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(54) **METHOD OF FORMING NANOCRYSTALS AND METHOD OF MANUFACTURING AN ORGANIC LIGHT-EMITTING DISPLAY APPARATUS INCLUDING A THIN FILM HAVING NANOCRYSTALS**

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(57) **ABSTRACT**

A method of forming nanocrystals includes loading a substrate into a chamber, applying a first voltage to a first target to form a thin film including a first metal compound on the substrate by sputtering, and applying a second voltage to a second target and forming nanocrystals in the thin film by sputtering.

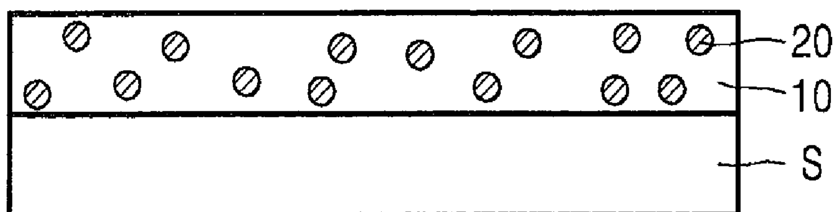


FIG. 1

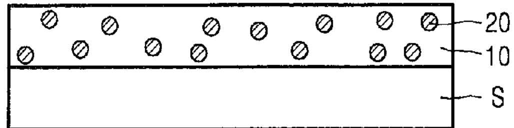


FIG. 2

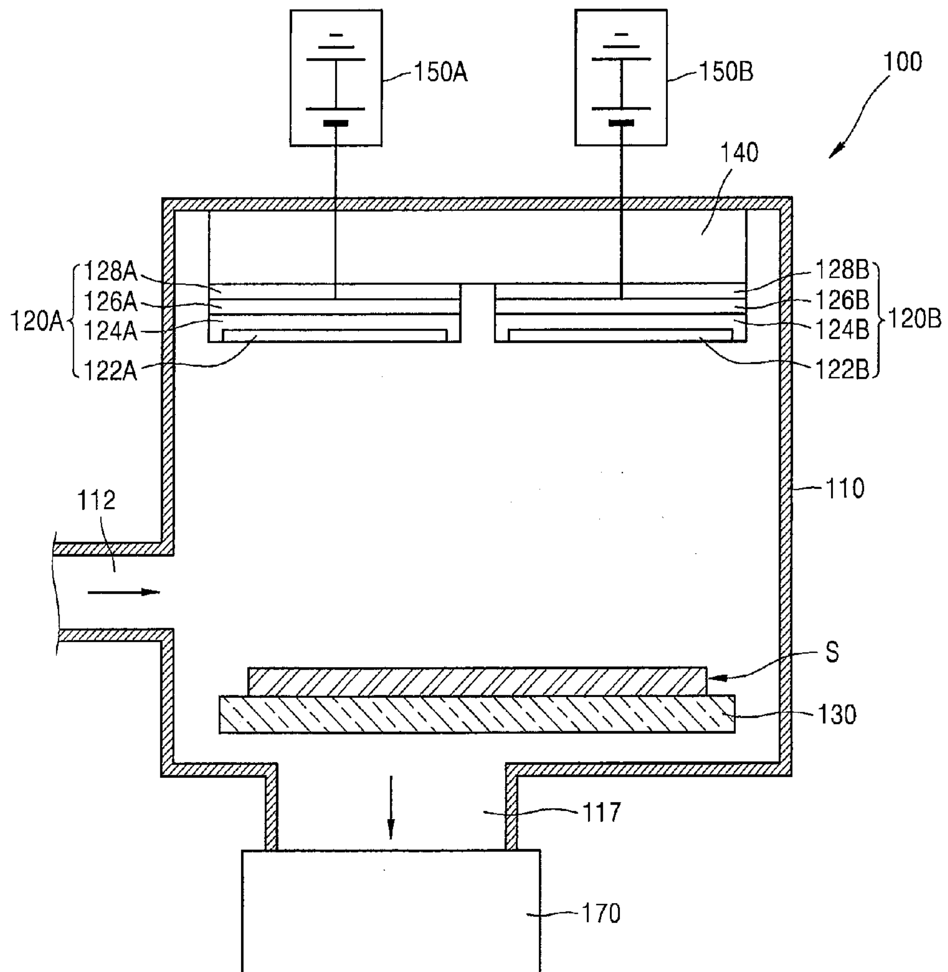


FIG. 3

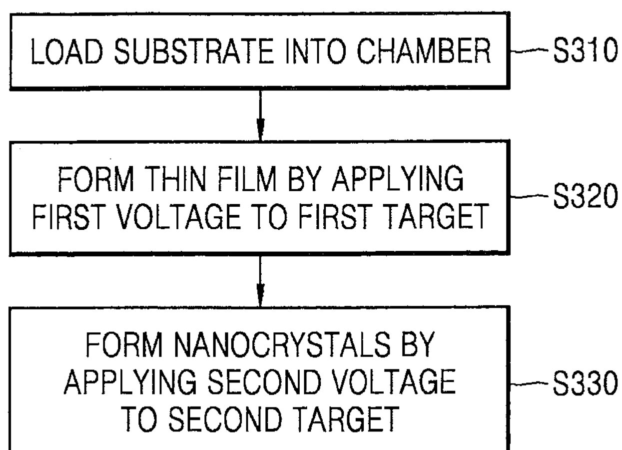


FIG. 4

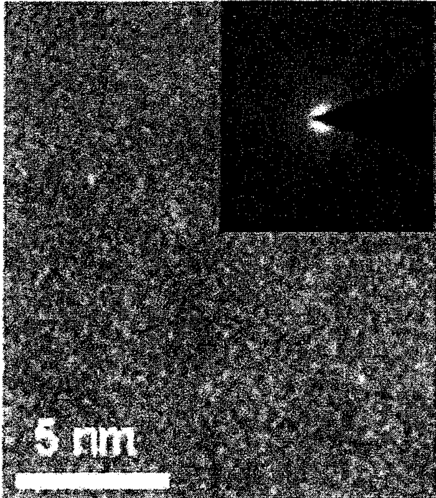


FIG. 5

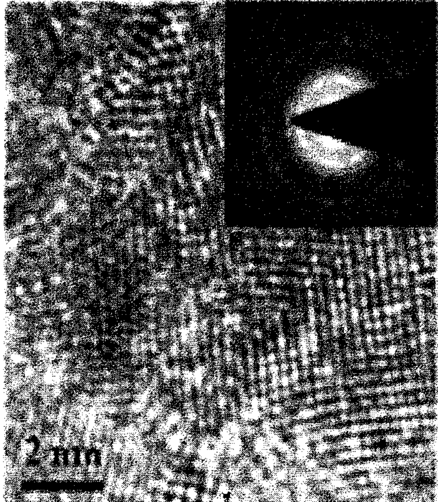


FIG. 6

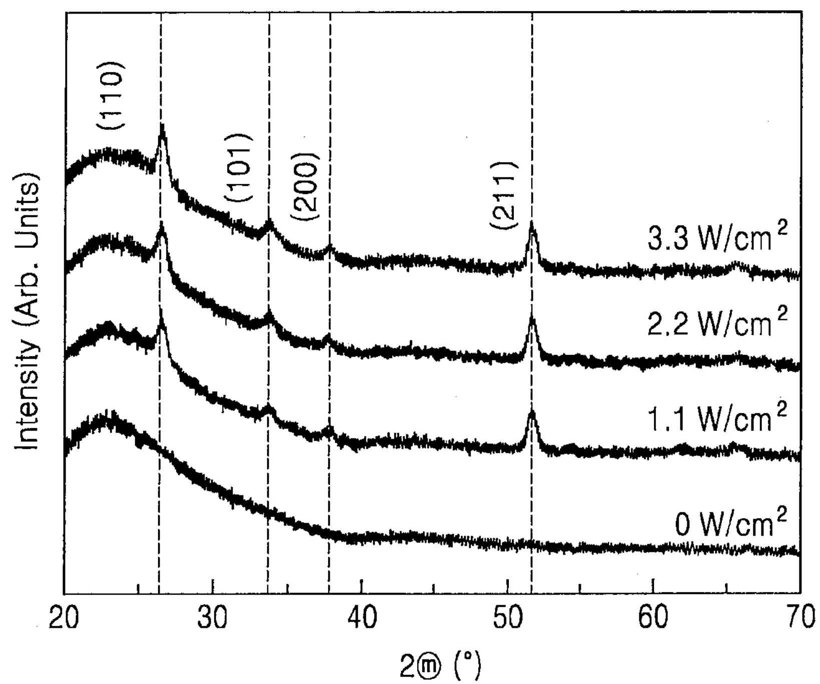


FIG. 7

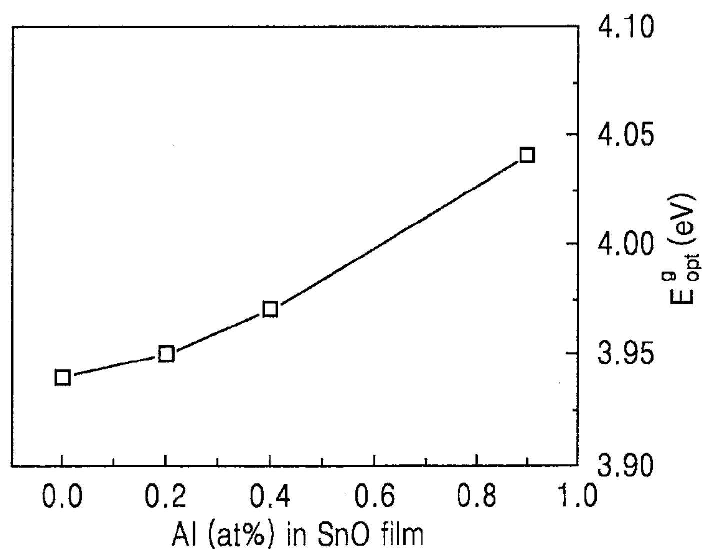


FIG. 8

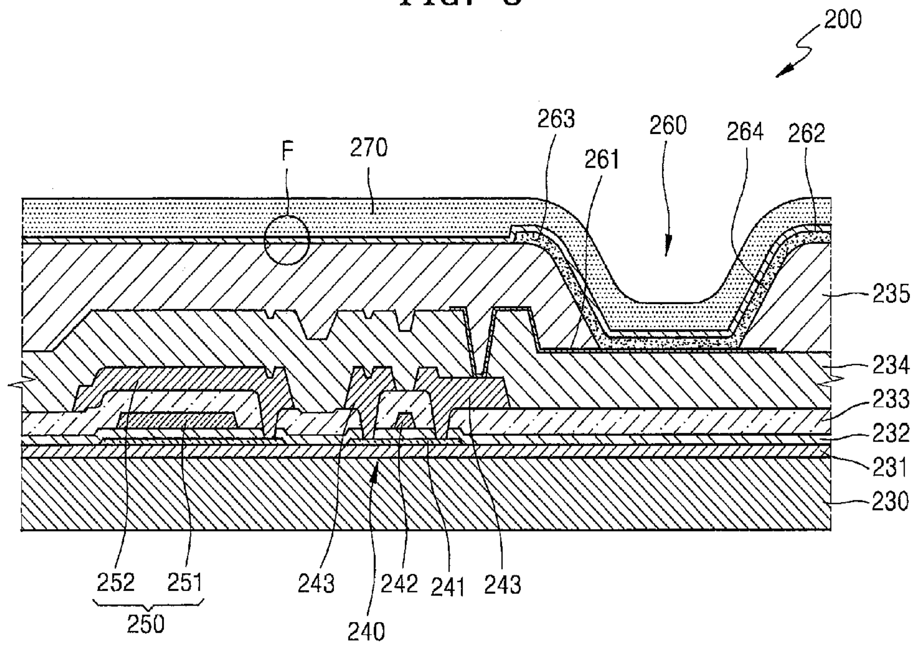
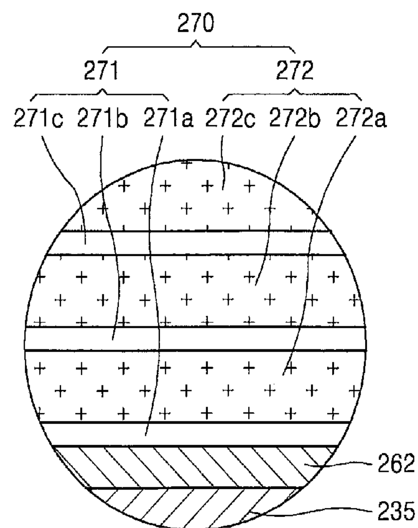


FIG. 9



