US 20050173240A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2005/0173240 A1**

Hihara et al. (43) **Pub. Date: Aug. 11, 2005**

(54) METHOD AND DEVICE FOR MANUFACTURING SEMICONDUCTOR OR INSULATOR/METALLIC LAMINAR COMPOSITE CLUSTER

(76) Inventors: **Takehiko Hihara**, Meito-ku, Nagoya-shi (JP); **Kenji Sumiyama**, Nagoya-shi (JP); **Ryoji Katoh**, Nagoya-shi (JP)

Correspondence Address:
THE WEBB LAW FIRM, P.C.
700 KOPPERS BUILDING
436 SEVENTH AVENUE
PITTSBURGH, PA 15219 (US)

(21) Appl. No.: **10/505,813**

(22) PCT Filed: **Jan. 27, 2003**

(86) PCT No.: **PCT/JP03/00716**

(30) **Foreign Application Priority Data**

Feb. 26, 2002 (JP) 2002-049310

Publication Classification

(51) **Int. Cl.**^{7} **C23C 14/00**; C23C 14/32

(52) **U.S. Cl.** **204/192.25**; 977/DIG. 1

(57) ABSTRACT

A semiconductor or nonconductor vapor is generated by sputtering targets **11U**, **11D** in a first sputtering chamber **10**, while a metal vapor is generated by sputtering targets **21U**, **21D** in a second sputtering chamber **20**. The semiconductor or nonconductor vapor and the metal vapor are aggregated to clusters during travelling through a cluster-growing tube **32** and injected as a cluster beam to a high-vacuum deposition chamber **30**, so as to deposit composite clusters on a substrate **35**. The produced composite clusters are useful in various fields due to high performance, e.g. high-sensitivity sensors, high-density magnetic recording media, nano-magnetic media for transportation of medicine, catalysts, perm-selective membranes, optical-magnet sensors and low-loss soft magnetic materials.

