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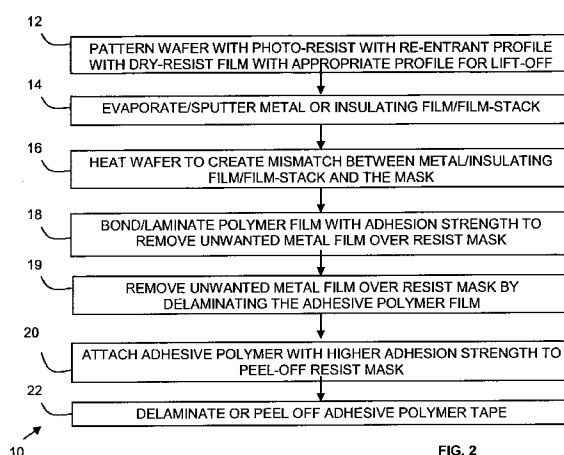


FIG. 2

(57) Abstract: A method of performing lift-off patterning process is disclosed which involves dry resist film or lithography and material deposition process followed by lamination with UV sensitive or equivalent adhesive film and then delaminating the top layer of thin film due to weak adhesion of deposited material with the underlying organic layer. In an embodiment, the unwanted dry resist film is stripped or peeled-off by again laminating a fresh layer of UV sensitive film and delaminating the unwanted dry resist film mask. As the sputtered or evaporated films are usually non-conformal, the thin and weakly adhered sidewall metal films easily gets delaminated by the polymer film during the delamination process and thus resulting in smooth edges for the metal patterns.

METHOD FOR LIFT-OFF PATTERNING FILMS ON A SUBSTRATE

FIELD OF THE INVENTION

This invention relates generally to the field of semiconductor manufacturing, and more particularly to a method and apparatus for lift-off patterning films on a semiconductor.

BACKGROUND OF THE INVENTION

A patterned conductor layer may be formed on a substrate by various methods well known in the field of electronic device fabrication. Subtractive etching is one common method. In subtractive etching, after a blanket film is deposited on the substrate, the film is etched through a photoresist mask in order to remove undesired portions. Such process however suffers from a number of disadvantages that restrict their application, particularly in the patterning of noble metals which are difficult to etch. To ensure complete etch removal of deposited material, the deposited metal has to be chemically reactive and volatile. Although this problem may be lessened by using ion-assisted etching or reactive ion etching, these processes cannot cater to all kinds of materials like gold (Au), copper (Cu), chromium (Cr), platinum (Pt), and the like. Patterning of metal structures over very high aspect ratio microstructures and highly uneven topographies as in micro electro mechanical systems (MEMS) and silicon optical sub-assembly systems is another major challenge in metal patterning.

Lift-off techniques or additive metallization is an alternative method used to overcome the above-mentioned issues in patterning of difficult metal films or metal stacks on a processed semiconductor substrate. One approach involves coating a photo resist layer on a substrate, and then patterning the layer through a photo mask. A metal layer is then formed on the patterned photo resist, which is subsequently lifted-off, taking with it the undesired portions of the metal layer. There are numerous attempts and publications which describes single layer and multilayered resist patterning process to specifically control the sidewall of the mask so that the deposited film can be made

discontinuous or very thin which can easily be broken by ultrasonic or megasonic agitation during the subsequent resist removal process. FIG. 1A-C schematically gives a simple overview of a typical lift-off process where a device substrate 2 is processed with lithography 4 having re-entrant profile 5 as shown in FIG. 1A, and a deposition of lift-off metal 6 shown in FIG. 1B. It may be seen from the drawing that metal fins 9 or re-deposited metal flakes 8 can cause failure in final device as shown in FIG. 1C. FIGS. 1A-1D is an illustration of a typical additive metallization or lift-off metallization process

A lift-off technique is commonly employed to selectively or additively pattern metals which are normally difficult to etch such as Gold (Au), Platinum (Pt) and metal stacks such as under-bump metallization and solder for packaging applications. While patterning etchable metals or metal stacks by photolithography and etching on planar surfaces is trivial, doing so over topographies tens of microns in height is quite difficult. The patterning of metals along steep sidewalls and drilled holes is extremely difficult with conventional photoresist and lithographic processes. The steep sides make it virtually impossible to get good step coverage with spin coated photoresist. Capillary forces cause photoresist to flow to regions of negative curvature and toward the edges of drilled holes, resulting in resist thickness varying by up to an order of magnitude. Such large variations in resist thickness make proper exposure and development of any pattern across a substrate a hopeless endeavor.

A challenge faced in conventional lift-off methods is that ultrasonic, LN₂ or CO₂ spray cleaning is not sufficient to remove the sidewall metal filaments that may occur as a result of the process, which is shown in FIG. 1C. Metals deposited on sidewalls and the foot of the resist mask causes residues in the edges of the metal patterns which are difficult to remove. Due to metal deposition on resist sidewalls, especially for thick resist/metal films, the metal on the sidewall remains as a filament, which may short the adjacent patterns. Re-deposition of metal contamination into deep grooves during metal strip is another common issue. Metal residues increase when thicker films are deposited. Etching is not preferred due to multiple metallization patterns. As the deposited metals cover the whole resist surface, prolonged ultrasonic agitation is required to break the metal continuity in the sidewall and remove the resist. Due to the

floating metal residues, the stripper needs to be filtered or constantly replenished. Conventional cleaning time is 1-2 hours per wafer. Also, overhanging films in the edge of the transferred patterns by lift-off can potentially cause bridging and result in failures of the device. Other challenges are that the re-deposition of metallic contaminations may occur in deep trenches and grooves, and metal/resist strip takes 1-2 hours to process due to the long time required to break the sidewall metal continuity. With poor line definition of the conventional lift-off techniques, lines having widths such as in the range of 30-50 μ m may be washed out. Additionally, prolonged ultrasonic cleaning may cause the bath to overheat which may lead to aborting the process.

There have been some attempts to address the above problems such as in United States Patent No. 5,554,488 and United States Patent No. 5,209,815. United States Patent No. 5,554,488 discloses a method of performing lift-off metallization by taking advantage of weak adhesion between SiO₂ and Si₃N₄ films with arsenic oxide in a GaAs substrate in fabricating high temperature metallization for fabrication of FETs in GaAs substrates. After patterning an inorganic hard mask like SiO₂ and Si₃N₄, the required metal is deposited and later the unwanted metal and hard mask is removed by attaching an adhesive tape and delaminating the unwanted metal along with the hard mask. The dielectric mask and unwanted metal is peeled from the weak adhesion region. This method however has limitations, such as: the process is suitable only for patterning on planar surfaces. Not suitable for implementing on highly uneven topographies as in MEMS and Optical sub-assembly applications. Additionally, the method is suitable only for compound semiconductor substrates like GaAs where the surface oxide has poor adhesion with SiO₂ and Si₃N₄ films which are used as high-temperature hard mask. The method also needs multilayered hard mask and sidewall undercut.

United States Patent No. 5,209,815 discloses another way of performing lift-off process by using a sacrificial release layer made of polyether sulfide polymer followed by multiple layers of organic resist coatings to form a reentrant sidewall profile to facilitate a breakage of deposited metal at the mask sidewall. The unwanted metals and resist mask is removed by using an adhesive tape as in previous prior art. The sacrificial polyether sulfone layer is first chemically etched before using the adhesive to peel-off

the metal/resist mask. This approach also has limitations, such as, suitable only for planar surfaces. Not suitable for implementing on highly uneven topographies as in MEMS and Optical sub-assembly applications. The polyether sulfone release layer and photoresist has to be coated on the substrate before the lift-off process and hence is highly unsuitable for MEMS and Optical MEMS application due to uneven topography. Additionally, the metal and the resist layers can be peeled-off only if the release layer is fully removed. Removal of release layer is highly design dependent and hence cannot be implemented for dark field type of masks which have large areas covered with photoresist.

There is a need to alleviate the problems associated with the conventional patterning of films and lift-off techniques.

