

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
10 November 2011 (10.11.2011)

PCT

(10) International Publication Number
WO 2011/139774 A2

(51) International Patent Classification:
G03F 7/00 (2006.01) *H01L 51/50* (2006.01)
H01L 21/027 (2006.01)

(21) International Application Number:
PCT/US2011/034145

(22) International Filing Date:
27 April 2011 (27.04.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/343,362 27 April 2010 (27.04.2010) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))



WO 2011/139774 A2

(54) Title: METHOD FOR FORMING AN ORGANIC DEVICE

(57) Abstract: The present invention provides a method for forming an organic device having a patterned conductive layer that includes providing a substrate, depositing organic materials over the substrate to form one or more organic layers, coating a photoresist solution over the one or more organic layers to form a photo-patternable layer, wherein the solution includes a fluorinated photoresist material and a first fluorinated solvent, selectively exposing portions of the photo-patternable layer to radiation to form a first pattern of exposed fluorinated photoresist material and a second pattern of unexposed fluorinated photoresist material, exposing the substrate to a second fluorinated solvent to develop the photo-patternable layer, removing the second pattern of unexposed fluorinated photoresist material without removing the first pattern of exposed fluorinated photoresist material, coating one or more conductive layers over the one or more organic layers and removing a portion of the one or more of the conductive layers to form a pattern. Particular embodiments of the present invention for forming arrays of top contact TFTs and a pixilated organic device are also provided.

METHOD FOR FORMING AN ORGANIC DEVICE

This application is being filed on 27 April 2011, as a PCT International Patent application in the name of Orthogonal, Inc., a U.S. national corporation, applicant for the designation of all countries except the U.S., and Christopher K. Ober, a
5 citizen of the U.S., Jin-Kyun Lee, a citizen of the U.S., Alexander Zakhidov, a citizen of the U.S., Margarita Chatzichristidi, a citizen of Greece, Priscilla Taylor, a citizen of the U.S., and John DeFranco, a citizen of the U.S., applicants for the designation of the U.S. only, and claims priority to U.S. Patent Application Serial No. 61/343,362 filed on 27 April 2010.

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BACKGROUND

The present disclosure describes a method for forming an organic device. More specifically, the present disclosure describes a high resolution method for patterning a conductive material layer that is deposited over an electrically active organic layer.

15 Various devices are known that can employ organic semiconductor materials in conjunction with a conductive element. Included among these are Organic Light Emitting Diodes (OLEDs), Organic Thin-Film Transistors (OTFTs), Organic PhotoVoltaic (OPV) devices, and Organic Memory (OMEM). These organic electronic devices have the advantage over similar inorganic devices in that the
20 organic materials can be much less expensive and require less expensive deposition methods than similar inorganic materials and devices. Further, in some cases, including OLEDs, it is possible to create large, active devices using organic semiconductor materials with characteristics that cannot be achieved using inorganic analogs.

25 Each of these example organic devices requires the deposition of multiple layers of material, including organic semiconductors and electrically conductive layers. Further, these devices often require an electrically conductive layer to be formed both on a substrate before deposition of organic materials and over the organic semiconductor layer. Further, they often require each of these electrically
30 conductive layers to be patterned. To provide high quality devices, it is necessary to

pattern this conductive layer with high resolution and to achieve a low cost device; it is desirable to pattern this conductive layer over very large substrates. The requirement for high resolution is necessary to facilitate high density OTFTs having large channel width to length ratios, high aperture ratio OLEDs, high density
5 OMEM devices and high aperture ratio OPV devices.

In inorganic devices, it is known to apply photolithographic techniques to pattern multiple thin film layers of inorganic semiconductors and inorganic electrically conductive layers with high resolution over large substrates. Unfortunately, the photolithographic materials and solvents applied to form these devices are known to
10 dissolve organic materials. Therefore, it is not possible to apply the photolithographic materials and solvents that are known to be used in inorganic devices to pattern multiple layers within organic devices, especially layers that include organic materials or layers that are formed on top of organic materials.

To overcome this problem, other strategies for patterning the organic materials are
15 being developed including applying printing or selective deposition techniques, such as inkjet deposition, shadow mask deposition, vapor deposition through shadowmasks, soft and hard imprint lithography among other techniques. Unfortunately these methods have well known resolution limits, deposition speed limits, and substrate size limits that are undesirable. Further, only a subset of these
20 techniques, specifically vapor deposition or sputtering through a shadowmask, are relevant to the deposition and patterning of highly electrically conductive metals over an organic layer. Finally, many of these methods can be applied to pattern organic semiconductors and conductors but are not equally useful for patterning inorganic conductors, which are often preferred due to low relative resistance as
25 compared to organic conductors, over organic semiconductors.

Recently photoresist materials and solvents have been discussed in the art to facilitate the use of photolithographic techniques to pattern the organic semiconducting layers of organic devices. For example, Zakhidov et al. in an article published in *Advanced Materials* in 2008 on pages 3481-3484 and entitled
30 "Hydrofluoroethers as Orthogonal Solvents for the Chemical Processing of Organic Electronic Materials" discussed a method for patterning organic material in which a fluorinated photoresist was deposited on a substrate, selectively exposed to an

energy source to render insoluble a portion of the photoresist, developing the photoresist in a solvent including hydrofluoroether to develop the pattern and to remove the portion of the organic material that was not deprotected; restoring the solubility of the deprotected photoresist through the use of another solvent;

5 depositing an active organic semiconductor over the remaining photoresist and lifting off the remaining photoresist to pattern the active organic semiconductor. As such, this paper demonstrates the patterning of a single organic semiconductor on a substrate. The method does not, however, provide a method to pattern an electrically conductive layer and especially an electrically conductive layer formed

10 over an organic layer. The same general process has been discussed by Lee et al. in an article published in the Journal of the American Chemical Society in 2008 on pages 11564 through 11565 and entitled "Acid-Sensitive Semiperfluoroalkyl Resorcinarene: An Imaging Material for Organic Electronics".

Hwang et al. in an article published in the Journal of Materials Chemistry in 2008 on

15 pages 3087-3090 and entitled "Dry photolithographic patterning process for organic electronic devices using supercritical carbon dioxide as a solvent" discussed constructing a device having patterned light output by forming a photoresist layer over an organic conductor and developing a pattern in the photoresist layer using supercritical carbon dioxide. Light emitting materials and a cathode were deposited

20 over the organic conductor and the remaining photoresist pattern to form a device in which the photoresist served as an insulator to limit the flow of electrons within some regions of the device. However, the active layers of the device were not patterned and therefore individual light emitting regions of the device could not be individually addressed to form individual light-emitting elements or pixels.

25 Taylor et al. in an article published in Advanced Materials on March 19, 2009 on pages 2314-2317 and entitled "Orthogonal Patterning of PEDOT:PSS for Organic Electronics using Hydrofluoroether Solvents" discusses the formation of a bottom contact thin film transistor in which an organic conductor (i.e., PEDOT:PSS) is formed on a substrate, a photoresist is formed and patterned over the conductor, the

30 conductor is etched, a second photoresist is applied and patterned before an organic semiconductor (i.e., Pentacene) is applied and patterned. While this paper discusses patterning of two organic layers, it does not discuss patterning of a conductive layer

over an organic semiconductor layer as is often required in the formation of many organic electronics devices. Further, the conductor is patterned through the use of oxygen plasma etching.

As noted earlier, there is a need for a method to facilitate high resolution patterning of a conductor over an organic layer. Further, such a method should be applicable to
5 devices formed on large substrates.

SUMMARY

The present disclosure describes a method for high resolution patterning of a conductive layer over an organic semiconductor layer within an organic electronics
10 device. This method includes first providing a substrate and depositing organic materials over the substrate to form one or more organic layers. A photoresist solution is coated over the one or more organic layers to form a photo-patternable layer, wherein the solution includes a fluorinated photoresist material and a first fluorinated solvent. The photo-patternable layer is then selectively exposed to
15 radiation to form a first pattern of exposed fluorinated photoresist material and a second pattern of unexposed fluorinated photoresist material. The substrate is then exposed to a second fluorinated solvent to develop the photo-patternable layer, which removes the second pattern of unexposed fluorinated photoresist material without removing the first pattern of exposed fluorinated photoresist material. One
20 or more conductive layers are then coated over the one or more organic layers and a portion of one or more of the conductive layers is removed to form a pattern.

At least some of the examples in the present disclosure provide the advantage of facilitating high resolution patterning of a conductive layer over an organic semiconductor layer to form low cost, high resolution, organic electronics devices.
25 This method provides a photolithographic method for forming conductive layers over organic layers, permitting organic semiconductor devices to be formed using a method that is capable of providing extremely small feature sizes on the order of 1 micrometer or less and is applicable to large substrates. Specifically, this technique can be applied to produce high quality, high resolution top gate organic TFTs, high
30 density organic memory devices, and OLED and OPV devices with high aperture ratios on a large substrate using processing equipment similar to equipment that is

well known and accepted within the inorganic thin film semiconductor industry for creating electronic devices on very large substrates.

BRIEF DESCRIPTION OF THE DRAWINGS

- FIG. 1 flow diagram depicting the steps of one embodiment of the present invention;
- 5
- FIG. 2 process diagram depicting the various stages of the development of a device formed using one embodiment of the method of the present invention;
- FIG. 3A plot showing response curves for a top-contact organic TFT formed using a method according to one aspect of the present invention;
- 10
- FIG. 3B plot showing response curves for a second top-contact organic TFT formed using a method according to one aspect of the present invention;
- FIG. 4 flow diagram depicting the steps for forming a top-contact organic TFT according to a method according to one aspect of the present invention;
- FIG. 5A-5J a series of top views of an array of organic TFTs formed according to a method according to one aspect of the present invention with each figure depicting the array at various stages of development
- 15
- FIG. 6 an image of a ring oscillator formed using a method according to one aspect of the present invention; and
- FIG. 7 a flow diagram depicting the steps for forming a pixilated organic device
- 20
- having a patterned top electrode according to an embodiment of the present invention.

DETAILED DESCRIPTION

The present disclosure describes a method for forming an organic device on a substrate with a patterned conductive layer, where the organic device includes an active organic layer formed between the substrate and the patterned conductive layer. Specifically, the present disclosure describes a process, in which a photoresist material and the conductive layer to be deposited over an active organic layer. The photoresist material is patterned and this pattern of photoresist material is either

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removed, simultaneously removing a portion of the conductive layer, or is used to protect a portion of the conductive layer during an etching process, permitting the remaining portion of the conductive layer to be removed. The use of fluorinated photoresist materials and solvents permits photolithographic techniques to be
5 utilized to pattern the conductive layer without disturbing the underlying organic materials.

