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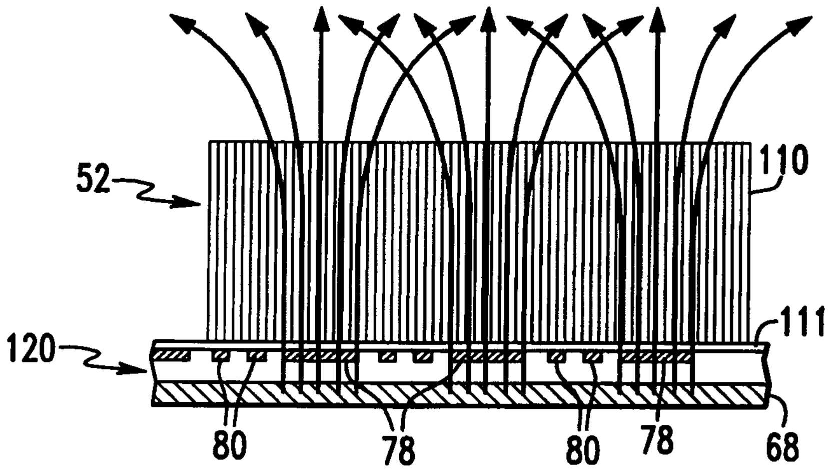
(57) Abstract

A fingerprint sensor includes an integrated circuit die and a protective covering of a z–axis anisotropic dielectric material, that includes a conductive layer defining an array of electric field sensing electrodes. The z–axis anisotropic dielectric layer focusses an electric field at each of the electric field sensing electrodes. The dielectric covering is relatively thick, but not result in defocussing of the electric fields propagating through the dielectric covering because of the z–axis anisotropy of the material. The z–axis anisotrophic dielectric layer is provided by a plurality of oriented dielectric particles in a cured matrix. The z–axis anisotropic dielectric layer comprise barium titanate in a polyimide matrix. The conductive layer comprises a plurality of cacitive coupling pads for permitting capacitive coupling with the integrated circuit die.



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Fingerprint Sensor Including an Anisotropic Dielectric Coating and Associated Methods

The present invention relates to the field of personal identification and verification, and, in particular, to the field of fingerprint sensing and processing.

Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. In particular, a common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in a database to determine proper identification of a person, such as for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. The specification of U.S. Patent No. 4,210,899 discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. The specification of U.S. Patent No. 4,525,859 similarly discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. In addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams.

The specification of U.S. Patent No. 4,353,056 discloses another approach to sensing a live fingerprint. In particular, the patent discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques. Unfortunately, the resilient materials required for the sensor may suffer from long term reliability problems. In addition, multiplexing techniques for driving and scanning each of the individual capacitors may be relatively slow and cumbersome. Moreover, noise and stray capacitances may adversely affect the plurality of relatively small and closely spaced capacitors.

The specification of U.S. Patent No. 5,325,442 discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying portion of the finger surface which, in turn, is at ground potential. The sensor may be fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes.

Unfortunately, driving the array of closely spaced sensing electrodes as disclosed in the Knapp et al. patent may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. Yet another difficulty with such a sensor, as with many optical sensors, is that different portions of the fingerprint may require relatively complicated post image collection processing to provide for usable signal levels and contrast to thereby permit accurate determination of the ridges and valleys of the fingerprint. The specification of U.S. Patent No. 4,811,414 discloses methods for noise averaging, illumination equalizing, directional filtering, curvature correcting, and scale correcting for an optically generated fingerprint image. Unfortunately, the various processing steps are complex and require considerable computational power in a downstream processor. Signal processing of other fingerprint circuits may also be relatively complicated and therefore expensive and/or slow.

The present invention includes a fingerprint sensor comprising an integrated circuit die comprising at least one conductive layer defining an array of electric field sensing electrodes for sensing a fingerprint, a dielectric covering adjacent the array of electric field sensing electrodes of said integrated circuit die and for contact by a finger, said dielectric covering comprising a z-axis anisotropic dielectric layer for focussing an electric field at each of the electric field sensing electrodes, in which said z-axis anisotropic dielectric layer defines an outermost protective surface for said integrated circuit die.

The invention also includes a method for making a fingerprint sensor comprising the steps of:

forming an integrated circuit die comprising at least one conductive layer defining an array of electric field sensing electrodes for sensing a fingerprint; forming a dielectric covering adjacent the array of electric field sensing electrodes of the integrated circuit die and for contact by a finger, the dielectric covering comprising a z-axis anisotropic dielectric layer for focussing an electric field at each of the electric field sensing electrodes, in which the step of forming the dielectric covering comprises forming same so that the z-axis anisotropic dielectric layer defines an outermost protective surface for the integrated circuit die.

An object is to provide such a protective covering and yet permit signals and power to be exchanged with the integrated circuit die of the sensor.

Other objects, and advantages in accordance with the present invention are provided by a fingerprint sensor comprising an integrated circuit die including a conductive layer defining an array of electric field sensing electrodes, and a dielectric covering adjacent the array of electric field sensing electrodes, and wherein the dielectric covering comprises a z-axis anisotropic dielectric layer for focussing an electric field at each of the electric field sensing electrodes. In other words, the dielectric covering may be relatively thick, but not result in defocussing of the electric fields propagating through the dielectric covering because of the z-axis anisotropy of the material.

For example, the z-axis anisotropic dielectric layer may have a thickness in range of about 0.0001 to 0.004 inches thick. Of course, the z-axis anisotropic dielectric layer is also preferably chemically resistant and mechanically strong to withstand contact with fingers, and to permit periodic cleanings with solvents.

The z-axis anisotropic dielectric layer may preferably define an outermost protective surface for the integrated circuit die. Accordingly, the dielectric covering may further include at least one relatively thin layer of an oxide, nitride, carbide, or diamond on the integrated circuit die and beneath the z-axis anisotropic dielectric layer.

The z-axis anisotropic dielectric layer may be provided by a plurality of oriented dielectric particles in a cured matrix. For example, the z-axis anisotropic dielectric layer may comprise barium titanate in a polyimide matrix. The z-axis dielectric layer may also be provided by a plurality of high dielectric portions aligned with corresponding electric field sensing electrodes, and a surrounding matrix of lower dielectric portions.