SUMMARY

An aspect of the invention provides a method of forming a patterned film of a first material on a semiconductor substrate comprising providing a semiconductor substrate having a surface; patterning the surface of the substrate with a resist layer forming a mask on surface of the substrate with a predefined pattern; depositing the first material on the patterned resist layer; applying a removal material on the first material, the first material and the resist layer sharing weakly bonded characteristics with one another, the adhesion between the resist layer to the first material is less than the adhesion of the first material to the removal material; and removing the removal material resulting in removal of the unwanted portions of the first material from the resist material, leaving the patterned film of the first material on the substrate. This is possible due to stronger bond between the first material and the substrate while the bond between the first material and the removal material is relatively weaker in the areas where the removal material makes contact with first material.

An embodiment of the invention further comprises removing the resist layer from the surface of the substrate leaving the semiconductor device on the surface of the substrate. The surface of the substrate may be non-planar. The first material may be a

conductive material such as a metal or a noble metal. The first material may also be an insulating material or a dielectric material or a combination of conductive and insulating materials. At least one additional layer may be formed over the first material by patterning the surface of the first material with a resist layer forming a mask on surface of the substrate with a predefined pattern; depositing the additional material on the patterned resist layer; the additional material to form a top layer, where the removal material is applied to the top layer, and the top layer and the resist layer share weakly bonded characteristics with one another while the top layer and the first material share a stronger bond. In this way, the adhesion between the resist layer to the top layer is less than the adhesion of the top material to the first material and the adhesion of the top layer to the removal material. The additional layer may be a metal. The additional materials may comprise depositing a plurality of additional layers on the first material layer to form a composite stack of layers, where the upper most layer of the plurality of additional layers forms the top layer, and the adhesion between the resist material and the top layer is less than the adhesion between each adjacent additional layer in the composite stack of layers. The composite stack may comprise different metal layers.

In an embodiment, the resist layer is an organic layer, a dry resist film and may form a photo resist mask. The patterning of the resist layer may comprise re-entrant and/or straight walled profiles. The patterning and removal lift-off material process of embodiments of the invention may be applied at different layers of the process as well as the surface of the substrate. The removal of the material comprising the first material or the top layer comprises fracturing the first material or the top layer at the edge of the pattern defined by the photo-resist mask. Applying and removing the removal material comprises laminating and delaminating a polymer film. The substrate may be heated to create a mismatch between the resist layer and the first material or the top layer material. Removal of the resist layer comprises bonding a polymer film with an adhesion strength to the resist layer greater than the adhesion strength of the resist layer to the substrate layer with an adhesive, UV tape, or the like.

In an embodiment, the organic layer is a dry resist film lithography, a spin-coated photo resist mask, or a low-adhesion photo definable polymer. The organic layer can also be a

low-adhesion etchable polymer mask. After deposition of the first material or the top layer, the removal of the unwanted deposited material comprises removing the material from the top surface and sidewalls of the patterned organic masking layer by laminating an adhesive film and then delaminating selectively the unwanted material. The lamination process comprises bonding an adhesive polymer film with an adhesion strength to the deposited material greater than the adhesion strength of the deposited material with the organic masking layer. The method of removal of unwanted material from the organic masking layer may optionally comprise heating the substrate to create a mismatch between the organic layer and the deposited layer and then delaminate the unwanted material from the organic masking layer easily. The removing of the organic layer from the substrate further comprises laminating and later delaminating a polymer film with an adhesion strength to the organic layer greater than the adhesion strength of the organic layer with the substrate layer.

In an embodiment, the deposited metal film or film stack have a weak adhesion interface between metal and the masking layer. The weak adhesion layer which promotes the delamination of unwanted metal is on the top of the masking layer. Due to the weak-adhesion interface on the top of the masking layer allows delamination of metal and masking layers separately. As a consequence, the unwanted metal film is effectively stripped or delaminated before the mask removal process, and the final mask removal process therefore may not contribute any metallic contamination or reliability issues. Though the polymer film is bonded to the entire surface during the lamination process, due to a stronger bond between the deposited material and the substrate compared to bond between the deposited film and the polymer film, the pattern formed by the deposited material remains intact on the substrate. Only the deposited material over the masking material is removed.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that embodiments of the invention may be fully and more clearly understood by way of non-limitative example from the following description taken in conjunction with the

accompanying drawings in which like reference numerals designate similar or corresponding elements, regions and portions, and in which:

FIGS. 1A-1C illustrates a conventional additive metallization or lift-off metallization process in accordance with an embodiment of the invention;

FIG. 2 is a flow chart of a method in accordance with an embodiment of the invention;

FIGS. 3A-3G illustrates the method of FIG. 2 in process steps in accordance with an embodiment of the invention;

FIG. 4 is a flow chart of a method in accordance with an embodiment of the invention;

FIGS. 5A-5E illustrates the method of FIG. 4 in process steps in accordance with an embodiment of the invention;

FIG. 6 is a flow chart of a method in accordance with an embodiment of the invention;

FIGS. 7A-7E illustrates the method of FIG.6 in process steps in accordance with an embodiment of the invention;

FIG. 8 is a flow chart of a method in accordance with an embodiment of the invention;

FIGS. 9A-9E illustrates the method of FIG. 8 in process steps in accordance with an embodiment of the invention;

FIGS. 10A-10B shows pictures comparing the results of a prior art method (FIG. 10A) with a method (FIG. 10B) in accordance with an embodiment of the invention; and

FIGS. 11A-11B show SEM images of cross-sectional views of dry film structure after lithography and after metal is deposited over resist in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

A method of performing lift-off patterning process is disclosed which involves dry resist film lithography and deposition of metal or insulating film or combination of the both films followed by lamination with UV sensitive or equivalent adhesive film and then delaminating the top layer of thin film due to weak adhesion of deposited metal with the underlying organic layer. The UV tape or UV sensitive adhesive film used refers to a class of organic film which displays strong adhesion when laminated to any surface under normal light but shows very low adhesion when exposed to a broadband UV light.

In another embodiment of this invention, the unwanted dry resist film is stripped or peeled-off by again laminating a fresh layer of UV sensitive film and delaminating the unwanted dry resist film mask. A feature of this technology is that it does not require any strong ultrasonic or mega sonic energy or thermal shock to break the adhesion of the film from the organic mask before stripping the metal or insulating film or combination of the both films and the organic mask. Another feature of an embodiment of the invention is that it does not require a highly reentrant mask profile or multiple layers to create undercut mask profile. As the sputtered or evaporated films are usually non-conformal, the thin and weakly adhered sidewall metal films easily gets delaminated by the adhesive polymer film during the delamination process and thus resulting in smooth edges for the lift-off patterns. A method of performing dry resist film lift-off patterning by the process of polymer film lamination and delamination process is disclosed. An embodiment may involve high temperature film deposition by using a high-temperature sacrificial mask layer. An embodiment may involve selective removal of metal or insulating film or combination of the both films and polymer masking layers by the lamination and delamination process. An embodiment may use UV/IR radiation to cause delamination of metal or insulating film or combination of the both films from the polymer mask by local heating to cause CTE (coefficient of thermal expansion) mismatch and delaminate easily.

