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(54) **METHODS FOR PATTERNING INDIUM TIN OXIDE FILMS**

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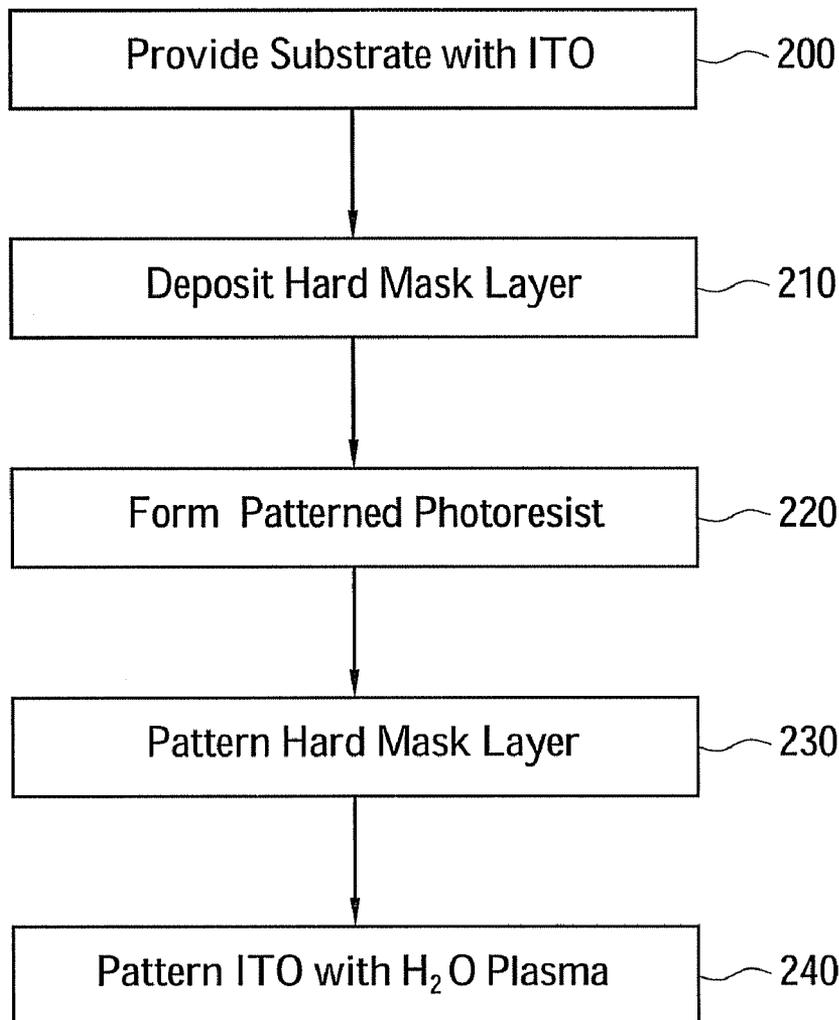
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(57) **ABSTRACT**

A method of patterning an indium tin oxide film includes the steps of forming a cap layer over the indium tin oxide film and subjecting exposed areas of the indium tin oxide film to a water plasma.

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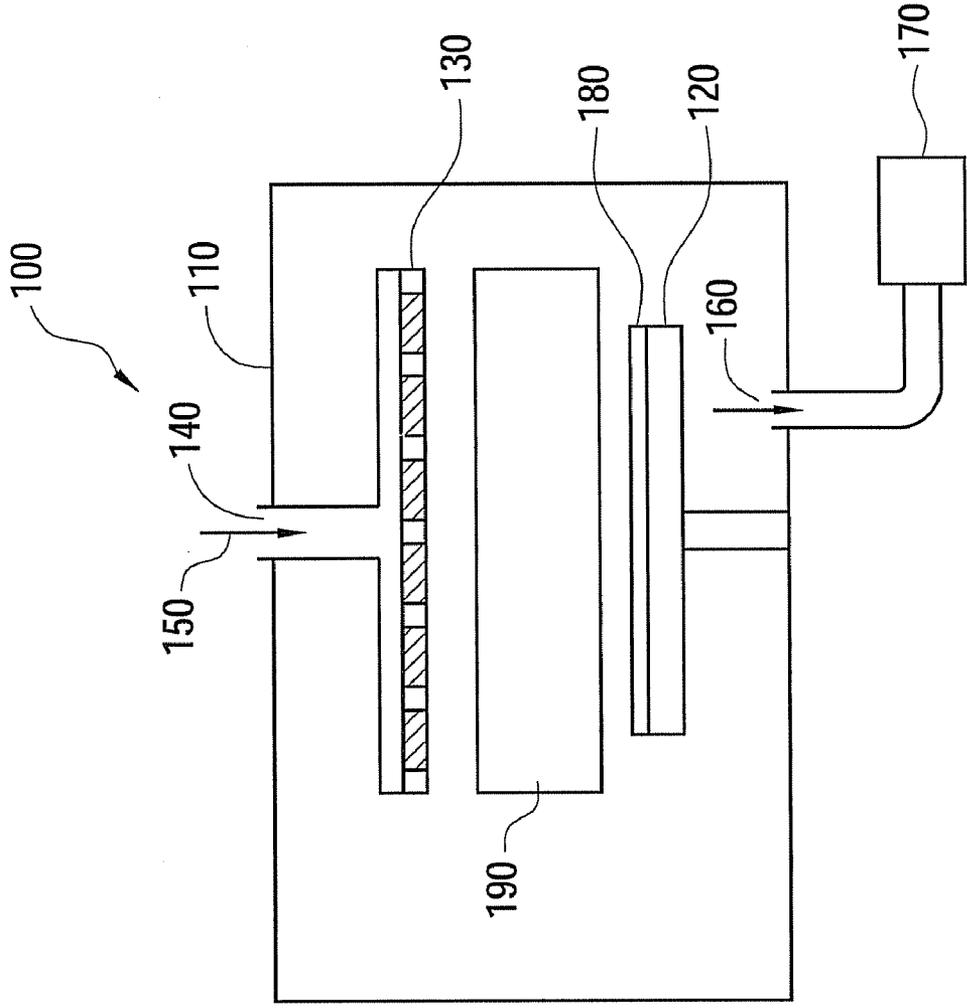