Another aspect of the invention relates to being able to completely cover the entire upper surface of the integrated circuit die, and permit electrical connection to the external devices and circuits. The conductive layer preferably comprises a plurality of capacitive coupling pads for permitting capacitive coupling with the integrated circuit die. Accordingly, the dielectric covering is preferably continuous over the capacitive coupling pads and the array of electric field sensing electrodes. The z-axis dielectric layer also advantageously reduces cross-talk between adjacent capacitive coupling pads. This embodiment of the invention presents no penetrations through the dielectric covering for moisture to enter and damage the integrated circuit die.

The fingerprint sensor preferably includes a package surrounding the integrated circuit die and dielectric covering. For the fingerprint sensor, the package preferably has an opening aligned with the array of electric field sensing electrodes. One or more finger contacting electrodes may be carried by the package and electrically connected to the integrated circuit die.

A method aspect of the invention is for making a fingerprint sensor. The method preferably comprises the steps of: forming an integrated circuit die comprising at least one conductive layer defining an array of electric field sensing electrodes for sensing a fingerprint; and forming a dielectric covering adjacent the array of electric field sensing electrodes of the integrated circuit die and for contact by a finger, the dielectric covering comprising a z-axis anisotropic dielectric layer for focussing an electric field at each of the electric field sensing electrodes. In embodiments of the invention other than for a fingerprint sensor, the z-axis anisotropic layer may provide and effective way to further protect the integrated circuit die while permitting capacitive coupling of signals and power to the circuits of the die.

The invention will now be described, by way of example, with reference to the accompanying drawings in which:

FIG. 1 is a top plan view of a fingerprint sensor.

FIG. 2 is a schematic view of a circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 3 is a greatly enlarged top plan view of the sensing portion of the fingerprint sensor as shown in FIG. 1.

FIG. 4 is a schematic diagram of another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 5 is a greatly enlarged side cross-sectional view of a portion of the fingerprint sensor as shown in FIG. 1.

FIG. 6 is a greatly enlarged side cross-sectional view of a portion of an alternate embodiment of the fingerprint sensor .

FIG. 7 is a greatly enlarged side cross-sectional view of another portion of the fingerprint sensor as shown in FIG. 1.

FIG. 8 is a schematic block diagram of yet another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 9 is a schematic circuit diagram of a portion of the circuit as shown in FIG. 8.

FIG. 10 is a schematic block diagram of still another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 11 is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. 10.

FIG. 12 is a schematic block diagram of an additional circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 13 is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. 12.

FIGS. 1-3 illustrate the fingerprint sensor **30** which includes a housing or package **51**, a dielectric layer **52** exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of output pins, not shown. A first conductive strip or external electrode **54** around the periphery of the dielectric layer **52**, and a second external electrode **53** provide contact electrodes for the finger **79** as described in greater detail below. The sensor **30** may provide output signals in a range of sophistication levels depending on the level of processing incorporated in the package .

The sensor **30** includes a plurality of individual pixels or sensing elements **30a** arranged in array pattern as perhaps best shown in FIG. 3. These sensing elements are relatively small so as to be capable of sensing the ridges **59** and intervening valleys **60** of a typical fingerprint. Live fingerprint readings as from the electric field sensor **30** in accordance with the present invention may be more reliable than optical sensing, because the impedance of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate. In contrast, an optical sensor may be deceived by a readily deceived by a photograph or other similar image of a fingerprint, for example.

The sensor **30** includes a substrate **65**, and one or more active semiconductor devices formed thereon, such as the schematically illustrated amplifier **73**. A first metal layer **66** interconnects the active semiconductor devices. A second or ground plane electrode layer **68** is above the first metal layer **66** and separated therefrom by an insulating layer **67**. A third metal layer **71** is positioned over another dielectric layer **70**. In the illustrated embodiment, the first external electrode **54** is connected to an excitation drive amplifier **74** which, in turn, drives the finger **79** with a signal may be typically in the range of about 1 KHz to 1 MHz. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor **30** may be relatively low, while the reliability is great.

Circularly shaped electric field sensing electrode **78** is on the insulating layer **70**. The sensing electrode **78** may be connected to sensing integrated electronics, such as the illustrated amplifier **73** formed adjacent the substrate **65** as schematically illustrated.

An annularly shaped shield electrode **80** surrounds the sensing electrode **78** in spaced relation therefrom. The sensing electrode **78** and its surrounding shield electrode **80** may have other shapes, such as hexagonal, to facilitate a close packed arrangement or array of pixels or sensing elements **30a**. The shield electrode **80** is an active shield which is driven by a portion of the output of the amplifier **73** to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electric field sensing electrodes **78**.

The sensor **30** includes only three metal or electrically conductive layers **66, 68** and **71**. The sensor **30** can be made without requiring additional metal layers which would otherwise increase the manufacturing cost, and, perhaps, reduce yields. Accordingly, the sensor **30** is less expensive and may be more rugged and reliable than a sensor including four or more metal layers.

The amplifier **73** is operated at a gain of greater than about one to drive the shield electrode **80**. Stability problems do not adversely affect the operation of the amplifier **73**. Moreover, the common mode and general noise rejection are greatly enhanced according to this feature of the invention. In addition, the gain greater than one tends to focus the electric field with resect to the sensing electrode **78**.

The sensing elements **30a** operate at very low currents and at very high impedances. For example, the output signal from each sensing electrode **78** is desirably about 5 to 10 millivolts to reduce the effects of noise and permit processing of the signals. The approximate diameter of each sensing element **30a**, as defined by the outer dimensions of the shield electrode **80**, may be about 0.002 to 0.005 inches in diameter. The ground plane electrode **68** protects the active electronic devices from unwanted excitation. The various signal feedthrough conductors for the electrodes **78, 80** to the active electronic circuitry may be readily formed.