One embodiment of a method of the present invention for forming an organic device having a patterned conductive layer in contact with and over at least a portion of an organic layer is depicted in the flow diagram of FIG. 1. FIG. 2 accompanies FIG. 1
10 and shows an organic device **20**, specifically portions of a top contact organic TFT, at various stages of development during this process. Within this method, the conductive layer is deposited over an organic layer such that it is in electrical contact with at least a portion of the organic layer and then patterned. As shown in FIG. 1, this method includes first providing **2** a substrate **22** as shown at stage **32** in FIG. 2.
15 One or more layers of organic semiconductor material, specifically a single layer of Pentacene in the device of FIG. 2, is then deposited **4** over the substrate **22** to form one or more organic layers **24**. As shown at stage **34** of FIG. 2, this forms a uniform layer of the organic layer pentacene over the substrate **22** within the active area of the device.

20 A photoresist solution is coated **6** over the one or more organic layers **24** to form a photo-patternable layer **26**, providing the structure as shown in stage **36** of FIG. 2. Typically, after coating, this photoresist solution is dried to remove the excess solvent. This photoresist solution includes a fluorinated photoresist material and a first fluorinated solvent. Portions of the photo-patternable layer **26** are selectively
25 exposed **8** to radiation to form a first pattern of exposed fluorinated photoresist material **26a** and a second pattern of unexposed fluorinated photoresist material **26b**. The first pattern of exposed fluorinated photoresist material **26a** and second pattern of unexposed fluorinated photoresist material **26b** is depicted in stage **38** of FIG. 2. A second drying or baking step can be performed after this exposure **8**.

30 The substrate **22**, including the photo-patternable layer **26** of photoresist material, is then exposed to a second fluorinated solvent to develop **10** the photo-patternable layer. This solvent removes the second pattern of unexposed fluorinated photoresist

material **26b** without removing the first pattern of exposed fluorinated photoresist material **26a**. As a result, the first pattern of exposed fluorinated photoresist material **26a** remains on the substrate **22** as shown in stage **40** of FIG. 2. As shown in FIG. 2, in certain embodiments, it is useful for the remaining first pattern of exposed fluorinated photoresist material **26a** to be undercut, such that the width **30** of the remaining first pattern of exposed fluorinated photoresist near the top of the first pattern of exposed fluorinated photoresist is greater than the width of the first pattern of exposed fluorinated photoresist at a point closer to the substrate **22**. While this undercut is desirable within some embodiments, other shapes of this first pattern of exposed fluorinated photoresist can be desirable in other embodiments.

One or more conductive layers **28** are then coated **12** over the one or more organic layers **24**. As shown in stage **42** of FIG. 2, this conductive layer **28** is coated over the organic layer **24** in the areas where the second pattern of unexposed fluorinated photoresist was removed and over the first pattern of exposed fluorinated photoresist **26a** in the areas where this first pattern of exposed fluorinated photoresist **26a** remains over the organic layer **24**. As shown in FIG. 2, the one or more conducting layers **28** can be coated through the use of a line of sight method, such as vapor deposition. Using a process such as this, the undercut provided in the first pattern of exposed fluorinated photoresist material, permits shadowing of the organic layer, such that the conductive layer **28** contains voids due to shadowing of the organic layer by the first pattern of exposed fluorinated photoresist material **26a**. As such, the conductive layer **28** can be divided into discontinuous segments, specifically first segment **28a** and second segment **28b** of conductive layer **28** in FIG. 2. This void permits the third solvent access to the first pattern of exposed fluorinated photoresist material **26a**. In another embodiment, the first pattern of exposed fluorinated photoresist material will not be undercut or a nondirectional coating process, such as sputtering can be applied which would permit the conductive layer **28** to be coated against the remaining first pattern of exposed fluorinated photoresist material **26a**. However, the thickness of this first pattern of exposed fluorinated photoresist material **26a** can be such to create pinholes or other voids in this layer along the edges of the first pattern of exposed fluorinated photoresist material. Such voids are important when the conductive layer is a metal or a doped inorganic oxide such that the third solvent can gain access to the first pattern of exposed fluorinated

photoresist material. These voids are not necessarily as important when the conductive layer is an organic material.

Finally, a portion **28b** of the first pattern of exposed fluorinated photoresist material is applied to remove **14** a portion of one or more of the conductive layers **28** to form
5 a patterned conductive layer **28a**. The portion **28b** of one or more of the conductive layers can be removed through one of multiple processes. Shown in FIG. 1, the one or more conductive layers **28a**, **28b** are coated over the first pattern of exposed fluorinated photoresist material **26a** and the step of developing **12** the photoresist permits the first pattern of exposed fluorinated photoresist material **26a** to be
10 removed, removing **12** a segment **28b** of one or more of the conductive layers through liftoff. Therefore, the step of applying the first pattern of exposed fluorinated photoresist material to remove **14** a segment **28b** of one or more of the conductive layers involves exposing the substrate **22** to a third fluorinated solvent to strip **16** the exposed fluorinated photoresist material **26a** and the segment **28b** of the
15 one or more conductive layers **28a**, **28b** that were deposited over the first pattern of exposed fluorinated photoresist material **26a**.

Within the present disclosure, the term “substrate” refers to any support on which organic materials can be coated to provide structural integrity. Substrates known in the art include rigid substrates, such as those typically formed from glass, and
20 flexible substrates, such as typically formed from stainless steel foil or plastic. The substrate **22** can also provide a portion of an environmental barrier to protect the organic material from moisture or oxygen, but this is not required. The substrate **22** can be opaque, transparent or semitransparent. The substrate **22** can further include one or more inorganic layers, such as metal buss lines or inorganic semiconductor
25 materials for conducting electricity to the organic device. The substrate **22** can include nonconductive layers of organic material to perform functions, such as insulating the active organic layer from conductive elements on the substrate or smoothing the surface of the substrate to permit a uniform layer of active organic materials **24** to be formed.

30 The term “organic layer” in the present disclosure refers to a layer of organic chemical compounds that provide an active electrical function. The organic materials from which the organic layer **24** will be formed will commonly be

semiconductors and will typically be formed in one or more thin layers, often less than 50 nm in thickness. These organic materials can be small molecule organic materials, monomers, polymers or mixtures of these materials. Within processes described in examples in the present disclosure, small molecule and monomer materials will commonly be coated using vacuum deposition. However they can also be solution coated. Polymers will typically be solution coated. Within some preferred embodiments of the present invention, these organic materials will be blanket coated. That is they will be deposited to uniformly coat a single large area of the substrate **22** to form the organic layer **24**. However, this is not required and in some embodiments, these materials can be patterned on the substrate **22** as they are deposited forming an organic layer **24** that is discontinuous across the surface of the substrate **22**. In a preferred embodiment, it is desirable for the last active organic material to be deposited before coating **6** the photoresist or coating **12** the conductive layer to contain polymer strands to provide stability to the organic layer. As such, the step of depositing organic materials over the substrate includes depositing at least one polymeric organic material and the photoresist solution is coated directly on top of the at least one polymeric organic material. By providing an active electrical function, the organic material serves to conduct electricity, serves as a semiconductor to control the flow of electricity, or serves as an insulator to prevent or reduce the flow of electricity.

In examples described in the present disclosure a photoresist solution is coated "over" the one or more organic layers to form a photo-patternable layer. The term "over" is defined such that an organic layer is deposited on the substrate prior to coating the photo-patternable layer. In some embodiments, the photo-patternable layer will be coated immediately on top of one or more organic layers. In another embodiment, one or more organic layers will be deposited and a patterned inorganic layer will be created over the organic layer, covering a portion of the organic layer and the photoresist solution will be coated such that it is in direct contact with a portion of the organic layer, without having any intermediate inorganic layer. In further embodiments, an inorganic layer is formed over the organic layer before applying the photoresist solution. Although it is possible that the inorganic layer could provide protection to the organic layer, in practical devices voids within the inorganic layer will often prevent such an inorganic layer from providing effective

protection to the organic layer from the photoresist solution and the second and third solvents. Therefore, in some embodiments it is important to use the fluorinated photoresist and solvents described in the present disclosure to achieve high yield even in circumstances where the organic layer is deposited onto the substrate prior to exposing the substrate to a photoresist solution even when the organic layer is somewhat protected by an intervening inorganic layer.

The term "conductive layer" refers to layer or a combination of multiple thin film layers formed after an organic layer, wherein the layer or combination of thin film layers functionally provide a single conductive element which is capable of creating an electrical field within the organic layer. The conductive layer can be transparent, semi-transparent, or opaque. Typical conductive layers useful in embodiments of the present invention will have a thickness of between 10 nm to permit the formation of a continuous film and less than 300 nm to permit the film to be permeated by the solvents described in the present disclosure. This conductive layer can be formed from organic or inorganic materials capable of providing electricity to the organic semiconductor layers. However, in some preferred embodiments of the present invention, these conductive layers will include an inorganic metal. This inorganic metal will preferably be applied through vapor deposition or sputtering.

Typical inorganic materials useful in forming such a conductive layer will include metals such as silver, gold, platinum, copper and aluminum; as well as certain doped metal oxides, such as indium tin oxide or indium zinc oxide. Once again, conductive layers can be formed using multiple methods including printing or sputtering. However, as discussed earlier, it can be desirable in certain embodiments to deposit the inorganic conductive layers using evaporation or other methods that provide line of sight deposition.

Typical organic materials for forming the conductive layer include highly ordered polymers, such as PEDOT/PSS. Conductive layers formed from organic materials can be formed using numerous methods, including printing methods. However, to increase deposition speed and decrease process time, it is preferred that these materials be deposited using blanket-coating methods including hopper or slot coating.

The fluorinated photoresist material can be a resorcinarene, a random copolymer of perfluorooctyl methacrylate with 2-nitrobenzyl methacrylate (to form "FOMA-NBMA"), a random copolymer of perfluorooctyl methacrylate with tert-butyl methacrylate (to form "FOMA-TBMA"), a random copolymer of perfluorodecyl methacrylate with 2-nitrobenzyl methacrylate (to form "FDMA-NBMA"), a random copolymer of perfluorodecyl methacrylate with tert-butyl methacrylate (to form "FDMA-TBMA"), block copolymers of FOMA-NBMA, FOMA-TBMA, FDMA-NBMA, FDMA-TBMA, derivatives thereof or other polymer photoresist or molecular glass photoresist having sufficient content to permit the photoresist to be dissolved in a fluorinated solvent such as a solvent formed from a hydrofluoroether. This fluorinated photoresist can be solubilized in a hydrofluoroether such as methyl nonafluorobutyl ether and then coated onto a substrate described in the present disclosure. The solvent can then be evaporated to form a photo-patternable layer. This first solvent will typically also include a photo-acid generator, for example N-hydroxynaphthalamide perfluorobutylsulfonate or other known photo-acid generator. In the presence of proper exposure, this photo-acid generator will liberate H⁺, which will react with the fluorinated photoresist material to transform it into an insoluble form. These materials and their use in conjunction with fluorinated solvents for performing photolithographic steps have been discussed in more detail in a co-pending document with the serial number PCT/US09/44863 and entitled "Orthogonal Processing of Organic Semiconductors," the contents of which is incorporated in its entirety herein.