METHOD OF FORMING NANOCRYSTALS AND METHOD OF MANUFACTURING AN ORGANIC LIGHT-EMITTING DISPLAY APPARATUS INCLUDING A THIN FILM HAVING NANOCRYSTALS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to and the benefit of Korean Patent Application No. 10-2013-0046929, filed on Apr. 26, 2013, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND

[0002] 1. Field

[0003] Embodiments of the present invention relate to a method of forming nanocrystals in a thin film and a method of manufacturing an organic light-emitting display apparatus by using a thin film having nanocrystals formed therein.

[0004] 2. Description of the Related Art

[0005] A vapor deposition method, an electrodeposition method, a chemical vapor deposition method, and a sputtering method are used in processes of forming thin films used in electronic components. Among these methods, the sputtering method has been widely used due to the fact that the microstructure and the composition of the formed thin film are highly controllable with high mass productivity.

[0006] A sputtering method (technique) is a film-forming technique in which plasma is used for generating ions which bombard a sputtering target so as to allow atoms of the sputtering target to be stacked as a layer on a substrate. In particular, the sputtering technique is used for forming thin films of metals, oxides, nitrides, and semiconductors in various manufacturing processes which are used in semiconductor and optoelectronic industries.

[0007] In a case where a thin film is deposited at a low temperature by using a sputtering technique, an amorphous thin film may be formed. However, such amorphous thin film may have limitations in increasing the density of the thin film or increasing (or improving) optical properties of the thin film. Many attempts have been made to overcome such limitations by doping or adding heterogeneous materials in a thin film process. However, the addition of the heterogeneous materials may cause the deterioration of other properties.

SUMMARY

[0008] Aspects of embodiments of the present invention are directed toward a method of forming a thin film including nanocrystals at a low temperature.

[0009] Aspects of embodiments of the present invention are directed toward a method of manufacturing an organic light-emitting display apparatus by using the thin film including nanocrystals.