The overall contact or sensing surface for the sensor **30** may desirably be about 0.5 by 0.5 inches – a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor **30** in accordance with the invention is also fairly tolerant of dead pixels or sensing elements **30a**. A typical sensor **30** includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor **30** may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

Turning to FIG. 4, the sensor may include power control means for controlling operation of active circuit portions **100** based upon sensing finger contact with the first external electrode **54** as determined by the illustrated finger sense block or circuit **101**. For example, the finger sense circuit **101** may operate based upon a change in impedance to an oscillator to thereby determine finger contact. Of course, other approaches for sensing contact with the finger are also contemplated by the invention. The power control means may include wake-up means for only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power. The power control means comprise protection means for grounding active circuit portions upon not sensing finger contact with the first external electrode. A combination of wake-up and protection controller circuits **101** are illustrated.

Moreover, the fingerprint sensor **30** may further comprise finger charge bleed means for bleeding a charge from a finger or other object upon contact therewith. The finger charge bleed means may be provided by the second external electrode **53** carried by the package **51** for contact by a finger, and a charge bleed resistor **104** connected between the second external electrode and an earth ground. As schematically illustrated in the upper right hand portion of FIG. 4, the second electrode may alternately be provided by a movable electrically conductive cover **53'** slidably connected to the package **51** for covering the opening to the exposed upper dielectric layer **52**. A pivotally connected cover is also contemplated by the present invention. Under normal conditions, the charge would be bled from the finger as the cover **53'** is moved to expose the sensing portion of the sensor **30**.

The finger charge bleed means and power control means may be such that the active portions remain grounded until the charge bleed means can remove the charge on the finger before powering the active circuit portions, such as by providing a brief delay during wake-up sufficient to permit the charge to be discharged through the resistor **104** as would be readily understood by those skilled in the art. Accordingly, power may be conserved in the sensor **30** and ESD protection provided by the sensor so that the sensor is relatively inexpensive, yet robust and conserves power.

Referring to FIG. 5 yet another significant feature of the sensor **30** is described. The dielectric covering **52** may preferably comprise a z-axis anisotropic dielectric layer **110** for focussing an electric field, shown by the illustrated field lines, at each of the electric field sensing electrodes 78. In other words, the dielectric layer **110** may be relatively thick, but not result in defocussing of the electric fields propagating therethrough because of the z-axis anisotropy of the material. Typically there would be a trade-off between field focus and mechanical protection. Unfortunately, a thin film which is desirable for focussing, may permit the underlying circuit to be more easily subject to damage.

The z-axis anisotropic dielectric layer **110** of the present invention, for example, may have a thickness in range of about 0.0001 to 0.004 inches. Of course, the z-axis anisotropic dielectric layer **110** is also preferably chemically resistant and mechanically strong to withstand contact with fingers, and to permit periodic cleanings with solvents. The z-axis anisotropic dielectric layer **110** define an outermost protective surface for the integrated circuit die **120**. Accordingly, the overall dielectric covering **52** may further include at least one relatively thin oxide, nitride, carbide, or diamond layer **111** on the integrated circuit die **120** and beneath the z-axis anisotropic dielectric layer **110**. The thin layer **111** will typically be relatively hard, and the z-axis anisotropic dielectric layer **110** is desirably softer to thereby absorb more mechanical activity.

The z-axis anisotropic dielectric layer **110** may be provided by a plurality of oriented dielectric particles in a cured matrix. For example, the z-axis anisotropic dielectric layer **110** may comprise barium titanate in a polyimide matrix.

Turning to FIG. 6, another variation of a z-axis dielectric covering **52'** is schematically shown by a plurality of high dielectric portions **112** aligned with corresponding electric field sensing electrodes **78**, and a surrounding matrix of lower dielectric portions **113**. This embodiment of the dielectric covering **52'** may be formed in a number of ways, such as by forming a layer of either the high dielectric or low dielectric portions, selectively etching same, and filling the openings with the opposite material. Another approach may be to use polarizable microcapsules and subjecting same to an electric field during curing of a matrix material. A material may be compressed to cause the z-axis anisotropy. Laser and other selective processing techniques may also be used.

The third metal layer **71** (FIG. 2) further includes a plurality of capacitive coupling pads **116a-118a** for permitting capacitive coupling of the integrated circuit die **120**. Accordingly, the dielectric covering **52** is preferably continuous over the capacitive coupling pads **116a-118a** and the array of electric field sensing electrodes **78** of the pixels **30a** (FIG. 1). It is known to create openings through an outer coating to electrically connect to the bond pads. Unfortunately, these openings would provide pathways for water and/or other contaminants to come in contact with and damage the die.

A portion of the package **51** includes a printed circuit board **122** which carries corresponding pads **115b-118b**. A power modulation circuit **124** is coupled to pads **115b-116b**, while a signal modulation circuit **126** is illustrative coupled to pads **117b-118b**. As would be readily understood by those skilled in the art, both power and signals may be readily coupled between the printed circuit board **122** and the integrated circuit die **120**, further using the illustrated power demodulation/regulator circuit **127**, and the signal demodulation circuit **128**. The z-axis anisotropic dielectric layer **110** also advantageously reduces cross-talk between adjacent capacitive coupling pads. This embodiment of the invention **30** presents no penetrations through the dielectric covering **52** for moisture to enter and damage the integrated circuit die **120**. In addition, another level of insulation is provided between the integrated circuit and the external environment.

In the sensor **30**, the package **51** has an opening aligned with the array of electric field sensing electrodes **78** (FIGS. 1-3). The capacitive coupling and z-axis anisotropic layer **110** may be advantageously used in a number of applications in addition to the illustrated fingerprint sensor **30**, and particularly where it is desired to have a continuous film covering the upper surface of the integrated circuit die **120** and pads **116a-118a**. FIGS. 8 and 9 shows impedance matrix filtering aspects t*he fingerprint sensor **30** may be considered as comprising an array of fingerprint sensing elements **130** and associated active circuits **131** for generating signals relating to the fingerprint image. The illustrated sensor **30** also includes an impedance matrix **135** connected to the active circuits for filtering the signals therefrom.

FIG. 9 refers to the impedance matrix **135** includes a plurality of impedance elements **136** with a respective impedance element connectable between each active circuit of a respective fingerprint sensing element as indicated by the central node **138**, and the other active circuits (outer nodes **140**). The impedance matrix **135** also includes a plurality of switches **137** with a respective switch connected in series with each impedance element **136**. An input signal may be supplied to the central node **138** via the illustrated switch **142** and its associated impedance element **143**. The impedance element may one or more of a resistor as illustrated, and a capacitor **134**.