In a preferred (but non-limiting) embodiment this photoresist can be a material composed of a copolymer of 1H,1H,2H,2H-perfluorodecyl methacrylate (FDMA) and tert-butyl methacrylate (TBMA). This material was found to have a high fluorine content to make it soluble in the fluorinated solvents described in the present disclosure. This statistical copolymer of FDMA and TBMA was prepared by free radical polymerization under a nitrogen atmosphere. A 25 ml round bottom flask equipped with a stir bar was filled with 1.4g of FDMA, 0.6g of TBMA, 0.01 g of AIBN and 2 ml of trifluorotoluene as a solvent. After polymerization, the reaction mixture was poured into hexane to precipitate the polymer and then filtered and dried under vacuum. The molecular weight of the copolymer was determined to be 30400 by size-exclusion chromatography and the molar composition of

FDMA:TBMA was found to be 35 mol%:65 mol% using ¹H NMR (Varian Inova-400 spectrometer) analysis with CDCl₃-CFC₃ (v/v – 1:3.5) as a solvent. The FDMA component of the resist is responsible for the solubility of the copolymer in fluorinated solvents whereas the TBMA groups in the unexposed regions make the copolymer less polar in the butyl-protected state. Upon exposure to a
5 photogenerated acid, these protecting groups undergo a chemically amplified deprotection reaction. The resulting polar methacrylic acid (MAA) units decrease copolymer solubility in fluorinated solvents. After the photo-patternable layer **26** is formed from this material together with a photoacid generator and exposed **8**, the
10 exposed pattern can be treated with a solubilizing agent, for example a silazine such as HMDS. This treatment re-protects the P(FDMA-*co*-MAA) film with siloxane groups and makes it soluble within fluorinated solvents to facilitate its removal for liftoff.

In another preferred (but non-limiting) embodiment the photoresist can be a
15 copolymer of FOMA and TBMA. For example, a solution of 110.10 g (0.7743 mol.) of tert-butyl methacrylate, (TBMA), 330.07 g (0.7636 mol.) of 1H,1H,2H,2H-perfluorooctyl methacrylate, (“FOMA”), 874.2 g of Novec 7600 and 5.51 g (0.0335 mol.) of azobisisobutyronitrile, (“AIBN”) was stirred in a jacketed reaction flask. The flask jacket was connected to a programmable, constant temperature bath
20 (“CTB”) capable of heating and maintaining a set jacket temperature. The solution was sparged with nitrogen at a rate of 0.5 L/minute for 1 hour at ambient temperature. A CTB program was initiated which heated the reaction jacket to 68 °C, holds this temperature for 1 hour, heats to 72 °C and holds for 1 hour, and finally heats to 76 °C and holds for 12 hours. When the heating program was completed,
25 the CTB was set to cool the reaction mixture to ambient temperature. The clear, colorless polymer solution obtained was diluted to a viscosity target by the addition of 3.714 kg of Novec™ 7600, and a small sample was removed and dried under vacuum for later characterization. In one embodiment, under yellow lights, 22.0 g of CIBA/BASF CGI-1907 photo acid generator (“PAG”) (5% by weight of the
30 original dry weight of TBMA) was dissolved in the remaining photoresist solution. The solution was filtered, and was then ready for use in the same fashion as was described above for FDMA-TBMA.

It should be noted that the resorcinarene, FOMA:TBMA and FDMA:TBMA random and block copolymers are chemically amplified resists. Within embodiments of the present invention, this attribute of these resists can be particularly desirable since they enable the expose photoresist step 8 to be performed through the application of a relatively low energy UV light exposure. This low energy UV light exposure will preferably require less than 1000 mJ/cm² and more preferably less than 100 mJ/cm² of energy. This is helpful since many organic materials useful in forming the one or more organic layers 24 will decompose in the presence of UV light and therefore, reduction of the energy during this step permits the photoresist to be exposed 8 without causing significant damage to the underlying one or more organic layers 24. Further, due to the high fluorine content in each of these photoresists, they are both hydrophobic and oleophobic. That is, the resulting material repels or resists both water and most organic solvents, permitting these materials to serve as an in-process encapsulation layer to protect the underlying organic materials from moisture and damage from organic solvents.

Fluorinated solvents appropriate for use of the first, second or third fluorinated solvent is perfluorinated or highly fluorinated liquids, which are typically immiscible with organic solvents and water. Among these solvents are one or more hydrofluoroethers (HFEs) such as methyl nonafluorobutyl ether, methyl nonafluoroisobutyl ether, isomeric mixtures of methyl nonafluorobutyl ether and methyl nonafluoroisobutyl ether, ethyl nonafluorobutyl ether, ethyl nonafluoroisobutyl ether (HFE 7100), isomeric mixtures of ethyl nonafluorobutyl ether and ethyl nonafluoroisobutyl ether (HFE 7200), 3-ethoxy-1,1,1,2,3,4,4,5,5,6,6,6-dodecafluoro-2-trifluoromethyl-hexane (HFE 7500), 1,1,1,2,2,3,4,5,5,5-decafluoro-3-methoxy-4-trifluoromethyl-pentane, 1, 1,1,2,3,3,3-hexafluoro-4-(1,1,2,3,3,3,-hexafluoropropoxy)-pentane (HFE 7600) and combinations thereof. The fluorinated solvent may also be selected from a broad range of fluorinated solvents, such as chlorofluorocarbons (CFSs): C_xCl_yF_z, hydrochlorofluorocarbons (HCFCs): C_xCl_yF_zH_w, hydrofluorocarbons (HFCs): C_xF_yH_z, perfluorocarbons (FCs); C_xF_y, hydrofluoroethers (HFEs): C_xH_yOC_zF_w, perfluoroethers: C_xF_yOC_zF_w, perfluoroamines: (C_xF_y)₃N, trifluoromethyl (CF₃)-substituted aromatic solvents: (CF₃)_xPh [benzotrifluoride,

bis(trifluoromethyl)benzene]. Other fluorinated solvents are also known and could be equally well applied for use in the first, second, or third fluorinated solvent.

The photoresist solution will typically include the photoresist material as described above in a fluorinated solvent, for example HFE 7500. Additionally, when the
5 photoresist is a chemically amplified resist material, such as a resorcinarene or the FDMA/TBMA copolymer, this solution will additionally contain a photoacid generator. An appropriate photoacid generator is 2-[1-methoxy]propyl acetate (PGMEA).

Generally, it is desirable that the first fluorinated solvent have a higher boiling point
10 than the second and third fluorinated solvent. Generally, the first fluorinated solvent will typically have a boiling point above 110 degrees Celsius while the second and third fluorinated solvents will have a boiling point below 110 degrees Celsius. For example, the first solvent can include HFE 7500 having a boiling point of 131 degrees Celsius at atmospheric pressure while the second and third solvents can
15 include HFE 7200 having a boiling point of 76 degrees Celsius at atmospheric pressure. The selection of these boiling points in this way serves to prevent any of the first fluorinated solvent remaining after the first baking step from being evaporated during later baking steps, reducing the dimensional stability of the first pattern of exposed photoresist material. Further, any baking or drying step
20 performed after the expose photoresist step 8 should be performed at a temperature less than the boiling point of the first fluorinated solvent and typically under 100 degrees Celsius.

The third fluorinated solvent will typically include a solubilizing agent to permit the
25 pattern of exposed photo-patternable material to become soluble in the fluorinated solvent. For example, materials such as a silazine, for example hexamethyldisilazane (HMDS; 1,1,1,3,3,3-hexamethyldisilazane) can be added to the third fluorinated solvent to render the first pattern of exposed photo-patternable material soluble. Such an agent can be added to a fluorinated solvent to form the third solvent, for example the third solvent can contain 5% HMDS and 95% HFE
30 7200. Other useful solubilizing agents include isopropyl alcohol (IPA) which can be formulated similarly to form a third solvent containing 5% IPA and 95% HFE 7200.

As noted earlier, a portion of the photoresist can be exposed to radiation to form a first pattern of exposed fluorinated photoresist material **26a** and a second pattern of unexposed photoresist material **26b**. For example, an ultraviolet lamp having a wavelength of 248 nm can be used to radiate the photoresist or a lamp with another wavelength, for example 365 nm can be applied. Experiments have verified that when the photoresist is formed from resorcinarene, an exposure of an exposure of about 84 mJ cm² at 248 nm is adequate to enable the necessary reaction while a dose of about 2700 mJ cm² is required when the wavelength is 365 nm.

As noted earlier, in some embodiments, it is useful for the exposure to create a profile that is an "undercut" profile, which is defined as having a width **30**, as shown in FIG. 2, measured along a line parallel to the substrate **22** that is larger at a distance farther from the substrate **22** than a distance nearer the substrate **22**, thus having a shape similar to the shape of **26a**. This undercut profile can be created through a number of possible methods; however, when applying the chemically amplified resists as described earlier, the inventors have observed that such a profile can be achieved by defocusing the radiation source, thus creating a defocused exposure.

The process provided in FIG. 1 has been applied to form a top contact thin film transistor, a portion of the layers from which were shown in FIG. 2. Experiments have demonstrated that the second pattern of unexposed fluorinated photoresist material was removed from the top of the organic layer **24**, permitting a low contact resistance between the conductive layer **28a** and the organic layer **24**. Therefore, this process was demonstrated to form a high quality top contact thin film transistor. This top contact organic TFT was shown to have certain advantages over the bottom contact organic TFTs discussed by Taylor in the prior art. Specifically the organic layer described in the present disclosure is uniform across the entire substrate and the contact resistance between the conductive layer and the organic layer is low permitting the transistor to have a low threshold.

The current at the drain of a TFT, which was formed using a method described in the present disclosure, as a function of the voltage differential between the source and drain is shown in the plot **52** of FIG. 3a. As this figure shows, the TFT permits the modulation of current at the drain as a function of gate voltage as illustrated by

the curves **54**. By fitting an equation $I = W/2L * u * C_r * (V_G - V_{TH})^2$ to these curves where I is the drain current, W and L are the width and length of the TFT channel, respectively, u is the mobility of the semiconductor in the TFT, C_r is the capacitance per unit area of the gate dielectric, V_G is the gate voltage and V_{TH} is the threshold voltage of the TFT; it was determined that the mobility of the resulting TFT could be as high as $0.45 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$. This is significantly higher than the mobility of the TFT reported by Taylor of $0.03 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ for a bottom contact TFT formed from similar materials.

