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(54) **Title:** ANTI-COUNTERFEITING FEATURES AND METHODS OF FABRICATION AND DETECTION

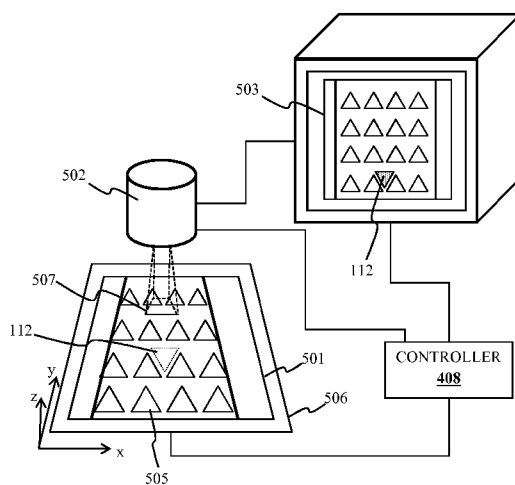


FIG. 5

(57) **Abstract:** Aspects of the present disclosure include an anti-counterfeiting pattern that is identifiable by sheet resistance mapping metrology, a method of fabricating such an anti-counterfeiting device, and a method of detecting such an anti-counterfeiting device by imaging the pattern with sheet resistance mapping metrology. This abstract is provided to comply with rules requiring an abstract that will allow a searcher or other reader to quickly ascertain the subject matter of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

ANTI-COUNTERFEITING FEATURES AND METHODS OF FABRICATION AND DETECTION

FIELD OF THE DISCLOSURE

The present disclosure is related to the field of anti-counterfeiting and authentication devices.

- 5 More specifically, aspects of the present disclosure are related to nanostructured devices with anti-counterfeiting features and methods of fabricating the same.

BACKGROUND

- This section describes background subject matter related to the disclosed embodiments of the present invention. There is no intention, either express or implied, that the background art
10 discussed in this section legally constitutes prior art.

Nanostructuring is necessary for many present applications and industries and for new technologies which are under development. Improvements in efficiency can be achieved for current applications in areas such as solar cells and LEDs, next generation data storage devices, architectural glass and bio- and chemical sensors, for example and not by way of limitation.

- 15 Nanostructured substrates may be fabricated using techniques such as e-beam direct writing, Deep UV lithography, nanosphere lithography, nanoimprint lithography, near-field phase shift lithography, and plasmonic lithography, for example.

- There is a need to identify nanostructures produced using specific equipment and process in order to protect and enforce Intellectual Property (IP) rights. Some desirable features for anti-
20 counterfeiting features/systems are a) they should be quite difficult to find and/or replicate; b) they should be manufactured using mass production methods in order to keep added cost down; and c) flexibility to change the anti-counterfeiting system frequently to avoid adoption of the method or system by counterfeiters.

- Various approaches have been proposed for counterfeit prevention and for authentication of
25 documents or valuable articles. Some of these methods are clearly visible to the naked eye and are intended for the general public, while others are hidden and only detectable by the competent authorities, or by automatic devices. For example, some methods use special paper, special inks, watermarks, micro-letters, security threads, holograms, etc. Nevertheless, there is still an urgent

need to develop and or embed anti-counterfeiting features or systems to a nanostructured device seamlessly and non-intrusively.

It is within this context that the present invention arises.

BRIEF DESCRIPTION OF THE DRAWINGS

5 FIGs. 1A-1C shows cross-sectional views of anti-counterfeiting devices according to aspects of the present disclosure.

FIG. 2A-2B shows top views of anti-counterfeiting patterns according to aspects of the present disclosure.

10 FIGs. 3A-3D are a sequence of cross-sectional schematic diagrams illustrating one possible method of fabrication of the device of FIG. 1A.

FIGs. 4A-4D illustrate an example of fabrication of metal mesh structures using a “lift-off” technique.

FIG. 5 is a schematic diagram illustrating use of a sheet resistance metrology system to image an anti-counterfeiting device according to an aspect of the present disclosure.

15 Fig. 6 is a screen shot of an example of a sheet resistance map a metal mesh imaged using a Terahertz imaging system equipment according to an aspect of the present disclosure.

FIG. 7 is an example of a covert anti-counterfeiting feature in the form of a company Logo as could be seen on a sheet resistance map according to an aspect of the present disclosure.

20 FIG. 8 is an example of a touch screen that incorporates a pattern of sheet resistance variation that can be revealed as an anti-counterfeiting pattern according to an aspect of the present disclosure.

DETAILED DESCRIPTION

The present disclosure generally relates to a device that incorporates an anti-counterfeiting pattern invisible to unaided human eyes but recognizable as anti-counterfeiting features by sheet
25 resistance mapping metrology. Sheet resistance is a measure of resistance of thin films that are

nominally uniform in thickness. It is commonly used to characterize materials made by semiconductor doping, metal deposition, resistive paste printing and glass coating.

Sheet resistance R_s for a film of material of resistivity ρ and thickness t is given by the ratio

$$R_s = \rho/t$$

- 5 A common unit for sheet resistance is "ohms per square" (denoted " Ω/sq " or " $\Omega/\square$ "), which is dimensionally equal to an ohm, but is exclusively used for sheet resistance. The name "ohms per square" reflects the fact that a square sheet with sheet resistance of, e.g., 10 ohm/square has an actual resistance of 10 ohm, regardless of the size of the square.

- 10 Several measuring methods have been implemented for sheet resistance measurement. For example, the four point measuring method uses a simple apparatus including a four point probe for measuring the resistivity of semiconductor samples. By passing a current through two outer probes and measuring the voltage through the inner probes allows the measurement of the substrate resistivity. Although possible in principle, four point probe measurements tend to be time consuming and limited in resolution. Moreover, four point probe techniques are impractical
15 for samples (e.g., metal mesh) that are protected (e.g., covered) with a polymer/barrier, or disposed under a functional material.

- In addition, non-contact and non-destructive methods have been widely used. Eddy current testing is one of the most extensively used non-destructive techniques for inspecting electrically conductive materials that does not require any contact between the sample and the sensor. Eddy
20 currents are electric currents induced within conductors by a changing magnetic flux in the conductor. These circulating eddies of current have inductance and thus induce magnetic fields. These fields can cause repulsion, attraction, propulsion, drag, and heating effects. The stronger the applied magnetic field, the greater the electrical conductivity of the conductor. The faster the field changes, the greater the currents that are developed and the greater the fields produced. For
25 this method, a sample under test is placed between two coils. Such a configuration may provide two magnetic fields that penetrate the sample, and the interaction between the magnetic fields and the sample induces eddy currents in the sample. The sample is then subjected to a relatively evenly distributed field so as to obtain an accurate sheet resistance measurement. The measuring accuracy of standard Eddy current metrology may be about less than 2% accuracy for a sensor

covering the sheet resistance range between 0.1 -10 ohm/sq. The accuracy may be about less than 3% accuracy for a sensor covering the range between 10 -100 ohm/sq. The accuracy may be about better than 5% for a sensor covering the range between 100 -1000 ohm/sq. Eddy current metrology provides non-contact, proximity (few mm distance) measurements, can scan a sample area relatively quickly compared to four point probe techniques, and can sense sheet resistance properties through some functional/protective/films and coatings.