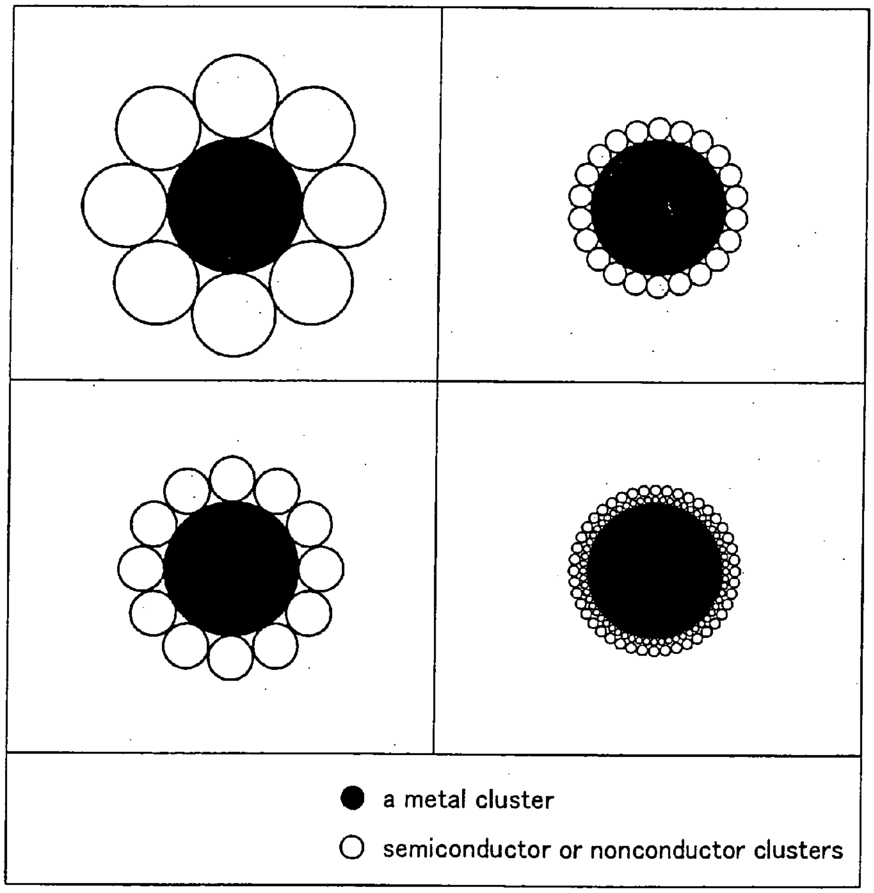


FIG.1

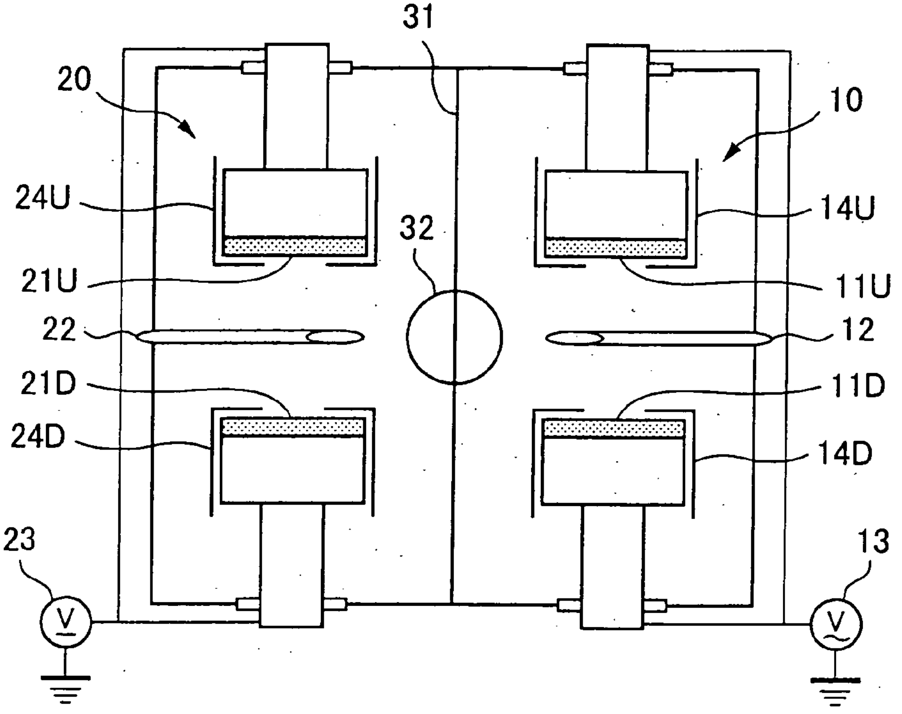

31
20
10
24U
14U
32
21U
11U