Alternatively, top contact TFTs were formed using Poly (3-Hexylthiophene) – (P3HT) as an organic semiconductor. The performance of the top contact TFT formed using this semiconductor is shown in the plot **56** of FIG. 3B. Once again drain current can be controlled by selection of the gate voltage as shown by curves **58**. The mobility for this device was $0.01 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$, which is lower than the mobility of the device employing Pentacene as expected. However, the mobility of this device is superior to devices using the same organic semiconductor that have been reported in the prior art.

Critical to the formation of such a top-contact TFT is the ability to successfully pattern the conductive layer **28** on top of an organic layer **24** such that the interface is robust between the two layers **24**, **28**, having a low resistivity. The inventors have demonstrated for the first time, the formation and removal of a photolithographic step on top of an organic layer to form such a top contact TFT. This process of performing photolithographic steps on top of organic layers, however, enables the construction of multiple, valuable organic electronic structures.

Although the method described in the present disclosure can be important to facilitate the formation of a single top-contact thin-film transistor, the method of described in the present disclosure can be utilized to form an array of multiple top-contact TFTs on a single substrate that is coated with a one or more conductive layers wherein these conductive layers are originally formed from a single conductive layer that is continuous over a large portion of the substrate. One method for forming such an array of multiple top-contact TFTs using a method described in the present disclosure is provided in the flow chart of FIG. 4 and a top view of one device formed through this process is depicted at various stages of

development within FIG. 5A through FIG. 5J. As shown in FIG. 4, a substrate is provided **62**. This substrate **90**, as shown in FIG. 5A has an array of one or more gate conductors **92a, 92b, 92c, 92d** and gate busses **94a, 94b** formed on the substrate **90**. The gate conductors will provide the gates for four separate top-
5 contact TFTs within this example and the two gate busses **94a, 94b** provide lines to provide a signal to the gate conductors **92a, 92b, 92c, 92d**. This substrate **90** can additionally have an insulating or dielectric layer **96** formed over the gate busses and importantly the one or more gate conductors **92a, 92b, 92c, 92d**. The gate
10 conductors, gate busses and insulating layer **96** can be formed from inorganic materials and can be patterned using known methods of the prior art, including through the use of traditional photolithographic techniques. Alternately, portions of these structures can be patterned using fluorinated photoresist materials and solvents and could be formed from organic materials.

An organic semiconductor layer can then be formed **64** over the substrate such that it
15 consists of an array of one or more discrete islands of organic semiconductor **106a, 106b, 106c, 106d** (as shown in FIG. 5F), wherein each discrete island of organic semiconductor is continuous over the substrate within the area of each TFT. Each island of organic semiconductor will form the channel of a TFT and will provide contact to the drain and source of the TFT. Note that the organic semiconductor
20 materials in this case are not continuous between the areas of neighboring TFTs. The organic semiconductor materials could be coated such that discrete islands of the organic semiconductor materials are formed within the area of each of the one or more TFTs using any desired method. However, according to a preferred embodiment of the present invention, these discrete islands are formed using the
25 steps indicated in detail within step **64** of FIG. 4.

Within the preferred embodiment, the method for forming **64** the discrete islands includes coating **80** a photoresist solution over the substrate **90** to form a photo-patternable layer **98** as shown in FIG. 5C. This photo-patternable layer is selectively
30 exposed **82** to radiation to form a third pattern of exposed photoresist material **100** and a fourth pattern of unexposed photoresist material **102**, wherein the third pattern of exposed photoresist material **100** is arranged to provide separation between the discrete islands of organic semiconductor material. The photo-patternable layer is

then exposed to a solvent to develop **84** the photo-patternable layer, removing the fourth pattern of unexposed photoresist material without removing the third pattern of exposed photoresist material. As shown in FIG. 5E, the result is a substrate with the third pattern of exposed photoresist material covering the majority of the substrate, with voids **104a, 104b, 104c, 104d** to the structure of the substrate that was formed before formation of the photo-patternable layer. Next an organic semiconductor layer is coated **86** over the third pattern of exposed photoresist material **100** and the voids **104a, 104b, 104c, 104d**. Finally, the third pattern of exposed photoresist material is exposed to an additional solvent to remove the third pattern of exposed photoresist material and the portions of the organic semiconductor layer over the third pattern of exposed photoresist material to pattern **88** the organic semiconductor layer into discrete islands of organic semiconductor materials **106a, 106b, 106c, 106d** as shown in FIG. 5F within the area of each top-contact TFT within the array of top-contact TFTs. Once one or more discrete islands of organic-semiconductor materials have been formed on the substrate **90**, the remaining steps (e.g., steps **66** through **74**) of the method to form the array of one or more top-contact TFTs can be performed.

The flow chart in FIG. 4 shows the remaining steps of this process. These include coating **66** a photoresist solution over the organic semiconductor layer to form a photo-patternable layer **108** as shown in FIG. 5G. This solution is then dried. Portions of the photo-patternable layer are then selectively exposed **68** to radiation to form a first pattern of exposed photoresist material **110** and a second pattern of unexposed photoresist material, indicated by pattern areas **112a 112b 112c 112d 112e**, wherein a portion of the first pattern of exposed photoresist material is deposited **70** over one or more of the discrete islands of organic semiconductor material **106a, 106b, 106c, 106d** in FIG. 5F and a portion of the first pattern of exposed photoresist material is deposited between the one or more discrete islands of organic semiconductor material. The portion of this first pattern of exposed photoresist material deposited over the one or more discrete islands of organic semiconductor material will define the channel of the TFT and the portion of this first pattern of exposed photoresist material deposited between one or more discrete islands of organic-semiconductor material will provide a separation between neighboring top-contact TFTs within the array of top-contact TFTs. The photo-

patternable layer is then exposed to a second solvent to develop **70** the photo-patternable layer, removing the second pattern of unexposed photoresist material without removing the first pattern of exposed photoresist material. One or more conductive layers are then coated **72** over at least a portion of the organic

5 semiconductor materials and the first pattern of exposed photoresist material to form an electrical contact between the one or more conductive layers and the organic semiconductor materials on at least two sides of the first pattern of exposed photoresist materials. This conductive layer is shown as **114** in FIG. 5I. Finally, the first pattern of exposed photoresist material is exposed to a third solvent to remove

10 **74** the first pattern of exposed photoresist material and at least a portion of the one or more conductive layers **114** to form a channel **120** between two discrete portions **122** and **124** of the one or more conductive layers for each of the thin-film transistors in the array of thin-film transistors as shown in FIG. 5J. The channel has a length **116** and a width **118**, the width **118** is typically more than twice the length

15 **116**. Note that in preferred embodiments, the first pattern of exposed photoresist material is a two-dimensional structure which simultaneously defines at least the channel **120** of one top-contact TFT and a separation region **126** between two adjacent top-contact thin film transistors **128a**, **128b** in the array of top-contact thin film transistors formed on the substrate **90**. In this preferred embodiment, the step

20 of exposing the first pattern of exposed photoresist material to a third solvent removes the first pattern of exposed photoresist material and a portion of the one or more conductive layers to define not only the channel itself but additionally the ends of the channel in the dimension parallel to the length of the channel to form the separation region **126** between adjacent top-contact TFTs **128a**, **128b**.

25 It can be noted that as described thus far, the method described in the present disclosure uses a photolithographic process to perform liftoff of the one or more conductive layers on top of the organic layer to remove **14** a portion of the conductive layer. It is also possible to coat the one or more conductive layers over the organic layers before coating the substrate with the photoresist solution to form

30 the photo-patternable layer. This photo-patternable layer can then be selectively exposed using techniques such as electron beam lithography to form very small features and the second pattern of unexposed fluorinated photoresist material removed. Finally, a portion of one or more of the conductive layers can be removed

using an etching process in the areas where the photo-patternable layers were removed. Thus the first pattern of exposed photoresist material is once again applied to remove 14 a portion of the conductive layer.

It should be noted that after the substrate 90 is coated with the photoresist solution, it is generally necessary to dry or bake the substrate to remove excess solvent from the photoresist solution. In actuality, the substrate is typically baked twice. The first baking step is typically conducted after the photoresist solution is deposited over the substrate to remove the excess solvent. Secondly, the substrate is often baked after selectively exposing portions of the photo-patternable layer to eliminate unwanted byproducts, such as nitrobenzyl groups that are created during the expose step and that can reduce the structural stability of the exposed resist material, or to thermally activate the cleaved photoacids when applying chemically amplified resists.

In one aspect of the present disclosure, the active semi-conductive and conductive organic materials, as well as certain conductive metals are highly reactive with oxygen and can be degraded by moisture. As such, the processing and development of devices containing these materials is sometimes critical. Small molecule organic materials and thin films of metal or doped metal oxides are often deposited within a vacuum which is void of moisture and oxygen. Therefore, contamination by oxygen or moisture is not an issue in these environments. However, at some of the photoresist materials and solvents described in the present disclosure cannot be handled in a vacuum. Therefore, it may be necessary to transport the substrate out of the vacuum after completion of vacuum deposition steps and into inert environments having near atmospheric pressure. In one embodiment, the photoresist materials and solvents will be applied within a dry nitrogen environment. Further, once the photoresist materials are applied, they provide a moisture barrier until they are removed. Therefore, the substrate can be removed from the dry nitrogen environment after an initial drying period and transferred to a baking oven within a normal atmospheric environment which contains moisture.

The term "near atmospheric pressure" refers to an environment that is not a vacuum. When vapor depositing small molecule OLEDs to obtain high efficiency and lifetime in embodiments of the present invention, it is helpful to remove the

substrate from the vacuum to coat **66, 80** the photoresist, expose **68, 82** the photoresist, develop **70, 84** the photoresist, and liftoff a portion of the photo-patternable layer to pattern **88** the semiconductor layer or remove **74** a portion of the conductive layer. Therefore, these operations must be performed in at “near
5 atmospheric pressure”. This term therefore applies to environments with between 0.01 Torr and 1000 Torr of pressure, more preferably between 1 and 1000 Torr of pressure and more preferably between 100 and 1000 Torr of pressure. Alternatively, “vacuum” refers to an environment with an atmospheric pressure significantly less than 0.01 Torr and commonly less than 10^{-4} Torr.

10 When applying polymeric active semi-conductive and conductive organic materials, as well as certain conductive metals or doped metal oxides, these materials can be coated using solution processing. For instance, it is possible to coat polymers in solution and it is possible to coat metal pastes or metal nanoparticles in solution. When applying these types of materials, the step of coating the one or more organic
15 layers will include depositing solutions containing these materials over the substrate and a drying process to remove the solvents from these materials. This coating and drying process can also take place in a dry nitrogen environment at, near or below atmospheric pressure.

