the cylindrical domains shrink to a minimum diameter and then collapse. For many applications, high densities of domains, and hence small domain diameters, are desirable.

One way of reducing the domain diameter results from the type of growth described herein which makes use of the magnetostrictive effect in epitaxial deposits. On cooling from the deposition temperature, the difference in thermal expansion between the deposit and the substrate produces mechanical strain in each. The deposit can be properly strained so that the magnetostrictive effect reduces the effective anisotropy constant in epitaxial (001) orthoferrite films. Since the domain diameter is proportional to the anisotropy constant, the

minimum domain diameter is reduced. Even if the magnetostrictive effect is not completely isotropic, it would not appreciably affect the virtually isotropic motion of cylindrical domains in the (001) plane.

Chemical vapor deposition of orthoferrite films on oriented substrates provide quite pure orthoferrites since extraneous chemicals which might be incorporated into the crystal are not present. Epitaxial films can routinely be controlled to a fraction of a thousandth of an inch by controlling the duration of the growth process. Since substrates are oriented and polished before being used, no polishing of the orthoferrite is necessary. Thus chemical vapor deposition of orthoferrite films yields deposits which are purer, more perfect and thinner than bulk crystal growth methods.

The inventive process includes such steps as are necessary to determine the best physical location of the substrate in the reaction chamber in order to obtain the desired deposit of film on the substrate. The process also includes the steps of elevating the temperature of a substrate (or seed) crystal in a reaction chamber and reacting oxidizing gases and/or oxygen with gases of certain metal halides at the substrate crystal or wafer surface to deposit film as well as depositing a multiple number of films insulated from each other.

The process further provides for depositing films of single crystalline structure on single crystal substrate wafers in accordance with the materials selected, and in accordance with the control steps used towards accomplishment of the aforesaid product or group of products.

The process described herein contains a sequence of steps necessary to determine the proper deposition conditions and the best physical location of the substrate in the reaction chamber in order to reproduce the desired type of deposit.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a cross section view of the reaction chamber used in the inventive process;

FIG. 2 is a plan view of a shift register illustrative of one type of device that may be fabricated by the inventive process;

FIG. 3 is a cross section taken at plane 3—3 of FIG. 2 showing details of the wires embedded in a layer. These wires are used for connecting to external equipments for generating, propagating and sensing motion of the single wall magnetic domains created in the film of the device; and

FIG. 4 is a cross section taken at plane 3—3 of FIG. 2 showing a mirror-image film and layer containing wires embedded therein on both major deposition surfaces of the substrate.

EXEMPLARY EMBODIMENT

In chemical vapor deposition processes, reactant vapors are brought together near a crystal substrate (or seed) so that they react to deposit an orthoferrite film on a substrate wafer. Chemical vapor depositions involve the reaction between a lanthanide, lanthanum or yttrium halide and an iron halide and oxygen, although not limited to these elements or compounds. The reaction chamber permits evaporation of the individual metal halides and intimate mixing of the vapors before they react with oxygen gas.

FIG. 1 illustrates a T-shaped reactor as shown at 10 for use in film deposition. FIGS. 2 and 3 are illustrative of a logic device created by the process. The reactor is designed for relatively high temperatures to accommodate for example the low volatility of metallic halide source materials. The T-shaped reactor includes horizontal chamber 20 and vertical chamber 30. Disposed about the horizontal chamber is reaction zone heater 21. Individual heaters 31, 32, and 33 are disposed about the vertical chamber to control source material temperatures. Enclosed within the vertical chamber are crucibles 34 and 35 for retaining source materials therein. These crucibles are inserted in premix tube 36, positioned and adjusted to their proper locations, are held thereat and are enclosed within premix tube 36. Tubular means 37 has an inlet therein for introducing HCl gas therein as an aid in transporting the

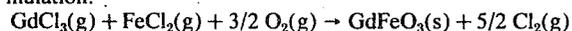
source material in crucible 34 so as to transport the source material thereof in gas form to reaction chamber 20. Tubular means 37 is also used for raising or lowering crucible 34 within premix tube 36. Crucible 35 is adjusted within the premix tube by means of support rod 38. Tubular inlet 39 is provided in premix tube 36 for injection therethrough of helium vapors. The entire premix tube 36 containing crucibles 34 and 35 together with ends of members 37, 38, and 39, extending from the premix tube can be moved up or down vertically as desired within chamber 30. Premix tube 36 is provided with an exit opening 40 at the upper end thereof for conducting the vaporized source materials mixed with the several carrier gases injected into the premix tube 36.