Fig. 1

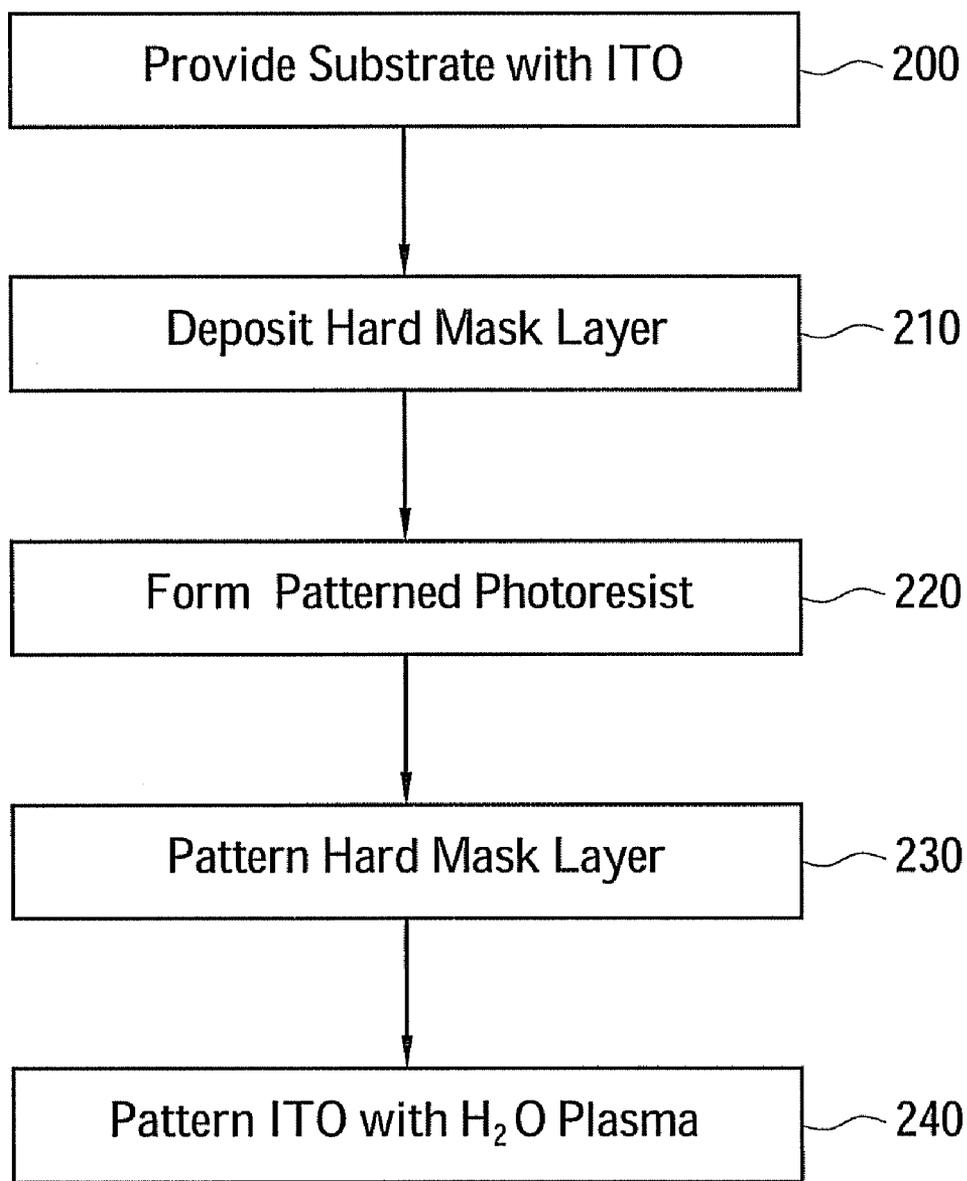


Fig. 2

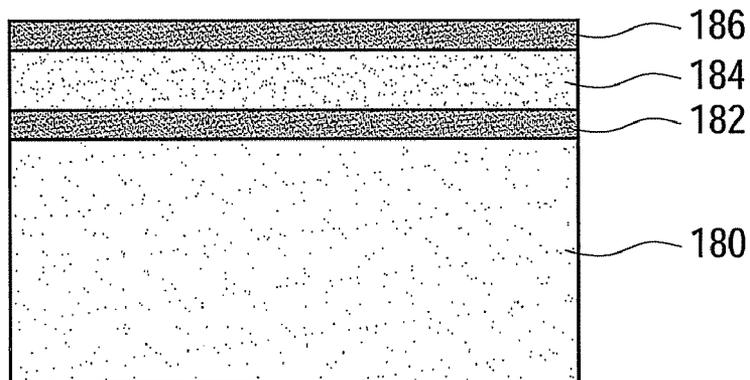


Fig. 3A

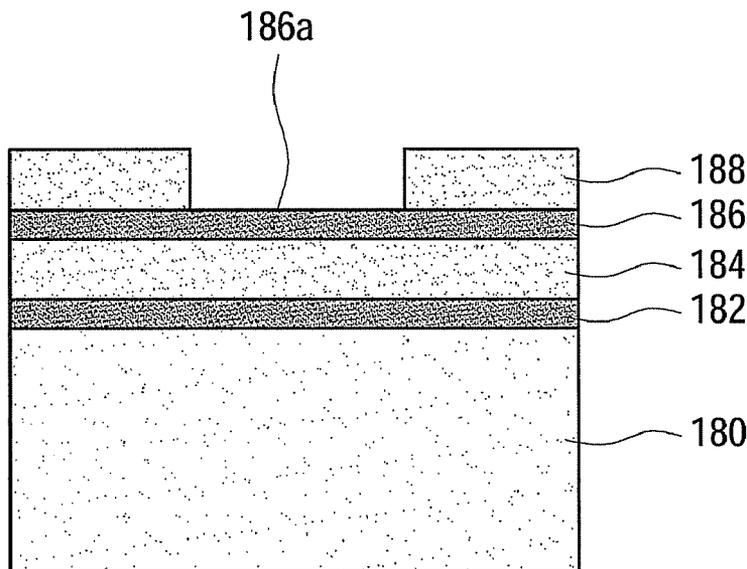


Fig. 3B