22
12
21D
11D
24D
14D
23
13
V
V

FIG.2

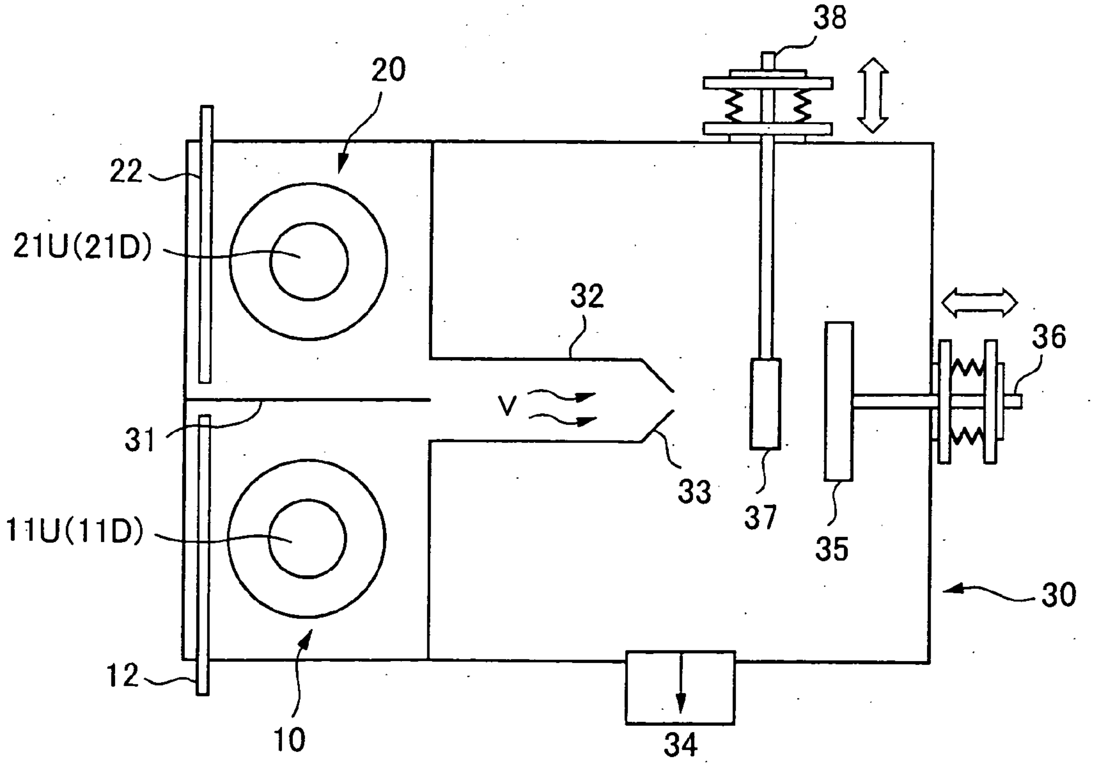
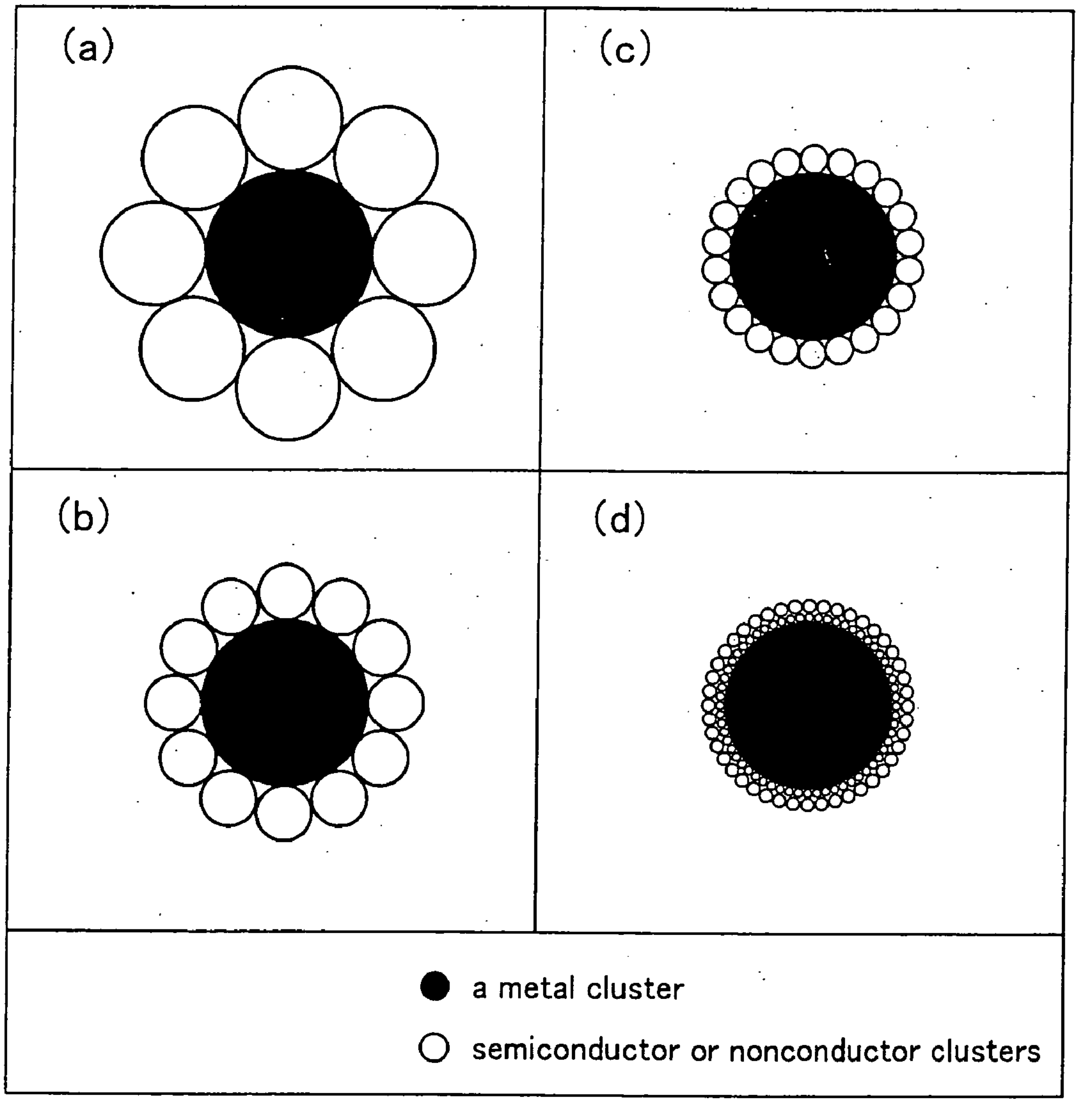