A method of performing lift-off patterning process is disclosed which can be implemented through embodiments as illustrated below. In all these various embodiments, a lift-off mask is formed preferably by dry resist film but not limited only to dry resist film. The material or material stack deposited on the resist film layer material may be any material difficult to etch under conventional processes. For example the material may be difficult to etch because the material is a noble metal and is inherently difficult to etch due to properties of noble metals. Additionally, metal stacks comprised of composite layers of metals may be difficult to selectively etch. Also difficult to etch is any material, which may not necessarily be a metal or noble metal, that is deposited or applied on non-planar substrate. For example, the lift-off material may be metallic or insulating type. Metal or metal stack is deposited by e-beam evaporation, sputtering or by any other technique to selectively adhere to the required region where the metal patterns are

required. The substrate may be any substrate such as for example silicon substrate, glass substrate, or the like. The whole metallized wafer is then laminated with UV tape or equivalent strong adhesive tape and then the unwanted metal is delaminated selectively from the organic masking layer. The delamination process results in peeling the metals from the unwanted areas due to poor adhesion of metals on the surface of the mask. In embodiments described through illustration, it has been shown that a normal spin-coated, spray coated, electroplated photo resist or dry resist films can be used as a lift-off mask. In other embodiments a masking process has been described which is suitable for doing higher temperature (300-400°C) material patterning by lift-off process. The material that is patterned by lift-off can be any material or material stack that is difficult to etch as described above such as noble metals, gold (Au), copper (Cu), chromium (Cr), platinum (Pt), gold (Au), and metal stacks such as under-bump metallization and solder for packaging applications, and the like. For example, the solder film may be Au/Sn solder film, deposited in the range of sub-micron to 10µm. Metallization thickness 162 can vary from sub-micron to several microns. In an embodiment the organic layer or dry resist film mask may have a thickness 160, for example, in the range of 20µm, and a metal deposition, for example Ti/Pt/Au, may be in the range of 0.1µm, 0.2µm and 1.0 µm, respectively, as shown in FIG. 11B. FIGS. 11A-11B shows SEM images of cross-sectional views of dry film structure after lithography and after metal of 1000Å Ti/10,000Å Au metal stack, as shown in FIG. 11A, patterned by lift-off is deposited over resist in accordance with an embodiment of the invention. An embodiment of the method of performing lift-off patterning process is disclosed which involves dry resist film or normal lithography and material deposition process followed by lamination with UV sensitive or equivalent adhesive film and then delaminating the top layer of thin film due to weak adhesion of deposited material with the underlying organic layer. In an embodiment, the unwanted dry resist film is stripped or peeled-off by again laminating a fresh layer of UV sensitive film and delaminating the unwanted dry resist film mask. As the sputtered or evaporated films are usually non-conformal, the thin and weakly adhered sidewall metal films easily gets delaminated by the polymer film during the delamination process and thus resulting in smooth edges for the metal patterns.

Embodiments of the invention disclosure relates to a process for forming a pattern of conductive material on a substrate for forming patterns of metallization for wide range of applications, for example, low to high-temperature metal or metal stack deposition, nano to micro-structures formation, for defining metal patterns on copper low-k wafers and on MEMS and optical sub-assembly wafers with deep cavities and grooves.

An overview of an embodiment with selective removal of lift-off metal and organic mask is shown in method 10 of FIG. 2 and FIG. 3A-G. To begin with, the method 10 shown in FIG. 2 comprises a dry resist film 32 lithography 12 and film deposition processes 14 for deposition of the lift-off layer 36 are performed followed by lamination 18 with UV sensitive or equivalent adhesive film 38 to bond with the deposited material film/stack layer and delaminating 19 to remove the top layer of unwanted deposited material film due to weak adhesion with the underlying organic layer. The resist material 32 may be any type of lithography, for example dry resist film lithography, organic layer, dry resist layer, positive photoresist lithography, negative photo-resist lithography, electron beam (EB) lithography, and the like. As shown in FIG. 3A the lithography has a re-entrant profile 34. The device wafer is patterned with the dry-resist film. The first material layer 36 or lift-off material in this embodiment is a metal or insulating material or combination of both layers that may be deposited by deposition techniques such as evaporation, sputtering, and the like of desired material, metal film, metal stack or the like as required. It will be appreciated that the lift-off material film 36 may be metallic as described in this embodiment, or another material such as an insulating material type material. The thickness of first material 36 may range for example from a few nanometers to a few hundreds of nanometers. In an embodiment, the substrate may optionally be heated 16 too, for example to any suitable temperature between 100°C and the maximum reflow temperature of the masking layer, to create a CTE mismatch between the lift-off material and dry resist masking layer. It may further be noted that the selection of this optional heating step depends on the maximum temperature the lift-off material 36 and the masking layer can withstand. In another embodiment of this invention the method shown, another polymer film 40 with appropriate adhesion strength which may be stronger can be applied 20 and delaminated to strip-off 22 the sacrificial dry resist film mask. In FIG. 3C and 3D, removal of unwanted metal by bond and peeling-off may be

performed with polymer film or tape lamination and delamination tools 38, and removal of resist or polymer mask as shown in FIG. 3E and 3F by bond and peeling-off with polymer tape may be performed which also saves chemical cleaning time. The continuity material 39 is removed as shown in FIG. 3D together with the lift-off material 36 and the delamination tool 38. UV tapes or adhesives 38,40 that may be used include E8320 from Lintec Advanced Technologies, Inc. of Tokyo, Japan; SP-series UV tapes from Furukawa Electric Co. Ltd. of Tokyo, Japan; DT and GT-series UV tapes from Semiconductor Tapes and Materials, Inc. (STM) of San Jose, California, United States of America; other tapes and adhesives commercially available, and the like. A feature of this technology is that it does not require any chemical etch step to break or fracture the metal continuity 39 in the mask sidewall. It also does not require any organic release polymer like Polyether Sulfone to facilitate delamination of unwanted metals on the photo resist mask. Another feature of the above embodiment is that dry resist film being usually greater than 20 μ m and also being a negative resist, it gives a good reentrant mask profile. Hence, it does not require multiple resist layers to make the profile reentrant for lift-off. As the sputtered or evaporated films are usually non-conformal, it is easily delaminated by the polymer film during the delamination process and thus resulting in smooth edges for the patterns. With this configuration, both the metal and dry resist film can be delaminated effectively by using UV films or equally strong adhesive film. It will be appreciated that the dry resist film based lift-off process is suitable for patterning metals/metal stacks over large grooves and uneven topographies which is peculiar to MEMS, wafer level packaging and optical sub-assembly application. It may be noted that a wide range of polymer films are available with wide choice of adhesion strength with various films to choose from. Automated systems are also available to attach and detach the polymer tape from the wafer surface, i.e. automatic taping and de-taping tools are available. As shown in FIG. 3G, the final clean pattern 42 formed after bond and peel process is shown. The lamination and delamination process is alternatively referred to as bond and peel process.

An overview of an embodiment with lift-off process with spin-coated, spray-coated, electroplated, or the like photo resist mask is shown in method 50 of FIG. 4 and FIGS. 5A-5E. In the case of normal topographies as in a semiconductor manufacturing

application, this embodiment can be used as a variant of another embodiment. Here a normal spin-coated or other type of photo resist masks 32 can be used (step 52) before performing the lift-off patterning process 54, applying a UV sensitive adhesive film 64 (step 56) with strong adhesive film with material film 36, that has a stronger adhesion than the adhesion between the material 36 and the resist material 32, and delaminate 57 the unwanted material 36 from the mask surface, for example delaminate weakly bonded metal/metal stack or insulating film/film stack on the resist mask. The layer of unwanted material film 36 easily debonds 57 due to weak adhesion with the underlying organic layer 32. A feature of this method is that it does not require any organic release polymer layer like polyether sulfone to facilitate delamination of unwanted metals on the photo resist mask, which simplifies the process. As described in another embodiment, the device wafers are patterned with photo-resist lithography 32 with re-entrant profile 34 for lift-off process as shown in FIG. 5A, where the deposition 54 of lift-off 36 material such as metal by evaporation, sputtering or the like of metal film or metal stack as required as shown in FIG. 5B. Laminate 56 the lift-off with UV sensitive polymer film or equivalent strong adhesive film and delaminate 57 the weakly bonded metal films attached to the resist. Removal 58,60, as shown in FIG. 5C and 5D of unwanted metal by bond and peeling-off with, for example polymer tape 64, may be followed by resist mask removal by stripper. The continuity material 68 is removed as shown in FIG. 5D together with the lift-off material 36 and the delamination tool 64. As shown in FIG. 5E, the final clean pattern 66 formed after bond and peel process is shown.