Filter control means may operate the switches **137** to perform processing of the signals generated by the active circuits **131**. In one embodiment, the fingerprint sensing elements **130** may be electric field sensing electrodes **78**, and the active circuits **131** may be amplifiers **73** (FIG. 2).

Ridge flow determining means **145** may be provided for selectively operating the switches **137** of the matrix **135** to determine ridge flow directions of the fingerprint image. More particularly, the ridge flow determining means **145** may selectively operate the switches **137** for determining signal strength vectors relating to ridge flow directions of the fingerprint image. The ridge flow directions may be determined based upon well known rotating slit principles.

The sensor **30** may include core location determining means **146** cooperating with the ridge flow determining means **145** for determining a core location of the fingerprint image. The position of the core is helpful, for example, in extracting and processing minutiae from the fingerprint image.

A binarizing filter **150** may be provided for selectively operating the switches **137** to convert a gray scale fingerprint image to a binarized fingerprint image. Considered another way, the impedance matrix **135** may be used to provide dynamic image contrast enhancement. In addition, an edge smoothing filter **155** may be readily implemented to improve the image. Other spatial filters **152** may also be implemented using the impedance matrix **135** for selectively operating the switches **137** to spatially filter the fingerprint image. Accordingly, processing of the fingerprint image may be carried out at the sensor **30** and thereby reduce additional downstream computational requirements.

In FIG. 9, the impedance matrix **135** may comprise a plurality of impedance elements with a respective impedance element **136** connectable between each active circuit for a given fingerprint sensing element **130** and eight other active circuits for respective adjacent fingerprint sensing elements.

The control means **153** sequentially powering sets of active circuits **131** to thereby conserve power. Of course, the respective impedance elements **136** are desirably also sequentially connected to perform the filtering function. The powered active circuits **131** may be considered as defining a cloud or kernel as would be readily appreciated by those skilled in the art. The power control means **153** may be operated in an adaptive fashion whereby the size of the area used for filtering is dynamically changed for preferred image characteristics. In addition, the power control means **153** may also power only certain ones of the active circuits corresponding to a predetermined area of the array of sensing elements **130**.

Reader control means **154** may be provided to read only predetermined subsets of each set of active circuits **131** so that a contribution from adjacent active circuits is used for filtering. In other words, only a subset of active circuits **131** are typically simultaneously read although adjacent active circuits **131** and associated impedance elements **136** are also powered and connected, respectively. For example, 16 impedance elements **136** could define a subset and be readily simultaneously read.

Accordingly, the array of sense elements **130** can be quickly read, and power consumption substantially reduced since all of the active circuits **131** need not be powered for reading a given set of active circuits. For a typical sensor, the combination of the power control and impedance matrix features described herein may permit power savings by a factor of about 10 as compared to powering the full array.

The fingerprint sensor **30** according to present invention to guard against spoofing or deception of the sensor into incorrectly treating a simulated image as a live fingerprint image. For example, optical sensors may be deceived or spoofed by using a paper with a fingerprint image thereon. The unique electric field sensing of the fingerprint sensor **30** of the present invention provides an effective approach to avoiding spoofing based upon the complex impedance of a finger.

FIG. 10 shows the fingerprint sensor **30** as including an array of impedance sensing elements **160** for generating signals related to a finger **79** or other object positioned adjacent thereto. The impedance sensing elements **160** are provided by electric field sensing electrodes **78** and amplifiers **73** (FIG. 2) associated therewith. In addition, a guard shield **80** may be associated with each electric field sensing electrode **78** and connected to a respective amplifier **73**. Spoof reducing means **161** is provided for determining whether or not an impedance of the object positioned adjacent the array of impedance sensing elements **160** corresponds to a live finger **79** to thereby reduce spoofing of the fingerprint sensor by an object other than a live finger. A spoofing may be indicated, such as by the schematically illustrated lamp **163** and/or used to block further processing. Alternately, a live fingerprint determination may also be indicated by a lamp **164** and/or used to permit further processing of the fingerprint image.

In one embodiment, the spoof reducing means **161** may include impedance determining means **165** to detect a complex impedance having a phase angle in a range of about 10 to 60 degrees corresponding to a live finger **79**. Alternately, the spoof reducing means **161** may detect an impedance having a phase angle of about 0 degrees corresponding to some objects other than a live finger, such as a sheet of paper having an image thereon, for example. In addition, the spoof reducing means **161** may detect an impedance of 90 degrees corresponding to other objects.

Turning now to FIG. 11, another embodiment of spoof reducing means is explained. The fingerprint sensor **30** may preferably includes drive means for driving the array of impedance sensing elements **160**, such as the illustrated excitation amplifier **74** (FIG. 2). The sensor also includes synchronous demodulator means **170** for synchronously demodulating signals from the array of impedance sensing elements **160**. Accordingly, in one particularly advantageous embodiment of the invention, the spoof reducing means comprises means for operating the synchronous demodulator means **170** at at least one predetermined phase rotation angle. For example, the synchronous demodulator means **170** could be operated in a range of about 10 to 60 degrees, and the magnitude compared to a predetermined threshold indicative of a live fingerprint. A live fingerprint typically has a complex impedance within the range of 10 to 60 degrees.

Alternately, ratio generating and comparing means **172** may be provided for cooperating with the synchronous demodulator means **170** for synchronously demodulating signals at first and second phase angles θ_1, θ_2, generating an amplitude ratio thereof, and comparing the amplitude ratio to a predetermined threshold to determine whether the object is a live fingerprint or other object. Accordingly, the synchronous demodulator **170** may be readily used to generate the impedance information desired for reducing spoofing of the sensor **30** by an object other than a live finger. The first angle θ_1 and the second θ_2 may have a difference in a range of about 45 to 90 degrees, for example.

The fingerprint sensor **30** also includes an automatic gain control feature to account for a difference in intensity of the image signals generated by different fingers or under different conditions, and also to account for differences in sensor caused by process variations. It is important for accurately producing a fingerprint image, that the sensor can discriminate between the ridges and valleys of the fingerprint. Accordingly, the sensor **30** includes a gain control feature, a first embodiment of which is understood with reference to FIG. 12.

