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Inventor(s)	Zhong; Yaoying et al.

Methods and apparatus for depositing amorphous indium tin oxide film

Abstract

Methods and apparatus for processing a substrate in a process chamber include: positioning a substrate on a substrate support in a process volume so that the substrate is opposite a sputter target comprising indium tin oxide; flowing a plasma-forming gas into the process volume; and sputtering the indium tin oxide onto the substrate while applying AC bias to the substrate.

Inventors: **Zhong; Yaoying (Singapore, SG), Hoi; Siew Kit (Singapore, SG), Chidambaram; Palaniappan (Singapore, SG), Chiam; Jaysen (Singapore, SG), Choo; Li Ying (Singapore, SG), Soh; Jay Min (Singapore, SG), Tan; Xiao (Singapore, SG), Xu; Haomin (Singapore, SG)**

Applicant: **Applied Materials, Inc.** (Santa Clara, CA)

Family ID: **1000007900345**

Assignee: **APPLIED MATERIALS, INC. (Santa Clara, CA)**

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Primary Examiner: McDonald; Rodney G

Attorney, Agent or Firm: Moser Taboada

Background/Summary

FIELD

(1) Embodiments of the present disclosure generally relate to substrate processing, and more particularly, to deposition of indium tin oxide films on substrates.

BACKGROUND

(2) Indium tin oxide (ITO) is often used in optoelectronics. For example, ITO films may be used as transparent electrodes in ultra light-emitting diodes (ULEDs). ITO films may be deposited on substrates, such as semiconductor wafers, with some physical vapor deposition (PVD) processes. However, the inventors have observed that some ITO films deposited by PVD are formed with columnar crystal structure with naturally existing grain boundaries which can, in some situations, be undesirable. For example, if etching processes are performed after ITO film deposition, etchant

may penetrate the ITO film through grain boundaries in the ITO film, leaving undesired compounds in underlying layers which may impact device performance.

(3) Some approaches to forming amorphous ITO films without grain boundaries include depositing ITO films with PVD processes at low substrate temperatures (e.g., room temperature). However, low temperatures can cause the ITO film to have higher resistivity, which, for a transparent electrode, is undesirable. The resistivity may be recovered by performing additional processes (e.g., annealing). The additional processes increase manufacturing time and cost.

(4) Thus, methods and apparatus are proposed that can provide amorphous ITO films on substrates without a need to perform additional processes to complete the ITO film, thereby reducing manufacturing time and cost.

SUMMARY

(5) Methods and apparatus for processing substrates are provided herein. In some embodiments, a method of processing a substrate in a process chamber includes: positioning a substrate on a substrate support in a process volume so that the substrate is opposite a sputter target comprising indium tin oxide; flowing a plasma-forming gas into the process volume; and sputtering the indium tin oxide onto the substrate while applying AC bias to the substrate.

(6) In some embodiments, a process chamber for processing a substrate includes: a chamber body having walls defining a processing volume; a substrate support having a support surface configured to support a substrate within the processing volume; a power source coupled to the substrate support, the power source configured to provide an AC bias to the substrate; a pulsed DC power supply configured to be coupled to a sputter target when the sputter target is installed during substrate processing; and a controller configured to: position the substrate on the support surface; flow a plasma-forming gas into the process volume; and sputter indium tin oxide, from the sputter target comprising indium tin oxide, onto the substrate while applying AC bias to the substrate.

(7) In some embodiments, process kit shields for a chamber for processing a substrate include: a lower shield having a first annular body, a first upper flange at a top of the first annular body, and a channel at a bottom of the first annular body, the first annular body having a plurality of first holes surrounding an opening configured to surround a substrate during substrate processing; and an upper shield having a second annular body and an second upper flange configured to seat on the first upper flange, the second annular body extending into the channel, the second annular body having a plurality of second holes, the second holes being spaced radially inward and below the first holes, wherein the first holes and the second holes are configured to define a flow path for a plasma-forming gas from a location below the substrate support through the first holes and the second holes and above the substrate support.