Another embodiment concerns selective removal of lift-off material over high temperature mask, as shown in the method 70 of FIG. 6 and FIGS. 7A-7E. To begin with, any standard high temperature inorganic films like silicon oxide or silicon nitride followed is deposited 72, such as by coating or deposition of a suitable organic film such as, for example, a low-k dielectrics which are known to have poor adhesion strength with metals and insulating materials like silicon dioxide and silicon nitride films. The low-adhesion strength polymer and the hard mask are patterned by standard lithography and etch process to create features for lift-off materials. A deposition process 74 is then performed followed by lamination with UV sensitive film or equivalent adhesive film. The film is then delaminated 78 to remove the unwanted material film from the weak

adhesion interface with the underlying organic layer. As explained in a previous embodiment, the weakly bonded organic layer can be removed easily by means of lamination and delamination with the UV sensitive adhesive film or any film with equivalent strength. Similarly, as explained in a previous embodiment, the UV sensitive adhesive film or equivalent film can be used to delaminate or strip-off the sacrificial low-adhesion organic layer on the hard mask. It will be appreciated that the low-adhesion polymer can be any high temperature lift-off polymer like PiRL-III supplied by Brewer Science Inc. of Rolla, Missouri, United States of America, and the like, or any standard low-k or ultra low-k dielectric film used for copper damascene process technology. Some polymers that bond well with metals include, for example, polyimide from E. I. du Pont de Nemours and Company of Wilmington, Delaware, United States of America, or BCB from The Dow Chemical Company of Midland, Michigan, United States of America, and the like. Lift-off polymers that have low adhesion to metals and insulating materials are hence a suitable choice for this application. A polymer such as PiRL-III can withstand up to 300 degrees Celsius (300°C). This embodiment is similar to a previous embodiment in many ways except for adding a low-adhesion polymer film over the mask to cause the lift-off metal to delaminate easily. In this embodiment, the device wafers are patterned 72 with low adhesion strength film 86 over hard mask 94 organic layers to create features for lift-off metallization 74, as shown in FIG. 7A and 7B where the deposit and pattern a stack of high-stress film 86 and hard mask layer, for example, SiO₂, having a suitable edge profile 84 for deposition of lift-off material 36, such as a metal. The edge profile 84 used for lift-off may be in the range of 80 to 90 degrees depending on the type of masking material used. The low adhesion strength film or high stress film 86 may be for example plasma deposited amorphous silicon and plasma deposited fluorocarbon films. If necessary, the SiO₂ can be recessed or wet etched to assist in the lift-off process. In embodiments, the deposit and pattern of low-adhesion film 72 may be any films which have poor adhesive strength with inorganic hard mask and metal films such as for example TEFLON-like films made of fluoro-carbons like C₄F₈, CHF₃, CF₄, C₃F₈, and the like. Thickness of the films 72 may range for example from 10 nanometers to a few hundred nanometers. TEFLON is a trademark registered by E. I. du Pont de Nemours and Company in the United States and other countries. The substrate may optionally be heated 76 to, for example to any temperature between 100°C and the

maximum reflow temperature of the organic masking layer, to create a CTE mismatch between the metal and masking layer. It may further be noted that the selection of this optional heating step depends on the maximum temperature the metal and masking layer can withstand. Laminate and delaminate 78 the lift-off metal with suitable UV sensitive polymer film or equivalent to peel the weakly bonded metal on the low-adhesion strength film, as shown in FIG. 7C. The sacrificial low-adhesion strength film is removed by bond and peeling-off with for example with UV sensitive polymer tape or any other adhesive film with suitable adhesive strength. The continuity material 96 is removed as shown in FIG. 7D together with the lift-off material 36 and the delamination tool 88. The hard mask can finally be removed 80 by for example plasma etching or selective chemical strip, as shown in FIG. 7D. It may be noted that metal and high-stress film delaminates due to weak adhesion. Removal 82 of any adhesive on wafer surface may be performed with resist strip to yield the final clean pattern 90 formed after bond and peel process is shown in FIG. 7E.

An overview of an embodiment with selective removal of lift-off metal over high-temperature mask is shown in the method 100 of FIG. 8 and FIG. 9A-E. This embodiment is a slight variation of another embodiment such that a high temperature organic lift-off mask 120 is used instead of the inorganic hard mask like silicon oxide or silicon nitride. The organic mask can be any of the lift-off polymer which serves the dual purpose of acting as a lift-off mask and also as a low-adhesion polymer layer which facilitates easy removal of unwanted material from the surface of the lift-off mask. The low-adhesion polymer can be photo definable or etchable polymer. Finally, as explained in another embodiment, the weakly bonded organic layer can be removed easily by means of lamination and delamination with the UV sensitive adhesive film or any film with equivalent strength. Similarly, as explained in another embodiment, the UV sensitive adhesive film or equivalent film can be used to delaminate or strip-off the sacrificial low-adhesion organic layer on the hard mask. The low-adhesion polymer can be any high temperature lift-off polymer such as PiRL-III supplied by Brewer Science Inc., and the like. Some polymers that bond well with metals and inorganic dielectric materials like silicon dioxide and silicon nitride include, for example, polyimide from E. I. du Pont de Nemours and Company or BCB from The Dow Chemical Company. Most

lift-off polymers are designed for low adhesion to metals and hence are a suitable choice for this application. A polymer such as PiRL-III can withstand up to 300 degrees Celsius (300°C). The polymer film in the range of 5 μm may be deposited. The high temperature polymer film may be deposited and pattern formed 102 to create the features of the lift-off patterns of high-temperature metal/insulating film or stack as required over the wafer may be evaporated or sputtered 104, as shown in FIG. 9A and 9B. The high-temperature film may be PiRL polymer from Brewer Science which is specially designed for high temperature applications, and has poor adhesion to metals and insulators like silicon dioxide and silicon nitride. The lift-off material 36 may be a metal film or metal stack as described in this embodiment and may be any metal such as Au, Cr, Ti, Pt and the like. In another embodiment the lift-off material may not be a metal, and may be a dielectric material or an insulator material, for example SiO_2 , Si_3N_4 , and the like. The lift-off material may be composite film stacks, for example Ti/Pt/Au which is used for under-bump metallization before solder bumping. The thickness of the film or film stack may vary for example from a few nanometers to a few hundreds of nanometers depending on the application. A polymer film is laminated 106 and delaminated to peel the weakly bonded metal 116, and removal 108 of unwanted metal by bond and peeling-off with, for example, polymer tape 112, 114, as shown in FIG. 9C and 9D. The continuity material 122 is removed as shown in FIG. 9D together with the lift-off material 116 and the delamination tool 114. In this embodiment the metal 116 breaks in the sidewall due to poor step coverage. As described in earlier embodiments, the polymer mask can be removed 108 by the lamination and delamination process with UV sensitive polymer tape or any other adhesive film with suitable adhesive strength or by plasma etching or selective chemical strip. Finally, any adhesive residue on the wafer surface may be removed 110, for example by resist strip process, to yield the final clean pattern 118 formed after the bond and peel process, as shown in FIG. 9E.

As discussed in the background where observations on conventional lift-off patterning process are made, metals deposited on sidewalls and the foot of the resist mask causes residues in the edges of the metal patterns which is difficult to remove. Metal residues increases for thicker films deposited. As the deposited metals cover the whole resist surface, it needs prolonged ultrasonic agitation to break the metal continuity in the

sidewall and remove the resist. Due to the floating metal residues, the stripper needs to be filtered or constantly replenished. Conventional cleaning time is approximately 1-2 hours per wafer. FIG. 10A-B shows Ti/Au metal stack patterned by conventional lift-off 5 by using ultrasonic metal/resist removal showing unclean edges 7 as shown in FIG. 10A, and clean pattern achieved by using dry resist film process and UV tape to delaminate the dry resist film and the metals as shown in FIG. 10B. It can be seen that a clean pattern 150 is achieved with straight edges 152. Thus, metal residue issues are alleviated by the lift-off process with polymer film peel-off process. Due to very good adhesion strength of metal on the substrate and due to poor adhesion on resist film, the metal is effectively removed during peel-off. Due to poor step coverage of metal over resist sidewall, the metal is cut-off during the polymer film detachment process. Additionally, the adhesion between metal and lift-off mask can be weakened further by UV exposure before polymer tape detachment process to effectively delaminate the metal.