Terahertz (THz) microprobe-based technology is another non-contact method that can be used for high-resolution measurements of sheet resistance distributions on large-scale areas. Specifically, AMO-GmbH, Germany proposed a measurement tool employing THz radiation in combination with contactless THz microprobes that enables micron-scale resolution and high-speed full wafer mapping. THz radiation penetrates fairly well through thin conductor layers with a thickness below skin-depth. In addition, the contactless THz microprobes can measure the sheet resistivity and thickness of large-area conductor films at very high speeds and up to 10 μm resolution. The term "Terahertz radiation" is used to describe electromagnetic radiation with frequencies between the high-frequency edge of the millimeter wave band, 300 gigahertz (3×10^{11} Hz), and the low frequency edge of the far-infrared light band, 3000 GHz (3×10^{12} Hz). Corresponding vacuum wavelengths of radiation in this band range from about 1 mm to about 0.1 mm (or 100 μm).

It should be noted that the above describes some example methods commonly used in the industry for sheet resistance mapping measurement. The term "sheet resistance mapping metrology" used in this disclosure is not limited to the measuring methods described above but also other methods applied for sheet resistance mapping measurement.

FIGs. **1A-1C** show three examples of an anti-counterfeiting device according to aspects of the present disclosure. The anti-counterfeiting device generally includes a structure **110** with an anti-counterfeiting pattern **112**. In one example, the structure **110** may be a conductive material. The anti-counterfeiting pattern **112** will be discussed in detail below. FIG **1A** shows an anti-counterfeiting device formed on top of a substrate **120** and a device layer **122** over the substrate. In one implementation, the substrate **120** may be a transparent conductive layer. By way of example and not by way of limitation, the substrate **120** may be a glass or polymer material. The device layer **122** may have device features **123** (e.g., integrated circuit structures) formed on it.

By way of example, the device layer **122** may include conductive materials, semiconductor materials, insulating materials, or some combination of two or more or even all three types of materials in the structures that form the device features.

As used herein, the term “substrate” generally refers to an object or structure onto which a layer is formed. In some contexts, the term substrate may refer to a single layer of material. In other contexts, the term substrate may refer to a structure made up of multiple layers.

FIG **2A** shows an anti-counterfeiting device formed in the same layer with the device features **123** over the substrate **120**. The structure **110** with the anti-counterfeiting pattern **112** may be placed in areas that do not affect the performance of a device. FIG. **1C** shows another embodiment where the anti-counterfeiting structure **110** formed hidden among the device features **123**. The anti-counterfeiting structure **110** could be a non-functional structure hidden among the device features **123**. Alternatively, one or more functional device features **123** could be configured to also serve as the anti-counterfeiting structure **110**.

The size of the anti-counterfeiting structure **110** could be large or small. In one example, the anti-counterfeiting structure **110** may be large enough in a size to cover the entire area of the device. In other examples, the anti-counterfeiting structure **110** may be in a size less than 100 micron x 100 micron. By way of example, and not by way of limitation, an anti-counterfeiting structure **110** having an area about 100 micron² would be large enough to be detected by sheet resistance mapping that utilizes Thz microprobe-based technology with at least 10 micron resolution.

The anti-counterfeiting pattern **112** should be invisible to the unaided human eye. That is, the anti-counterfeiting pattern **112** should not be visible to the naked eye without conventional aids (e.g., viewing under ultraviolet light or with optical filters or tools/equipment, such as magnifying glasses, microscopes, and the like. In some implementations, the anti-counterfeiting pattern **112** could be invisible to a conventionally-aided human eye.

In one embodiment, the lines in the anti-counterfeiting pattern **112** are characterized by a linewidth less than 2 microns. Lines below 2 microns are generally invisible to the unaided human eye. The pitch and/or height in the anti-counterfeiting pattern are not critical as long as they are within reasonable limits. In one example, the pitch in the anti-counterfeiting pattern is

about 2x the linewidth, and the height is about the same size of the linewidth or smaller. In addition, the anti-counterfeiting pattern **112** could be designed and made to have a very similar optical transmission, color and haze (below the sensitivity of the unaided human eye) to the substrate and/or surrounding materials, thus to be absolutely invisible to the human eye.

5 The anti-counterfeiting pattern **112** contains features that are distinguishable from the surrounding device features and thus identifiable as anti-counterfeiting features upon detection by sheet resistance mapping metrology. In one implementation, the anti-counterfeiting pattern **112** may be in the form of recognizable characters, such as letters, numbers, symbols, company logo, etc. In some implementations, the anti-counterfeiting pattern **112** may be a pattern similar
10 to the surrounding device features that is deliberately shifted and/or rotated to make them stand out as shown in FIG. **2A**. In some other implementations, the anti-counterfeiting pattern **112** may be in a distinctly different shape than the surrounding device features. In one example as shown in FIG. **2B**, the anti-counterfeiting patterns may be ovals and the surrounding device features have a pattern of triangles. In certain implementations, the anti-counterfeiting pattern
15 may be a bar code. In some other implementations, the anti-counterfeiting pattern may be any other coded structure or pattern. In one implementation, the anti-counterfeiting pattern has features in lower density comparing to the density of the surrounding device features. In some implementations, the anti-counterfeiting pattern is characterized by a specific gradient of sheet resistance, e.g., due to a thickness gradient. That is, the anti-counterfeiting pattern has unique
20 pattern of sheet resistance that may have much larger variations of sheet resistance to be outside of measurement noise and may be identifiable as anti-counterfeiting features upon detection.

The anti-counterfeiting pattern **112** invisible to unaided human eyes is readily recognizable as anti-counterfeiting features that are provided deliberately on a device, when it is imaged with sheet resistance mapping metrology. The anti-counterfeiting structure should be sufficiently
25 different in appearance from the surrounding device features so that the anti-counterfeiting pattern stands out in a sheet resistance map. Depending on the sensitivity of detection/interrogation equipment, the difference may be small but must be above the noise level. The interrogation may be performed by using sheet resistance mapping metrology tools to get a sheet resistance distribution map. Alternatively, the interrogation could be a combination
30 of electrical and optical metrology. In one example, the anti-counterfeiting structure may be

detected by utilizing sheet resistance mapping metrology tools in combination with optical tools (e.g., color filters, polarizers or optical metrology tools to detect optical transmission, haze and color).