FIG. 12, illustrates the portion of the fingerprint sensor **30** including an array of fingerprint sensing elements in the form of the electric field sensing electrodes **78** and surrounding shield electrodes **80** connected to the amplifiers **73**. Other fingerprint sensing elements may also benefit from the following automatic gain control implementations.

The signal processing circuitry of the sensor **30** preferably includes a plurality of analog-to-digital (A/D) converters **180** as illustrated. Moreover, each of these A/D converters **180** may have a controllable scale. Scanning means **182** sequentially connects different elements to the bank of A/D converters **180**. The illustrated gain processor **185** provides range determining and setting means for controlling the range of the A/D converters **180** based upon prior A/D conversions to thereby provide enhanced conversion resolution. The A/D converters **180** may comprise the illustrated reference voltage input V_{ref} and offset voltage input V_{offset} for permitting setting of the range. Accordingly, the range determining and setting means may also comprise a first digital-to-analog D/A converter **186** connected between the gain processor **185** and the reference voltage V_{ref} inputs of the A/D converters **180** as would also be readily understood by those skilled in the art. In addition, a second D/A converter **189** is also illustratively connected to the offset voltage inputs V_{offset} from the gain processor **185**.

The gain processor **185** may comprise histogram generating means for generating a histogram, as described above, and based upon prior A/D conversions. The graph adjacent the gain processor **185** in FIG. 12 illustrates a typical histogram plot **191**. The histogram plot **191** includes two peaks corresponding to the sensed ridges and valleys of the fingerprint. By setting the range for the A/D converters **180**, the peaks can be readily positioned as desired to thereby account for the variations discussed above and use the full resolution of the A/D converters **180**.

FIG. 13 shows the A/D converters **180** including an associated input amplifier for permitting setting of the range. In this variation, the range determining and setting means may also comprise the illustrated gain processor **185**, and wherein the amplifier is a programmable gain amplifier (PGA) **187** connected to the processor. A digital word output from the gain processor **185** sets the gain of the PGA **187** so that full use of the resolution of the A/D converters **180** is obtained for best accuracy. A second digital word output from the gain processor **185** and coupled to the amplifier **187** through the illustrated D/A converter **192** may also control the offset of the amplifier.

The range determining and setting means of the gain processor **185** may comprise default setting means for setting a default range for initial ones of the fingerprint sensing elements. The automatic gain control feature of the present invention allows the D/A converters **180** to operate over their full resolution range to thereby increase the accuracy of the image signal processing.

A fingerprint sensor includes an integrated circuit die and a protective covering of a z-axis anisotropic dielectric material, that includes a conductive layer defining an array of electric field sensing electrodes. The z-axis anisotropic dielectric layer focusses an electric field at each of the electric field sensing electrodes. The dielectric covering is relatively thick, but not result in defocussing of the electric fields propagating through the dielectric covering because of the z-axis anisotropy of the material. The z-axis anisotropic dielectric layer is provided by a plurality of oriented dielectric particles in a cured matrix. The z-axis anisotropic dielectric layer comprise barium titanate in a polyimide matrix. The conductive layer comprises a plurality of capacitive coupling pads for permitting capacitive coupling with the integrated circuit die.

CLAIMS:

1. A fingerprint sensor comprising an integrated circuit die comprising at least one conductive layer defining an array of electric field sensing electrodes for sensing a fingerprint, a dielectric covering adjacent the array of electric field sensing electrodes of said integrated circuit die and for contact by a finger, said dielectric covering comprising a z-axis anisotropic dielectric layer for focussing an electric field at each of the electric field sensing electrodes, in which said z-axis anisotropic dielectric layer defines an outermost protective surface for said integrated circuit die.

2. A fingerprint sensor as claimed in claim 1 wherein said z-axis anisotropic dielectric layer has a thickness in range of about 0.0001 to 0.004 inches, and said z-axis anisotropic dielectric layer is chemically resistant and mechanically strong.

3. A fingerprint sensor as claimed in claim 1 or 2 wherein said z-axis anisotropic dielectric layer comprises a plurality of oriented dielectric particles in a cured matrix, and said z-axis anisotropic dielectric layer comprises barium titanate in a polyimide matrix.

4. A fingerprint sensor as claimed in any one of claims 1 to 3 wherein said z-axis anisotropic layer comprises an array of high dielectric portions aligned with corresponding electric field sensing electrodes, and a matrix of low dielectric portions surrounding the high dielectric portions, in which said dielectric covering further comprises at least one relatively thin layer of an oxide, nitride, carbide, and diamond on said integrated circuit die and beneath said z-axis anisotropic dielectric layer, and said at least one conductive layer comprises a plurality of capacitive coupling pads for permitting capacitive coupling with said integrated circuit die; and said dielectric covering is continuous over said capacitive coupling pads and the array of electric field sensing electrodes whereby the z-axis dielectric layer reduces cross-talk between adjacent capacitive coupling pads.

5. A sensor comprising an integrated circuit die comprising at least one conductive layer defining an array of electric field sensing electrodes and a plurality of capacitive coupling pads, a dielectric covering adjacent the array of electric field sensing electrodes and said capacitive coupling pads of said integrated circuit die, said dielectric covering comprising a z-axis anisotropic dielectric layer for focussing an electric field at each of the electric field sensing electrodes and for reducing cross-talk between adjacent capacitive coupling pads, and said z-axis anisotropic dielectric layer defines an outermost protective surface for said integrated circuit die, preferably with said z-axis anisotropic dielectric layer has a thickness in range of about 0.0001 to 0.004 inches, and said z-axis anisotropic dielectric layer is chemically resistant and

mechanically strong.

6. A sensor as claimed in claim 5 wherein said z-axis anisotropic dielectric layer comprises a plurality of oriented dielectric particles in a cured matrix, in which said z-axis anisotropic dielectric layer comprises barium titanate in a polyimide matrix, and said z-axis anisotropic layer comprises an array of high dielectric portions aligned with corresponding electric field sensing electrodes, and a matrix of low dielectric portions surrounding the high dielectric portions.

7. A sensor as claimed in claims 5 or 6 wherein said dielectric covering further comprises at least one relatively thin layer of an oxide, nitride, carbide, and diamond on said integrated circuit die and beneath said z-axis anisotropic dielectric layer, also comprising a package surrounding said integrated circuit die and dielectric covering, and wherein said package has an opening aligned with the array of electric field sensing electrodes, and at least one finger contacting electrode carried by said package and electrically connected to said integrated circuit die so that the sensor is a fingerprint sensor.