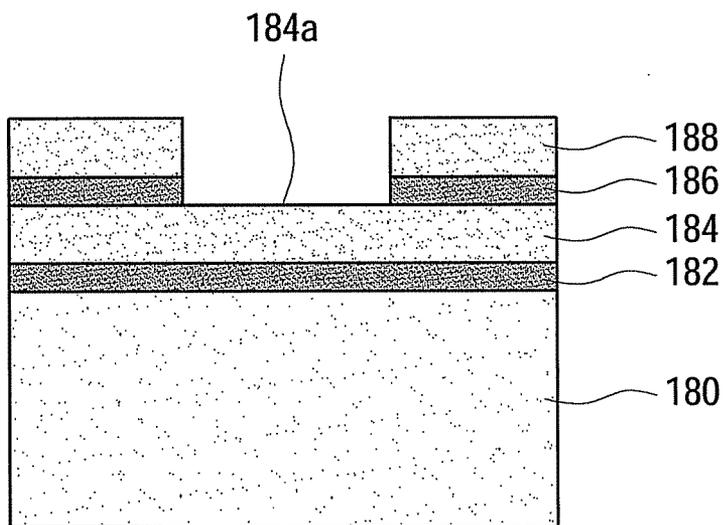


Fig. 3C

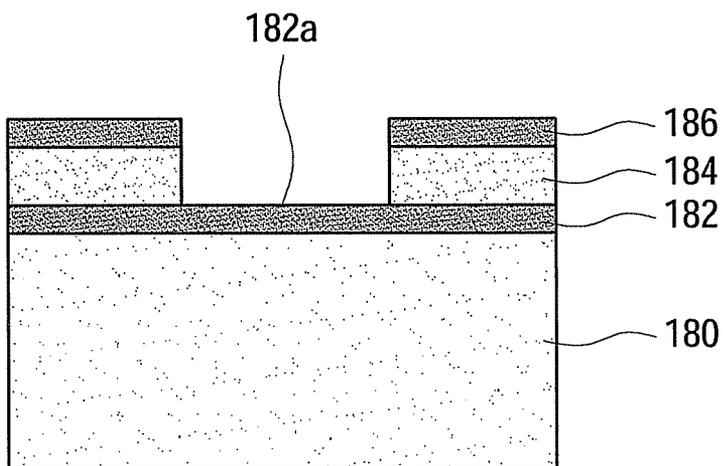


Fig. 3D

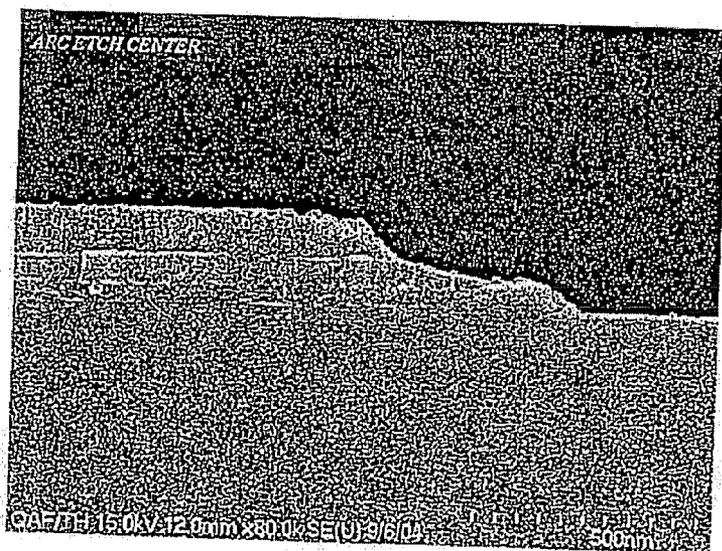


Fig. 4A (Prior Art)