38
20
22
21U(21D)
32
36
V
31
33
37
11U(11D)
35
30
12
10
34

FIG.3


(a)
(c)
(b)
(d)
● a metal cluster
○ semiconductor or nonconductor clusters

METHOD AND DEVICE FOR MANUFACTURING SEMICONDUCTOR OR INSULATOR/METALLIC LAMINAR COMPOSITE CLUSTER

TECHNICAL FIELD OF THE INVENTION

[**0001**] The present invention relates to a method of producing composite clusters, wherein a metal is lamellarily compounded with a semiconductor or nonconductor, useful as various functional elements, and also relates to an apparatus for production of such composite clusters.

BACKGROUND OF THE INVENTION

[**0002**] Aggregate of fine particles are useful as functional elements, e.g. gas sensors and permselective membranes, in various industrial fields due to its big specific surface area and good affinity with an atmospheric gas.

[**0003**] Various methods have been proposed so far for producing aggregate of fine particles. For instance, starting material is evaporated and condensed to fine particles in vapor-phase synthesis. According to a colloidal process, fine particles are precipitated from an electrolytic liquid and stabilized with a surfactant. An aerosol process for spraying and pyrolysis of a metal ion-containing liquid, a gas-atomizing process for spraying a mixture of molten metal with an inert gas through a nozzle, and a milling process for mechanically crushing solid material are also proposed for production of such aggregate.

[**0004**] The aerosol process, the milling process and the gas-atomizing process are advantageous for mass-production of clusters but unsuitable for production of clusters, which have particle size conditioned to nanometer order for performance originated in nano-sized particles. The colloidal process can not avoid inclusion of impurities in a product, although clusters of several nanometers in particle size can be mass-produced. The inclusion of impurities degrades quality of the product.

[**0005**] On the other hand, the vapor-phase process promotes growth of clusters in a clean vacuum atmosphere without invasion of impurities. The clusters produced by the vapor-phase process has a chemically active surface effective for improvement of functionality. However, the active surface causes unfavorable oxidation and coalescence of clusters, when fine particles are deposited on a substrate. The oxidation and coalescence impede realization of the functionality originated in nano-sized particles, regardless of very fine clusters.

SUMMARY OF THE INVENTION

[**0006**] The present invention aims at production of metal/semiconductor or metal/nonconductor composite clusters, which exhibit various properties originated in composite structure, under stable conditions, by compounding metal clusters with semiconductor or nonconductor clusters in a high-vacuum atmosphere.

[**0007**] According to the present invention, a semiconductor or nonconductor vapor is generated by sputtering a semiconductor or nonconductor target, while a metal vapor is generated by sputtering a metal target. These sputtering processes are conducted simultaneously but in each system independent from the other. A mixture of the metal vapor with the semiconductor or nonconductor vapor is fed into a cluster-growing tube and then injected as a cluster beam to a substrate preset in an deposition chamber held at a high degree of vacuum. The mixture is deposited as composite clusters on the substrate.

[**0008**] The present invention also proposes an apparatus for production of composite clusters. A semiconductor or nonconductor target is preset in a first sputtering chamber. A metal target is preset in a second sputtering chamber. A movable partition is located between the first and second sputtering chambers. The sputtering chambers communicate through a cluster-growing tube with an deposition chamber held at a high degree of vacuum. The cluster-growing tube is directed to a substrate, which is preset in the deposition chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0009**] **FIG. 1** is a sectional side view illustrating a composite cluster-manufacturing apparatus shown from a side of sputtering chambers.

[**0010**] **FIG. 2** is a sectional plan view illustrating the same apparatus.

[**0011**] **FIG. 3** is a diagram illustrating some examples of composite clusters, which were produced by the inventive process.

BEST MODES OF THE INVENTION

[**0012**] The present invention uses a composite cluster-manufacturing apparatus schematically shown in **FIGS. 1 and 2**. The apparatus has a first sputtering chamber **10** and a second sputtering chamber **20**, each separated from the other by a movable partition **31**.