The flow rate of the source material from crucible 35 can be varied by varying the temperature of heater 33 for the particular embodiment shown. The flow rate of the source material from crucible 34 can also be varied by varying the temperature of heater 31 and, in addition, by varying the flow rate of the gas introduced into the crucible from the inlet of means 37. The horizontal reaction chamber includes inlet 22 through which helium and oxygen gases may be injected, and has exhaust output 23 for emitting gases from the chamber. The gases from opening 40 transport the premixed metal halide vapors into the reaction zone of the reactor.

The crystal (or seed) substrate 26 is placed on a fused-silica holder 25 in horizontal chamber 20. The position of holder 25 may be adjusted during the process if desired.

Generally, during the process, the temperature of the crystal substrate wafer is elevated by means of the reaction zone heater 21. The source material heaters 31, 32 and 33 are elevated to temperatures which provide approximately 0.1 atm. of vapor pressure of each metal halide.

After each heater has reached the desired temperature the premix tube 36 containing the source material crucibles 34 and 35 is raised into position in the vertical chamber 30. Gases are introduced into the vertical chamber through inlet in member 37 and through tubular means 39 to conduct the metal halide vapors through opening 40 of the premix tube into the horizontal reaction chamber 20. Oxygen from inlet 22 of chamber 20 is then reacted with the metal halide vapors at the upper portion the crystal surface to produce the desired growth compound thereon. Specifically, an example of a typical reaction is expressible in the following approximate formulation:



The substrate crystal for the gadolinium orthoferrite film may be yttrium orthoaluminate or one of the other substrate compounds listed hereinbelow. Anhydrous gadolinium chloride (GdCl_3) and iron (II) chloride (FeCl_2) are contained in individual crucibles in their separate temperature zones of chamber 30.

Dry helium is introduced into the premix tube at inlet 39 to transport the GdCl_3 and FeCl_2 vapors, which are the reacting vapors of the metal halides, from the crucibles into the reaction zone of the horizontal chamber 20. Dry hydrogen chloride (HCl) gas introduced at inlet 37 flows directly into crucible 34 which holds the GdCl_3 . The HCl gas sweeps the heavy GdCl_3 vapors out of the crucible into the helium gas stream and prevents the very reactive GdCl_3 vapors from reacting at an uncontrollably fast rate with the oxygen gas from inlet 22. Helium is injected through inlet 22, along with oxygen into the horizontal chamber 20.

The reaction deposition zone is in the downstream portion of the horizontal chamber in proximity of the T-junction of chambers 20 and 30. The substrate wafer 26 is placed on holder 25 which is inserted into the upstream portion of chamber 20. The process parameters such as heat from heaters 31, 32 and 33 and gas flows through 22, 37 and 39 members may be adjusted until the desired reaction conditions are obtained, at which time substrate seed or wafer 26 on quartz holder 25 may be positioned in the downstream portion of chamber 20. To obtain information as to the exact location where the desired vapor is ready for deposition on the sub-

strate, a test sample material similar to wafer 26 or a fused quartz test plate may be inserted on holder 25 in the proximity of the T-junction. A reddish-brown colored film will deposit on the material substituting for wafer 26 indicative of the orthoferrite deposition zone, when conditions for deposition and location of deposition zone are both proper. Only 2 to 4 minutes of reaction time is used for this test. Thereafter, the substituting test-sample is removed and substrate 26 on holder 25 is inserted into chamber 20 through inlet 22 and positioned exactly as determined by the calibrations on rod 28 which is determinative of test sample positioning, so that vapors of the reaction are permitted to be deposited on the upper surface of substrate 26, thereby forming the desired monocrystalline film on the monocrystalline substrate wafer.

Details as to the positioning of the substrate in chamber 20 are important. Holder 25 has apertures 27 at either end thereof which are used for inserting therein a hooked-end of calibrated rod 28. Rod 28 positions holder 25 in its proper location so as to obtain the reddish-brown deposition on the test sample. When the reddish-brown color is obtained, the marking at rod 28 coinciding with the edge of opening 22 is noted, so that holder 25 with actual substrate 26 thereon may be reinserted and exactly positioned at the location where the reddish-brown deposition occurred. Rod 28 is removed thereafter until the film has been completely deposited, at which time rod 28 is again used for removing holder 25 together with deposited film 29 on substrate 26.

It should be noted that normally the film will deposit on the surface of the substrate 26 which is not contiguous or in contact with holder 25. Upon deposition of the film on one surface thereof, the other surface, previously in contact with holder 25 may be coated with a similar film by simply inverting the substrate so that the now-coated surface is adjoining the surface of holder 25.