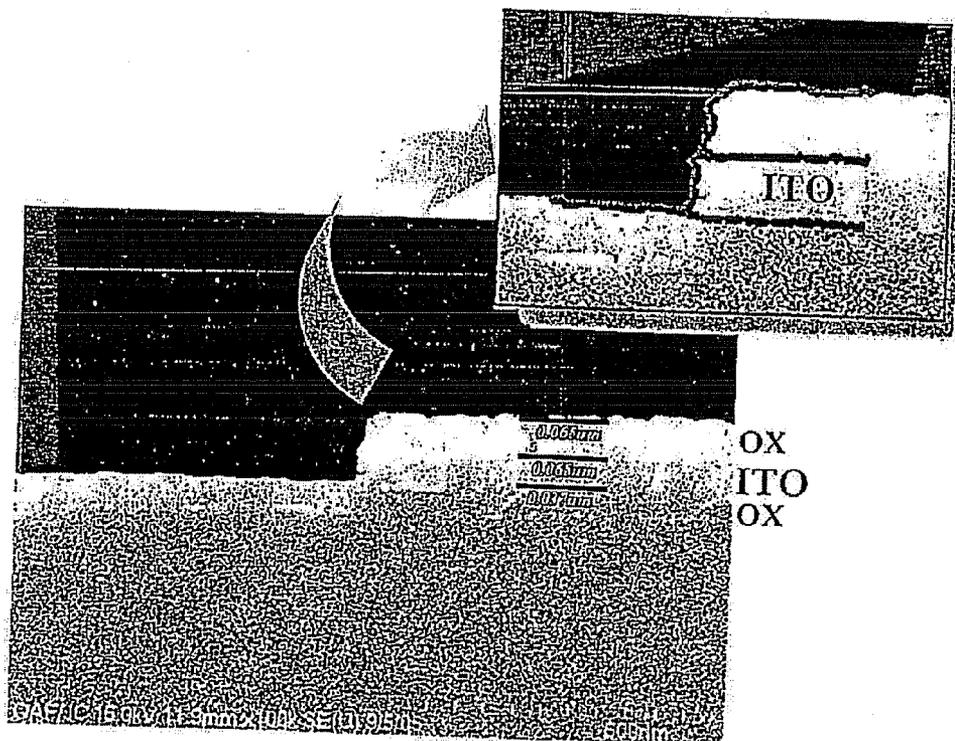


Fig. 4B

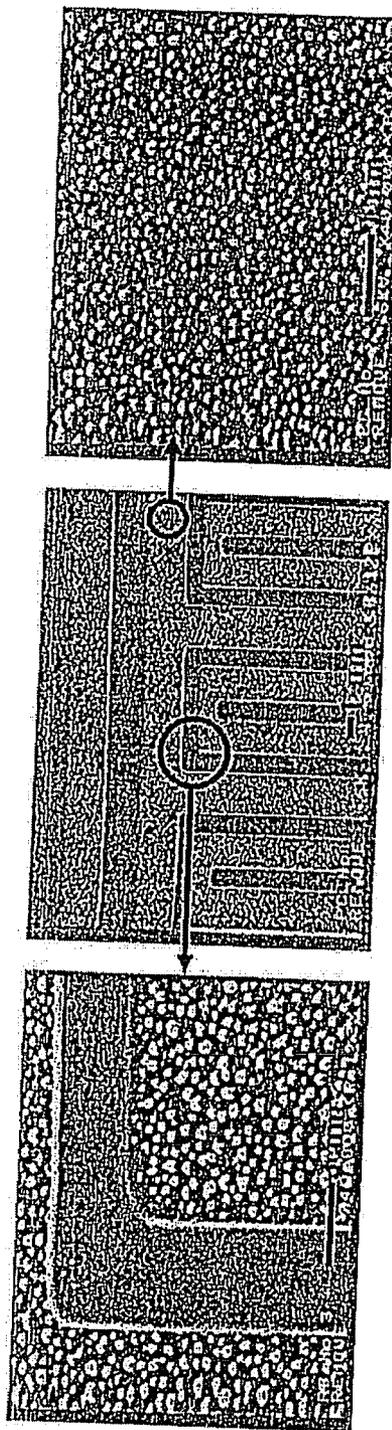


Fig. 5C

Fig. 5B

Fig. 5A

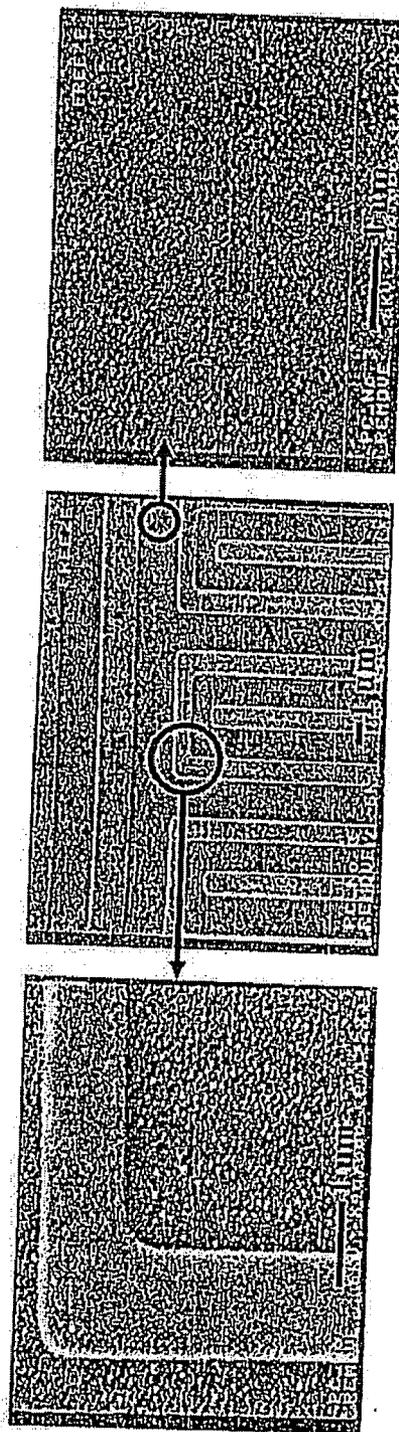


Fig. 6C

Fig. 6B

Fig. 6A

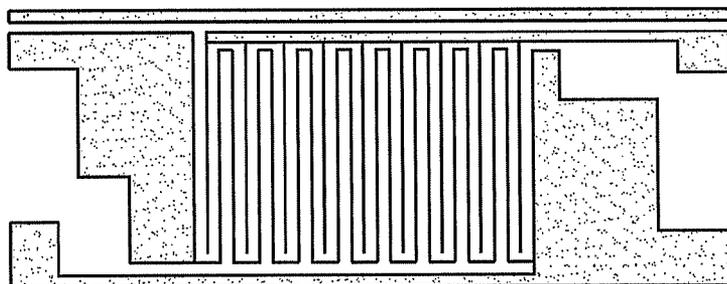


Fig. 7A

19.5V, 1.055uA

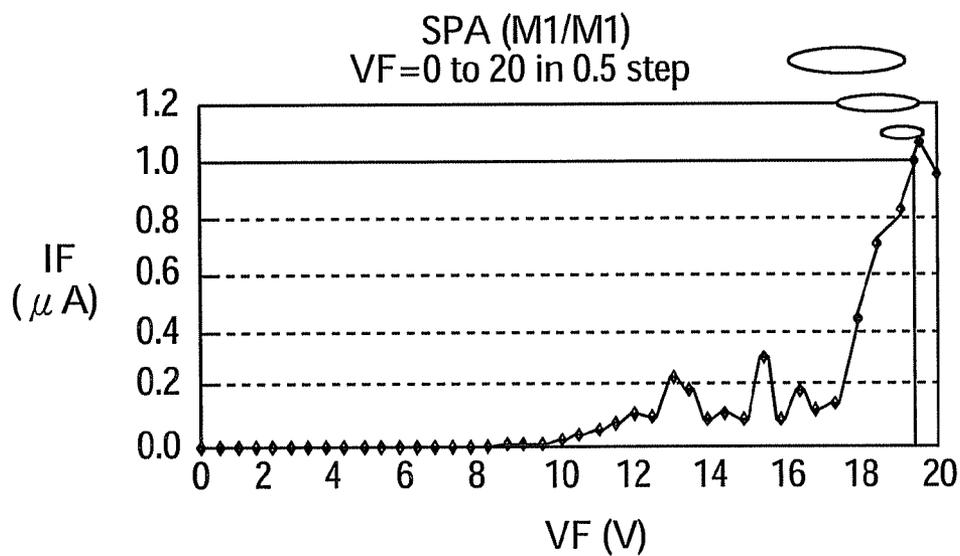


Fig. 7B

METHODS FOR PATTERNING INDIUM TIN OXIDE FILMS

FIELD OF INVENTION

[0001] This invention relates to semiconductor fabrication. More particularly, this invention relates to methods for patterning indium tin oxide films.

BACKGROUND OF THE INVENTION

[0002] Indium tin oxide (ITO) is an electrically conductive material which, when used as a thin film (e.g., between about 100 Å to about 2200 Å in thickness), is also optically transparent. Because of these characteristics, ITO is used in various applications including, but not limited to, optical microelectromechanical systems (MEMS), flat panel displays, solar cells, touch screens, camera lenses, and surface heater sensors.

[0003] ITO may be formed by doping Indium oxide (In_2O_3) with tin (Sn), which replaces the In^{3+} atoms of the In_2O_3 . Thin films of ITO may be deposited on a surface using one or more of a variety of techniques including, but not limited to, electron beam evaporation, physical vapor deposition, sputtering, or pulsed laser deposition.