20 In embodiments of the present invention, it is possible to coat the organic semiconductor materials, the conductive materials or the photolithographic materials using a printing process or other selective deposition technique. However, such methods are not necessary and are often slower than blanket-coating processes. Therefore, in preferred embodiments of the present invention at least one and
25 preferably all three of these processes include a blanket coating process in which the coating process involves coating these materials in one continuous sheet across the surface of the substrate. When evaporating or sputtering materials, this will include performing these steps in such a way that the entire surface to be coated is exposed to the deposition process such that at least the entire width or length of the area to be
30 coated is simultaneously exposed. When performing solution coating, this step will include exposing at least the entire width or length of the area to be coated simultaneously, for instance using slot or hopper coating techniques but can include two dimensional coating techniques, such as spin coating.

To further illustrate the usefulness of the present invention, an example method according to the present invention was applied to form a hybrid electronic circuit containing both inorganic and organic materials. Specifically, this method was applied to form a ring oscillator containing a connected network of TFTs using organic semiconductor materials. To build this ring oscillator poly(2,5-bis(thiophene-2-yl)-3,7-ditri-decanyltetrathienoacene) (P2TDC13FT4) was selected as the organic semiconductor. This polymer was selected since it can easily be formed via spin-coating and is environmentally stable, permitting this spin coating to be performed in air.

To develop this device, a substrate, specifically a silicon wafer, was provided **2**. A 40 nm gold film was deposited and patterned to be the Gate electrode for each of 5 TFTs within the ring oscillator. Then 50 nm of Al₂O₃ followed by 2 nm of SiO₂ were deposited by atomic layer deposition and patterned to form the gate dielectric for each TFT. SiO₂ termination was selected since silicon oxide can be easily primed by silanes, such as hexamethyldisilazane. Then a Cr/Au interconnect layer was formed and patterned to connect the TFTs to one another. Each of these layers was formed from inorganic layers and could have been formed with traditional photolithographic methods, photoresists, and solvents. However, in this device, each of these layers was patterned using the photolithographic methods and materials as discussed within this disclosure. Specifically, liftoff was performed using highly-fluorinated photoresists and hydrofluoroethers as solvents.

Next 50 nm of P2TDC13FT4 was deposited to form the organic layer **24** within the area of the channel for each of the five TFTs. Note at this point, the P2TDC13FT4 is continuous over the channel of each TFT. Thus this patterning step creates discrete islands of organic semiconductor material (e.g., **106a**) within the channel area of each TFT. Finally, the process in certain embodiments of the present invention was applied with 40 nm of Au being applied over the first pattern of exposed fluorinated photoresist material to serve as the conductive layer **28**. This photoresist material was lifted off using hydrofluoroether as a solvent to remove a portion of the conductive layer according to an embodiment of the present invention.

A semi-perfluoroalkyl reorcinarene small molecule compound was used as the resist for the first two layers, namely the gate and the dielectric layers. A polymeric resist, specifically the copolymer of FDMA and TBMA, was used as the photoresist for the remaining three steps, specifically the interconnect layer, the organic layer and the top conductive Au layer.

A microscopic image of a ring oscillator **132** formed using the process according to certain embodiments of the present invention is shown in FIG. 6. As shown, the TFTs **134a**, **134b**, **134c**, **134d**, and **134e** have a channel length **116** of 1 micrometer. Also shown is an inverter **136** formed using the method in an embodiment of the present invention. Alignment of the layers was always better than 1 micrometer, demonstrating the alignment accuracy of the present method. For these devices mobilities of 0.05 to 0.1 $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ with a threshold voltage of -7V were observed. These devices had an on/off ratio reaching 10^5 . The ring oscillator began to oscillate at about 12 Volts and reach an oscillation frequency of 15 kHz at 55V. This corresponds to a delay of 7 microseconds per stage, which compares favorably with organic TFT ring oscillators made with other methods. Note that the TFTs were successfully formed, indicating the ability to pattern an inorganic conducting layer **28** over an organic layer **24** to form the channel of the TFTs. These devices were formed with high yield and a small channel length, demonstrating the ability of the method according to certain aspects of the present invention to successfully pattern small features in an organic or inorganic conducting layer that is deposited on top of an organic layer of active semiconductor. Further, since the materials according to certain embodiments of the present invention provide the ability to use fabrication equipment similar to that used for traditional photolithographic patterning of purely inorganic devices, this demonstrates the usefulness of certain embodiments of the present invention to create organic electronics devices using equipment and methods similar to those used within the inorganic electronics industry. In addition, this device demonstrated the ability to use the fluorinated photoresists and solvents to pattern inorganic and organic layers that are deposited on the substrate such that the layers are interspersed with one another. As such, a single set of chemistry can be applied to form hybrid devices that include both organic and inorganic compounds,

facilitating the development of devices in which the class of material is selected based upon its utility without being constrained by the available patterning technology.

5 As indicated earlier, the method according to certain embodiments of the present invention provides the capability to pattern a conductor that is coated over and in electrical contact with an organic semiconductor material using photolithographic techniques. This method can be useful in the fabrication of various organic devices in which it is necessary to pattern a conductive material layer that is formed on top
10 of and in electrical contact with at least a portion of a layer of organic semiconductor. Besides top contact TFTs as described earlier, this method can be applied to other organic electronics devices. Among these applications is the patterning of the top electrode in organic LED or OLED devices, patterning of the top electrode in organic memory devices, and patterning of the top electrode in
15 organic photovoltaic devices. Each of these devices can require the patterning of a conductive layer that is coated over an organic semiconductor. Further, organic memory devices can require the patterning of two conductive layers within the device, one of which is a charge trapping layer, the other of which serves as an electrode. In such devices, it should be acknowledged that each conductive layer
20 can be patterned using separate but identical process steps.

Therefore, the method can be used to form a pixilated organic device. The term pixilated refers to a device having an array in at least one dimension but preferably in two dimensions where the array includes multiple, individually addressable
25 elements. This can be achieved using a process, such as the one shown in FIG. 7. As shown this process includes first providing **142** a substrate having a first conductive layer over the substrate to form a first electrode. In some embodiments, it can be necessary to pattern this first electrode, for instance into stripes or a two-dimensional array of independent electrode elements.

30

Organic semiconductor materials are then deposited **144** over the first conductive layer to form a first stack of one or more organic semiconductor layers. Typically, these layers will be formed in continuous layers as their lateral resistivity is high

enough to preclude cross-talk between individual elements in the pixilated device. These layers will typically include multiple layers of organic semiconductor materials, including layers for transport of holes or electrons, injection of holes or electrons, and an active layer for emitting light in an OLED device or absorbing
5 light and converting the energy to electricity in an OPV device.

A photoresist solution is then coated **146** over the one or more organic layers to form a photo-patternable layer. According to aspects of the present disclosure, the photoresist solution includes a fluorinated photoresist material and a first fluorinated
10 solvent as described earlier. This photo-patternable layer is then dried and selectively exposed **148** to radiation to form a first pattern of exposed fluorinated photoresist material and a second pattern of unexposed fluorinated photoresist material. In these embodiments, the first pattern of exposed fluorinated photoresist material is formed within the area between adjacent pixels while the second pattern
15 of exposed fluorinated photoresist material defines the location of the second electrode for the organic device of interest.

The substrate, and the photo-patternable layer is exposed to a second fluorinated solvent to develop **150** the photo-patternable layer, removing the second pattern of
20 unexposed fluorinated photoresist material without removing the first pattern of exposed fluorinated photoresist material. As such, the area where the second electrode is to be deposited is free from photoresist material and the photoresist material only remains in the area between segments of the second electrode.

25 Next, a second conductive layer is coated **152** over the one or more organic layers and the first pattern of exposed fluorinated photoresist material. The portions of the conductive layer that is in direct contact with the one or more organic layers form the second electrode for the device. In some embodiments of the present invention, the first pattern of exposed fluorinated photoresist material can be designed to
30 prevent the conductive layer from being continuous over this structure. For example, by providing walls of photoresist material that have a height greater than the thickness of the conductive layer or providing a first pattern of exposed fluorinated photoresist material having a strong undercut, the conductive layer can

- be formed such that it is not continuous between sections of the first pattern of exposed photoresist material. Under these conditions, because the photoresist is electrically insulating, the device can be complete at this stage. However, at least in some instances, the conductive layer can be continuous over the first pattern of exposed photoresist material. When the photoresist material is structured such that the conductive layer is continuous over the first pattern of exposed fluorinated photoresist material, this photoresist material must be removed to remove the portion of the conductive layer deposited over the first pattern of exposed fluorinated photoresist material. Therefore, the optional step of exposing the substrate to a third solvent containing a fluorinated solvent can be performed to remove the exposed fluorinated photoresist material and a portion of the one or more conductive layers to pattern the second electrode for the organic device, forming a second patterned electrode, thus forming a pixilated device.
- The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

List of Reference Labels in the Drawings

	2	providing substrate step
	4	deposit organic semiconductor material step
	6	coat photoresist solution step
5	8	expose fluorinated photoresist step
	10	develop photo-patternable layer step
	12	coat conductive layer step
	14	remove portion of conductive layer step
	20	organic device
10	22	substrate
	24	one or more organic layers
	26	photo-patternable layer
	26a	first pattern of exposed fluorinated photoresist material
	26b	second pattern of exposed fluorinated photoresist material
15	28	conductive layer
	28a	first segment of conductive layer
	28b	second segment of conductive layer
	30	width near the top of the first pattern of exposed fluorinated photoresist material
20	32	substrate stage
	34	organic-coated substrate stage
	36	photoresist-coated substrate stage
	38	patterned photoresist stage

	40	developed photoresist stage
	42	conductive layer –coated stage
	44	completed top contact TFT stage
	52	plot
5	54	curves
	56	plot
	58	curves
	62	provide substrate step
	64	pattern organic semiconductor into discrete islands step
10	66	coat photoresist step
	68	expose photoresist step
	70	develop photoresist step
	72	coat conductive layers step
	74	remove portion of conductive layer step
15	80	coat with photoresist step
	82	expose photoresist step
	84	develop photoresist step
	86	coat organic semiconductor step
	88	pattern organic semiconductor step
20	90	substrate
	92a	gate conductor
	92b	gate conductor