(8) Other and further embodiments of the present disclosure are described below.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Embodiments of the present disclosure, briefly summarized above and discussed in greater detail below, can be understood by reference to the illustrative embodiments of the disclosure depicted in the appended drawings. However, the appended drawings illustrate only typical embodiments of the disclosure and are therefore not to be considered limiting of scope, for the disclosure may admit to other equally effective embodiments.

(2) FIG. **1** is a flow chart of a method in accordance with some embodiments of the present disclosure.

(3) FIG. **2** is a schematic of an amorphous indium tin oxide film deposited on a substrate in accordance with some embodiments of the present disclosure.

(4) FIG. **3** is a schematic of a process chamber in accordance with some embodiments of the

present disclosure.
(5) FIG. **4** is a partial section view of process kit shields in accordance with some embodiments of the present disclosure.
(6) FIG. **5**A is a partial section view of process kit shields in accordance with some embodiments of the present disclosure.
(7) FIG. **5**B is an isometric view of an upper shield shown in FIG. **5**A.
(8) FIG. **6**A is a partial section view of process kit shields in accordance with some embodiments of the present disclosure.
(9) FIG. **6**B shows details of a portion A of the upper shield shown in FIG. **6**A.
(10) FIG. **7**A is a partial section view of process kit shields in accordance with some embodiments of the present disclosure.
(11) FIG. **7**B shows details of a portion B of the upper shield shown in FIG. **6**A.
(12) To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. The figures are not drawn to scale and may be simplified for clarity. Elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.
DETAILED DESCRIPTION
(13) Embodiments of methods and apparatus for processing substrates are provided herein. In some embodiments, the methods and apparatus described herein are provided to reduce or eliminate naturally occurring grain boundaries in ITO films deposited on substrates. In some embodiments, the methods and apparatus provide for an amorphous ITO film to be deposited on substrates in a PVD process using an AC bias that avoids multiple processes to complete the ITO film. By using an AC bias during ITO PVD deposition, argon atoms introduced over the substrate are induced to bombard the film surface thereby disturbing natural crystal formation so that grain boundaries are not formed.
(14) FIG. **1** depicts a method **100** of processing a substrate in a process chamber in accordance with some embodiments of the present disclosure. In some embodiments, the method **100** may begin at block **102** by positioning a substrate on a substrate support in a processing volume of a process chamber, such as process chamber **300**, so that the substrate is opposite a sputter target comprising indium tin oxide. In some embodiments, at block **104**, the method **100** may include flowing a plasma-forming gas into the process volume. The plasma-forming gas may be directed above the substrate in the process volume by at least one hole of the plurality of holes. In some embodiments, the plasma-forming gas may be comprised of at least one of argon at a flow rate of 50 sccm to 400 sccm, or oxygen at a flow rate of 0.5 sccm to 20 sccm. In some embodiments, the method **100** may include maintaining a temperature of the substrate at 100 C to 450 C. In some embodiments, the method **100** may include maintaining a temperature of the substrate at 0 C to 50 C.
(15) In some embodiments, at block **106**, the method **100** may include sputtering the indium tin oxide onto the substrate while applying AC bias to the substrate, thereby forming an amorphous ITO film on the substrate, as shown in FIG. **2**.
(16) In some embodiments, sputtering the indium tin oxide includes applying pulsed DC power to the sputter target. The pulsed DC power may be 500 W to 10,000 W. The pulsed DC power may be applied at a duty cycle of 5% to 15%. In some embodiments, the applied AC bias may be 100 W to 1500 W. In some embodiments, the AC bias may be applied for less than one minute.
(17) Although the methods in accordance with the present disclosure, such as method **100**, can be used to form an amorphous ITO film of uniform thickness, the methods can be used to deposit an amorphous ITO film of varying thickness. In some embodiments, ITO material may be formed as a film or layer on a substrate and subjected to additional process flows such as etching, filling and/or capping to form features, which may produce ITO films of varying thicknesses, such as the ITO film shown in FIG. **2**.
(18) In some embodiments, and as shown in FIG. **2** depicting a substrate **200** having a surface **204**

on which an amorphous indium tin oxide film **202** may be deposited. The surface **204** may include at least one of silver, aluminum, or tantalum. At least some portions of the surface **204** may form a reflector. In some embodiments, the amorphous indium tin oxide film **202** may be deposited on the surface **204** as a layer of uniform thickness and later subject to additional processing, such as etching to produce a areas of various thickness.