It will be appreciated that other variations may be made to the methods discussed without departing from the invention. For example, in the embodiments it is noted that the deposited material film or film stack have a weak adhesion interface between the deposited material film/film stack and the masking layer. Further, in embodiments, the same method of lamination and delamination is used to strip or remove the sacrificial weak-adhesion material. It is also noted that in embodiments, a weak-adhesion layer which promotes the delamination of unwanted metal is on the top of the masking layer unlike in previous attempts made in the prior art wherein the weak-adhesion layers are below the masking layers. Also, the previous attempts in the prior art have focused on delaminating the unwanted metal and masking layer together, whereas in embodiments the weak-adhesion interface on the top of the masking layer allows delamination of metal and masking layers separately. As a consequence, the unwanted metal film is effectively stripped or delaminated before the mask removal process. Hence, in the final mask removal process there would not be any metallic contamination or reliability issues. Embodiments of the invention make use of weak bonding of dry-film resist to the substrate. Mechanical peeling or delamination may be employed which causes the poorly adhered sidewall metals to break from the edges easily resulting in good patterns.

A dry-film, low-adhesion strength lift-off polymer, or the like may be used which shows poor adhesion with metal layers which does not require an additional weakening process, for example by chemical treatment or the like, to weaken the interface between the metal and the mask materials. Similarly, a UV release film, adhesive film or the like may be used to peel-off the metal and the dry-film resist without weakening the interface, such as by chemical treatment or the like. Embodiments of the invention are suited for both planar and highly uneven topographies as in MEMS, optical sub-assembly applications, and the like. Embodiments may be used for depositing at many different temperatures, such as for example ambient temperature, room temperature, and high temperatures such as high temperature metals, for example 300-400°C, and the like. It will be appreciated that the lift-off of embodiments of the invention is applicable for both inorganic and organic dry resist film mask. Embodiments of the invention reduce the risk of pattern damage due to re-deposition of metal and resist residues during the photo-resist strip and clean processes, minimizing overhanging films in the edge of the transferred patterns by lift-off, or the use of aggressive cleaning methods like ultrasonic, LN₂ or CO₂ spray cleaning. Additionally, since these aggressive cleaning methods are not required in an embodiment of the invention, the method reduces the costs of post-deposition clean.

While embodiments of the invention have been described and illustrated, it will be understood by those skilled in the technology concerned that many variations or modifications in details of design or construction may be made without departing from the present invention.

CLAIMS:

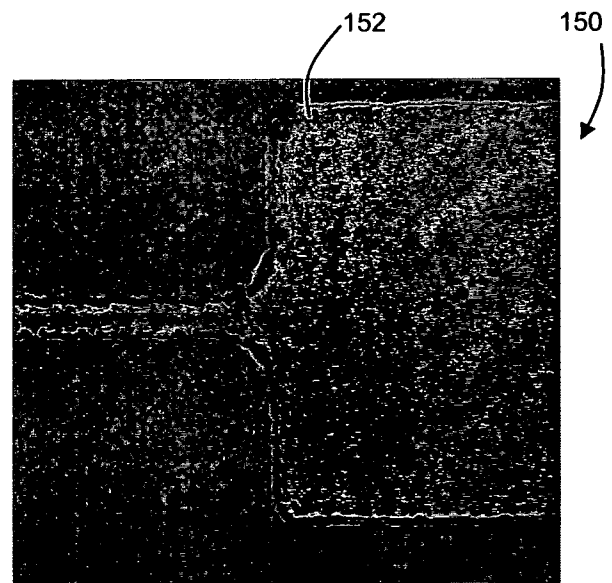
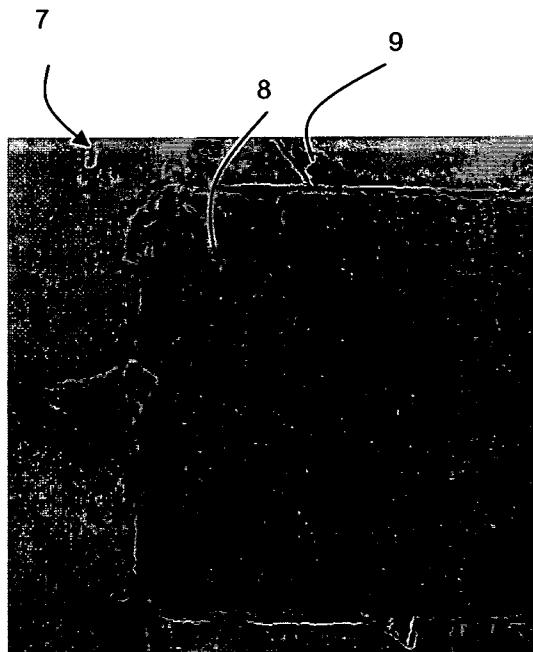
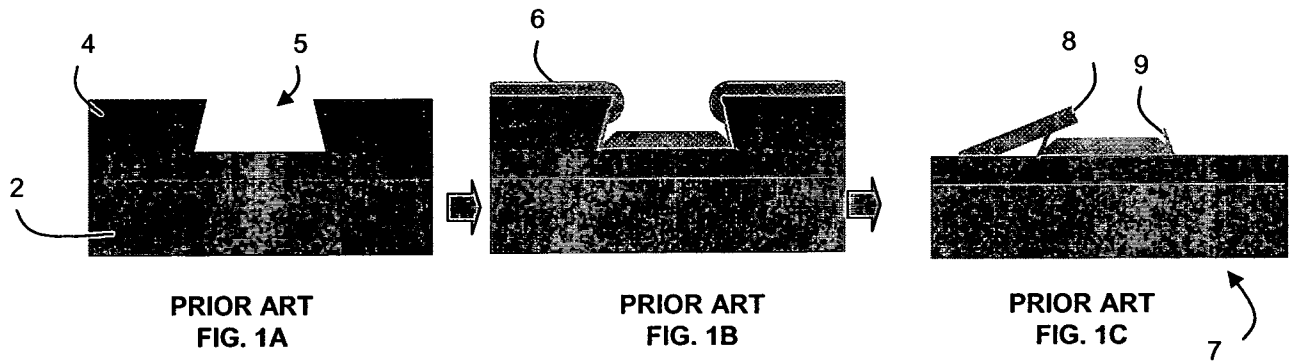
1. A method of forming a patterned film of a first material on a semiconductor substrate comprising:
providing a semiconductor substrate having a surface;
patterning the surface of the substrate with a resist layer forming a mask on surface of the substrate with a predefined pattern exposing the surface of the substrate;
depositing the first material on the patterned resist layer and the exposed surface of the substrate;
applying a removal material on the first material, the first material and the resist layer sharing weakly bonded characteristics with one another, the adhesion between the resist layer to the first material is less than the adhesion of the first material to the removal material, the adhesion between the first material and the exposed surface of the substrate is more than the adhesion between the first material and the removal material; and
removing the removal material resulting in removal of the unwanted portions of the first material from the resist material, leaving the patterned film of the first material on the substrate.
2. The method of claim 1 further comprising removing the resist layer from the surface of the substrate leaving the semiconductor device on the surface of the substrate.
3. The method of claim 1 or 2 wherein the surface of the substrate is non-planar.
4. The method of any one of the preceding claims wherein the first material is a conductive material.
5. The method of any one of the preceding claims wherein the first material is a metal.