[0004] Electrically conductive and optically transparent ITO structures are typically made by depositing a thin film of ITO on a desired substrate, forming a patterned photoresist layer on the ITO film, and etching areas of the ITO film which are exposed by the patterned photoresist layer to pattern the ITO film into a desired structure.

[0005] ITO films are currently etched using dry and wet methods. One commonly used ITO film dry etching method is reactive ion etching (RIE). The RIE method uses a plasma that typically comprises a major proportion of chloroform (CHCl_3) gas, which supplies a polymer, and a minor proportion of a polymer suppressant gas such as boron trichloride (BCl_3) or chlorine (Cl_2). The ion bombardment of the BCl_3/Cl_2 mixture performs the patterning process. The high ion ratio bombardment of the RIE process is an effective method to pattern the ITO film. The RIE process, however, produces an ITO pattern edge with an inclined or tapered edge profile, rather than a vertical edge profile, which limits critical dimension reductions. This process control problem is due to inadequate ITO etch selectivity, wherein the ion bombardment starts to etch the edges of the photoresist pattern, thereby causing the inclined or tapered edge profile of the ITO pattern.

[0006] In an effort to improve ITO etch selectivity in RIE, methane (CH_4) hydrogen (H_2) gas mixtures have been used to pattern ITO films, however, this gas mixture is potentially explosive and is therefore, unsuitable without relatively expensive gas exhausting equipment operating continuously to remove any build-ups of this gas mixture.

[0007] Wet chemical etching is a commonly used wet etching method for patterning ITO films. ITO films may be patterned with a hydrofluoric solution (HF) such as $\text{HF}:\text{H}_2\text{O}_2:10\text{H}_2\text{O}$ or more commonly with a hydrochloric (HCl) solution such as $\text{HCl}:\text{H}_2\text{O}$. Etching rates using the $\text{HF}:\text{H}_2\text{O}_2:10\text{H}_2\text{O}$ solution are very high at between about 100 Å (angstroms)/second to about 150 Å/second, and are often uncontrollable.

[0008] The $\text{HCl}:\text{H}_2\text{O}$ solution in undiluted form containing 36% HCl by volume corresponding to a molar solution, has an etch rate of about 2500 Å/minute. When patterning

with the HCl solution, a certain amount of ITO varying from about 0.5 μm to about 1.5 μm is often etched away from underneath the photoresist etch mask. Hence, the edge profile of the ITO pattern is not vertical, instead being undercut and in severe cases, thin traces of the photoresist may remain on the substrate.

[0009] The non-vertical edge profiles of the ITO pattern reduce the sharpness and resolution of the ITO pattern, which in turn, increases the probability of photo-alignment rejection in further processing. In addition, the less than sharp edge profile of the ITO pattern limits further reductions in line width and critical dimension. Thus, in ITO display applications where panel sizes continue to become smaller, it is desirable to increase pixel size by reducing the space between the pixels. The inability to fabricate ITO patterns with reduced line width and critical dimension, limits the size of the pixels in small displays.

[0010] Accordingly, an ITO patterning method is needed which allows further reductions in ITO pattern line width and critical dimension.

SUMMARY

[0011] A method of patterning an indium tin oxide film is disclosed herein. The method comprises the steps of forming a cap layer over the indium tin oxide film and subjecting exposed areas of the indium tin oxide film to a gas phase etchant comprising water.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 schematically depicts an exemplary plasma process chamber that may be used in the method.

[0013] FIG. 2 shows a flowchart of an embodiment of a water plasma ITO patterning method.

[0014] FIGS. 3A-3D are cross-sectional views illustrating a substrate after performing certain steps of the water plasma ITO patterning method.

[0015] FIGS. 4A and 4B are cross-sectional scanning electron microscope photographs which compare the edge profiles of thin films of ITO patterned using a prior art RIE process (FIG. 4A) and the water plasma ITO patterning method (FIG. 4B).

[0016] FIGS. 5A-5C are scanning electron microscope photographs at different magnifications of a thin film of electrically conductive, optically transparent ITO patterned for 240 seconds using the water plasma ITO patterning method.

[0017] FIGS. 6A-6C are scanning electron microscope photographs at different magnifications of a thin film of electrically conductive, optically transparent ITO patterned for 300 seconds using the water plasma ITO patterning method.

[0018] FIG. 7A is a test pattern used in WAT spacing testing under the control rules of a generic IC fabrication process.

[0019] FIG. 7B is a graph showing the results of WAT spacing testing under the control rules of a generic IC fabrication process.

DETAILED DESCRIPTION OF THE INVENTION

[0020] A method is disclosed for patterning an electrically conducting, optically transparent thin film of amorphous indium tin oxide (ITO) on a surface, using a cap layer (operative as a hard mask) and a plasma comprising water as

an etchant species. The areas of the ITO thin film not covered and protected by the cap layer react with water plasma under high and are removed from the surface.