[**0013**] A couple of targets **11**U and **11**D are located in the first sputtering chamber **10**. The targets **11**U and **11**D face to each other with a gap of 10 cm or so. Inert gas such as Ar is fed through a supply tube **12** to a space between the targets **11**U and **11**D. The targets **11**U, **11**D are semiconductive or nonconductive material, in the case where the sputtering chamber **10** is operated for generation of a semiconductor or nonconductor vapor. When a high voltage is applied between the targets **11**U and **11**D from a high-frequency power source **13**, glow discharge occurs between the targets **11**U and **11**D, and the targets **11**U, **11**D are sputtered by ionized inert gas atoms, resulting in vaporization of the semiconductive or nonconductive material. The targets **11**U and **11**D may be partially covered with shields **14**U and **14**D, so as to limit a glow-discharging area.

[**0014**] The second sputtering chamber **20** also has a couple of targets **21**U and **21**D and a supply tube **22** for introduction of inert gas to a space between the targets **21**U and **21**D. The targets **21**U, **21**D are conductive material, e.g. a transition metal, in the case where the sputtering chamber **20** is operated for generation of a reactive metal vapor. When a high voltage is applied between the targets **21**U and **21**D from a D.C. power source **23**, glow discharge occurs between the targets **21**U and **21**D, and the targets **21**U, **21**D are sputtered by ionized inert gas atoms, resulting in vaporization of the conductive material. The targets **21**U and **21**D may be partially covered with shields **24**U and **24**D, so as to limit a glow-discharging area.

[**0015**] Generation of the semiconductor or nonconductor vapor is performed under different conditions from generation of the metal vapor. For instance, gaps between the targets **11**U and **11**D and between the targets **21**U and **21**D are adjusted to approximately 10 cm, while gaps between the targets **11**U, **11**D and the shields **14**U, **14**D and between the targets **21**U, **21**D and the shields **24**U, **24**D are adjusted to approximately 0.2 mm so as to inhibit arc-discharge therebetween. Internal pressures of the sputtering chambers **10**, **20** are held at a relatively higher value, e.g. 133-1333 Pa by introduction of Ar gas. Glow-discharge necessary for vaporization of the targets **11**U, **11**D and **21**U, **21**D is started by application of predetermined voltages between the targets **11**U and **11**D and between the targets **21**U and **21**D.

[**0016**] When sputtering conditions, e.g. currents and voltages, for the targets **11**U, **11**D and **21**U, **21**D are independently controlled, interference between the targets **11**U, **11**D and **21**U, **21**D is avoided. Compositions of the metal vapor and the semiconductor or nonconductor vapor as a cluster source are properly adjusted by control of electric powers applied to the targets **11**U, **11**D and **21**U, **21**D.

[**0017**] The semiconductor or nonconductor vapor and the metal vapor are carried as a mixture V by an inert gas stream from the sputtering chambers **10**, **20** through a cluster-growing tube **32** and a nozzle **33** to a deposition chamber **30**. The deposition chamber **30** is preferably held at a degree of vacuum less than a few Pa, in order to assure a smooth flow of the gaseous mixture through the cluster-growing tube **32**. The high-vacuum deposition chamber **30** is also advantageous for suppressing coalescence of clusters, which have flown into the deposition chamber **30**.

[**0018**] A flow rate of the gaseous mixture V, which is carried to the cluster-growing tube **32**, and a flow ratio of the semiconductor or nonconductor vapor to the metal vapor are controlled by sputtering conditions in the sputtering chambers **10**, **20** and positioning of the movable partition **31**. Nano-sized lamellar clusters, i.e. composite clusters of the metal with the semiconductor or nonconductor is formed and grown up to nanometer size, during travel of the gaseous mixture V through the cluster-growing tube **32**,

[**0019**] The composite clusters are passed through the cluster-growing tube **32** and injected together with an Ar gas stream from the nozzle **33** by differential, since the deposition chamber **30** is evacuated by a mechanical booster pump **34**. The nozzle **33** is directed to the substrate **35** in the deposition chamber **30**, and a distance from the nozzle **33** to the substrate **35** is variable by adjustment of a handling shaft **36**. A thickness sensor **37**, e.g. a crystal oscillator, is provided between the nozzle **33** and the substrate **35**, in order to measure a deposition rate of the clusters on the substrate **35** and an effective thickness of a deposition layer. A position of the thickness sensor **37** in relation with the substrate **35** is controllable by adjustment of a movable shaft **38**.