8. An integrated circuit comprising an integrated circuit die comprising at least one conductive layer defining a plurality of capacitive coupling pads, a dielectric covering adjacent said capacitive coupling pads of said integrated circuit die, said dielectric covering comprising a z-axis anisotropic dielectric layer for reducing cross-talk between adjacent capacitive coupling pads, in which said z-axis anisotropic dielectric layer defines an outermost protective surface for said integrated circuit die.

9. An integrated circuit as claimed in claim 8 wherein said z-axis anisotropic dielectric layer has a thickness in range of about 0.0001 to 0.004 inches, in which said z-axis anisotropic dielectric layer is chemically resistant and mechanically strong, and said z-axis anisotropic dielectric layer comprises a plurality of oriented dielectric particles in a cured matrix.

10. An integrated circuit as claimed in claims 8 or 9 wherein said z-axis anisotropic dielectric layer comprises barium titanate in a polyimide matrix, said z-axis anisotropic layer comprises an array of high dielectric portions aligned with corresponding electric field sensing electrodes, and a matrix of low dielectric portions surrounding the high dielectric portions, and said dielectric covering further comprises at least one relatively thin layer of an oxide, nitride, carbide, and diamond on said integrated circuit die and beneath said z-axis anisotropic dielectric layer, and including a package surrounding said integrated circuit die and dielectric covering.

11. A method for making a fingerprint sensor comprising the steps of:

forming an integrated circuit die comprising at least one conductive layer defining an array of electric field sensing electrodes for sensing a fingerprint; forming a dielectric covering adjacent the array of electric field sensing electrodes of the integrated circuit die and for contact by a finger, the dielectric covering comprising a z-axis anisotropic dielectric layer for focussing an electric field at each of the electric field sensing electrodes, in which the step of forming the dielectric covering comprises forming same so that the z-axis anisotropic dielectric layer defines an outermost protective surface for the integrated circuit die.

12. A method as claimed in claim 11 wherein the step of forming the dielectric covering comprises forming same so that the z-axis anisotropic dielectric layer has a thickness in range of about 0.0001 to 0.004 inches, the dielectric covering comprises forming same so that the z-axis anisotropic dielectric layer is chemically resistant and mechanically strong, and the step of forming the dielectric covering comprises forming same so that the z-axis anisotropic dielectric layer comprises a plurality of oriented dielectric particles in a cured matrix.

13. A method as claimed in claim 12 wherein the step of forming the dielectric covering comprises forming same so that the z-axis anisotropic dielectric layer comprises barium titanate in a polyimide matrix, the step of forming the dielectric covering also comprises forming same so that the z-axis anisotropic layer comprises an array of high dielectric portions aligned with corresponding electric field sensing electrodes, and a matrix of low dielectric portions surrounding the high dielectric portions, and further comprises at least one relatively thin layer of an oxide, nitride, carbide, and diamond on the integrated circuit die and beneath the z-axis anisotropic dielectric layer.

14. A method as claimed in claims 11, 12, or 13, wherein the step of forming at least one conductive layer further comprises forming same to include a plurality of capacitive coupling pads for permitting capacitive coupling with the integrated circuit die; and wherein the step of forming the dielectric covering comprises forming same to be continuous over the capacitive coupling pads and the array of electric field sensing electrodes whereby the z-axis dielectric layer reduces cross-talk between adjacent capacitive coupling pads, also comprising the step of forming a package surrounding the integrated circuit die and dielectric covering, and wherein the package has an opening aligned with the array of electric field sensing electrodes.

15. A method of making an integrated circuit comprising providing an integrated circuit die, forming a dielectric covering adjacent the integrated circuit die, the dielectric covering comprising a z-axis anisotropic dielectric layer, and forming the dielectric covering comprises forming same so that the z-axis anisotropic dielectric layer defines an outermost protective surface for the integrated circuit die, with the step of forming the dielectric covering comprises

forming same so that the z-axis anisotropic dielectric layer has a thickness in range of about 0.0001 to 0.004 inches and forming the dielectric covering comprises forming same so that the z-axis anisotropic dielectric layer is chemically resistant and mechanically strong, with the step of forming the dielectric covering comprises forming same so that the z-axis anisotropic dielectric layer comprises a plurality of oriented dielectric particles in a cured matrix.

16. A method as claimed in claim 15 wherein the step of forming the dielectric covering comprises forming same so that the z-axis anisotropic dielectric layer comprises barium titanate in a polyimide matrix, in which the step of forming the dielectric covering comprises forming same so that the z-axis anisotropic layer comprises an array of high dielectric portions aligned with corresponding electric field sensing electrodes, and a matrix of low dielectric portions surrounding the high dielectric portions, the dielectric covering comprises at least one relatively thin layer of an oxide, nitride, carbide, and diamond on the integrated circuit die and beneath the z-axis anisotropic dielectric layer, and comprising the step of forming a package surrounding the integrated circuit die and dielectric covering.