	92c	gate conductor
	92d	gate conductor
	94a	gate buss
	94b	gate buss
5	96	insulating layer
	98	photo-patternable layer
	100	third pattern of exposed photoresist material
	102	fourth pattern of unexposed photoresist material
	104a	void
10	104b	void
	104c	void
	104d	void
	106a	discrete island of semiconductor material
	106b	discrete island of semiconductor material
15	106c	discrete island of semiconductor material
	106d	discrete island of semiconductor material
	108	photo-patternable layer
	110	first pattern of exposed photoresist material
	112a	second pattern of unexposed photoresist material
20	112b	second pattern of unexposed photoresist material
	112c	second pattern of unexposed photoresist material
	112d	second pattern of unexposed photoresist material

- 112e second pattern of unexposed photoresist material
- 114 conductive layer
- 116 channel length
- 118 channel width
- 5 120 channel
- 122 portion of conductive layer
- 124 portion of conductive layer
- 126 separation region
- 128a top contact thin film transistor
- 10 128b top contact thin film transistor
- 132 ring oscillator
- 134a organic TFT
- 134b organic TFT
- 134c organic TFT
- 15 134d organic TFT
- 134e organic TFT
- 136 inverter
- 142 provide substrate with electrode step
- 144 deposit organic material step
- 20 146 coat with photoresist step
- 148 expose photoresist step
- 150 develop photoresist step

152 coat conductive layers step

154 remove portion of conductive layer step

CLAIMS

What is claimed is:

- 1) A method for forming an organic device having a patterned conductive layer, including:
 - 5 a. providing a substrate;
 - b. depositing organic materials over the substrate to form one or more organic layers;
 - c. coating a photoresist solution over the one or more organic layers to form a photo-patternable layer, wherein the solution includes a fluorinated
10 photoresist material and a first fluorinated solvent;
 - d. selectively exposing portions of the photo-patternable layer to radiation to form a first pattern of exposed fluorinated photoresist material and a second pattern of unexposed fluorinated photoresist material;
 - e. exposing the substrate to a second fluorinated solvent to develop the
15 photo-patternable layer, removing the second pattern of unexposed fluorinated photoresist material without removing the first pattern of exposed fluorinated photoresist material;
 - f. coating one or more conductive layers over the one or more organic layers; and
 - 20 g. removing a portion of the one or more of the conductive layers to form a pattern.
- 2) The method according to claim 1, wherein the one or more conductive layers are coated over the first pattern of exposed fluorinated photoresist material and the
25 step of removing a portion of one or more of the conductive layers includes exposing the substrate to a third fluorinated solvent to remove the exposed fluorinated photoresist material and the portion of the one or more conductive layers deposited over the first pattern of exposed fluorinated photoresist material.
- 30 3) The method according to claim 1, wherein the one or more conductive layers are coated over the organic layers before coating the substrate with the photoresist solution, the photo-patternable layer is then formed, selectively exposed and the

second pattern of unexposed fluorinated photoresist material is removed and further wherein the step of removing a portion of one or more of the conductive layers includes an etching process.

- 5 4) The method of claim 1, wherein the one or more organic layers are deposited to form a continuous layer.
- 10 5) The method of claim 1, further including two baking steps, wherein a first baking step is performed after coating a photoresist solution over the one or more organic layers and a second baking step is performed after selectively exposing portions of the photo-patternable layer.
- 15 6) The method of claim 1 wherein the photoresist solution contains a co-polymer of perfluorooctyl methacrylate and tert-butyl methacrylate.
- 7) The method of claim 1, wherein the step of coating of the one or more organic layers is performed in a vacuum and wherein the step of coating at least one photoresist layer is performed at atmospheric pressure in a dry environment.
- 20 8) The method of claim 1, wherein the step of coating the one or more organic layers includes a solution deposition and a drying process.
- 9) The method of claim 1, wherein the solution deposition coating is a blanket deposition process.
- 25 10) The method of claim 1, wherein the conductive layer is formed from one or more of a metal, a conductive metal oxide, or a conductive polymer.
- 11) The method of claim 1, wherein the photo-patternable layer includes a chemically amplified resist.
- 30 12) The method of claim 1, wherein the first fluorinated solvent has a boiling point above 110 degrees C.

- 13) The method of claim 10, wherein the second fluorinated solvent has a boiling point lower than the boiling point of the first fluorinated solvent.
- 5 14) The method of claim 1, wherein the method is used to form an organic TFT, an organic LED, an organic memory element, an organic photovoltaic device or a touch screen.
- 10 15) The method of claim 1, wherein the step of depositing organic materials over the substrate includes depositing at least one polymeric organic material and wherein the photoresist solution is coated directly on top of the at least one polymeric organic material.
- 15 16) A method of forming an array of one or more top-contact thin film transistors, including:
- a. providing a substrate;
 - b. forming an organic semiconductor layer over the substrate, including one or more discrete islands of organic semiconductor material which is continuous over the substrate within a portion of each TFT;
 - 20 c. coating a photoresist solution over the organic semiconductor layer to form a photo-patternable layer;
 - d. selectively exposing portions of the photo-patternable layer to radiation to form a first pattern of exposed photoresist material and a second pattern of unexposed photoresist material, wherein at least a portion of the first
25 pattern of exposed photoresist material is located over one or more of the discrete islands of organic semiconductor material and a portion of the first pattern of exposed photoresist material is located between one or more of the discrete islands of organic semiconductor material;
 - e. exposing the substrate to a second solvent to develop the photo-
30 patternable layer, removing the second pattern of unexposed photoresist material without removing the first pattern of exposed photoresist material;

- 5 f. coating one or more conductive layers over at least a portion of the organic semiconductor materials and the first pattern of exposed photoresist material to form electrical contact between the one or more conductive layers and the organic semiconductor materials on at least two sides of the first pattern of exposed photoresist materials within at least one discrete island of organic semiconductor material; and
- 10 g. exposing the first pattern of exposed photoresist material to a third solvent to remove the first pattern of exposed photoresist material and a portion of the one or more conductive layers to form a channel in the one or more conductive layers for each of the thin-film transistors in the array of thin-film transistors, the channel having a length and a width, the width more than twice the length.

15 17) The method according to claim 16, wherein the first pattern of exposed photoresist material is a two-dimensional structure defining the channel and a separation region between two or more top-contact thin film transistors in the array of top-contact thin film transistors; and the step of exposing the first pattern of exposed photoresist material to a third solvent removes the first pattern of exposed photoresist material and a portion of the one or more

20 conductive layers to additionally form the ends of the channel in the dimension parallel to the length of the channel.

18) A method of forming a pixilated organic device, including:

25 a. providing a substrate having a first conductive layer over the substrate to form a first electrode;

b. depositing organic semiconductor materials over the first conductive layer to form a first stack of one or more organic semiconductor layers;

c. coating a photoresist solution over the one or more organic layers to form a photo-patternable layer, wherein the photoresist solution includes a

30 fluorinated photoresist material and a first fluorinated solvent;

d. selectively exposing portions of the photo-patternable layer to radiation to form a first pattern of exposed fluorinated photoresist material and a second pattern of unexposed fluorinated photoresist material;

- e. exposing the substrate to a second fluorinated solvent to develop the photo-patternable layer, removing the second pattern of unexposed fluorinated photoresist material without removing the first pattern of exposed fluorinated photoresist material; and
 - 5 f. coating a second conductive layer over the one or more organic layers and the first pattern of exposed fluorinated photoresist material to form a second electrode.
- 19) The method according to claim 18, further including exposing the substrate to a
10 third solvent containing a fluorinated solvent to remove the exposed fluorinated photoresist material and a portion of the one or more conductive layers to pattern the second electrode for the organic device, forming a second patterned electrode.
- 15 20) The method according to claim 18, wherein the organic device is an OLED, an OPV device, or an OMEM device and wherein the method of patterning the second electrode provides an array of individually-addressable elements.