Anti-counterfeiting devices according to aspects of the present disclosure may be very useful and advantageous in applications involving articles or documents that need to protect against illicit copying, such as credit cards, passports, driver licenses, valuable articles and/or nanostructured devices packaging for drugs, food, software, music, data CD and DVD, or other products, instrumentation and devices. Anti-counterfeiting devices according to aspects of the present disclosure may be placed on objects sensitive to light (so optical interrogation methods are not desirable or possible). Furthermore, no coding of anti-counterfeiting feature is necessary as long as an image of the feature can be clearly seen on a sheet resistance map. In another example, the device according to aspects of the present disclosure may be utilized as part of RFID tagging and a substrate (e.g., a transparent conductor) may be used as an antenna. The interrogation by sheet resistance mapping metrology tools may provide additional data about a product.

There are several ways for fabricating anti-counterfeiting device of the present disclosure. FIGS. **3A-3E** are a sequence of cross-sectional schematic diagrams illustrating one possible method of fabrication of the device of FIG. **1A** where the anti-counterfeiting device is formed on top of a substrate and a device layer. It should be understood that the anti-counterfeiting structure may be formed in the same layer with those device features over the substrate as in FIG. **1B** or the anti-counterfeiting structure may be formed hidden within the device features as in FIG. **1C**.

FIG. **3A** depicts a structure **110** provided on a substrate **120**. The substrate **120** may be a transparent conductive layer. A patterned device layer with device features **123** is deposited over the substrate. The structure **110** may be a conductive layer. A layer of photo-sensitive material **124** may be deposited over the structure **110** as shown in FIG. **3B**. The photosensitive material **124** could be a photoresist. The photoresist could be a positive resist or a negative resist. A positive resist is a type of photoresist in which the portion of the photoresist that is exposed to light becomes soluble to the photoresist developer. The portion of the photoresist that is unexposed remains insoluble to the photoresist developer. A negative resist is a type of photoresist in which the portion of the photoresist that is exposed to light becomes insoluble to

the photoresist developer. The unexposed portion of the photoresist is dissolved by the photoresist developer.

The photosensitive layer **124** may be patterned utilizing conventional photolithography or rolling mask lithography (RML) and then developed. The developed photosensitive layer **124** includes a pattern of openings **126** that expose underlying portions of the structure **110**, as shown in FIG. **3C**. The pattern of openings **126** is corresponding to an anti-counterfeiting pattern to be formed on the substrate **120**. The patterned photosensitive material **124** and the structure **110** can be subjected to an etch process that removes portions of the structure **110** exposed by the openings **126** in the resist layer, as shown in FIG. **3D**. The etch process can be an anisotropic process, such as a plasma etch process or ion milling. Remaining portions of the photosensitive material **124** can then be removed leaving behind the anti-counterfeiting pattern **112** as shown in FIG. **1A**.

In an alternative implementation, metal mesh structures may be formed by deposition of materials through a template can be followed by lift-off of template materials (photoresists, etc.), e.g., as shown in FIGs. **4A-4D**. In this technique, a layer of photosensitive material **404** (e.g., a positive or negative resist) is formed on a substrate **402**, as shown in FIG. **4A**. The substrate **402** can be, e.g., glass or a polymer material. The photosensitive layer **404** can be patterned using RML, e.g., as discussed above, and then developed. The developed photosensitive layer includes a pattern of openings **405** that expose underlying portions of the substrate **402**, as shown in FIG. **4B**.

A layer of metal **401** is deposited over the patterned photosensitive material **404** as shown in FIG. **4C**. Deposition of the metal layer **401** can be implemented using physical vapor deposition (PVD), sputtering, chemical vapor deposition (CVD), atomic layer deposition (ALD), MVD and other vacuum-based techniques. Non-vacuum methods can also be used, like sol-gel, electroplating, electroless plating, and the like. One preferred metal deposition technique that is useful for forming metal mesh structures is to deposit metal-containing materials from a liquid phase (e.g. as a metal ink) onto the substrate through the patterned photosensitive layer, e.g., using a roller. The metal material may also be sprayed onto the template and substrate. Also, other coating methods for liquid film deposition could be used such as, but not limited to, slot die and gravure coating. An example of such a technique is described, e.g., in U.S. Patent No. 8,334,217, which is incorporated herein by reference. Metal-containing materials can be chosen

to attach only to template materials or only to substrate material exposed through the template. The width and pitch of the metal mesh structures is determined by the corresponding pitch and width in the patterned rolling mask that is used to pattern the photosensitive layer. The thickness of the metal structures can be controlled by optimization of process transfer speed, viscosity of precursor, number of contact cycles with the roller, and other processing parameters.

The patterned photosensitive material **404** is then removed in a lift-off process taking with it overlying portions of the metal layer **401**. Portions of the metal layer that are in direct contact with the substrate remain behind following the liftoff process, leaving behind a pattern metal layer as shown in FIG. **4D**. Some implementations that use a metal-containing ink to form the metal layer **401** include a sintering step to solidify the patterned metal layer. The sintering could take place before lift-off or afterwards.

Using lift-off in conjunction with RML does not require etching the metal layer, e.g., with plasma etch. Plasma etch is a vacuum process that is not compatible with processing of large area flexible substrates. Lift-off also allows for recycling of the metal portions that have been removed in the lift-off process.

Lift-off in conjunction with metal ink deposition is highly desirable because it removes any vacuum operation from the manufacturing process. Thus metal mesh fabrication can be implemented in a roll-to-roll process, as opposed to a batch process. In addition to being a vacuum process, etching can result in a roughened substrate and/or roughened metal line edges.

Another option for fabricating the anti-counterfeiting device is to form a pattern of conductive material on the substrate by conductive ink deposition using inkjet technology. For example, a pattern of metal ink could be formed with a conventional inkjet printer.

Another option for fabricating the anti-counterfeiting device is to form a pattern of conductive material on the substrate using gravure printing technology. In this type of printing a pattern of conductive ink, e.g., metal ink, is deposited onto a surface of the substrate using an engraved roller having a corresponding pattern engraved into its surface. In some gravure printing implementations, the substrate may pass between the engraved roller and a pressure roller as the ink is applied. The pattern of ink on the substrate surface may be dried or cured by a subsequent heating stage.

Another option for fabricating the anti-counterfeiting device is to deposit conductive material onto a surface of the substrate through a stencil mask. In this type of fabrication, a stencil mask having a desired pattern of openings is placed on a surface of the substrate or in close proximity to the surface of the substrate. The openings expose selected portions of the substrate.