6. The method of any one of the preceding claims wherein the first material is a noble metal.
7. The method of any one of claims 1-3 wherein the first material is an insulating material.
8. The method of any one of the preceding claims further comprising depositing at least one additional layer on the first material to form a top layer, the removal material is applied to the top layer, the top layer and the resist layer sharing weakly bonded characteristics with one another, the adhesion between the resist layer to top layer is less than the adhesion of the top material to the first material and the adhesion of the top layer to the removal material.
9. The method of claim 8 wherein an additional layer is a metal.
10. The method of claims 8 or 9 wherein the at least one additional material comprises depositing a plurality of additional layers on the first material layer to form a composite stack of layers, the upper most layer of the plurality of additional layers forms the top layer, the adhesion between the resist material and the top material is less than the adhesion between each adjacent additional layer in the composite stack of layers.
11. The method of claim 10 wherein the composite stack comprises different metal layers.
12. The method of any one of the preceding claims wherein the resist layer is an organic layer.
13. The method of any one of claims 1-12 wherein the resist layer is a dry resist film.

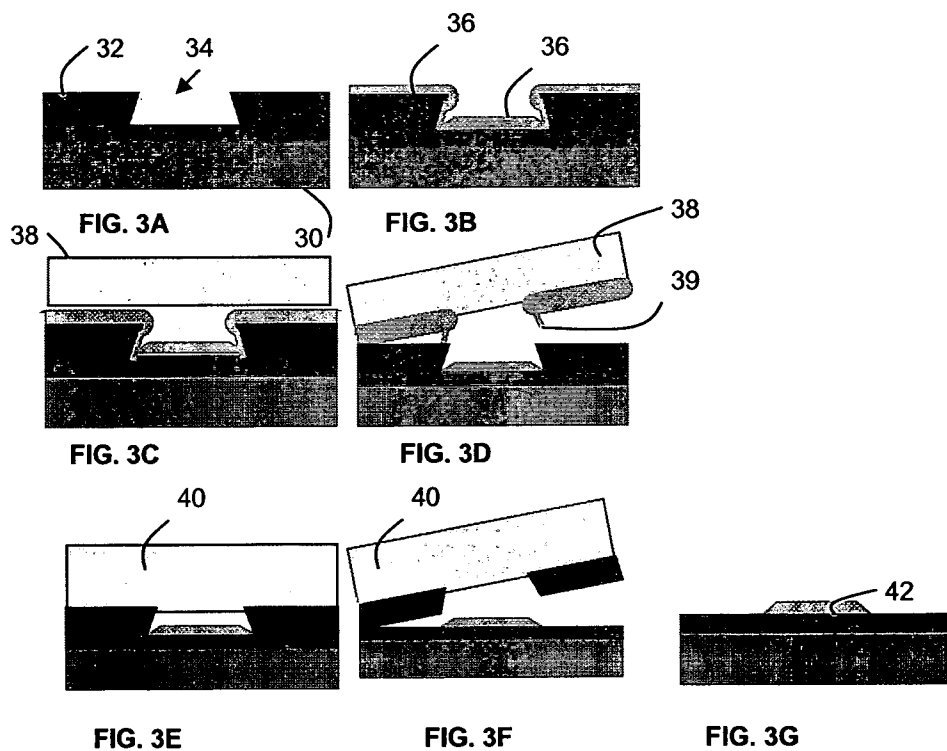
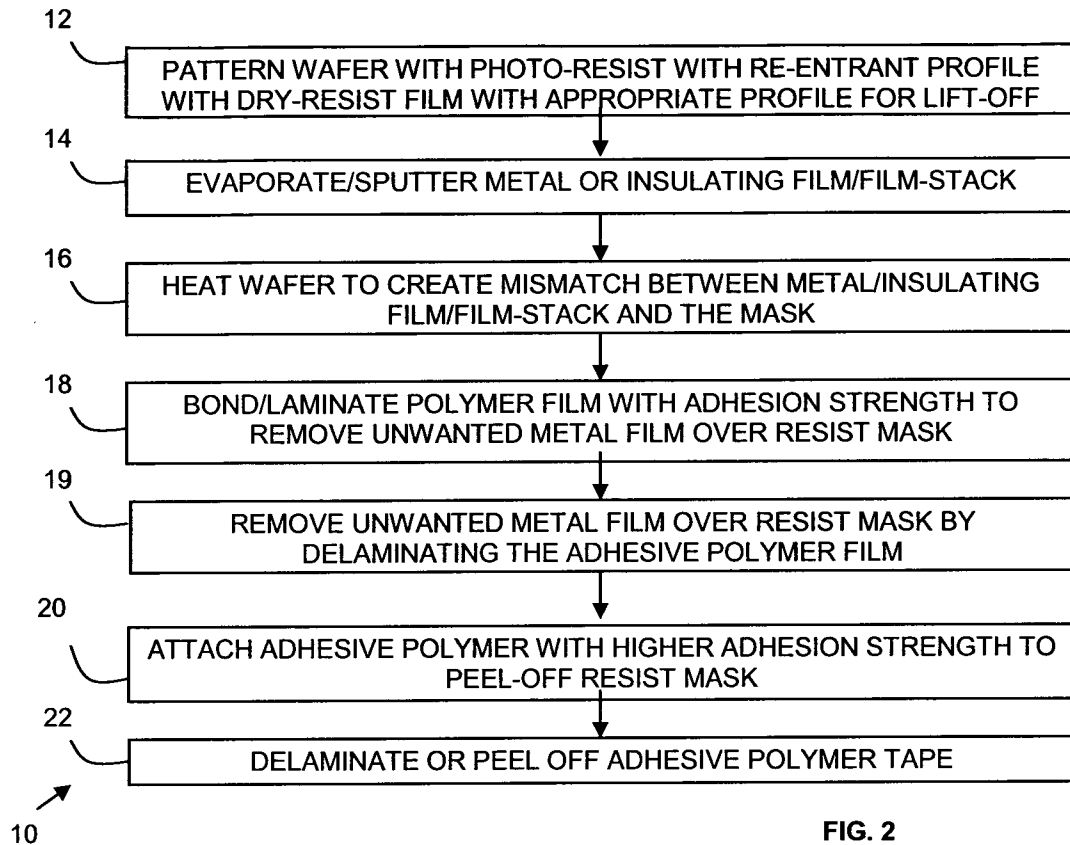
14. The method of any one of the preceding claims wherein the resist layer forms a photo resist mask.
15. The method of any one of the preceding claims wherein the resist material is a low-adhesion photo definable polymer.
16. The method of any one of claims 1-14 wherein the resist material is a low-adhesion etchable polymer.
17. The method of any one of the preceding claims wherein the patterning of the resist layer comprises re-entrant profiles.
18. The method of any one of the preceding claims wherein patterning of the resist layer comprises straight walled profiles.
19. The method of any one of the preceding claims wherein the removal of the first material comprises fracturing the first material.
20. The method of any one of the preceding claims wherein applying and removing the removal material comprises laminating and delaminating a polymer film.
21. The method of any one of the preceding claims further comprising heating the substrate to create a mismatch between the resist layer and the first material.
22. The method of any one of the preceding claims wherein the removing of the resist layer from the substrate comprises bonding a polymer film with an adhesion strength to the resist layer greater than the adhesion strength of the resist layer to the substrate layer.

23. The method of any one of the preceding claims wherein the applying of the removal material comprises an adhesive.
24. The method of any one of claims wherein the applying of the removal material comprises UV tape.