It should also be noted that the above-stated process may be used in conjunction with a mask for masking such upper portions of the upper surface of substrate wafer 26 that are not desired to be coated with film 29 and leave such portions as desired to be coated uncovered by the mask, a plurality of films such as 29 on any one surface of substrate wafer 26 may therefore be produced in this manner.

Films are formed on substrates in accordance with the examples in the Table 1 below, which specifies the control process parameters that were considered.

TABLE 1

Materials and Conditions	Composition A	Composition B	Composition C
	GdFeO ₃ YAlO ₃	YFeO ₃ CaTiO ₃	YFeO ₃ YAlO ₃
substrate material	1,145	1,144	1,175
substrate temperatures in degrees centigrade			
vertical helium flow rate in liters per minute	11.5	5.5	6.0
horizontal helium flow rate in liters per minute	4.32	2.75	2.75
hydrogen chloride gas flow rate in milliliters per minute	60	22	16
oxygen flow rate in milliliters per minute	37	33	33
GdCl ₃ or YCl ₃ transport rate in grams per hour	1.13	1.03	0.516
FeCl ₂ transport rate in grams per hour	4.47	1.47	1.18
film thickness in microns	4.5	6.6	4.1

	7	8
run duration in minutes	15	30
orthoferrite deposition rate in microns per hour	18.0	13.2
crystallographic (001)GdFeO ₃		(001)YFeO ₃ (101)YFeO ₃
orientations	(001)YAIO ₃	(010)CaTiO ₃ (101)YAIO ₃

Although only details of several compositions have been illustrated in Table 1, it is understood that all compositions as composed of the element formulations given in Table 2, below are applicable to this invention.

Several combinations of film and substrate materials have been illustrated as examples in Table 1, above. However, a number of other combinations may be provided by combining at least two of the elements of the film material with at least two of the elements of the substrate material indicated in Table 2, below. Wherein, the film material is to be used for providing single wall magnetic domains, one of the two elements thereof should be the element iron (Fe).

TABLE 2

Film Compound Formula JQO ₃	Substrate Compound Formula JQ-oxide
J Portion	Q Portion
cerium	aluminum
praseodymium	cerium
neodymium	praseodymium
promethium	gallium
samarium	indium
europium	scandium
gadolinium	titanium
terbium	samarium
dysprosium	vanadium
holmium	europium
erbium	chromium
thulium	gadolinium
ytterbium	chromium
lutetium	yttrium
lanthanum	lutetium
yttrium	lanthanum
	yttrium
	magnesium
	calcium
	strontium
	barium
	lead
	cadmium
	lithium
	sodium
	potassium
	Q Portion
	gallium
	indium
	scandium
	titanium
	vanadium
	chromium
	manganese
	iron
	rhodium
	zirconium
	hafnium
	molybdenum
	niobium
	tantalum
	tungsten

The elements of the group of lanthanides are herein defined as cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium.

Following deposition of a single crystalline orthoferrite layer on a substrate, useful devices may be made from the orthoferrite, such as described by U.S. Pat. No. 3,460,116. Referring to FIGS. 2 and 3, a shift register is shown at 100. A similar shift register is substantially depicted in U.S. Pat. No. 3,460,116 and its manner of operation is discussed in detail therein.

The device 100 shown in FIGS. 2 and 3 which will therefore be made by this process will be comprised of substrate 26 with film 29 deposited thereon. When the device at 100 having the capability of producing, propagating and sensing single wall domains is completed, the configuration will include at least one insulating layer 101 such as silicon monoxide (SiO) or Magnesium fluoride (MgF₂) which will be attached to film 29 and have the several means for producing, propagating and sensing single wall domains embedded therein and held securely thereby.

One approach to preparing layer 101, includes evaporating a metallic conductor 102 on the surface of film 29 through a suitable mask superimposed on the surface of film 29, said mask having the pattern of conductor 102 therein. This evaporation may be performed in a chamber similar to that