[0021] The method may be performed in any suitable plasma process chamber including, but not limited to, a conventional resist strip chamber, a plasma etch reactor. FIG. 1 schematically depicts an exemplary plasma process chamber 100 that may be used in the method. The plasma process chamber includes a housing 110 that defines the plasma process chamber 100. A platform 120 is provided inside the chamber 100 for mounting a substrate. A showerhead-shape gas inlet nozzle 130 is disposed above the wafer platform 120. Reaction gases are routed into the chamber 100 via a gas inlet 140, which communicates with the inlet nozzle 130. An exhaust outlet 160 connected to a vacuum pump 170 is used to evacuate the process chamber 100. Electric field generating means (not shown) are used to generate an electric field in the chamber 100 of a sufficient magnitude such that a process fluid flowing in the chamber 100, breaks down and becomes ionized. A plasma may be initiated by releasing or discharging free electrons inside the chamber 100 using, for example, field emission from a negatively biased electrode within the chamber 100.

[0022] Referring now to FIG. 2, which shows a flowchart of an embodiment of the method, the method commences in step 200 with a substrate 180 having a dielectric layer 182 formed thereon and a thin film 184 of electrically conductive, optically transparent amorphous ITO formed on the dielectric layer 182. In other embodiments, the dielectric layer may be omitted so that the thin film of ITO 184 is formed directly on the substrate 180.

[0023] The substrate 180 may comprise an optically transparent glass material or any other suitable substrate material, depending upon the application. The dielectric layer 182 is optically transparent and has a sufficiently high index of refraction so that it operates as an anti-reflective coating (ARC). The optical transparency of the dielectric layer 182 generally depends upon the thickness of the layer. Thicker dielectric layers provide less light scattering but reduce the optical transparency, stress and the adhesion of the layer. The exact thickness of the dielectric layer 182 depends upon the thickness of the ITO. Dielectric materials having suitable optical and mechanical properties include, but are not limited to, niobium oxide (Nb_2O_5), tellurium dioxide (TeO_2), tantalum oxide (Ta_2O_3), and alumina (Al_2O_3). The dielectric layer 182 may be deposited using one or more of a variety of techniques including, but not limited to, electron beam evaporation, physical vapor deposition, sputtering, or pulsed laser deposition.

[0024] The thin ITO film 184 should be deposited to a thickness which provides the ITO film with good electrical conductivity, i.e., less than 20 ohm/square and good optical transparency, i.e., higher than about 90 percent light transmission. In some embodiments, the thin film 184 of ITO may be formed to a thickness ranging between about 100 Å to about 2200 Å. The thin film of ITO 184 may be deposited using one or more of a variety of techniques including, but not limited to, electron beam evaporation, physical vapor deposition, sputtering, or pulsed laser deposition.

[0025] In step 210 a cap layer 186 is deposited on the thin film 184 of ITO, as shown in the cross-sectional view of the substrate 180 shown in FIG. 3A. In some embodiments, the cap layer 186 may comprise an oxide film, such as SiO_2 ,

deposited to a thickness greater than 100 Å by plasma enhanced chemical vapor deposition or any other suitable method.

[0026] In step 220 of the flowchart shown in FIG. 2, a layer 188 of photoresist is deposited on the hard mask layer 186 and patterned to expose selected areas 186a of the hard mask layer 186. The photoresist layer 188 may be deposited and patterned using conventional photolithographic methods. The cross-sectional view of FIG. 3B shows the substrate 180 after completion of step 220.

[0027] In step 230 of the flowchart shown in FIG. 2, the exposed areas 186a of the hard mask layer 186 are removed to pattern the hard mask layer 186 into a desired pattern. The exposed areas 186a of the hard mask layer 186 may be removed using conventional dry or wet etching methods. The cross-sectional view of FIG. 3C shows the substrate 180 after completion of step 230. Upon completion of the hard mask patterning step, the patterned photoresist layer 188 may be removed using conventional photoresist removal methods.

[0028] In step 240 of the flowchart shown in FIG. 2, the substrate 180 mounted on the wafer platform 120 inside the plasma process chamber 100 (FIG. 1) and a process gas 150 containing one or more chemical species is introduced under pressure into the plasma process chamber 100, via the gas inlet 140 and inlet nozzle 130. The one or more chemical species are ionized by the electric field generated within the chamber.

[0029] In some embodiments, the one or more chemical species may comprise water (H_2O) and N_2 based species. Of these species, the H_2O based species is a reactive species that reacts with exposed areas 184a of thin film 184 of ITO, which are not covered by the cap layer 186. The N_2 is non-reactive species.

[0030] The pressure (partial pressure) exerted by the process gas 150 inside the plasma process chamber 100 before initiating a plasma is set to between about 0.5 Torr and about 5.0 Torr. The flow rate of the H_2O based species of the process gas 150 is set between about 200 sccm (standard cubic centimeters per minute) and about 1500 sccm. The flow rate of the N_2 species in the process gas 150 is set between about 100 sccm and about 1000 sccm. The temperature of the chamber 100 is set between about 200° C. and about 300° C. In a preferred embodiment, the pressure exerted by the process gas 150 is set to 2.0 Torr, the gas flow rate of the H_2O species is set to 500 sccm, the gas flow rate of the N_2 species is set to 200 sccm, and the chamber temperature is 245° C.