(19) The method **100** may be performed in a suitable PVD process chamber having DC, AC, and/or radio frequency (RF) power sources, such as a process chamber **300** described below and depicted in FIG. **3**. FIG. **3** depicts a schematic, cross-sectional view of a process chamber **300** (physical vapor deposition chamber) in accordance with some embodiments of the present disclosure. Examples of suitable PVD chambers include the IMPULSE™ PVD process chambers, commercially available from Applied Materials. Inc., of Santa Clara, Calif. Other process chambers from Applied Materials. Inc or other manufacturers may also benefit from the apparatus disclosed herein.

(20) In some embodiments, and as shown in FIG. **3**, the process chamber **300** may include a chamber body **301** having chamber walls **308** defining a process volume **348** and a substrate support **302** having a support surface configured to support a substrate **304** within the processing volume **348**. The chamber wall **308** may be grounded and may be as shown in FIG. **3** or may be a grounded shield (a ground shield **340** is shown covering at least some portions of the process chamber **300** above the sputter target **306**. In some embodiments, the ground shield **340** could be extended below the target to enclose the substrate support **302** as well.).

(21) In some embodiments, the process chamber includes a feed structure for coupling RF and DC energy to the sputtering sputter target **306**. The feed structure is an apparatus for coupling RF and DC energy to the sputtering sputter target **306**, or to an assembly containing the sputter target **306**, for example, as described herein. A first end of the feed structure can be coupled to an optional RF power source **318** and a DC power source **320**, which can be respectively utilized to provide RF and pulsed DC energy to the sputter target **306**. For example, the DC power source **320** may be utilized to apply a negative voltage, or bias, to the sputter target **306**. In some embodiments, the DC power source **320** may be a pulsed DC power supply configured to be coupled to the sputter target **306** when the sputter target is installed during substrate processing. The pulsed DC power source **320** may supply DC power of 500 W to 10,000 W during substrate processing. In some embodiments, the pulsed DC power may be applied at a duty cycle of 5% to 15%. The pulse frequency for pulsed dc may be 5% to 30%.

(22) In some embodiments, RF energy optionally supplied by the RF power source **318** may have a suitable frequency as described above, or can range in frequency from about 2 MHz to about 60 MHZ, or, for example, non-limiting frequencies such as 2 MHZ, 13.56 MHz, 27.12 MHz, or 60 MHz can be used. In some embodiments, a plurality of RF power sources may optionally be provided (i.e., two or more) to provide RF energy in a plurality of the above frequencies. The feed structure may be fabricated from suitable conductive materials to conduct the RF and DC energy from the RF power source **318** and the DC power source **320**. In embodiments, RF power source **318** is excluded, and DC power source **320** is configured to apply a negative voltage, or bias, to the sputter target **306**.

(23) In some embodiments, the feed structure may have a suitable length that facilitates substantially uniform distribution of the respective RF and DC energy about the perimeter of the feed structure. For example, in some embodiments, the feed structure may have a length of between about 1 to about 12 inches, or about 4 inches. In some embodiments, the body may have a length to inner diameter ratio of at least about 1:1. Providing a ratio of at least 1:1 or longer provides for more uniform RF delivery from the feed structure (i.e., the RE energy is more uniformly distributed about the feed structure to approximate RF coupling to the true center point of the feed structure. The inner diameter of the feed structure may be as small as possible, for example, from about 1 inch to about 6 inches, or about 4 inches in diameter. Providing a smaller inner diameter (ID)