[0010] According to an embodiment of the present invention, there is provided a method of forming nanocrystals including: loading a substrate into a chamber; applying a first voltage to a first target to form a thin film including a first metal compound on the substrate by sputtering; and applying a second voltage to a second target and forming nanocrystals in the thin film by sputtering.

[0011] The first target and the second target may include different metals.

[0012] The first metal compound may be a metal oxide or a metal nitride.

[0013] The second voltage may be higher than the first voltage.

[0014] A diameter of the nanocrystals may be determined by a value of the voltage applied to the second target.

[0015] The forming of the nanocrystals may include doping the thin film with a second metal compound from the second target.

[0016] A density of the nanocrystals may be determined by a doping amount of the second metal compound.

[0017] The first metal compound may be amorphous.

[0018] A thickness of the thin film may be about 100 nm or less.

[0019] A process temperature in the chamber may be about 100° C. or less.

[0020] A density of the thin film may be increased by the formation of the nanocrystals.

[0021] Optical bandgap energy of the thin film may be increased by the formation of the nanocrystals.

[0022] The nanocrystals may be formed by crystallization of at least one metal of the first metal compound and a second metal compound from the second target.

[0023] The first metal compound may include at least one of SnO_x, ZnO, InO_x, TiO_x, indium tin oxide (ITO), and WO_x.

[0024] According to another embodiment of the present invention, there is provided a thin film having nanocrystals formed by the above-described method of forming nanocrystals.

[0025] According to another embodiment of the present invention, there is provided a method of manufacturing an organic light-emitting display apparatus including: loading a substrate including at least some components of the organic light-emitting display apparatus into a chamber; applying a first voltage to a first target to form a thin film including a first metal compound on the substrate by sputtering; and applying a second voltage to a second target and forming nanocrystals in the thin film by sputtering.

[0026] The organic light-emitting display apparatus may include a first electrode, an intermediate layer including an organic light-emitting layer, a second electrode, and an encapsulation layer, the electrodes and layers being on the substrate and the thin film having the nanocrystals formed therein may be included in the encapsulation layer.

[0027] The encapsulation layer may include an organic layer and an inorganic layer.

[0028] The inorganic layer may include the thin film including the nanocrystals.

[0029] The thin film may be amorphous.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] The above and other features and aspects of embodiments of the present invention will become more apparent by describing in detail example embodiments thereof with reference to the attached drawings in which:

[0031] FIG. **1** is a schematic view illustrating a thin film including nanocrystals, according to an embodiment of the present invention;

[0032] FIG. **2** is a schematic view illustrating a sputtering apparatus according to an embodiment of the present invention;

[0033] FIG. **3** is a flowchart illustrating a method of forming a thin film including nanocrystals, according to an embodiment of the present invention;

[0034] FIG. **4** is a transmission electron micrograph of a tin oxide thin film grown by a low temperature process;

[0035] FIG. **5** is a transmission electron micrograph of a tin oxide thin film doped with aluminum oxide;

[0036] FIG. **6** is a graph illustrating changes in the density of a thin film according to an increase in a doping amount of aluminum oxide;

[0037] FIG. **7** is a graph illustrating optical bandgap energy of thin films according to the increase in the doping amount of aluminum oxide;

[0038] FIG. **8** is a cross-sectional view schematically illustrating an organic light-emitting display apparatus according to an embodiment of the present invention; and

[0039] FIG. **9** is an enlarged view of region F shown in FIG. **8**.

DETAILED DESCRIPTION

[0040] Hereinafter, aspects of the present invention will be described in more detail by explaining embodiments of the present invention with reference to the attached drawings.

[0041] Like reference numerals in the drawings denote like elements. Moreover, detailed descriptions related to well-known functions or configurations may be ruled out in order not to unnecessarily obscure subject matters of embodiments of the present invention.

[0042] Expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

[0043] FIG. **1** is a schematic view illustrating a thin film **10** including nanocrystals **20**, according to an embodiment of the present invention. Referring to FIG. **1**, and in one embodiment, the nanocrystals **20** are formed in the thin film **10**. Herein, the thin film **10** may be formed of a metal compound, and the metal compound may be a metal oxide or a metal nitride. The nanocrystals **20** may be formed of a metal.

[0044] For example, in one embodiment, the thin film **10** is formed of a metal (such as zinc (Zn), copper (Cu), indium (In), silver (Ag), tin (Sn), antimony (Sb), nickel (Ni), or iron (Fe)), including oxygen and/or nitrogen as a component. For example, in one embodiment, the thin film **10** is formed of a metal oxide, such as indium tin oxide (ITO), ZnO, SnO_x, ZrO_x, TiO_x, or AlO_x, and/or a metal nitride, such as TiN, SiN, or AlN. Also, the thin film **10** may be formed by doping a base metal compound formed of a metal compound, such as SnO_x, ZnO, InO_x, TiO_x, ITO, or WO_x, with a metal compound, such as NiO_x or SiO_x.