shown in FIG. 1, wherein the contents of vessel 34 are metallic granules such as copper, gold, silver or aluminum, the other vessel 35 being removed, temperatures adjusted and oxygen flow eliminated. Following this step, the mask is removed and vessel 34 may be loaded with the insulating granules such as MgF₂ which are evaporated and deposited as a film over conductor 102 and over the remaining unexposed surface of film 29. Thereafter, another mask having pattern of wire 103 may be superimposed on the insulating surface and by having suitable metallic material in vessel 34, the pattern of wire 103 may be deposited in a similar manner as the pattern of conductor 102 was deposited. After removing the mask of wire 103, an additional coating of insulating material may be deposited over the surface of wire 103 and over the remaining portions of the previously deposited insulating film. A mask having pattern of wire 104 may then be laid down over the insulating surface and additional conductive material deposited by the same evaporation method used to form wire 104. Similarly, wires 105 and 106 may be formed by having the patterns thereof in masks as wire 104 and additional conductive material deposited. Also similarly, the masks being removed, additional insulating material is deposited over wires 104, 105 and 106 and over the unexposed insulating surface upon which said wires have been deposited. A mask having pattern of wire 107 is then laid down over the surface and wire 107 is formed in a similar manner to formation of the other wires on the insulating surface. The mask is then removed and additional insulating material is deposited over the wire 107 and the unexposed insulating surface in the same manner as previously accomplished. A mask having a pattern of wire 108 is then laid over the insulating surface and conductor 108 is formed by the same vacuum deposition method. Finally, the mask is removed and insulating material is deposited over conductor 108 covering said conductor and possibly portions of the remaining unexposed insulating surface, thereby encapsulating all the wires within layer 101 which is now firmly attached to the surface of film 29.

It is noted that in connection with the deposition of wires 104, 105 and 106 and at their crossover points, and possible crossover with wires 102, 103, 107 and 108, that a wire need not be deposited in its entirety at one time, which results in the requirement that insulating material be deposited between these various wires at their crossover locations. Suitable masks may be used in providing portions of wire depositions and insulation depositions so that the total number of individual depositions may be reduced.

It is noted that by using a suitable mask in conjunction with the process of providing layer 101 to cover such portions as are not desired to have a layer such as 101 formed thereon and by leaving uncovered by the mask such portions as desired to be formed with layers such as layer 101, a plurality of layers of films such as 29 may be produced in the same manner as layer 101 was produced.

FIG. 4 illustrates deposition of a film 29' on the other major unexposed surface of wafer 26 and thereon layer 101'. Film 29' is identical in substantive matter as film 29, and layer 101' is identical to layer 101. Both films 29 and 29' are therefore deposited in the same way, and both layers 101 and 101' are also both deposited in the same way and may contain the identical wires embedded therein. FIG. 4, is therefore illustrative of a multilayer device having magnetic domains. It is also conceivable that multiple films of magnetic nonmagnetic materials on top of each other may be deposited sequentially on the same side of the substrate surface, employing JQ combination for film formation from Table 2 to produce the magnetic and/or nonmagnetic layers of films and/or substrates.

A useful orthoferrite device at 100 will require means 101 for generating, propagating and detecting single wall magnetic domains in film 29. A current pulse in loop 103 provides means for drawing a positive region from border 130 of device 100 up to location 110, and a pulse on wire 104 at 111, isolates a portion of the positive region at location 110, thereby

generating a single wall magnetic domain thereat. By sequentially pulsing wires 104, 105 and 106 respectively at 111, 112, and 113, the single wall magnetic domain is propagated along the shift register shown herein from location 110 to intermediate locations 125 and 126, ultimately terminating at location 114. At location 114, an interrogation pulse in wire 107 collapses the single wall magnetic domain, inducing a detection pulse in wire 108.

The shift register device has been discussed for the purpose of enabling the illustration of the types of additional fabrication processes required in connection with the orthoferrite layer on a substrate in the form of a useful device. Other types of devices may also require current carrying conductors, and in addition, employ magnetic layers, semiconductor layers or external optical light source and other detecting components. Wire 102 is connected to an initializing circuit for providing a pulse therein so as to rearrange the domains in film 29 to provide the border thereof as explained in U.S. Pat. No. 3,460,116.

In another approach to preparing layer 101, the current carrying conductors may be metal films laid down by vacuum evaporation. Typically, copper, aluminum, or gold may be used. The conductor patterns may be defined by masking during evaporation, or the entire area may be coated and the patterns defined by photolithographic etching processes, well known in the semiconductor device arts. Each of the conductors must be electrically isolated from the others so that layers of insulation, such as silicon monoxide (SiO) or magnesium fluoride (MgF₂), may be evaporated between metal evaporations as hereinabove described. Here again, the region covered by the insulating material may be limited by masking during evaporation or the entire area may be coated and patterns defined by photolithographic etching processes. The number of separate evaporation steps will depend on the number of conductor crossovers, and the ingenuity in designing patterns for conductor and insulator depositions.