facilitates improving the length to ID ratio without increasing the length of the feed structure.
(24) The second end of the feed structure may be coupled to a source distribution plate **322**. The source distribution plate includes a hole **324** disposed through the source distribution plate **322** and aligned with a central opening of the feed structure. The source distribution plate **322** may be fabricated from suitable conductive materials to conduct the RF and DC energy from the feed structure.
(25) The source distribution plate **322** may be coupled to the sputter target **306** via a conductive member **325**. The conductive member **125** may be a tubular member having a first end **326** coupled to a target-facing surface **328** of the source distribution plate **322** proximate the peripheral edge of the source distribution plate **322**. The conductive member **325** further includes a second end **330** coupled to a source distribution plate-facing surface **332** of the target **306** (or to the backing plate **346** of the target **306**) proximate the peripheral edge of the target **306**.
(26) A cavity **334** may be defined by the inner-facing walls of the conductive member **325**, the target-facing surface **328** of the source distribution plate **322** and the source distribution plate-facing surface **332** of the sputter target **306**. The cavity **334** is fluidly coupled to the central opening **315** of the body via the hole **324** of the source distribution plate **322**. The cavity **334** and the central opening **315** of the body may be utilized to at least partially house one or more portions of a rotatable magnetron assembly **336** as illustrated in FIG. **3** and described further below. In some embodiments, the cavity **334** may be at least partially filled with a cooling fluid, such as water or the like.
(27) A ground shield **340** may be provided to cover the outside surfaces of the lid of the process chamber **300**. The ground shield **340** may be coupled to ground, for example, via the ground connection of the chamber body. The ground shield **340** has a central opening to allow the feed structure to pass through the ground shield **340** to be coupled to the source distribution plate **322**. The ground shield **340** may comprise any suitable conductive material, such as aluminum, copper, or the like. An insulative gap **339** is provided between the ground shield **340** and the outer surfaces of the source distribution plate **322**, the conductive member **325**, and the sputter target **306** (and/or backing plate **346**) to prevent the RF and DC energy from being routed directly to ground. The insulative gap may be filled with air or some other suitable dielectric material, such as a ceramic, a plastic, or the like.
(28) In some embodiments, a ground collar may be disposed about the body and lower portion of the feed structure. The ground collar is coupled to the ground shield **340** and may be an integral part of the ground shield **340** or a separate part coupled to the ground shield to provide grounding of the feed structure. The ground collar may be made from a suitable conductive material, such as aluminum or copper. In some embodiments, a gap disposed between the inner diameter of the ground collar and the outer diameter of the body of the feed structure may be kept to a minimum and be just enough to provide electrical isolation. The gap can be filled with isolating material like plastic or ceramic or can be an air gap. The ground collar prevents crosstalk between the RF feed and the body, thus improving plasma, and processing, uniformity.
(29) An isolator plate **338** may be disposed between the source distribution plate **322** and the ground shield **340** to prevent the RF and DC energy from being routed directly to ground. The isolator plate **338** has a central opening to allow the feed structure to pass through the isolator plate **338** and be coupled to the source distribution plate **322**. The isolator plate **338** may comprise a suitable dielectric material, such as a ceramic, a plastic, or the like. Alternatively, an air gap may be provided in place of the isolator plate **338**. In embodiments where an air gap is provided in place of the isolator plate, the ground shield **340** may be structurally sound enough to support any components resting upon the ground shield **340**.
(30) The sputter target **306** may be supported, on a grounded conductive aluminum adapter such as **342** through a dielectric isolator **344**. The sputter target **306** comprises a material to be deposited on the substrate **304** during sputtering, such as ITO. In some embodiments, the backing plate **346** may

be coupled to the source distribution plate-facing surface **332** of the sputter target **306**. The backing plate **346** may comprise a conductive material, such as aluminum, or the same material as the target, such that RF and DC power can be coupled to the sputter target **306** via the backing plate **346**. Alternatively, the backing plate **346** may be non-conductive and may include conductive elements (not shown) such as electrical feedthroughs or the like for coupling the source distribution plate-facing surface **332** of the sputter target **306** to the second end **330** of the conductive member **325**. The backing plate **346** may be included for example, to improve structural stability of the sputter target **306**.

(31) The substrate support **302** has a material-receiving, substrate support surface facing the principal surface of the target **306** and supports the substrate **304** in the processing volume **348** during sputter deposition in planar position opposite to the principal surface of the target **306**. The processing volume **348** is defined as the region above the substrate support **302** during substrate processing (for example, between the target **306** and the substrate support **302** when in a processing position).