[0045] The nanocrystals **20** may not only increase the density of the thin film **10**, but may also increase (or improve) optical properties of the thin film **10** by being distributed in the thin film **10**. Herein, the nanocrystals **20** may be formed of the same metal as that of the thin film **10**. For example, in one embodiment, the metal constituting the nanocrystals **20** is one or more of Zn, Cu, In, Ag, Sn, Sb, Ni, and Fe. Also, a diameter of the nanocrystals **20** may be in a range of about 1 nm to about 20 nm. The diameter of the nanocrystals **20** may be controlled by values of voltages applied to targets **122**A and **122**B as sources of the nanocrystals **20** during a sputtering process, and the density of the nanocrystals **20** may be controlled by power densities applied to the targets **122**A and **122**B as the sources of the nanocrystals **20** during the sputtering process.

[0046] Any substrate S may be used so long as it is suitable for the preparation of a thin film. A substrate formed of a material, such as glass, GaAs, quartz, $LiNbO_3$, $LiTaO_3$, silicon (Si), SiC, SiO_2, ZnO, MgZnO, sapphire, platinum (Pt), or SiN, may be used, and for example, in one embodiment, a sapphire substrate or a SiN substrate is used. For example, in one embodiment, a process pressure is in a range of about 0.1 Pa to about 1 Pa. The sputtering process may be performed at a low temperature. For example, in one embodiment, the sputtering process is performed at about 100° C.

[0047] A thickness of the thin film **10** is not particularly limited and may be increased according to process time. However, the thickness of the thin film **10** may be about 100 nm or less in order to reduce the process time and secure the stability of the process.

[0048] FIG. **2** is a schematic view illustrating a sputtering apparatus **100** according to an embodiment of the present invention. Referring to FIG. **2**, in one embodiment, the sputtering apparatus **100** includes a chamber **110** providing a space for the sputtering process, target units (or targets) **120**A and **120**B respectively disposed (or located) in the chamber **110** and having materials to be deposited on the substrate S mounted therein, a substrate mounting unit **130** disposed (or positioned) to face the target units **120**A and **120**B and for stably placing the substrate S thereon, and a pump **170** coupled to an exhaust pipe **117** of the chamber **110**.

[0049] The chamber **110** provides a space for performing a sputtering process and a deposition process, wherein in one embodiment the chamber **110** further includes a gas inlet **112** that provides reaction gas for generating plasma between the targets **122**A and **122**B and the substrate mounting unit **130**, and the exhaust pipe **117** for exhausting residual reaction gas. The residual reaction gas may be easily exhausted without using a separate exhaust pump by coupling the exhaust pipe **117** to the vacuum pump **170** controlling the pressure in the chamber **110**. Herein, the reaction gas may be argon (Ar) gas which may generate plasma at a low electric power in order to reduce (or prevent) damage to the substrate S stably placed on the substrate mounting unit **130**.

[0050] A process pressure in the chamber **110** may be in a range of about 0.1 Pa to about 1 Pa. The sputtering process may be performed at a low temperature. For example, in one embodiment, the sputtering process is performed at a temperature in the chamber of about 100° C.

[0051] In one embodiment, the substrate S is mounted on the substrate mounting unit **130**, and the substrate mounting unit **130** supports the substrate S to face the target units **120**A and **120**B.

[0052] A target transfer unit (or target transferor) **140** is a device for transferring the target units **120**A and **120**B, wherein the target transfer unit **140** may induce uniform sputtering on the substrate S by transferring the target units **120**A and **120**B. The target transfer unit **140** may horizontally or vertically move or rotate the target units **120**A and **120**B.

[0053] In one embodiment, the two target units **120**A and **120**B are located at a region facing the substrate S in the chamber **110**. The two target units **120**A and **120**B may be positioned next to each other while facing the substrate S. The target units **120**A and **120**B may respectively include targets **122**A and **122**B, target plates **124**A and **124**B, cathode plates **126**A and **126**B, and magnets **128**A and **128**B.

[0054] In one embodiment, a sputtering phenomenon occurs in which ions in the chamber **110** that have been generated by accelerated electrons collide with the targets **122**A and **122**B to allow materials on surfaces of the targets **122**A and **122**B to escape therefrom. The materials that escape from the surfaces of the targets **122**A and **122**B are

deposited on the substrate S to form a thin film, and an organic light-emitting display apparatus may be realized by using the thin film.

[0055] The targets **122**A and **122**B may be formed of different materials. The thin film **10**, including the nanocrystals **20**, may be formed on the substrate S by using the targets **122**A and **122**B formed of mutually different materials. For example, in one embodiment, if any one of the targets **122**A and **122**B is formed of tin oxide and the other one is formed of aluminum oxide, tin or aluminum nanocrystals are formed in an amorphous thin film, including tin oxide and aluminum oxide, on the substrate S. Thus, voltages having different values may be applied to the targets **122**A and **122**B in order to form the thin film **10** including the nanocrystals **20**.