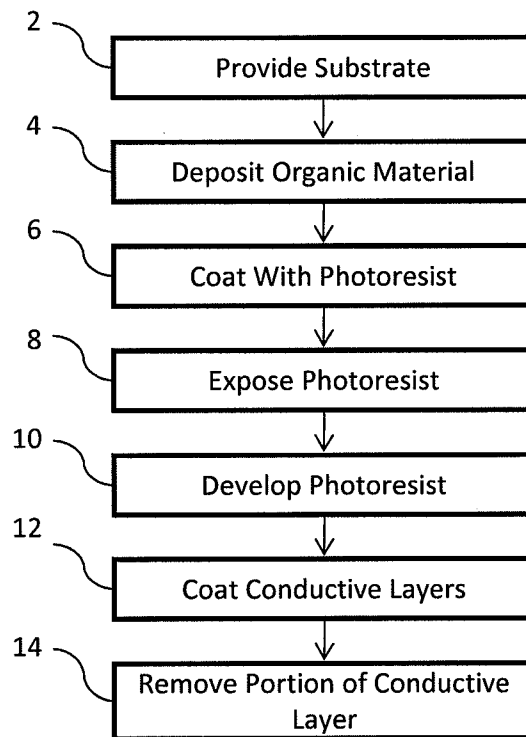


FIG. 1

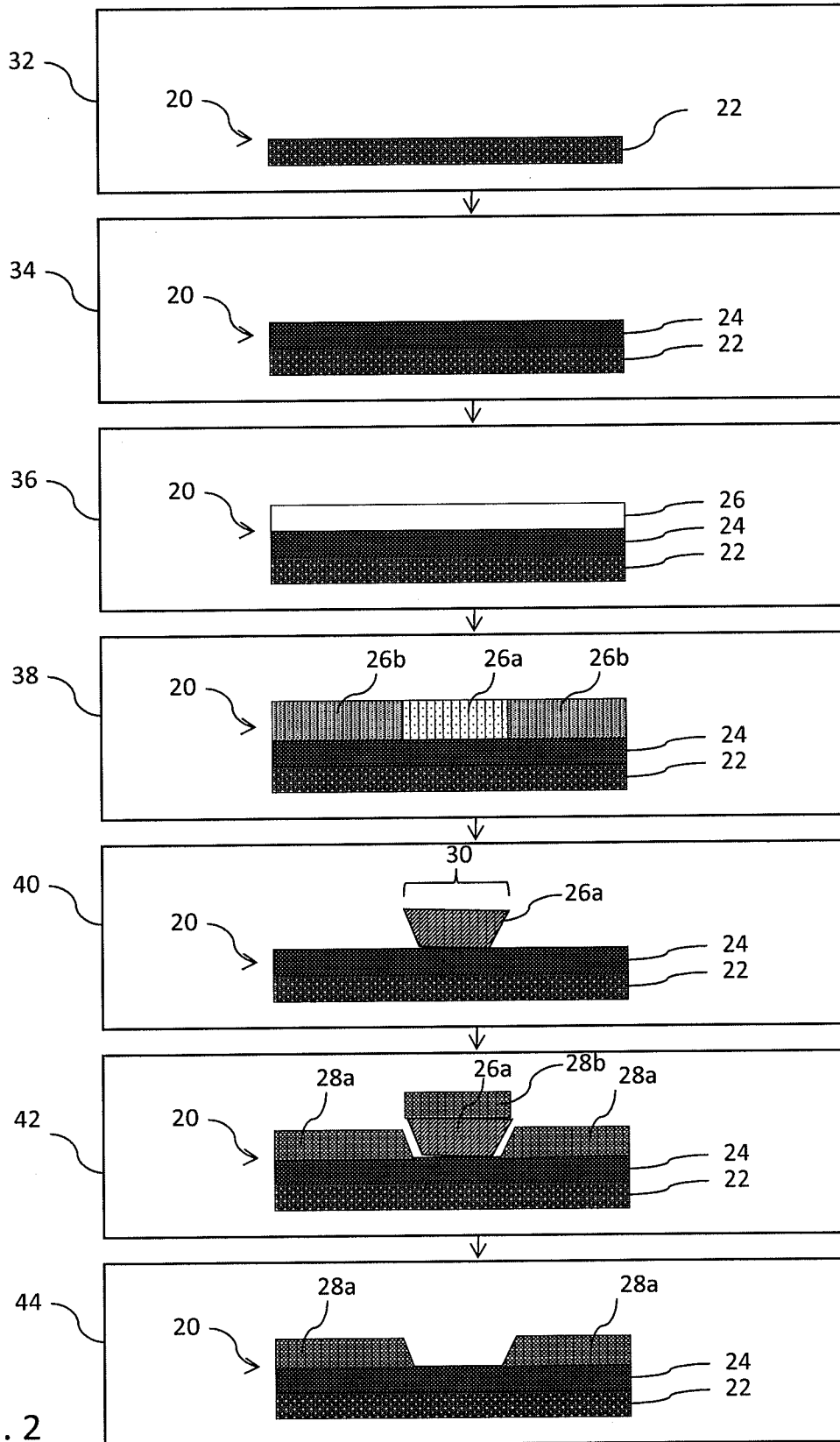


FIG. 2

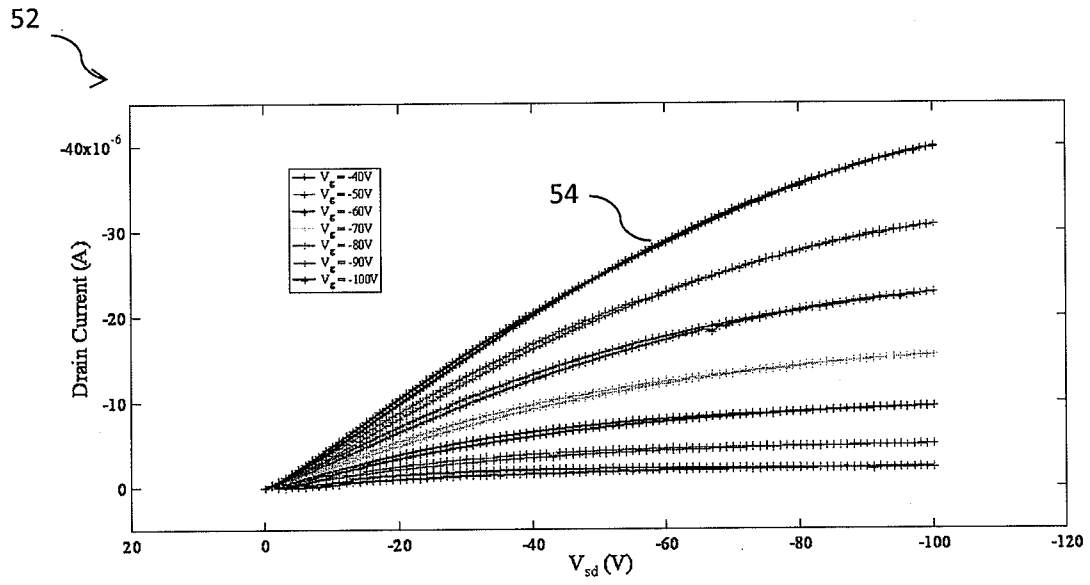


FIG. 3A

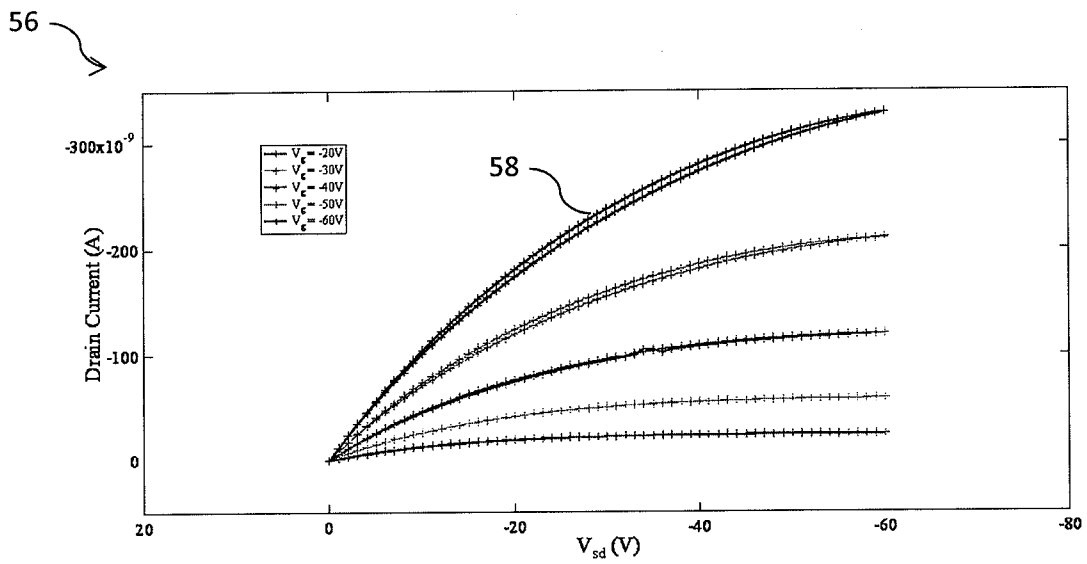


FIG. 3B