(32) In some embodiments, the substrate support **302** may be vertically movable through a bellows **350** connected to a bottom chamber wall **352** to allow the substrate **304** to be transferred onto the substrate support **302** through a load lock valve (not shown) in the lower portion of processing the process chamber **300** and thereafter raised to a deposition, or processing position. One or more plasma-forming gases may be supplied from a gas source **354** through a mass flow controller **356** into the lower part of the process chamber **300**. In some embodiments, the plasma-forming gas may be comprised of at least one of argon at a flow rate of 50 sccm to 400 sccm, or oxygen at a flow rate of 0.5 sccm to 20 sccm. An exhaust port **358** may be provided and coupled to a pump (not shown) via a valve **360** for exhausting the interior of the process chamber **300** and facilitating maintaining a desired pressure inside the process chamber **300**.

(33) In some embodiments, substrate support **302** includes an air passage **371** for providing a back-side gas to substrate **304**. In embodiments, closing air passage **371** and restricting the flow of back-side gas applied to a substrate **304** will increase the temperature of the substrate **304**. In some embodiments, the process chamber **300** may be configured to maintain a temperature of the substrate at 100 C to 450 C. In some embodiments, the process chamber **300** may be configured to maintain a temperature of the substrate at 0 C to 50 C.

(34) In some embodiments, the process chamber may include an RF power source **363** coupled to the substrate support via a tuning network **399** for providing an AC bias to the substrate **304** of 100 W to 1500 W. RF power supplied by the RF power source **363** may range in frequency from about 2 MHz to about 60 MHz, for example, non-limiting frequencies such as 2 MHZ, 13.56 MHZ, or 60 MHz can be used.

(35) When argon in a plasma-forming gas is introduced in the processing volume **348** during ITO deposition, AC bias may be applied to the substrate. The AC bias attracts the argon towards the substrate and bombards the ITO film being deposited to disturb ITO crystal formation resulting in an amorphous ITO film.

(36) A rotatable magnetron assembly **336** may be positioned proximate a back surface (e.g., source distribution plate-facing surface **332**) of the sputter target **306**. The rotatable magnetron assembly **336** includes a plurality of magnets **366** supported by a base plate **368**. The base plate **368** connects to a rotation shaft **370** coincident with the central axis of the process chamber **300** and the substrate **304**. A motor **372** can be coupled to the upper end of the rotation shaft **370** to drive rotation of the magnetron assembly **336**. The magnets **366** produce a magnetic field within the process chamber **300**, generally parallel and close to the surface of the sputter target **306** to trap electrons and increase the local plasma density, which in turn increases the sputtering rate. The magnets **366** produce an electromagnetic field around the top of the process chamber **300**, and magnets **366** are rotated to rotate the electromagnetic field which influences the plasma density of the process to more uniformly sputter the sputter target **306**. For example, the rotation shaft **370** may make about

0 to about 150 rotations per minute.

(37) In some embodiments, the process chamber **300** may further include a process kit shield **374** connected to a ledge **376** of the adapter **342**. The adapter **342** in turn is sealed and grounded to the aluminum chamber sidewall such as chamber wall **308**. Generally, the process kit shield **374** extends downwardly along the walls of the adapter **342** and the chamber wall **308** downwardly to below an upper surface of the substrate support **302** and returns upwardly until reaching an upper surface of the substrate support **302** (e.g., forming a u-shaped portion **384** at the bottom). Alternatively, the bottommost portion of the process kit shield need not be a u-shaped portion **384** and may have any suitable shape. The process kit shield **374** may include holes near the elevation of the substrate **304** to permit conductance of plasma forming gas into the processing volume **348**. A cover ring **386** rests on the top of an upwardly extending lip **388** of the process kit shield **374** when the substrate support **302** is in a lower, loading position but rests on the outer periphery of the substrate support **302** when the substrate support **302** is in an upper, deposition position to protect the substrate support **302** from sputter deposition. An additional deposition ring (not shown) may be used to shield the periphery of the substrate **304** from deposition.