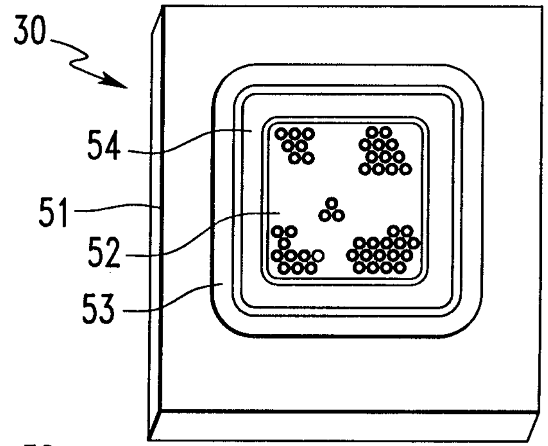
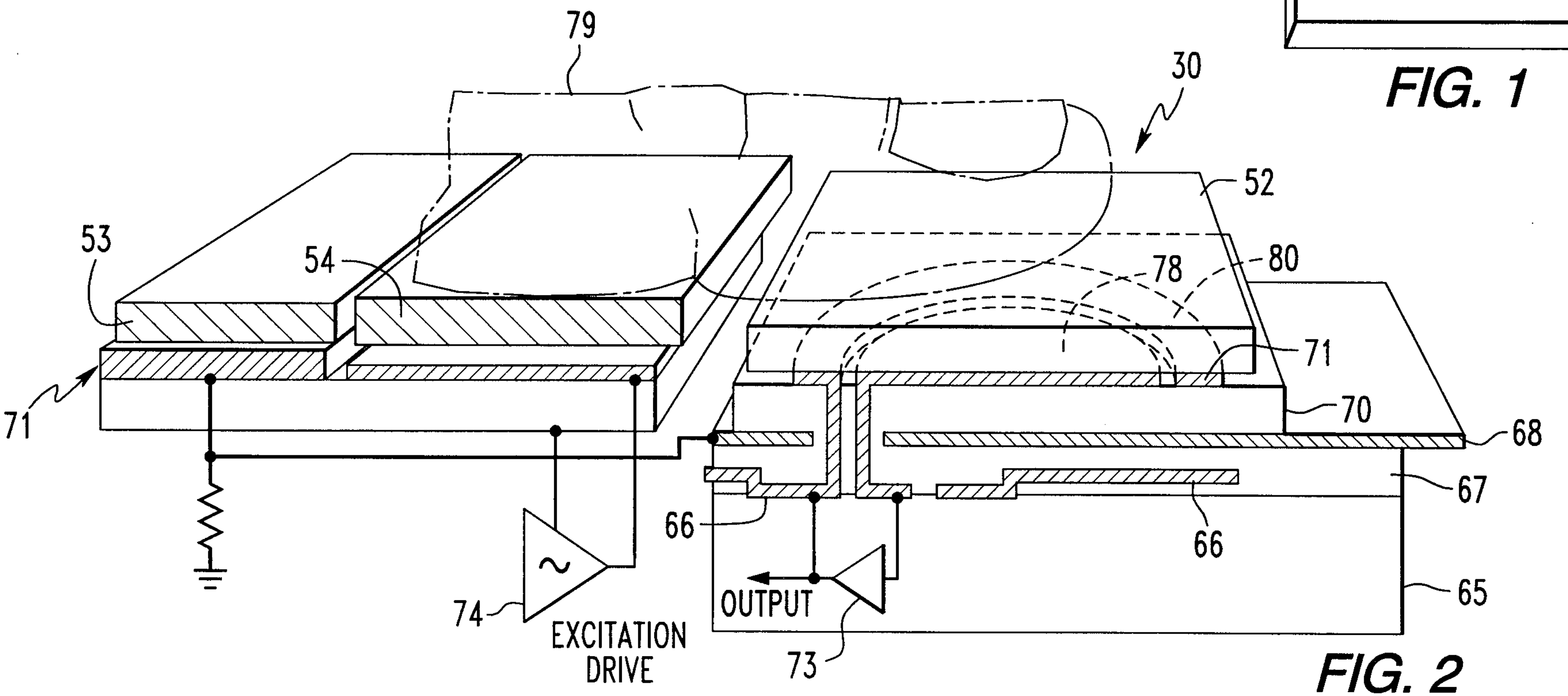

30
54
51
52
53

FIG. 1


79
30
52
53
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80
78
71
71
70
68
67
66
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65
74
73
OUTPUT
EXCITATION
DRIVE