5 Conductive material may then be deposited over the stencil mask and onto the exposed portions of the substrate underlying the openings in the stencil mask. The material may be deposited using any suitable technique, e.g., metal ink printing, chemical vapor deposition (CVD), physical vapor deposition (e.g., laser-assisted metal deposition), and the like. The stencil mask may then be removed leaving behind a pattern of conductive material on the substrate surface.

10 Another option for fabricating the anti-counterfeiting device is metal layer ablation by scanning a laser beam across a layer of metal to ablate selected portions of the layer.

Another option for fabricating the anti-counterfeiting device is laser-assisted deposition. In this technique the conductive material is formed from an interaction between one or more reactant gases and a laser beam. The beam may be operated in a pulsed mode. The beam passes through
15 the reactant gas(es) and impinges on a surface of the substrate either at perpendicular incidence or at an angle. A reaction between the gas, the substrate surface, and the laser beam forms a conductive material that adheres to the surface. If the beam spot is sufficiently small, a pattern of conductive material could be produced without a mask by selectively turning the beam on and off as the substrate moves relative to the beam or vice versa. Alternatively, a mask may be used
20 in conjunction with laser-assisted deposition to form the pattern. By way of example, silicon can be deposited on a glass surface using Silane (SiH_4) as a reactant gas and a laser beam characterized by a vacuum wavelength of 193 nm. Such a beam of sufficient intensity could be produced, e.g., using a pulsed ArF laser.

Yet another option for fabricating the anti-counterfeiting device is to use laser-assisted etch.

25 This technique uses a highly absorbing media in contact with the material being etched. By way of example, a metal target in contact with the material to be etched (e.g., quartz, glass, or semiconductor) may be used as an absorber. Removal of the material is assisted by the plasma generated by the metal target where the laser light is absorbed.

The laser etching of materials can be also assisted with a suitable liquid solution (for example CrO_3) in contact with the material to be etched. In such cases a temperature increase resulting from strong absorption of laser light at the thin interface between the liquid and the material enhances the etching. The rapid temperature increase leads to heating of the material and thermal decomposition of the solution into non-soluble Cr_2O_3 deposits. The thin film of non-soluble Cr_2O_3 formed on the substrate results in a further rise of the laser induced temperature that follows the absorption of subsequent laser pulses. Due to the difference in the thermal expansion coefficients between the Cr_2O_3 film and material substrate the removal of the material is achieved.

FIG. 5 illustrates the use of a sheet resistance metrology system **500** to image an anti-counterfeiting pattern. The system **500** generally includes a sensor head **502** coupled to an imaging system **504**. The sensor head **502** produces an output signal in response to some form of input that is applied to a sample **501** that includes an anti-counterfeiting pattern **112** of the type described above. The output signal is related to the input signal in a way that depends on the sheet resistance of the sample **501**. The imaging system **504** interprets the output signal from the sensor head **502** and generates an image **503** of the sample **501**, which can be stored in electronic form or presented on a visual display. In the image **503**, differences in sheet resistance are made apparent, e.g., using a suitable color or intensity scale. In the illustrated example, the sample **501** includes multiple device structures **505** and the anti-counterfeiting pattern **112** (shown in phantom) is invisible to the unaided eye but visible in the image **503**, which may be in the form of a sheet resistance map of the sample **501** or a portion thereof.

The sample **501** can be any suitable product, device, or material that bears an anti-counterfeiting pattern. By way of example, and not by way of limitation, the anti-counterfeiting pattern may be integrated into a sample in the form of a touch screen sensor, smart window, electromagnetic interference (EMI) shield, transparent heater, or solar panel.

The system may include an optional stage **506** and controller **508**. The sample may be mounted to the stage **506**. The stage can translate and/or rotate the sample with respect to the sensor head **502**. The controller **408** may be a special purpose computer or a general purpose computer configured to control operation of one or more of the sensor head **502**, the imaging system **504**, and the stage **506**.

By way of example, and not by way of limitation, the sensor head **502** may include an element that detects terahertz (THz) radiation. The system may include or work in conjunction with a source that directs THz radiation toward the sample. In some configurations, the THz radiation source may be integrated into the sensor head. In some implementations, the THz radiation may be directed at a small portion **507** of the sample **501** and/or the sensor may only detect THz radiation emitted from that small portion. In such cases, the stage **506** can translate the sample **501** with respect to the sensor head with respect to x, y, and z axes so that the sensor head **502** can collect TeraHertz (THz) radiation from different parts of the sample. The controller **508** can provide the imaging system **504** with stage position information that the imaging system can correlate with the output signal from the sensor head **502** to produce the image **503**.

In alternative implementations, the sensor head **502** may include electromagnets that produce a changing magnetic flux within the sample **501** or small portion **507** thereof and sensors that detect the effects of the resulting eddy currents within the sample. Again, the stage **506** can translate the sample **501** with respect to the sensor head with respect to x, y, and z axes so that the sensor head **502** can sense eddy currents from different parts of the sample.

By way of example, Fig. 6 is a screen shot of an example of a sheet resistance map a metal mesh imaged using a Terahertz imaging system equipment according to an aspect of the present disclosure. The image was obtained using a TeraSpike-800-X-HRS Terahertz imaging system from AMO GmbH of Aachen, Germany. The sheet resistance map in the image us for a metal mesh having about 3 Ohm/sq deviations of sheet resistance over an 80mmx80mm area.

There are many different possible configurations for anti-counterfeiting devices within the scope of the present disclosure. By way of example, and not by way of limitation, FIG. 7 shows an example of a covert anti-counterfeiting feature in the form of a company logo as could be seen on a sheet resistance map.

By way of alternative example, anti-counterfeiting devices of the type described in this disclosure may be implemented as integrated parts of a functional transparent metal mesh conductor element (electrode) in various devices. For example, the transparent conductor for capacitive touch sensor in a display, which is created on a glass (cover lens) or polymer film, can be engineered to have a specific and distinctive pattern of sheet resistance distribution (e.g., in

the form of Logo, bar code, image, etc.). Such sheet resistance distribution could be designed to have a range that would not affect the basic performance of the device as a touch screen (e.g., few Ohm/sq deviations), and would add an anti-counterfeiting feature to the device. Similarly, such "integrated anti-counterfeiting conductors" could be used as EMI shields and transparent heaters (in displays and other products), electrodes in smart windows (electrochromic devices), solar panels, OLED lighting products, etc. etc.