(38) In some embodiments, a magnet **390** may be disposed about the process chamber **300** for selectively providing a magnetic field between the substrate support **302** and the sputter target **306**. For example, as shown in FIG. **3**, the magnet **390** may be disposed about the outside of the chamber wall **308** in a region just above the substrate support **302** when in processing position. In some embodiments, the magnet **390** may be disposed additionally or alternatively in other locations, such as adjacent the adapter **342**. The magnet **390** may be an electromagnet and may be coupled to a power source (not shown) for controlling the magnitude of the magnetic field generated by the electromagnet.

(39) In some embodiments, the process chamber **300** may include a controller **310** coupled to various components of the process chamber **300** to control the operation thereof. In some embodiments, and as shown in FIG. **3**, the controller **310** may include a central processing unit (CPU) **312**, a memory **314**, and support circuits **316**. The controller **310** may control the process chamber **300** directly, or via computers (or controllers) associated with particular process chamber and/or support, system components. The controller **310** may be one of any form of general-purpose computer processor that can be used in an industrial setting for controlling various chambers and sub-processors. The memory, or computer readable medium, **434** of the controller **310** may be one or more of readily available memory such as random access memory (RAM), read only memory (ROM), floppy disk, hard disk, optical storage media (e.g., compact disc or digital video disc), flash drive, or any other form of digital storage, local or remote. The support circuits **316** are coupled to the CPU **312** for supporting the processor in a conventional manner. These circuits include cache, power supplies, clock circuits, input/output circuitry and subsystems, and the like. The methods as described herein may be stored in the memory **314** as software routine that may be executed or invoked to control the operation of the process chamber **300** in the manner described herein. The software routine may also be stored and/or executed by a second CPU (not shown) that is remotely located from the hardware being controlled by the CPU **312**. The controller **310** may be configured to position the substrate **304** on the support surface, flow a plasma-forming gas into the process volume **348**, and sputter indium tin oxide, from the sputter target **306** comprising indium tin oxide, onto the substrate while applying AC bias to the substrate **304**. In some embodiments, the controller **310** may be configured to sputter the indium tin oxide by applying pulsed DC power to the sputter target **306**.

(40) In some embodiments, the present disclosure provides a computer readable medium, having instructions stored thereon which, when executed, cause a physical vapor deposition reactor chamber to perform the methods, such as method **100**, in accordance with the present disclosure.

(41) In some embodiments, flowing the plasma-forming gas may include introducing the plasma-forming gas through a plurality of holes in the process kit shield **374** into the processing volume

348. FIG. **4** shows process kit shields **400** for a chamber, such as process chamber **300**, in accordance with some embodiments of the present disclosure. In some embodiments, and as shown in FIG. **4**, the process kit shields **400** may include a lower shield **402** having a first annular body **404**, a first upper flange **406** at a top of the first annular body **404**, and a channel **407** at a bottom of the first annular body **404**, The first annular body **404** may have a plurality of first holes **408** surrounding an opening **410** configured to surround a substrate during substrate processing.

(42) The process kit shields **400** may include an upper shield **412** having a second annular body **414** and a second upper flange **416** configured to seat on the first upper flange **406**, as shown in FIG. **4**. In some embodiments, and as shown in FIG. **4**, the second annular body **414** extends into the channel **407** of the lower shield **402**. The upper shield **412** may shield the lower shield from ITO deposits and may advantageously direct a flow of plasma-forming gas upward and over the substrate during substrate processing, which may be advantageous for amorphous ITO film deposition as discussed more fully below.