[0031] An electric field is generated inside the chamber 100 by the electric field generating means. In one embodiment, the electric field used to excite the plasma may be in the microwave or RF frequency range and the power of such a field may be about 1400 watts. Free electrons are discharged inside the plasma process chamber 100 and travel through the process gas to generate a H_2O plasma 190 in the chamber 100. As the H_2O plasma 190 stabilizes, the pressure exerted by the process gas 150 inside the plasma process chamber 100 is adjusted to between about 0.5 Torr and about 5.0 Torr, and preferably 2.0 Torr. The temperature of the chamber is maintained between about 200° C. and about 300° C., and preferably 245° C.

[0032] The H_2O plasma 190 is highly etch selective to the thin film of ITO relative to the hard mask layer 186 and the dielectric layer 182 (or the substrate 180 in embodiments not

employing the dielectric layer 182). Consequently, as shown in the cross-sectional view of the substrate 180 FIG. 3D, the H₂O plasma 190 reacts with the exposed areas 184a of the thin film 184 of ITO to remove same without substantially reacting with the cap layer 186 or the corresponding underlying areas 182a of dielectric layer 182 (or substrate 180 in embodiments not employing the dielectric layer 182). In some embodiments, the cap layer 186 is removed. In other embodiments, the cap layer 186 may remain.

[0033] FIGS. 4A and 4B are cross-sectional scanning electron microscope photographs which compare the edge profiles of thin films of ITO patterned using a prior art RIE process (FIG. 4A) and the water plasma ITO patterning method described above (FIG. 4B). As can be seen, the RIE process produces an ITO pattern edge with an inclined or tapered edge profile, which limits line width and critical dimension reductions. In contrast, the superior ITO etch selectivity of the water plasma patterning method produces a substantially vertical edge profile which allows for further reductions in ITO line widths and critical dimensions.

[0034] FIGS. 5A-5C are scanning electron microscope photographs at magnifications of 40,000x, 8000x, and 40,000x of a thin film of electrically conductive, optically transparent ITO patterned for 240 seconds using the water plasma method. FIGS. 6A-6C are scanning electron microscope photographs at magnifications of 40,000x, 8000x, and 40,000x of a thin film of electrically conductive, optically transparent ITO patterned for 300 seconds using the water plasma method. In both examples, the exposed areas of the thin film of ITO were completely removed after reaction with the water plasma.

[0035] WAT spacing testing under the control rules of a generic IC fabrication process, further confirmed the patterning performance of the water plasma thin film ITO patterning method. More specifically, a thin film of electrically conductive, optically transparent amorphous ITO was patterned into a test pattern, as shown in FIG. 7A using the water plasma method. The spacing result of the test pattern revealed no ITO residue remaining between the lines of ITO and the test pattern passed the control limits of the 1.0 um pattern design, i.e., from about 12 volts to about 20 volts (VF on the x-axis) and from about 0.15 to about 1 microamps (IF on the y-axis) and the long term testing value under the same condition was 17 volts, as shown in the graph of FIG. 7B.

[0036] The thermal crystallization temperature of the thin film 184 of amorphous ITO is slightly higher than 150° C. The growth of crystallites dispersed in the amorphous matrix may be suppressed by increasing the amount of H₂O in the plasma, while sharply enhancing the nucleation of the crystallites. The amount of bonded hydrogen increases and that

of oxygen vacancies decreases at the same time, with the introduction of inhomogeneity in the amorphous matrix. Specifically, the oxygen vacancies are effectively terminated by the —OH species generated by the added H₂O in the plasma, which reduces the number of oxygen vacancies and suppresses the crystal growth with the H₂O addition. After the crystallization is completed and the thin film 184 of ITO is patterned, the remaining ITO crystallites in the thin film 184 are minimal and small, i.e., less than 0.1 um.

[0037] One of ordinary skill in the art will appreciate that the water plasma thin film ITO patterning method may be performed in-situ without additional equipment tools. Compared with the prior art etching methods, the water plasma patterning method provides better pattern edge profile control via superior ITO etch selectivity. In addition, the water plasma method is suitable for processes which involve ITO patterning including, but not limited to, optical MEMS processes.

[0038] While the foregoing invention has been described with reference to the above, various modifications and changes can be made without departing from the spirit of the invention. Accordingly, all such modifications and changes are considered to be within the scope of the appended claims.

1. A method of patterning an indium tin oxide film, the method comprising the steps of:

- forming a cap layer over the indium tin oxide film;
- forming a photoresist layer over the cap layer;
- patterning the photoresist layer to expose selected areas of the cap layer;
- removing the exposed selected areas of the cap layer to expose selected areas of the indium tin oxide film;
- and subjecting the exposed selected areas of the indium tin oxide film to a plasma phase etchant comprising water.

2. The method of claim 1, wherein the cap layer comprises an oxide.

3. The method of claim 1, wherein the subjecting step is performed at a pressure between about 0.5 Torr and about 5.0 Torr.

4. The method of claim 1, wherein the subjecting step is performed at a temperature between about 200° C. and about 300° C.

5. The method of claim 1, wherein the water is provided in a process gas at a flow rate of between about 200 sccm and about 1500 sccm.

6-12. (canceled)

13. The method of claim 1, wherein the plasma phase etchant comprises water plasma.

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