[**0020**] Atoms and molecules vaporized from the targets **11**U, **11**D and **21**U, **21**D are fed together with Ar as a carrier gas into the cluster-growing tube **32**. The atoms, the molecules and the Ar atoms repeatedly come into ternary collision and forms cluster nuclei in the tube **32** while discharging a latent heat. The cluster nuclei are gradually grown up to composite clusters while absorbing gaseous atoms. Since the clusters are formed in a material stream from the sputtering chambers **10**, **20** to the deposition chamber **30**, growth of the clusters depends on a flow rate of the material stream.

[**0021**] A growth mode of clusters in a plasma-gas condensation process is explained by (1) mutual collision and coalescence of clusters and (2) successive deposition of a metal vapor on embryos as cluster nuclei. Probably, deposition and re-vaporization of metal atoms on and from the cluster nuclei are repeated at an early stage, and clusters come into mutual collision and coalesce together at a latter stage. Since size distribution of the clusters as a whole is determined by these actions, production of mono-disperse clusters is expected by introducing clusters to a high-vacuum atmosphere and depositing them on a substrate before coalescence.

[**0022**] The cluster-growing tube **32** enables mixing the semiconductor or nonconductor clusters with the metal clusters in a high-vacuum atmosphere, so as to produce the composite clusters that the semiconductor or nonconductor clusters are compounded with the metal clusters in various state. For instance, when the semiconductor or nonconductor clusters, which are deposited on the metal clusters as a core, form shelly surface layers, further coalescence of metal clusters on the substrate is inhibited, so that properties originated in nano-size are imparted to the metal clusters.

[**0023**] Multi-layered composite clusters, which have metal clusters as a core, are bestowed with predetermined properties by controlling number of the semiconductor or nonconductor clusters coalescent to the metal clusters in correspondence to a relative size of the semiconductor or nonconductor clusters with the metal clusters or by depositing the semiconductor or nonconductor clusters as several layers, as shown in **FIG. 3**. Moreover, coalescence and mixing of the semiconductor or nonconductor clusters with the metal clusters are limited in a zone inside the cluster-growing tube **32** by insertion of the partition **31**. The coalescence and mixing can be started at an earlier stage by detachment of the partition **31** on the contrary. Size-control of the semiconductor or nonconductor clusters as well as the metal clusters is performed by changing electric powers applied to the targets **11**U, **11**D and **21**U, **21**D, a pressure and a temperature of an inert gas and/or a length of the cluster-growing tube **32**. A shape of the multi-layered composite clusters is variously varied in response to the size-control, as shown in **FIG. 3**.

[**0024**] The other features of the present invention will be apparently understood from the following examples.

[**0025**] A first sputtering chamber **10** was held at an internal pressure of 500 Pa by introduction of Ar as an inert gas at a flow rate of 150 sccm. Si targets. **11**U, **11**D, which were preset in the chamber **10**, were sputtered at an electric power of 100 W for generation of Si vapor. Fe targets **21**U, **21**D, which were preset in a second sputtering chamber **20** held at an internal pressure of 500 Pa by introduction of Ar at a flow rate of 150 sccm, were sputtered at an electric power of 400 W for generation of Fe vapor.

[**0026**] A glass plate as a substrate **35** and a carbon film for TEM observation were preset in a deposition chamber **30**. A nozzle **33** of 5 mm in diameter was attached to a top of a cluster-growing tube **32** and located at a position faced to the substrate **35**. A distance between the nozzle **33** and the substrate **35** was adjusted to 5 cm. The chamber **30** was held at 1×10^{-4} Pa as an initial pressure and 300K.

[**0027**] A gaseous mixture of Si and Fe, i.e. sputtering products, is sucked into the cluster-growing tube **32** by a differential pressure between the sputtering chambers **10**, **20** and the deposition chamber **30**. When Ar gas passed through the tube **32** at a flow rate of 300 sccm and velocity of 0.5 m/sec., an internal pressure of the deposition chamber **30** reached 1 Pa. Collision and coalescence of Si and Fe atoms were repeated, while the gaseous mixture was travelling through the cluster-growing tube **32**. The resultant mixture was injected as a cluster beam through the nozzle **33** to the substrate **35** at a velocity of 300 m/sec. Consequently, Si and Fe clusters were deposited on the substrate **35** at a rate of 1 nm/sec.