[0056] Next, in one embodiment, the target plates **124**A and **124**B fix the targets **122**A and **122**B, which are the sources of materials deposited on the substrate S by sputtering. The cathode plates **126**A and **126**B are positioned on the target plates **124**A and **124**B and are coupled to a power supply unit (or power supply) to apply voltages to the targets **122**A and **122**B. In addition, the magnets **128**A and **128**B apply magnetic fields in order to reduce the possibility of (or prevent) the escape of electrons generated from plasma to other parts of the sputtering apparatus **100**.

[0057] The power supply unit (or power supplier) is coupled to the cathode plates **126**A and **126**B in the chamber **110** to apply voltages thereto, and thus generates the plasma between the substrate S and the targets **122**A and **122**B.

[0058] Voltage supply units (or voltage suppliers) **150**A and **150**B may respectively apply different values of voltages to the target **122**A and the target **122**B. For example, in one embodiment, a first voltage is applied to the target **122**A, and a second voltage that is higher than the first voltage is applied to the target **122**B. Voltage application times of the voltage supply unit **150**A and the voltage supply unit **150**B may differ. For example, in one embodiment, when a period of time (e.g., a set or predetermined period of time) elapses after the voltage supply unit **150**A applies the first voltage to the target **122**A, the voltage supply unit **150**B applies the second voltage to the target **122**B. Thus, the base metal compound may be formed from the target **122**A, and the nanocrystals **20** may be formed from the target **122**B.

[0059] FIG. **3** is a flowchart illustrating a method of forming the thin film **10** including the nanocrystals **20**, according to an embodiment of the present invention.

[0060] In this embodiment, the substrate S is loaded on the substrate mounting unit **130** of the chamber **110** (S**310**). Reaction gas, such as Ar gas, is provided to a space in the chamber **110** through the gas inlet **112**.

[0061] In a case where a material formed on the substrate S by the sputtering apparatus **100** according to the embodiment of the present invention is a material including oxygen or nitrogen, i.e., an oxide or a nitride, oxygen or nitrogen is introduced into the chamber **110**, in addition to the Ar gas. A pressure in the chamber **110** may be in a range of about 0.1 Pa to about 1 Pa. Also, a temperature in the chamber **110** may be about 100° C. or less.

[0062] Thereafter, a first voltage is applied to the target **122**A to form a thin film on the substrate S by sputtering (S**320**). Specifically, when the first voltage is applied to the target **122**A through the voltage supply unit **150**A, sputtering plasma is generated in the chamber **110**. In one embodiment, the plasma is composed of γ-electrons, cations, anions, and/or the like. The sputtering plasma collides with the target **122**A, and particles sputtered from the target **122**A, i.e., a first metal compound, are deposited on the substrate S. Because, in one embodiment, the first metal compound is formed at a low temperature, the first metal compound may be amorphous. The first voltage may be in a range from about 100 V to about 150 V.

[0063] A thickness of the thin film **10** may be determined by the application time of the voltage applied to the target **122**A. For example, the longer the application time of the voltage applied to the target **122**A is, the larger the thickness of the thin film **10** may become.

[0064] The thin film **10** is formed, and a second voltage is then applied to the target **122**B to form nanocrystals by sputtering (S**330**). Specifically, when the second voltage is applied to the target **122**B through the voltage supply unit **150**B, sputtering plasma is generated in the chamber **110**. The second voltage may be higher than the first voltage, and for example, may be in a range from about 150 V to about 200 V. In one embodiment, the plasma is composed of γ-electrons, cations, anions, and/or the like. The sputtering plasma collides with the target **122**B, and the thin film **10** is doped with particles sputtered from the target **122**B, i.e., a second metal compound. The thickness of the thin film **10** may be slightly increased due to the doping with the second metal compound.

[0065] Because, in one embodiment, the second metal compound is formed by a voltage difference greater than that of the first metal compound, the thin film **10** may be doped with the second metal compound at a rate faster than that of the first metal compound. Because the first metal compound is doped with the second metal compound at a fast rate and the second metal compound may collide with the first metal compound, a portion of the first metal compound or the second metal compound may be crystallized. Therefore, oxygen or nitrogen of the first metal compound or the second metal compound in the thin film **10** may escape from metals, and the metals may be crystallized. The crystallized metals may have a nanoscale diameter. For example, the diameter of the nanocrystals **20** may be in a range from about 1 nm to about 20 nm.

[0066] The diameter of the nanocrystals **20** may be determined by a value of the voltage applied to the target **122**A. For example, the higher the voltage applied to the target **122**A is, the larger the diameter of the nanocrystals **20** may be. Also, a density of the nanocrystals **20** may be determined by a doping amount of the second metal compound. For example, the higher the doping amount of the second metal compound is, the higher the density of the nanocrystals **20** may be.

[0067] In FIG. **3**, and in one embodiment, the thin film **10**, including the nanocrystals **20**, is formed by applying a voltage to the target **122**B after a voltage is applied to the target **122**A. However, embodiments of the present invention are not limited thereto. In another embodiment, the thin film **10**, including the nanocrystals **20**, may be formed by intermittently applying a voltage to the target **122**B during the application of a voltage to the target **122**A.