(43) The second annular body **414** may have a plurality of second holes **418** that are spaced radially inward and below the first holes **408**. The first holes **408** and the second holes **418** are configured to define a flow path for the plasma-forming gas from a location below the substrate support (such as substrate support **302**) through the first holes **408** and the second holes **418** and above the substrate support. In some embodiments, the first holes **408** are equally spaced about the first annular body **404**. In some embodiments, the second holes **418** are spaced equally about the second annular body **414**. The first holes **408** and the second holes **418** may be of various shapes, such as circular or oblong. In some embodiments, the second holes **418** may each have an area of 2.5 mm.sup.2 to 130 mm.sup.2. Sizes outside the range may not provide suitable conditions for ITO deposition. For example, second holes **418** having an area less than 2.5 mm.sup.2 may not provide sufficient conductance of plasma-forming gas into the processing volume **348** for adequate edge uniformity of the ITO film and the smaller second holes **418** may be more susceptible to becoming clogged from ITO deposits. Also, second holes **418** having an area greater than 130 mm.sup.2 may be too large to adequately protect the lower shield **402** from ITO deposits.

(44) By locating the second holes **418** inwardly and below the first holes **408**, a flow path for the plasma-forming gas is defined from a location below the substrate support **302** through the first holes **408** and the second holes **418** and above the substrate support **302** in the processing volume **348**. Providing more plasma forming gas over the substrate increases the availability of argon over the substrate used to bombard the ITO film to sufficiently disrupt crystal formation during deposition under AC bias so that the ITO film is amorphous. Also, by sizing the second holes **418** as described above, a conductance of the plasma-forming gas can be increased in the processing volume **348**, which can increase the availability and uniformity of argon in the processing volume **348** over the substrate so that during substrate processing with AC bias, the effect of argon bombardment will be more uniformly applied to the ITO film. As a result, deposition uniformity of the amorphous ITO film can be improved across the entire substrate.

(45) FIGS. **5**A and **5**B show the process kit shields **400** where the second holes **418** are formed as elongated slots that are arranged in a single row. While a single row of second holes **418** is shown, multiple rows of second holes **418** are possible to increase conductance of plasma-forming gas into the processing volume **348**. In some embodiments the slots may have a length of about 20 mm to 25 mm and a width of about 3 mm to 8 mm.

(46) In some embodiments, and as shown in FIGS. **6**A and **6**B, the second holes **418** may be relatively smaller than the second holes **418** shown in FIGS. **5**A and **5**B. In some embodiments, the second holes shown in FIGS. **6**A and **6**B may be about 1.6 mm to 2.0 mm in diameter. There may be 1500-2000 second holes **418**, and the second holes may be spaced at a pitch of 2.2 mm to 2.8 mm.

(47) In some embodiments, and as shown in FIGS. **7**A and **7**B, the upper shield **412** may be configured like the upper shield shown in FIGS. **6**A and **6**B, but may include one or more annular

protruding ribs **702** extending about an inner surface **604** of the second annular body **414** above the plurality of second holes **418**. In some embodiments, the second holes **418** may be arranged in a plurality of rows with a rib **702** between one or more rows. Each rib **702** may protrude inwardly (i.e., radially) from the inner surface **704** a certain distance to protect or otherwise shield the second holes **418** from being occluded by ITO material which could reduce conductance of plasma-forming gas through the second holes **418**. In some embodiments, the rib **702** may have a vertical thickness of about 1 mm to 2 mm and may extend inwardly about 1 mm to 2 mm.

(48) Thus, methods and apparatus for depositing ITO on substrates have been provided herein. The methods and apparatus advantageously provide for an amorphous ITO film on substrate surfaces by utilizing an AC bias during pulsed sputter deposition to attract more argon atoms toward the substrate **304** to bombard the ITO film and disrupt crystal formation. The methods advantageously provide excellent coverage uniformity of an ITO film on substrate surfaces by increasing conductance of argon into the processing volume during ITO deposition. The deposited amorphous ITO film has suitable resistivity such that no additional processes are needed to render the ITO film suitable as an electrode, such as of a ULED.

(49) While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof.