Distribution of sheet resistance described in the example of a touch screen can be interrogated (revealed) by touch of a finger or stylus (multi-touch, slide, or other movement on the surface). The resulting image or trace could be revealed directly on the touch screen display (using some "drawing software"). By way of example as shown in FIG. 8, when a touch sensor **802** is interrogated by passing a finger **801** over it in a pattern of straight lines **803** the variation in sheet resistance within the touch sensor results in curved traces **805** on a display **806** when the inputs are interpreted conventionally through a processor **804**. The "non-linearity" of the traces **805** shows the sheet resistance distribution in the touch sensor **802**. Such sheet resistance distributions may be engineered as a distinctive and recognizable pattern, such as a company logo image, bar code, QR code, number, etc.

The hardware and/or software of the processor **804** that interprets the touch sensor input is based on the assumption that the sheet resistance is uniform (or varies in some known way). Varying the sheet resistance of the touch sensor while maintaining conventional assumptions in the sensor interpretation software/hardware of the processor **804** causes straight traces to be interpreted and displayed as bent lines. In some implementations the processor may implement an algorithm that operates in two modes, a normal touch screen mode and an anti-counterfeiting mode. In the normal mode the algorithm recognizes any sheet resistance/capacitance values that fall within a specified range (+/-X) as the same values (uniform/linear response) and ignore fine variations within that range, e.g., by averaging the input data. In the anti-counterfeiting mode, by contrast, the algorithm treats fine variations of sheet resistance/capacitance as signal data and interprets such variations accordingly (e.g., by not averaging the input data).

As may be realized from the foregoing description, aspects of the present disclosure provide anti-counterfeiting that is relatively simple to fabricate but relatively difficult to detect.

More generally it is important to note that while the above is a complete description of the preferred embodiments of the present invention, it is possible to use various alternatives, modifications and equivalents. Therefore, the scope of the present invention should be determined not with reference to the above description but should, instead, be determined with
5 reference to the appended claims, along with their full scope of equivalents. Any feature described herein, whether preferred or not, may be combined with any other feature described herein, whether preferred or not. In the claims that follow, the indefinite article “a”, or “an” when used in claims containing an open-ended transitional phrase, such as “comprising,” refers to a quantity of one or more of the item following the article, except where expressly stated
10 otherwise. Furthermore, the later use of the word “said” or “the” to refer back to the same claim term does not change this meaning, but simply re-invokes that non-singular meaning. The appended claims are not to be interpreted as including means-plus-function limitations or step-plus-function limitations, unless such a limitation is explicitly recited in a given claim using the phrase “means for” or “step for.”

WHAT IS CLAIMED IS:

- 1 1. An anti-counterfeiting device, comprises:
2 a structure having an anti-counterfeiting pattern, wherein the anti-counterfeiting pattern
3 is identifiable as an anti-counterfeiting feature by sheet resistance mapping metrology.
- 1 2. The device of claim 1, wherein the anti-counterfeiting pattern is invisible to unaided
2 human eyes
- 1 3. The device of claim 1, wherein the structure is formed in a device layer where device
2 features are formed.
- 1 4. The device of claim 1, wherein the structure is formed on top of a device layer where
2 device features are formed.
- 1 5. The device of claim 2, wherein lines in the anti-counterfeiting pattern are in a linewidth
2 less than 2 microns.
- 1 6. The device of claim 1, wherein the anti-counterfeiting pattern is in a form of recognizable
2 characters.
- 1 7. The device of claim 1, wherein the anti-counterfeiting pattern is a pattern similar to
2 surrounding device features that is deliberately shifted and/or rotated.
- 1 8. The device of claim 1, wherein the anti-counterfeiting pattern is a bar code.
- 1 9. The device of claim 1, wherein the anti-counterfeiting pattern is characterized by a
2 specific gradient of sheet resistance.
- 1 10. The device of claim 1, wherein the sheet resistance mapping metrology includes using
2 Eddy current metrology or Terahertz microprobe-based metrology.
- 1 11. The device of claim 1 wherein the structure having the anti-counterfeiting pattern is
2 integrated into a touch screen sensor, smart window, electromagnetic interference (EMI)
3 shield, transparent heater, or solar panel.

1 12. A method for detecting an anti-counterfeiting device having an anti-counterfeiting
2 pattern, comprising imaging the anti-counterfeiting pattern with a sheet resistance
3 mapping metrology system.

1 13. The method of claim 12, wherein the sheet resistance mapping metrology includes using
2 Eddy current metrology or Terahertz microprobe-based metrology.

1 14. The method of claim 12, wherein lines in the anti-counterfeiting pattern are characterized
2 by a linewidth less than 2 microns.

1 15. The method of claim 12, wherein the anti-counterfeiting pattern is integrated into a
2 sample in the form of a touch screen sensor, smart window, electromagnetic interference
3 (EMI) shield, transparent heater, or solar panel.

1 16. A method of fabricating anti-counterfeiting devices, comprising:
2 forming a structure over a substrate, wherein the structure has an anti-counterfeiting
3 pattern, wherein the anti-counterfeiting pattern is identifiable as anti-counterfeiting
4 features by sheet resistance mapping metrology.

1 17. The method of claim 16 wherein the anti-counterfeiting pattern is invisible to unaided
2 human eyes.

3 18. The method of claim 16, wherein forming the structure over the substrate comprises
4 providing a photosensitive layer on a conductive layer over the substrate, patterning and
5 developing the photosensitive layer to form a patterned photosensitive layer, etching and
6 removing portions of the conductive layer exposed from the photosensitive layer and the
7 photosensitive layer to form the structure with the anti-counterfeiting pattern.

1 19. The method of claim 16, wherein forming the structure over the substrate includes
2 disposing a photo-sensitive material over the substrate, developing the photo-sensitive
3 material to produce a mesh pattern in the developed photo-sensitive material and using
4 the developed photo-sensitive material includes forming a layer of conductive material
5 over the developed photo-sensitive material and onto portions of the substrate exposed by
6 openings in the developed photo-sensitive material, and removing the photo-sensitive

7 material leaving behind conductive material on the substrate at the portions
8 corresponding to the openings.

1 20. The method of claim 16, wherein forming the structure over the substrate includes
2 applying a pattern of conductive material to a surface of the substrate using inkjet
3 technology.

1 21. The method of claim 16, wherein forming the structure over the substrate includes
2 applying a pattern of conductive material to a surface of the substrate using gravure
3 printing technology.

1 22. The method of claim 16, wherein forming the structure over the substrate includes
2 patterning a layer of metal over the substrate.

1 23. The method of claim 22, wherein the layer of metal is patterned by laser ablation.

2 24. The method of claim 16, wherein forming the structure over the substrate includes laser-
3 assisted deposition or etch.

4 25. The method of claim 16, wherein forming the structure over the substrate includes
5 depositing metal through a stencil mask.