[**0028**] A position of the partition **31** was changed under the above conditions, in order to investigate positional effects of the partition **31** on a structure of composite clusters.

[**0029**] Under the condition that a zone for coalescing and mixing the semiconductor clusters with the metal clusters was limited to an inner space of the cluster-growing tube **32** by insertion of the partition **31**, Si clusters, which have grew to 5 nm in diameter, were mixed with Fe clusters. As a result, composite clusters had particle size of 10 nm in average with distribution of 8-12 nm and the structure (a) in **FIG. 3** that a few Si clusters of 5 nm or less in diameter coalesced to Fe clusters.

[**0030**] A zone for coalescing and mixing the semiconductor clusters with the metal clusters is widely expanded by detachment of the partition **31**. When the targets **11**U, **11**D and **21**U, **21**D were sputtered with 100 W and 400 W, respectively, without insertion of the partition **31**, Si clusters of 1 nm in diameter were mixed with Fe clusters of 10 nm in diameter at an earlier stage. Since Si clusters had a bigger surface energy than Fe clusters due to the differential particle size, Fe clusters were coated with Si clusters. Consequently, the produced composite clusters had the structure (d) in **FIG. 3** that many Si clusters were multi-layered on Fe clusters.

[**0031**] In correspondence to change of an effective area of the partition **31** to ⅔ and ⅓, the structures of composite clusters were changed to (b) and (c) in **FIG. 3**, respectively.

[**0032**] The positional effects of the partition **31** on coalescence of Si clusters, as the above, enables production of composite clusters with various structures. Since properties of the composite clusters is differentiated by the structure, the composite clusters suitable for a certain purpose can be offered by control of the structure. For instance, the composite clusters (a), which have relatively big Si clusters coalesced to Fe clusters, are super paramagnetic as an aggregate of single-domain Fe particles at a normal temperature. The other composite clusters (b)-(d), which have relatively small Si clusters coalesced to Fe clusters, are ferromagnetic at a normal temperature due to dipole-dipole interaction between the particles. Coercivity of the composite clusters (b) was 800 A/dm, and coercivity of the composite clusters (d) was 80 A/dm. That is, coercivity is reduced as a decrease of Si cluster layers in total thickness on Fe clusters, but any of the composite clusters (b)-(d) is useful as functional material with low-loss soft magnetic property.

INDUSTRIAL APPLICABILITY OF THE INVENTION

[**0033**] According to the present invention as mentioned above, a semiconductor or nonconductor vapor and a metal vapor are generated in sputtering chambers, each of which is independently operated from the other, and carried as a gaseous mixture through a cluster-growing tube to a high-vacuum deposition chamber. Composite clusters, which are formed and grown up in the cluster-growing tube, are deposited on a substrate, which is preset in the deposition chamber, without repetition of coalescence and aggregation, so that mono-disperse composite clusters of a semiconductor or nonconductor compounded with a metal can be produced. Since a compounded structure of the clusters is changed by controlling a position of a movable partition between the sputtering chambers and/or flow rates of Ar, the metal vapor and the semiconductor or nonconductor vapor, various properties are imparted to the composite clusters. The produced composite clusters are useful in various fields due to high performance, e.g. high-sensitivity sensors, high-density magnetic recording media, nano-magnetic media for transportation of medicine, catalysts, permselective membranes, optical-magnet sensors and low-loss soft magnetic materials.

1-**2**. (canceled)

3. A method of producing composite clusters of a semiconductor or nonconductor with a metal, comprising:

sputtering at least one semiconductor or nonconductor target to generate a semiconductor or nonconductor vapor in a first sputtering chamber;

simultaneously sputtering at least one metal target to generate a metal vapor in a second sputtering chamber independently operated from the first sputtering chamber;

carrying both the semiconductor or nonconductor vapor and the metal vapor as a gaseous mixture into a cluster growing tube, wherein composite clusters are formed from the gaseous mixture; and

injecting a cluster beam through a nozzle of the cluster-growing tube to a substrate preset in a high vacuum deposition chamber, so as to deposit composite clusters on the substrate.

4. The method of claim 3, wherein a movable partition is located between the first and second sputtering chambers which, when the moveable partition is moved, the change in position of the moveable partition affects the formation of the composite clusters, enabling formation of composite clusters with various structures.

5. The method of claim 3, wherein internal pressures of the sputtering chambers are held at a relatively higher value than the deposition chamber by evacuating air from the deposition chamber with a mechanical booster pump in order to assure a smooth flow of the gaseous mixture through the cluster-growing tube.