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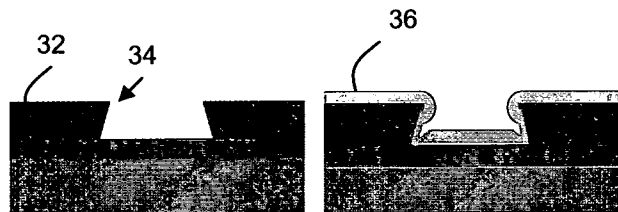
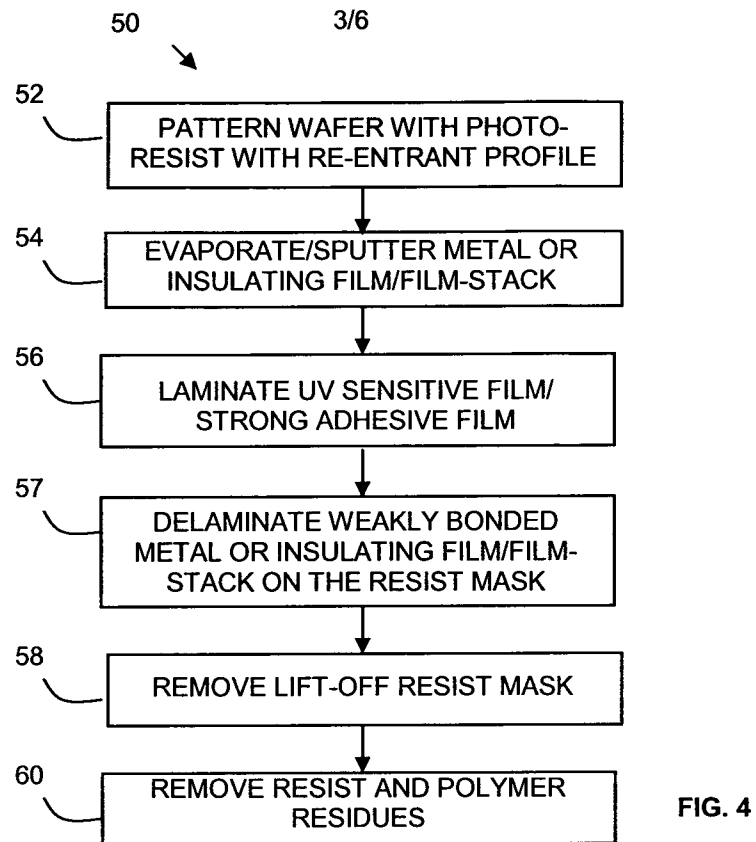


FIG. 5A

FIG. 5B

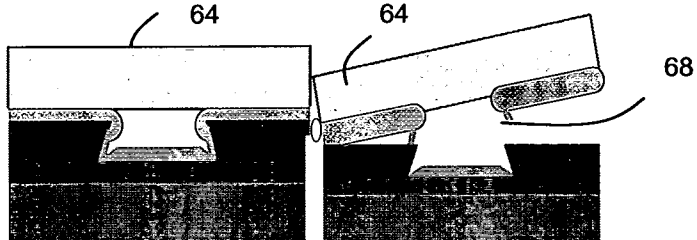


FIG. 5C

FIG. 5D

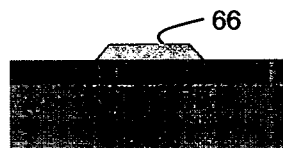


FIG. 5E

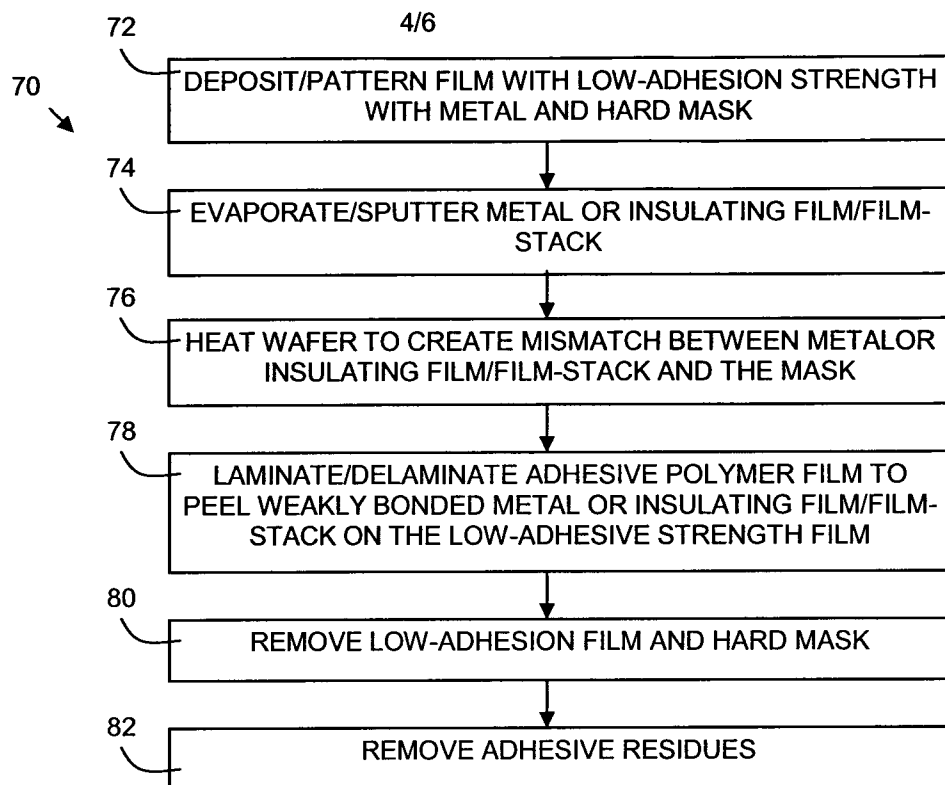


FIG. 6

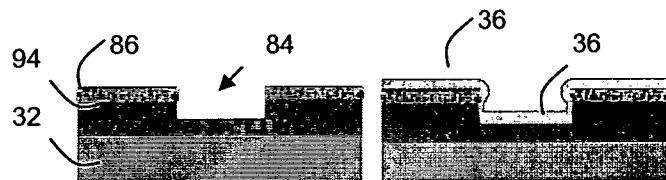


FIG. 7A

FIG. 7B

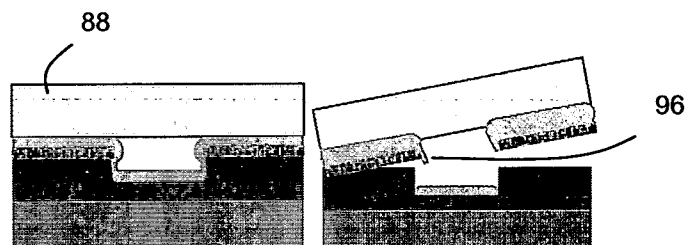


FIG. 7C

FIG. 7D

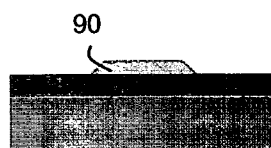


FIG. 7E

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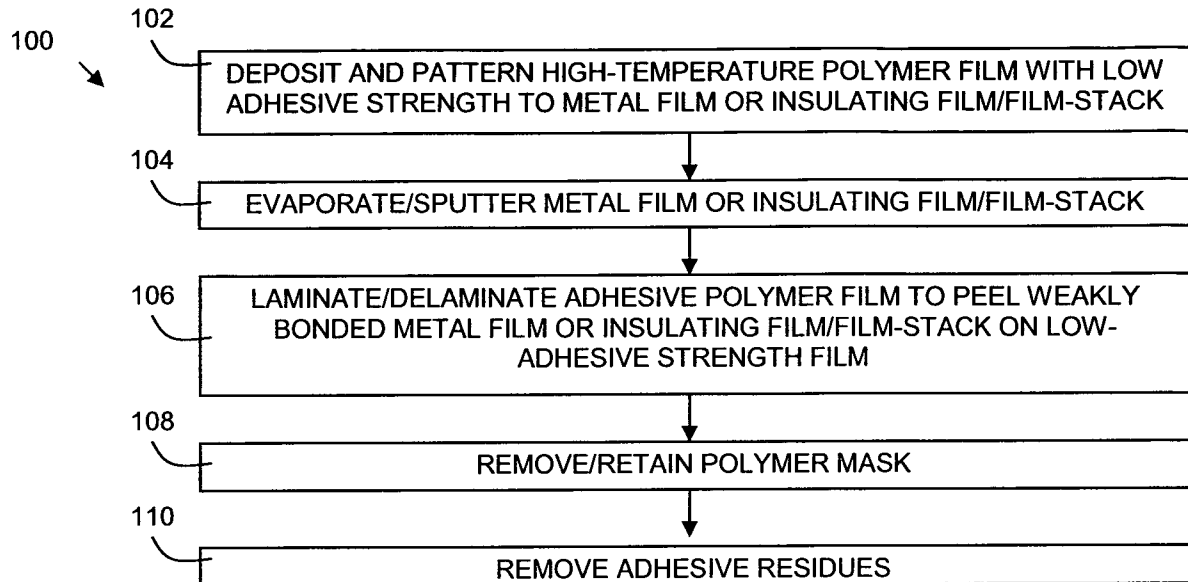