6 26. The method of claim 16, wherein lines in the anti-counterfeiting pattern are characterized
7 by a linewidth that is less than 2 microns.

1 27. The method of claim 16, wherein the anti-counterfeiting pattern is integrated into a
2 sample in the form of a touch screen sensor, smart window, electromagnetic interference
3 (EMI) shield, transparent heater, or solar panel.

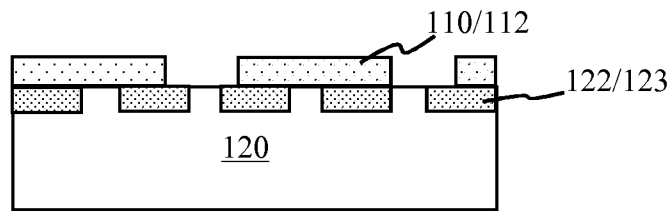


FIG. 1A

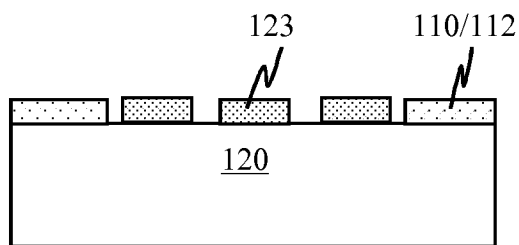


FIG. 1B

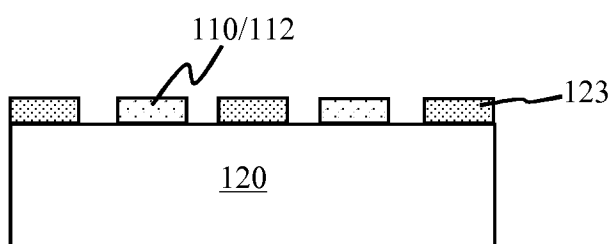


FIG. 1C

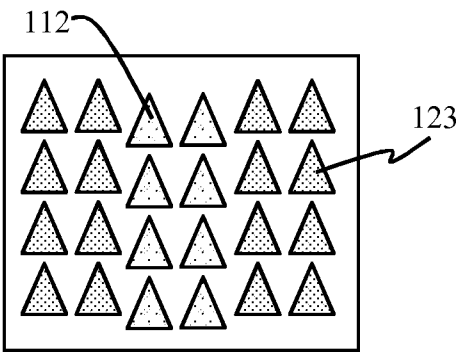


FIG. 2A

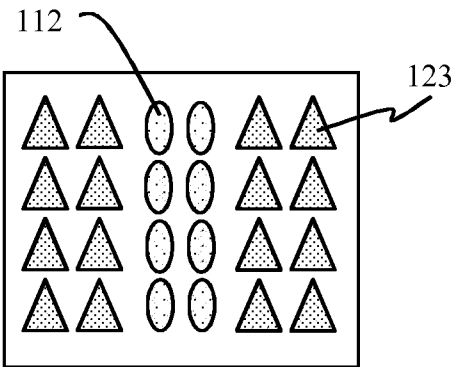


FIG. 2B

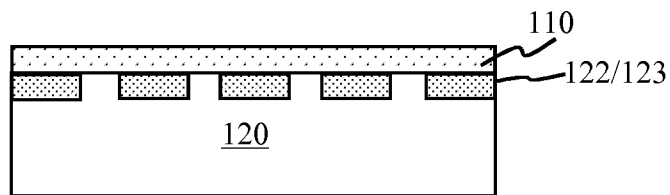


FIG. 3A

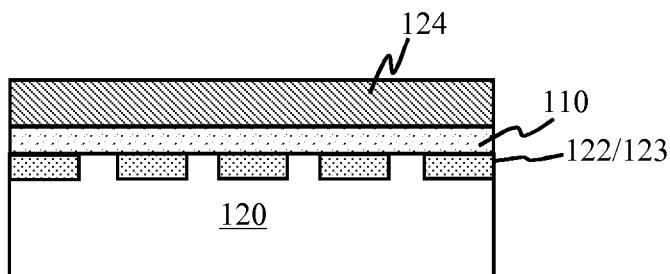


FIG. 3B

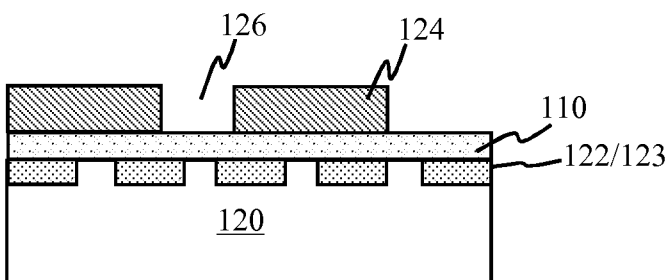


FIG. 3C

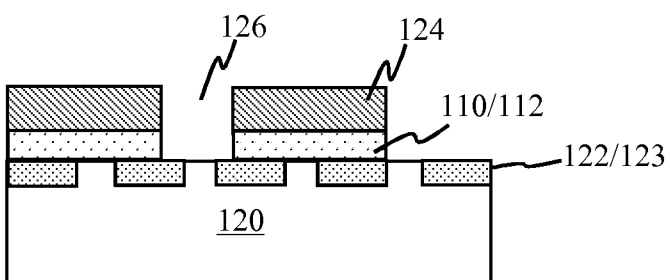


FIG. 3D

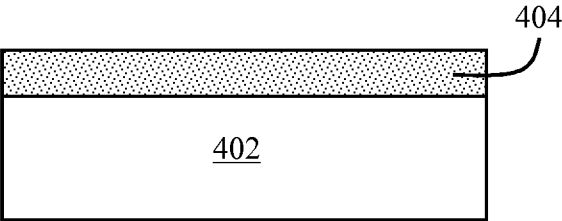


FIG. 4A

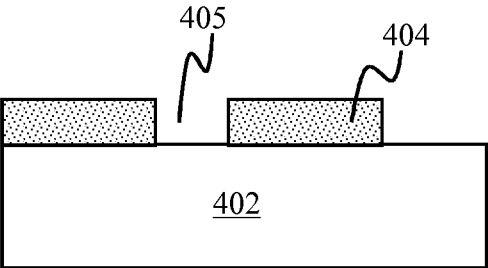


FIG. 4B

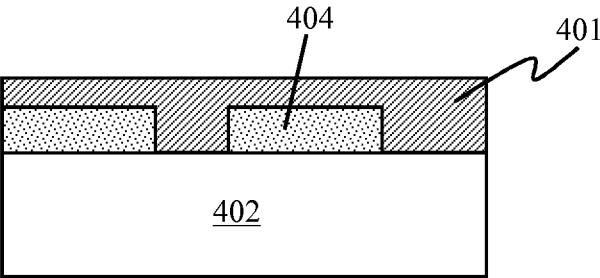


FIG. 4C

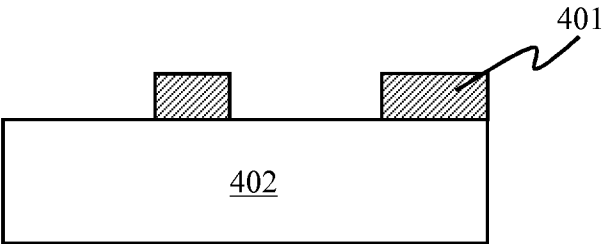


FIG. 4D

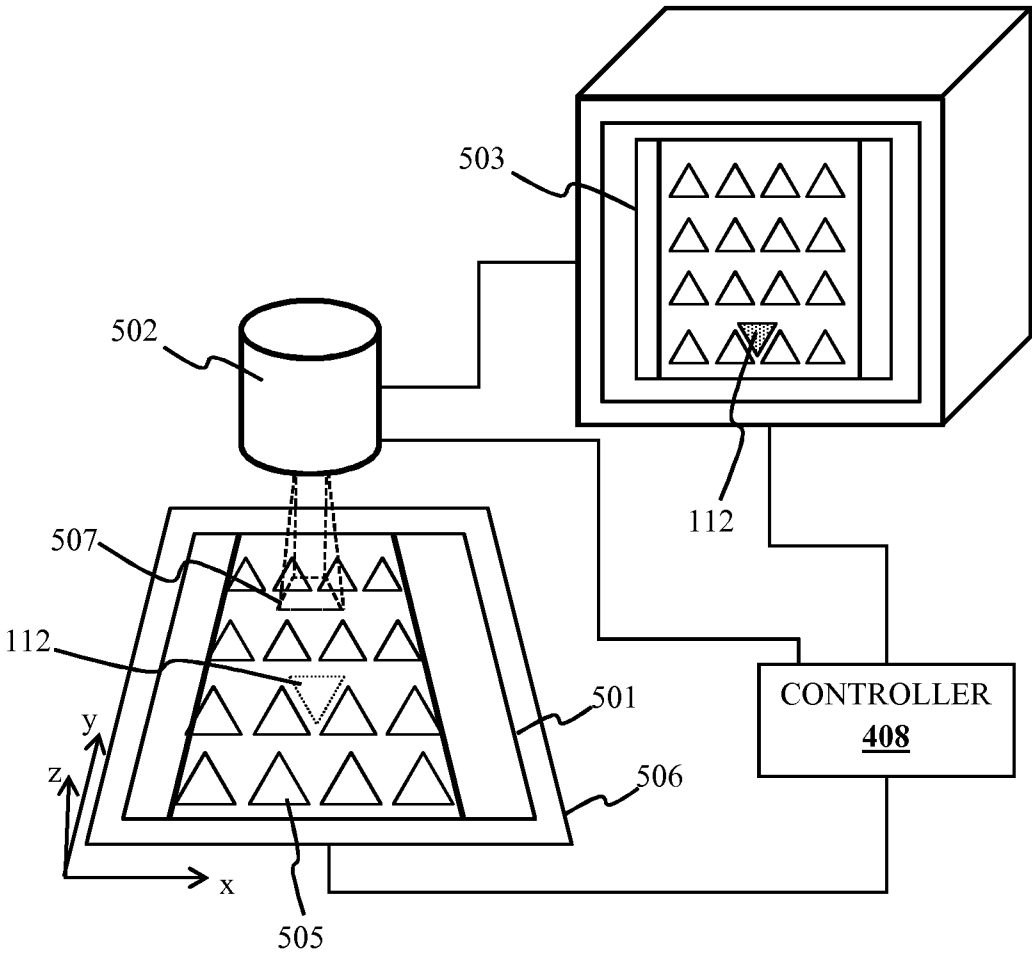


FIG. 5

Rolith TMEsample2 7/13 measured with TeraSpike-800-X-HRS

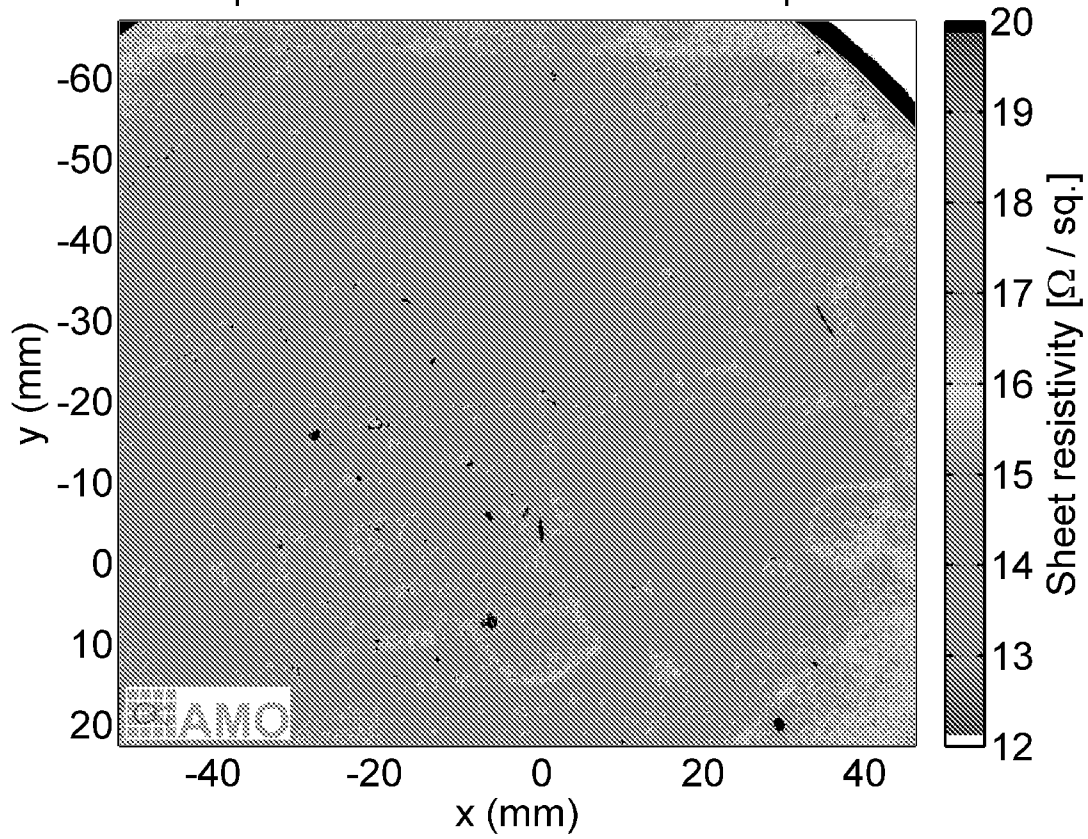


FIG. 6