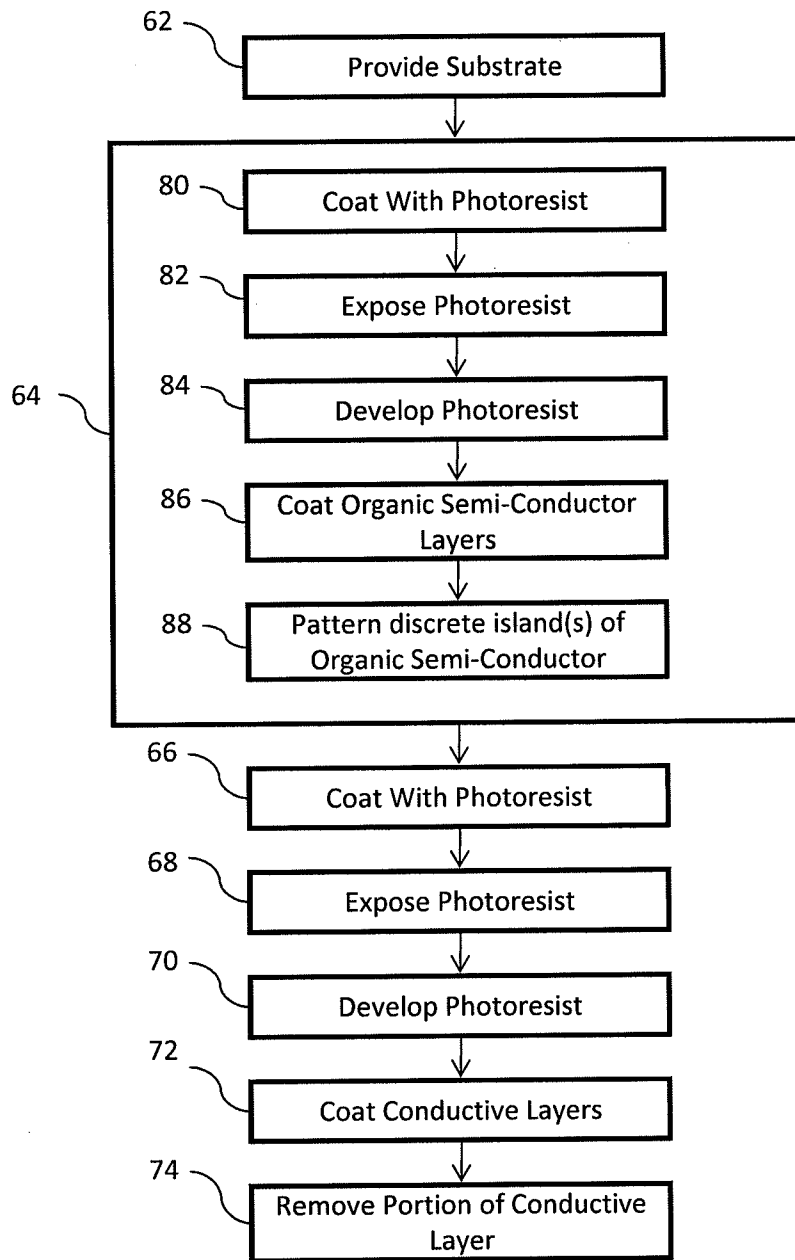
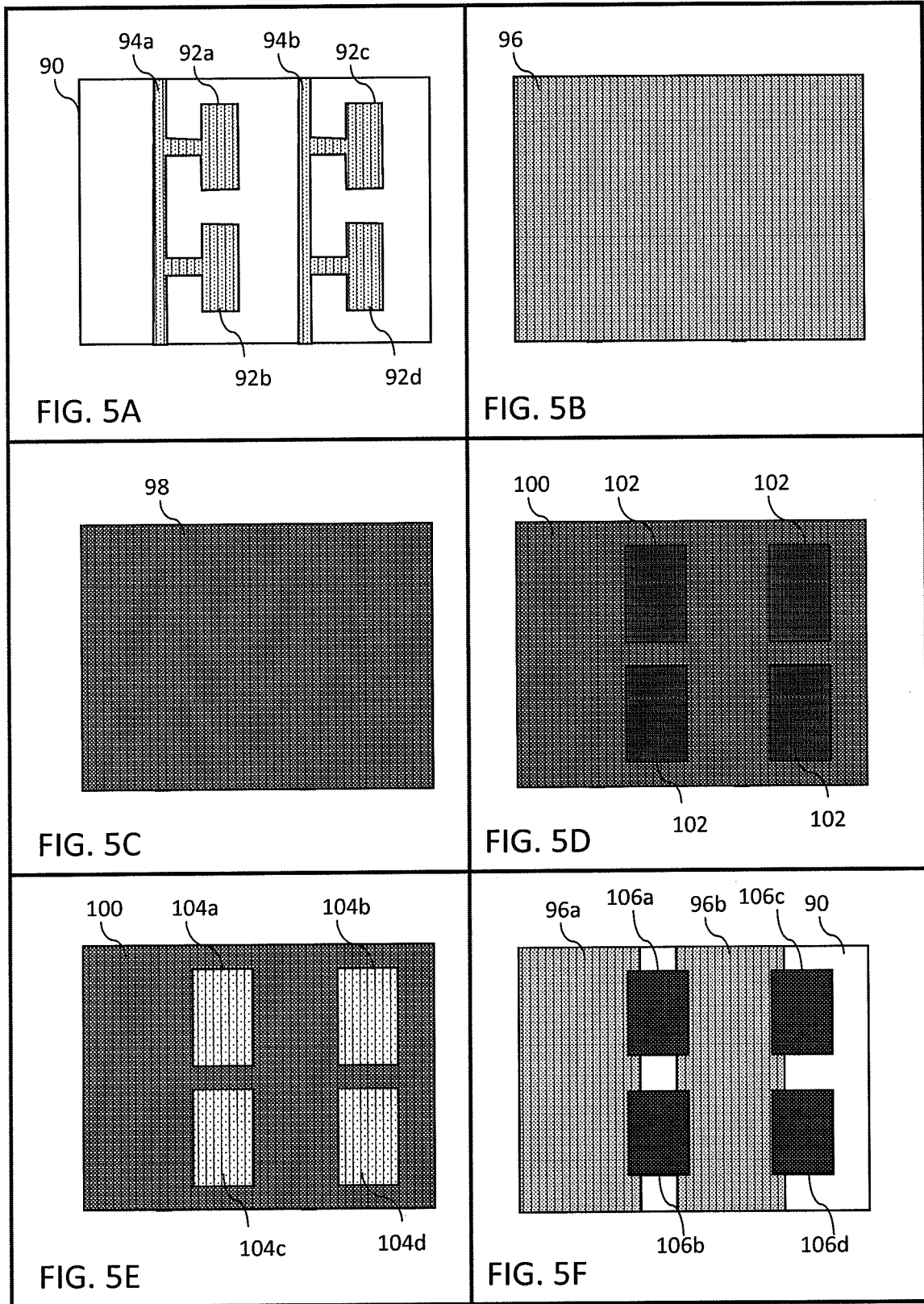
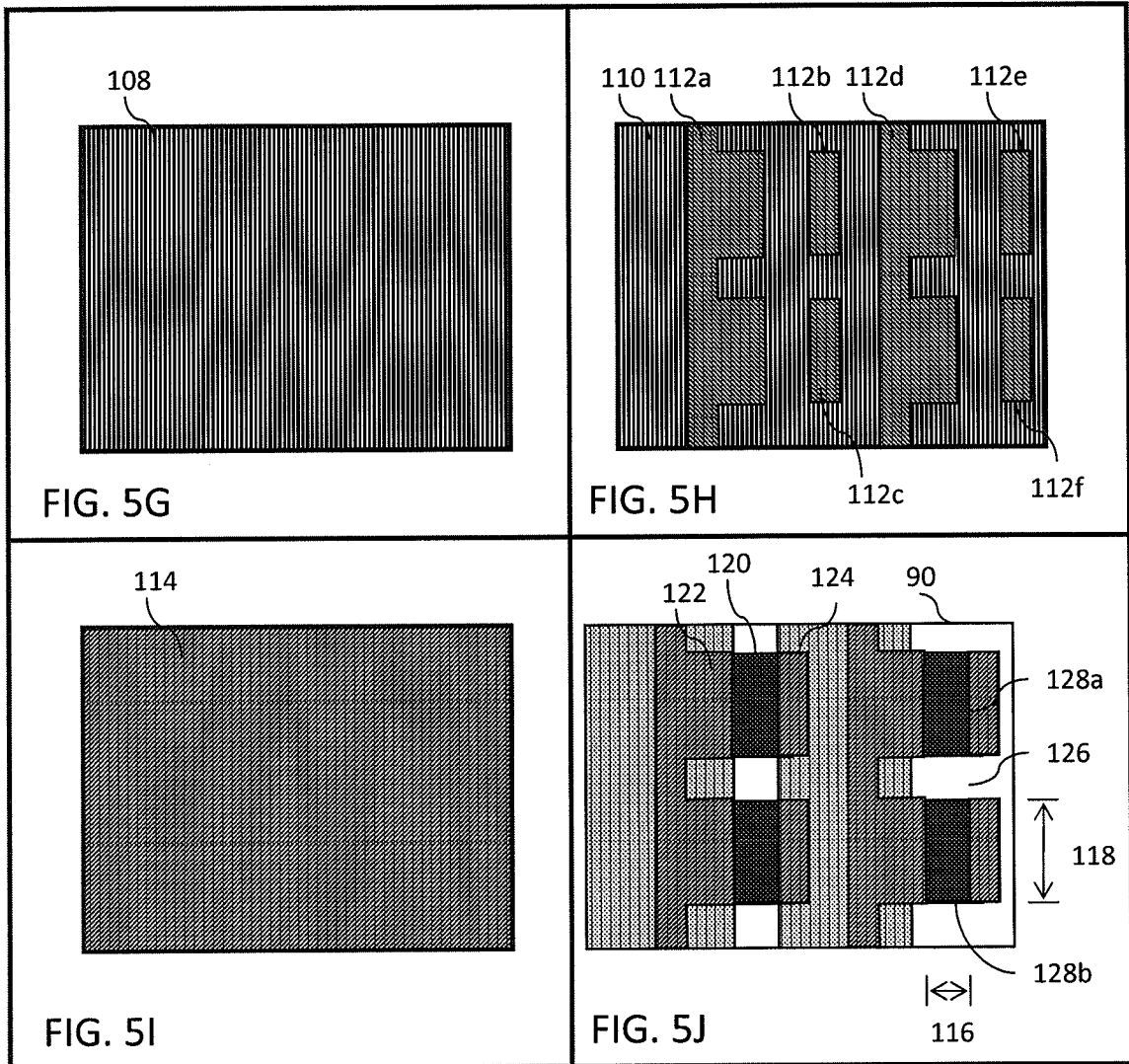


FIG. 4





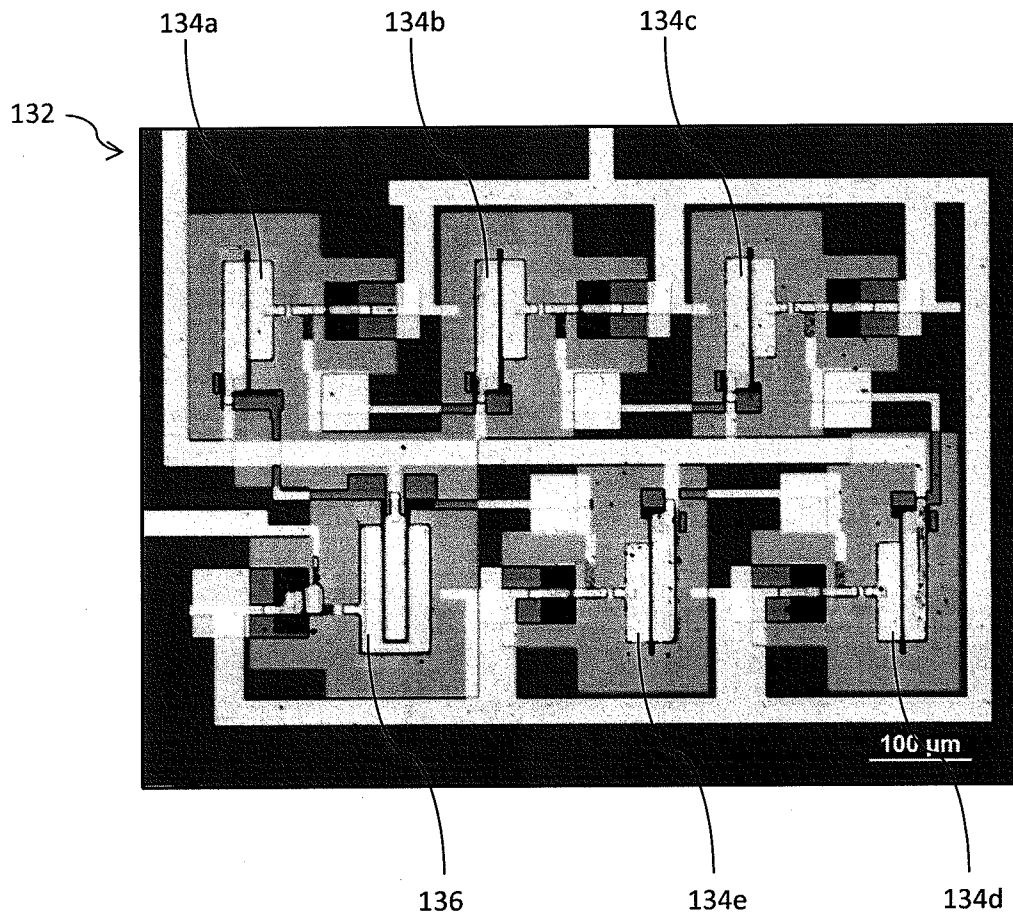


FIG. 6

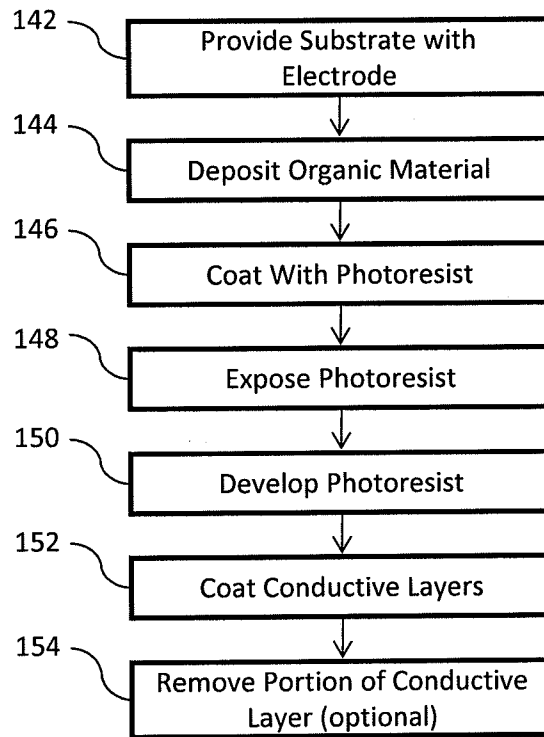


FIG. 7