FIG. 8

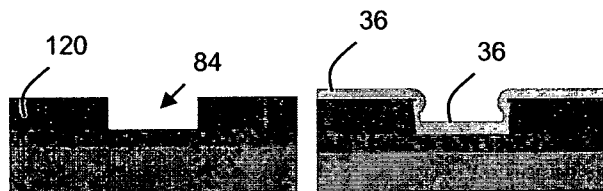


FIG. 9A

FIG. 9B

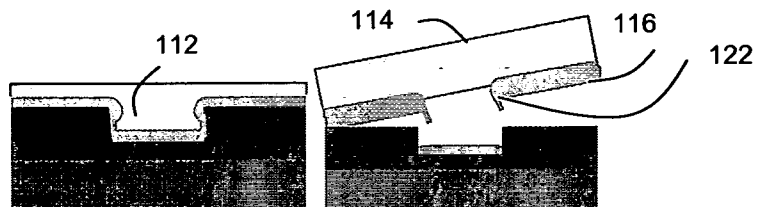


FIG. 9C

FIG. 9D

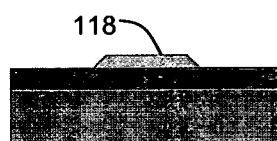


FIG. 9E

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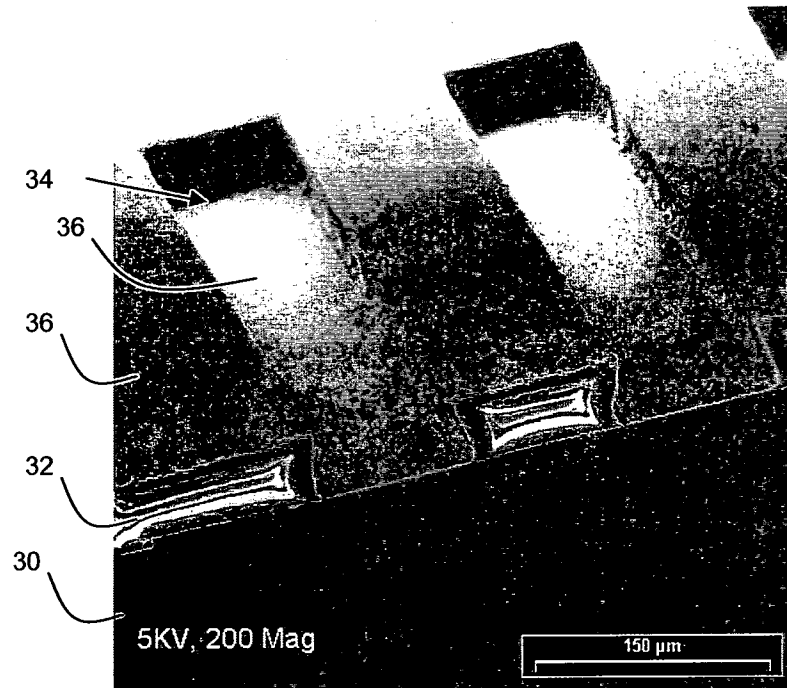


FIG. 11A

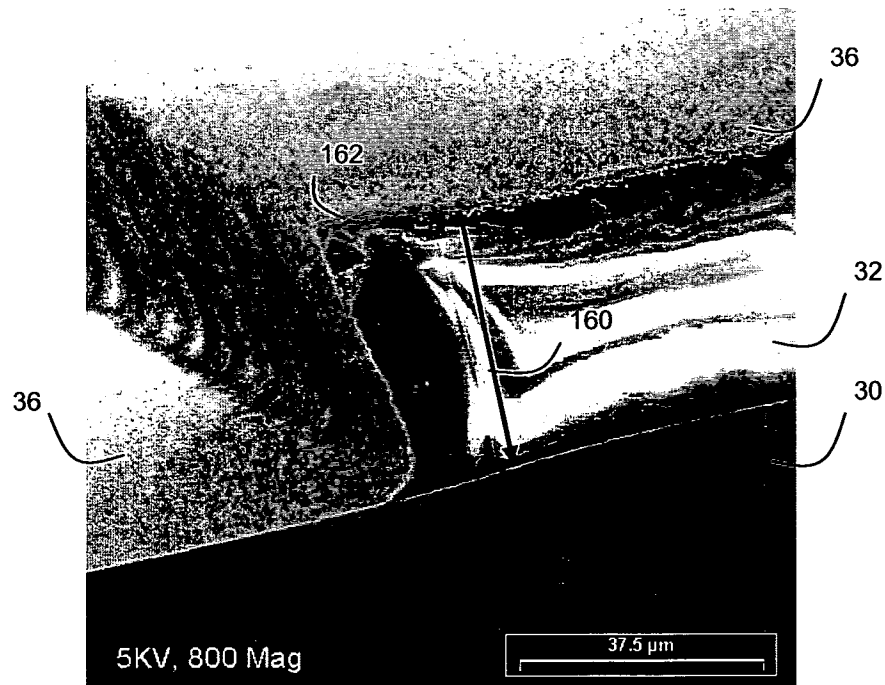


FIG. 11B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2008/000003

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

G03F 7/00 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DWPI: limit H01L/IC or G03F/IC, (lithography or photolithography or lift off or pattern), (tapping or de tapping or UV tape or coat or cover or laminate or delaminate or remove or adhesive or stick or bond or attach or detach or stripping or peel or eliminate or release or clean), (weak or less or strong) (bond or link or attach or adhesive or connect) or mismatch

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1229388 A2 (NITTO DENKO CORPORATION) 7 August 2002 Paragraphs 0010, 0021, 0023 and 0024	1-6, 12-20 and 22-24
X	US 5554488 A (RIOUX) 10 September 1996 Column 6, lines 35-50, column 7, lines 57-67, Figs. 9-10	1-6, 8-11, 13-14, 17-19 and 22-23
X	US 5209815 A (FLEMING ET AL.) 11 May 1993 Column 3, lines 47-68, column 5, lines 31-49, Figs. 2I, 2L	1-7, 12-19 and 22-23,



Further documents are listed in the continuation of Box C



See patent family annex

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
28 March 2008

Date of mailing of the international search report
10 APR 2008

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2008/000003

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JOHN ET AL., "PHOTOLITHOGRAPHIC PATTERNING OF ORGANIC ELECTRONIC MATERIALS", Organic Electronics, 2006, vol. 7, pages 22-28 Whole documents	1-3, 7, 12-19 and 22-23
X	EP 0971270 B1 (NITTO DENKO CORPORATION) 19 March 2003 Paragraphs 0010, 0024	1-3, 20 and 22-24
X	US 6652700 B1 (NAMIKAWA ET AL.) 25 November 2003 Column 3, lines 154, column 5, lines 5-41, Figs. 2A-F	1-6 and 12-24
X	US 5959011 A (MIZUNO ET AL.) 28 September 1999 Column 2, lines 50-67, Column 3, lines 1-44, Figs. 1, 2a-2b	1-3, 12-20 and 22-24

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2008/000003

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
EP	1229388	JP	2002231600	KR	2002006381	US	2002100553
US	5554488	NONE					
US	5209815	JP	5121402				
EP	0971270	EP	1248156	JP	11265075	JP	2000029230
		US	6245188	US	6565704	US	2001015259
US	6652700	EP	1206166	JP	2001076871	WO	0101735
US	5959011	US	5466325				
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.							
END OF ANNEX							