COMPARATIVE EXAMPLE

[0068] As a comparative example, a tin oxide thin film was grown to a thickness of about 50 nm by reactive sputtering at a vacuum pressure and room temperature. FIG. **4** shows a transmission electron micrograph of the tin oxide thin film grown by a low temperature process. As illustrated in FIG. **4**, a diffraction pattern was absent in the micrograph. Therefore, it may be confirmed that the tin oxide thin film grown by a low temperature process was amorphous.

EXAMPLE

[0069] A first voltage (about 150 V) was applied to the target **122**A formed of tin oxide to form a tin oxide thin film by sputtering at a vacuum pressure and room temperature. A second voltage (about 200 V) that was higher than the first voltage was applied to the target **122**B formed of aluminum oxide to dope the tin oxide thin film with aluminum oxide by sputtering. FIG. **5** is a transmission electron micrograph of the tin oxide thin film doped with aluminum oxide. As illustrated in FIG. **5**, a diffraction pattern was presented in the micrograph. Therefore, it may be confirmed that crystals were formed by doping the tin oxide thin film with aluminum oxide.

[0070] FIG. **6** is a graph illustrating changes in the density of a thin film according to an increase in a doping amount of aluminum oxide. The tin oxide thin film was doped with aluminum oxide at power densities of 0 W/cm^2, 1.1 W/cm^2, 2.2 W/cm^2, and 4.4 W/cm^2. As illustrated in FIG. **6**, it may be confirmed that the density of the thin film increased as the doping amount of the aluminum oxide increased. That is, in a case where it is desired to form a higher-density amorphous thin film including nanocrystals, the doping amount of the second metal compound may be increased.

[0071] FIG. **7** is a graph illustrating optical bandgap energy of thin films according to an increase in the doping amount of aluminum oxide. As illustrated in FIG. **7**, the optical bandgap energy of a tin oxide thin film having no aluminum was about 3.93 eV. However, when aluminum was included in an amount of about 1% in a tin oxide thin film, the optical bandgap energy of the thin film increased to about 4.04 eV, meaning that defects, which may be included in the thin film, were mitigated (or removed).

[0072] Thus, in a case of forming a metal compound thin film, if a heterogeneous metal compound is deposited, a crystalline phase may be obtained during the formation of the thin film due to fast sputtered particles.

[0073] In the present example, the heterogeneous metal compound is deposited by sputtering. However, embodiments of the present invention are not limited thereto. The targets may be formed of the same metal compound, and a thin film, including nanocrystals, may be formed by differing values of the voltages applied to the targets.

[0074] The above-described thin film, including nanocrystals, may be used as a component of an organic light-emitting display apparatus. For example, an encapsulation layer of the organic light-emitting display apparatus may be formed as the above-described thin film including nanocrystals.

[0075] FIG. **8** is a cross-sectional view schematically illustrating an organic light-emitting display apparatus **200** according to an embodiment of the present invention, and FIG. **9** is an enlarged view of region F shown in FIG. **8**.

[0076] In one embodiment, the organic light-emitting display apparatus **200** is formed on a substrate **230**. The substrate **230** may be formed of glass, plastic, or metal.

[0077] A buffer layer **231** is formed on the substrate **230**, wherein the buffer layer **231** provides a flat surface on the substrate **230** and contains an insulator to reduce (or prevent) the penetration of moisture and foreign matter in a direction toward the substrate **230**.

[0078] A thin film transistor (TFT) **240**, a capacitor **250**, and an organic light-emitting device **260** are formed on the buffer layer **231**. The thin film transistor **240** mainly includes an active layer **241**, a gate electrode **242**, and source/drain electrodes **243**. The organic light-emitting device **260** includes a first electrode **261**, a second electrode **262**, and an intermediate layer **263**.

[0079] The capacitor **250** includes a first capacitor electrode **251** and a second capacitor electrode **252**.

[0080] Specifically, the active layer **241** is positioned on a top surface of the buffer layer **231** in a pattern (e.g., a predetermined pattern). The active layer **241** may contain an inorganic semiconductor material, such as silicon, an organic semiconductor material, or an oxide semiconductor material, and may be formed by implanting a p-type or n-type dopant. The first capacitor electrode **251** is formed at the same layer as the gate electrode **242**, and the first capacitor electrode **251** may be formed of the same material as that of the gate electrode **242**.

[0081] A gate dielectric layer **232** is formed on the active layer **241**. The gate electrode **242** is formed on the gate dielectric layer **232** so as to correspond to the active layer **241**. An interlayer dielectric **233** is formed to cover the gate electrode **242**, and the source/drain electrodes **243** are formed on the interlayer dielectric **233** to be in contact with areas (e.g., predetermined areas) of the active layer **241**. The second capacitor electrode **252** is formed at the same layer as the source/drain electrodes **243**, and the second capacitor electrode **252** may be formed of the same material as that of the source/drain electrodes **243**.