Claims

1. A method of processing a substrate in a process chamber, the method comprising: positioning a substrate on a substrate support in a process volume so that the substrate is opposite a sputter target comprising indium tin oxide; flowing a plasma-forming gas into the process volume; and sputtering the indium tin oxide onto the substrate while applying AC bias to the substrate, wherein flowing the plasma-forming gas includes introducing the plasma-forming gas through a plurality of holes in process kit shields comprising: a lower shield having a first annular body, a first upper flange at a top of the first annular body, and a channel at a bottom of the first annular body, the first annular body having a plurality of first holes surrounding an opening configured to surround a substrate during substrate processing; and an upper shield having a second annular body and a second upper flange configured to seat on the first upper flange, the second annular body having an end extending into the channel, the end spaced from the first annular body, the second annular body having a plurality of second holes, the second holes being spaced radially inward and below the first holes, wherein the first holes and the second holes are configured to define a flow path for the plasma-forming gas from a location below the substrate support through the first holes and the second holes to a location above the substrate.
2. The method of claim 1, wherein sputtering the indium tin oxide includes applying pulsed DC power to a sputter target.
3. The method of claim 2, wherein the pulsed DC power is 500 W to 10,000 W.
4. The method of claim 3, wherein the pulsed DC power is applied at a duty cycle of 5% to 15%.
5. The method of claim 1, wherein the plasma-forming gas is comprised of at least one of argon at a flow rate of 50 sccm to 400 sccm, or oxygen at a flow rate of 0.5 sccm to 20 sccm.
6. The method of claim 1, further comprising maintaining a temperature of the substrate at 100 C to 450 C.
7. The method of claim 1, further comprising maintaining a temperature of the substrate at 0 C to 50 C.
8. The method of claim 1, wherein the applied AC bias is 100 W to 1500 W.
9. The method of claim 1, wherein the indium tin oxide is deposited on a surface of the substrate that includes at least one of silver, aluminum, or tantalum.
10. The method of claim 1, wherein AC bias is applied for less than one minute.
11. A process chamber for processing a substrate, the process chamber comprising: a chamber body

having walls defining a processing volume; a substrate support having a support surface configured to support a substrate within the processing volume; a power source coupled to the substrate support, the power source configured to provide an AC bias to the substrate; a pulsed DC power supply configured to be coupled to a sputter target when the sputter target is installed during substrate processing; a controller configured to: position the substrate on the support surface; flow a plasma-forming gas into the process volume; and sputter indium tin oxide, from the sputter target comprising indium tin oxide, onto the substrate while applying AC bias to the substrate; and process kit shields comprising: a lower shield having a first annular body, a first upper flange at a top of the first annular body, and a channel at a bottom of the first annular body, the first annular body having a plurality of first holes surrounding the substrate support; and an upper shield having a second annular body and a second upper flange configured to seat on the first upper flange, the second annular body having an end extending into the channel, the end spaced from the first annular body, the second annular body having a plurality of second holes, the second holes being spaced radially inward and below the first holes, wherein the first holes and the second holes are configured to define a flow path for a plasma-forming gas from a location below the substrate support through the first holes and the second holes to a location above the substrate.
12. The process chamber of claim 11, wherein the controller is configured to sputter the indium tin oxide by applying pulsed DC power to the sputter target.
13. The process chamber of claim 12, wherein the pulsed DC power is 500 W to 10,000 W.
14. The process chamber of claim 13, wherein the pulsed DC power is applied at a duty cycle of 5% to 15%.
15. The process chamber of claim 11, wherein the applied AC bias is 100 W to 1500 W.
16. Process kit shields for a chamber for processing a substrate, the process kit shields comprising: a lower shield having a first annular body, a first upper flange at a top of the first annular body, and a channel at a bottom of the first annular body, the first annular body having a plurality of first holes surrounding an opening configured to surround a substrate during substrate processing; and an upper shield having a second annular body and a second upper flange configured to seat on the first upper flange, the second annular body having an end extending into the channel, the end spaced from the first annular body, the second annular body having a plurality of second holes, the second holes being spaced radially inward and below the first holes, wherein the first holes and the second holes are configured to define a flow path for a plasma-forming gas from a location below the substrate support through the first holes and the second holes to a location above the substrate.
17. The process kit shields of claim 16, wherein each of the second holes has an area of 2.5 mm.sup.2 to 130 mm.sup.2.
18. The process kit shields of claim 16, further comprising an annular protruding rib extending about an inner surface of the annular body above the plurality of second holes.