For other types of devices which employ magnetic or semiconductor layers on the surface of the orthoferrite films, suitable layers may be deposited by vacuum evaporation or chemical vapor deposition. Typically, magnetic nickel-iron alloy compositions may be evaporated on certain regions of the orthoferrite layer to provide small local fields which assist in holding or moving the single wall magnetic domains.

It should be noted that the wires shown in layer 101 or 101' could have also been replaced by magnetic means communicating with the film or films to create, propagate and/or sense the change in position of the created and propagated single wall magnetic domains.

It should be also noted that the additional film 29' deposited on the substrate as shown or in such other manner as described is also of the pseudopervoskite-type structure and single crystalline.

Hence, due to the magnetization requirements, the components of film formulation would be iron and the remaining metallic component may be one or more of the elements detailed in Table 2. The magnetic materials or compounds of films 29 or 29' will have a first magnetization direction substantially orthogonal to an imaginary plane parallel to the thickness of said film and providing for at least one single wall magnetic domain with a second magnetization direction opposite to the first magnetization direction and having a boundary unconstrained along said second magnetization direction, said single wall magnetic domain being free to move in a plurality of directions substantially orthogonal to the second magnetization direction. At least one of the constituents of the JQ combination of the substrate wafer formulation is different from at least one of the constituents of the JQ combination of the film formulation. Such difference stresses the film which may thereby contribute to a substantial reduction in the area of the magnetic domain thus formed. The area of the domain, by the means established for creating same, is oriented orthogonally to the second magnetization direction, such area lying in said imaginary plane.

We claim:

1. A method of forming a composite structure suitable for containing bubble domains therein comprising the steps of providing a single crystal substrate, and forming a magnetic single crystal film on said substrate with sufficient mechanical strain in said film to provide said film with sufficient uniaxial anisotropy for the formation of bubble domains therein, said film having a thickness less than 25 microns and sufficient magnetization for the formation of bubble domains therein, whereby said film has a JQO₃ formulation wherein, the J constituent of said film formulation has one element selected from the group consisting of cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, lanthanum, and yttrium, and the Q constituent of said film formulation is taken from the group consisting of iron, aluminum, gallium, indium, scandium, titanium, vanadium, chromium and manganese.
2. A method as described in claim 1 where said Q constituent of said film formulation is iron.
3. A method as described in claim 2 whereby said single crystal substrate has a JQ-oxide formulation wherein: the J constituent of said substrate formulation is at least one element selected from the group consisting of cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, lanthanum, yttrium, magnesium, calcium, strontium, barium, lead, cadmium, lithium, sodium and potassium; and the Q constituent of said substrate formulation is at least one element selected from the group consisting of indium, gallium, scandium, titanium, vanadium, chromium, manganese, rhodium, zirconium, hafnium, molybdenum, tungsten, niobium, tantalum, and aluminum.
4. A method as described in claim 2 whereby the film is formed by the steps of, conducting at least one of a plurality of metal halides into the reaction chamber, injecting at least one reacting gas and at least one carrier gas into the reaction chamber reaction therein with the metal halides thereby producing reaction products of the halides and gases, inserting a test sample for selecting the location of said substrate within said reaction chamber, removing said test sample, and inserting said substrate at the selected location for deposition of at least one of the reaction products on said substrate to form said monocrystalline film thereon.
5. A method as described in claim 3 whereby: said J constituent of said substrate formulation is at least one element selected from the group consisting of cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, lanthanum and yttrium; and said Q constituent of said substrate formulation is at least one element selected from the group consisting of indium, gallium, scandium, titanium, vanadium, chromium, manganese, rhodium, and aluminum.
6. A method of forming a bubble domain comprising the steps of providing a single crystal substrate, and forming a first magnetic single crystal film on said substrate with sufficient mechanical strain in said film to provide said film with sufficient uniaxial anisotropy for the formation of bubble domains therein and having a thickness less than 25 microns, whereby said film has a JQO₃ formulation wherein, the J constituent of said film formulation has at least one element selected from the group consisting of cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbi-

11

um, thulium, ytterbium, lutetium, lanthanum and yttrium, and the Q constituent of said film formulation is taken from the group consisting of iron, gallium, indium, scandium, titanium, vanadium, chromium, and manganese, and forming a second magnetic single crystal film having a JQO_3 formulation wherein said J and said Q constituents are

12

taken from the same groups as set forth for said first single crystal film, and said second film having sufficient mechanical strain therein to provide sufficient uniaxial anisotropy for the formation of bubble domains therein and having a thickness less than 25 microns.

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