[0082] A passivation layer **234** is formed to cover the source/drain electrodes **243**, and a separate insulation layer may be further formed on the passivation layer **234** for the planarization of the thin film transistor **240**.

[0083] The first electrode **261** is formed on the passivation layer **234**. The first electrode **261** is formed to be electrically coupled to any one of the source/drain electrodes **243**. A pixel-defining layer **235** is formed to cover the first electrode **261**. An opening **264** (e.g., a predetermined opening) is formed at the pixel-defining layer **235**, and the intermediate layer **263**, including an organic light-emitting layer, is then formed in a region limited by the opening **264**. The second electrode **262** is formed on the intermediate layer **263**.

[0084] An encapsulation layer **270** is formed on the second electrode **262**. The encapsulation layer **270** may contain an organic material or an inorganic material, and may have a structure in which the organic material and the inorganic material are alternatingly stacked.

[0085] The encapsulation layer **270** may be formed by using the above-described method of forming a thin film **10** including the nanocrystals **20** of embodiments of the present invention. That is, a thin film may be formed on a substrate having the second electrode **262** formed thereon.

[0086] In one embodiment, the encapsulation layer **270** includes an inorganic layer **271** and an organic layer **272**, in which the inorganic layer **271** includes a plurality of layers **271***a*, **271***b*, and **271***c*, and the organic layer **272** includes a plurality of layers **272***a*, **272***b*, and **272***c*. The plurality of layers **271***a*, **271***b*, and **271***c* of the inorganic layer **271** may be formed of the above-described metal oxide thin film including nanocrystals.

[0087] As described above, a thin film including nanocrystals may be formed by sputtering at a low temperature. Therefore, the density and optical properties of the thin film may be increased (or improved).

[0088] Also, an organic light-emitting display apparatus may be manufactured by using the thin film having increased (or improved) density and optical properties.

[0089] While aspects of the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the present invention as defined by the following claims, and equivalents thereof.

What is claimed is:

1. A method of forming nanocrystals, the method comprising:
- loading a substrate into a chamber;
- applying a first voltage to a first target to form a thin film comprising a first metal compound on the substrate by sputtering; and
- applying a second voltage to a second target and forming nanocrystals in the thin film by sputtering.

2. The method of claim **1**, wherein the first target and the second target comprise different metals.

3. The method of claim **1**, wherein the first metal compound is a metal oxide or a metal nitride.

4. The method of claim **1**, wherein the second voltage is higher than the first voltage.

5. The method of claim **1**, wherein a diameter of the nanocrystals is determined by a value of the voltage applied to the second target.

6. The method of claim **1**, wherein the forming of the nanocrystals comprises doping the thin film with a second metal compound from the second target.

7. The method of claim **6**, wherein a density of the nanocrystals is determined by a doping amount of the second metal compound.

8. The method of claim **1**, wherein the first metal compound is amorphous.

9. The method of claim **1**, wherein a thickness of the thin film is about 100 nm or less.

10. The method of claim **1**, wherein a process temperature in the chamber is about 100° C. or less.

11. The method of claim **1**, wherein a density of the thin film is increased by the formation of the nanocrystals.

12. The method of claim **1**, wherein optical bandgap energy of the thin film is increased by the formation of the nanocrystals.

13. The method of claim **1**, wherein the nanocrystals are formed by crystallization of at least one metal of the first metal compound and a second metal compound from the second target.

14. The method of claim **1**, wherein the first metal compound comprises at least one of SnO_x, ZnO, InO_x, TiO_x, indium tin oxide (ITO), and WO_x.

15. A thin film having nanocrystals formed by the method of forming nanocrystals of claim **1**.

16. A method of manufacturing an organic light-emitting display apparatus, the method comprising:
- loading a substrate comprising at least some components of the organic light-emitting display apparatus into a chamber;
- applying a first voltage to a first target to form a thin film comprising a first metal compound on the substrate by sputtering; and
- applying a second voltage to a second target and forming nanocrystals in the thin film by sputtering.

17. The method of claim **16**, wherein the organic light-emitting display apparatus comprises: a first electrode; an intermediate layer comprising an organic light-emitting layer; a second electrode; and an encapsulation layer; the electrodes and layers being on the substrate and
- the thin film having the nanocrystals formed therein is included in the encapsulation layer.

18. The method of claim **17**, wherein the encapsulation layer comprises an organic layer and an inorganic layer.

19. The method of claim **18**, wherein the inorganic layer comprises the thin film comprising the nanocrystals.

20. The method of claim **16**, wherein the thin film is amorphous.

* * * * *

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专利名称(译)	形成纳米晶体的方法和制造包括具有纳米晶体的薄膜的有机发光显示装置的方法		
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摘要(译)

形成纳米晶体的方法包括将衬底装载到腔室中，将第一电压施加到第一靶以通过溅射在衬底上形成包括第一金属化合物的薄膜，以及将第二电压施加到第二靶并且在第二靶中形成纳米晶体。通过溅射薄膜。