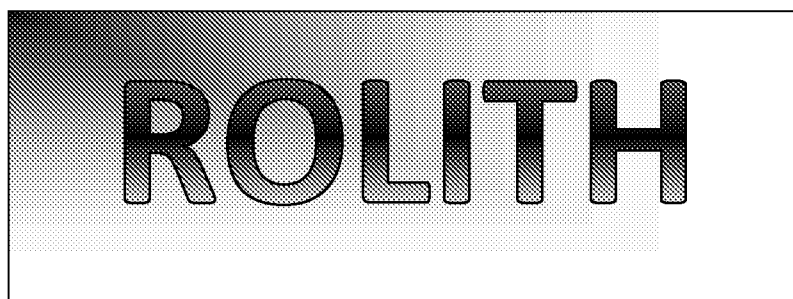
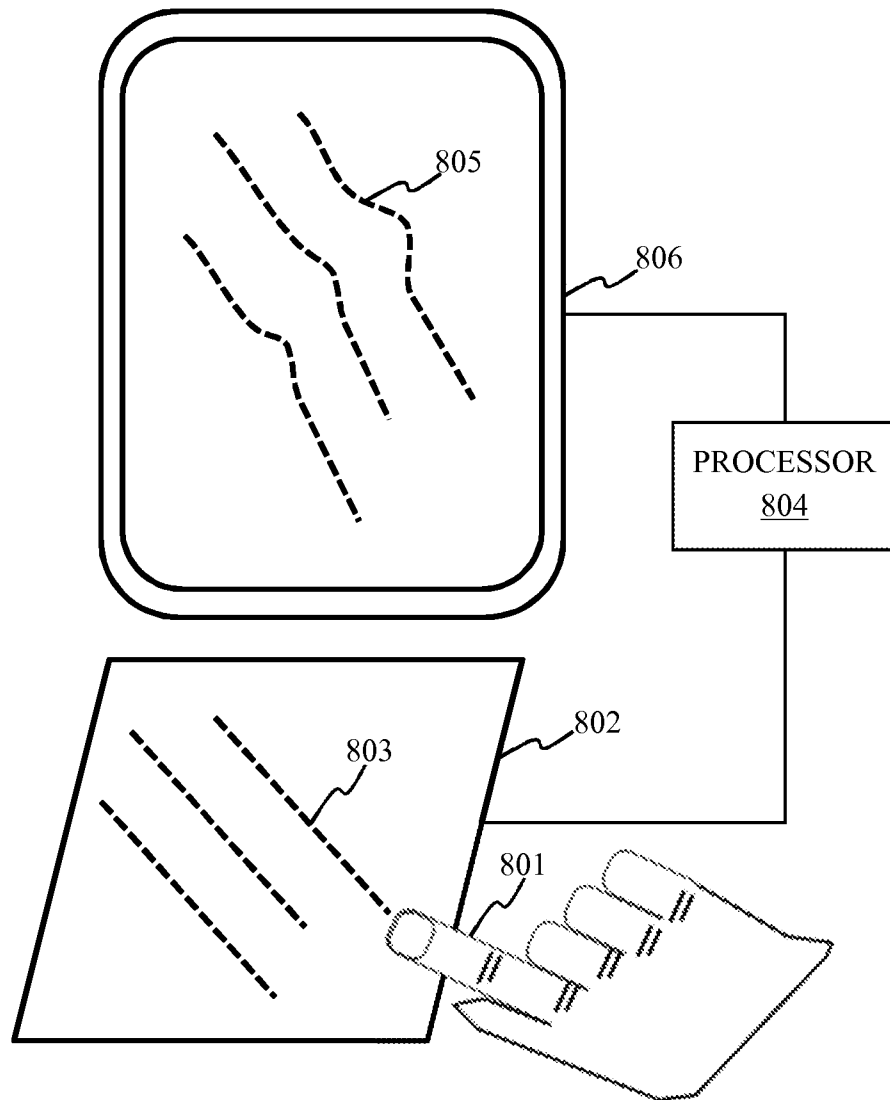


FIG. 7

**FIG. 8**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2014/039602

A. CLASSIFICATION OF SUBJECT MATTER <i>B42D 25/30 (2014.01)</i> <i>G01N 27/02 (2006.01)</i> <i>G07D 7/02 (2006.01)</i> 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) B42D 25/00, 25/30, 25/36, 25/373, G01N 27/00, 27/02, 27/04, 27/12, G07D 7/00, 7/02 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) PatSearch (RUPTO internal), USPTO, PAJ, K-PION, Esp@cenet, Information Retrieval System of FIPS		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 99/64251 A1 (FLEX PRODUCTS INC) 16.12.1999, abstract	1, 6, 7, 11, 12, 15 2-5, 8-10, 13, 14, 27
X Y	JP 2011189508 A (HITACHI MAXELL) 29.09.2011, paragraphs [0002], [0012], [0025], [0033]	16, 18-21 9, 17, 22-27
Y	JP 2008126475 A (NATIONAL PRINTING BUREAU) 05.06.2008, paragraph [0025]	2, 5, 17
Y	US 2010/0001508 A1 (WAYNE ROBERT TOMPKIN et al) 07.01.2010, fig.3D, 3E	3, 4, 22, 23
Y	EP 2028017 A2 (DE LA RUE INTERNATIONAL LIMITED) 25.02.2009, paragraph [0023]	24
☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents:	“A” document defining the general state of the art which is not considered to be of particular relevance “E” earlier document but published on or after the international filing date “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) “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 “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 “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 “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 “&” document member of the same patent family	
Date of the actual completion of the international search	Date of mailing of the international search report	
26 February 2015 (26.02.2015)	12 March 2015 (12.03.2015)	
Name and mailing address of the ISA/RU: Federal Institute of Industrial Property, Berezhkovskaya nab., 30-1, Moscow, G-59, GSP-3, Russia, 125993 Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37	Authorized officer M. Salnikov Telephone No. (499) 240-25-91	

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2014/039602

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6404643 B1 (AMERASIA INTERNATIONAL TECHNOLOGY) 11.06.2002, col.5, lines 66-67	25
Y	JPH 07243198 A (HONSHU PAPER CO LTD) 19.09.1995, abstract	5, 14, 26
Y	KR 20080026698 A (SK TELECOM CO LTD) 26.03.2008, abstract	8
Y	JPS 61120961 A (TEIJIN LTD) 09.06.1986, abstract	10, 13