6. The method of claim 3, wherein the distance between the nozzle and the substrate is varied by adjusting a handling shaft attached to the substrate.

7. The method of claim 3, wherein a thickness sensor controlled by adjusting a movable shaft attached thereto is provided between the nozzle and the substrate in order to measure a deposition rate of the cluster beam on the substrate and an effective thickness of a deposition layer.

8. The method of claim 3, wherein the first sputtering chamber and the second sputtering chamber each has a supply tube therein for introducing an inert gas to a space between the targets.

9. The method of claim 3, wherein the at least one semiconductor or nonconductor target and the at least one metal target is partially covered with a shield to limit a glow-discharging area.

10. An apparatus for producing composite clusters of a semiconductor or nonconductor with a metal, comprising:

a first sputtering chamber, wherein at least one semiconductor or nonconductor target is preset for generation of a semiconductor or nonconductor vapor;

a second sputtering chamber, wherein at least one metal target is preset for generation of a metal vapor, said first sputtering chamber and said second sputtering chamber communicating through a cluster-growing tube;

a movable partition located between the first and second sputtering chambers;

a high-vacuum deposition chamber communicating with the cluster-growing tube; and

a nozzle attached to a top of the cluster-growing tube and directed to a substrate preset in the high-vacuum deposition chamber, wherein the semiconductor or nonconductor vapor and the metal vapor are injected as a cluster beam to the substrate.

11. The apparatus of claim 10, wherein the movable partition is located between the first and second sputtering chambers which, when the moveable partition is moved, the change in position of the moveable partition affects the formation of the composite clusters, enabling formation of composite clusters with various structures.

12. The apparatus of claim 10, wherein internal pressures of the sputtering chambers are held at a relatively higher value than the deposition chamber by evacuating air from the deposition chamber with a mechanical booster pump in order to assure a smooth flow of the semiconductor or nonconductor and metal vapors through the cluster-growing tube.

13. The apparatus of claim 10, wherein the distance between the nozzle and the substrate is varied by adjusting a handling shaft attached to the substrate.

14. The apparatus of claim 10, wherein a thickness sensor controlled by adjusting a movable shaft attached thereto is provided between the nozzle and the substrate in order to measure a deposition rate of the cluster beam on the substrate and an effective thickness of a deposition layer.

15. The apparatus of claim 10, wherein the first sputtering chamber contains two semiconductor or nonconductor targets facing each other with a gap therebetween and the second sputtering chamber contains two metal targets facing each other with a gap therebetween, each semiconductor or nonconductor target and metal target partially covered with a shield to limit a glow-discharging area.

16. The apparatus of claim 15, wherein the first sputtering chamber and the second sputtering chamber each has a supply tube therein for introducing an inert gas to a space between the targets.

17. An apparatus for producing composite clusters of a semiconductor or nonconductor with a metal, comprising:

a first sputtering chamber, wherein at least one semiconductor or nonconductor target is preset for generation of a semiconductor or nonconductor vapor;

a second sputtering chamber, wherein at least one metal target is preset for generation of a metal vapor, and wherein each sputtering chamber has a supply tube therein for introducing an inert gas to the at least one target, and further wherein said first sputtering chamber and said second sputtering chamber communicate through a cluster-growing tube;

a shield that partially covers each target to limit a glow-discharging area.

a movable partition located between the first and second sputtering chambers, wherein when the moveable partition is moved, the change in position of the moveable partition affects the formation of the composite clusters, enabling formation of composite clusters with various structures;

a high-vacuum deposition chamber communicating with the cluster-growing tube, wherein internal pressures of the sputtering chambers are held at a relatively higher value than the deposition chamber by evacuating air from the deposition chamber with a mechanical booster pump in order to assure a smooth flow of the semiconductor or nonconductor and metal vapors through the cluster-growing tube;

a nozzle attached to a top of the cluster-growing tube and directed to a substrate preset in the high-vacuum deposition chamber, wherein the semiconductor or nonconductor vapor and the metal vapor are injected as a cluster beam to the substrate, and further wherein the nozzle and the substrate is varied by adjusting a handling shaft attached to the substrate; and

a thickness sensor controlled by adjusting a movable shaft attached thereto between the nozzle and the substrate in order to measure a deposition rate of the cluster beam on the substrate and an effective thickness of a deposition layer.

* * * * *