FIG. 2

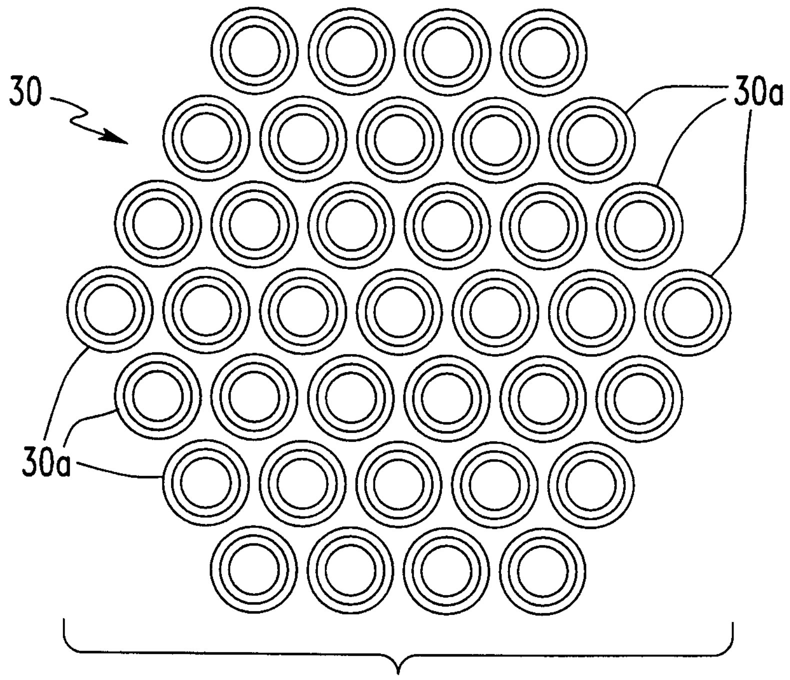
30
30a
30a

FIG.3

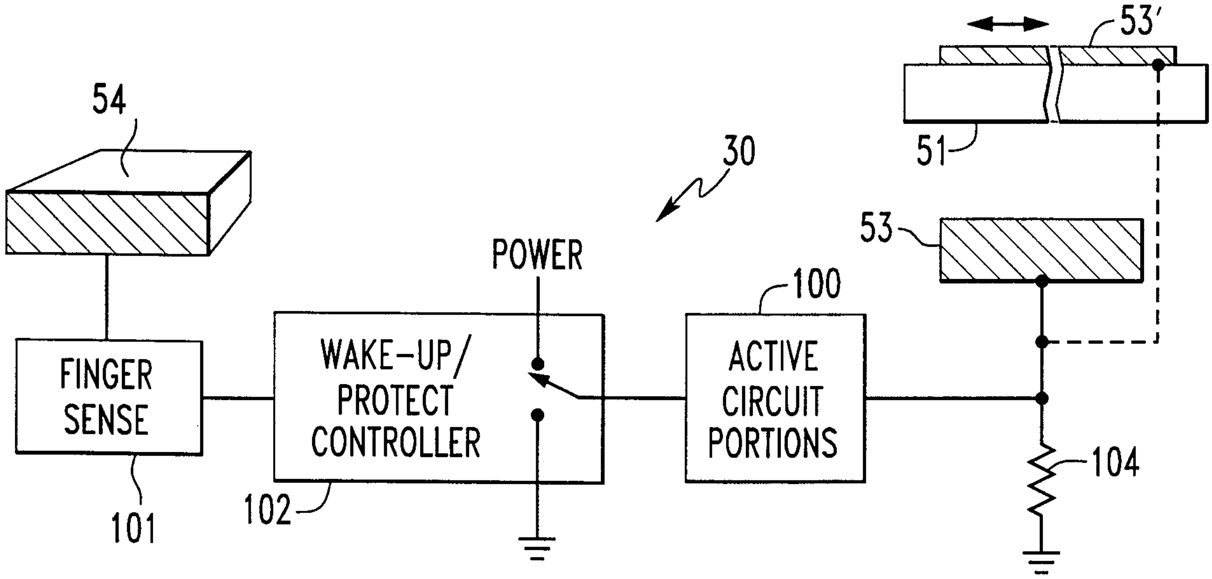
53′
51
30
54
53
POWER
100
FINGER SENSE
WAKE-UP/ PROTECT CONTROLLER
ACTIVE CIRCUIT PORTIONS
104
101
102

FIG.4

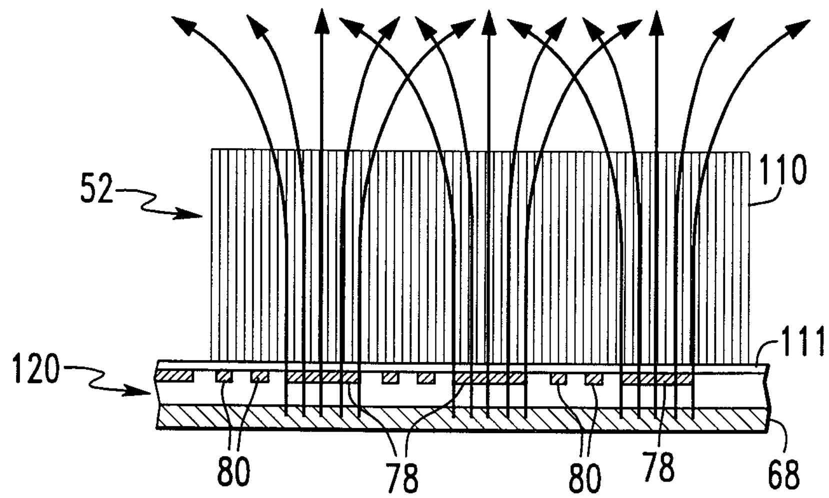

FIG. 5

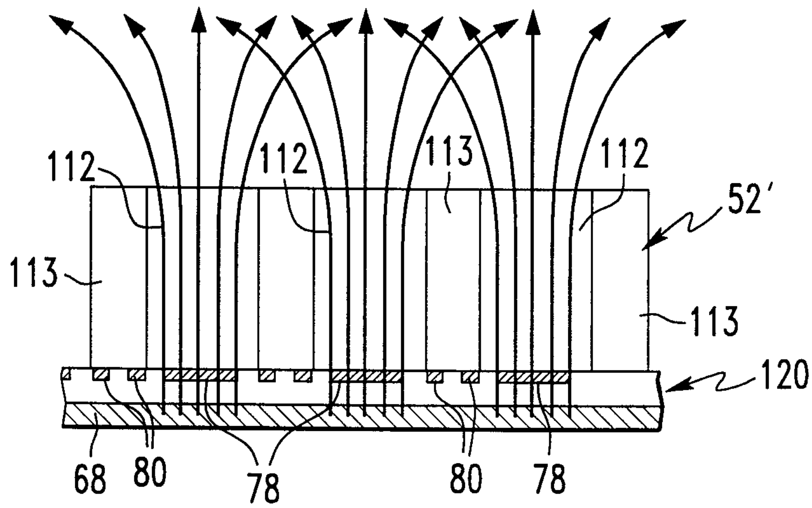

FIG. 6

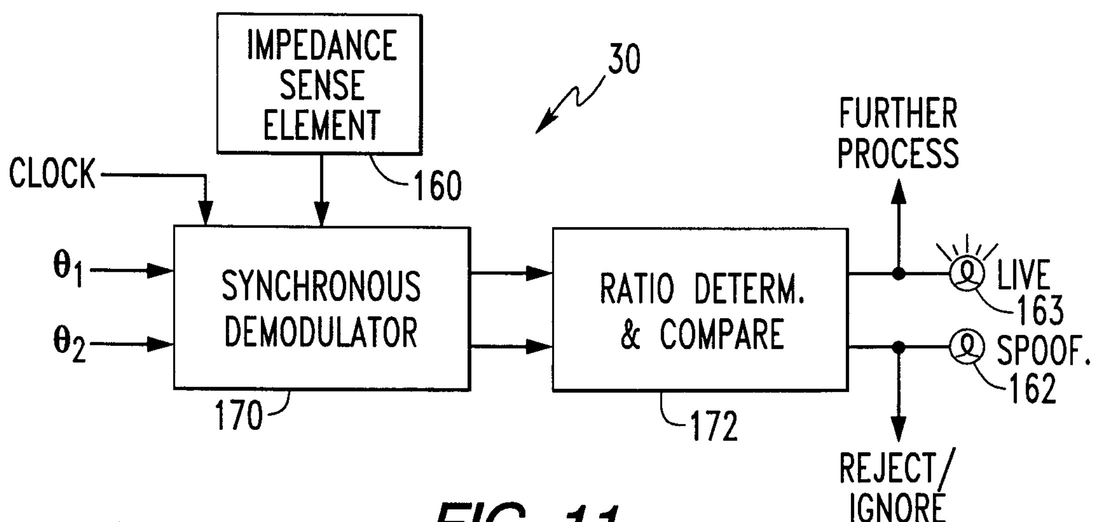

FIG. 11

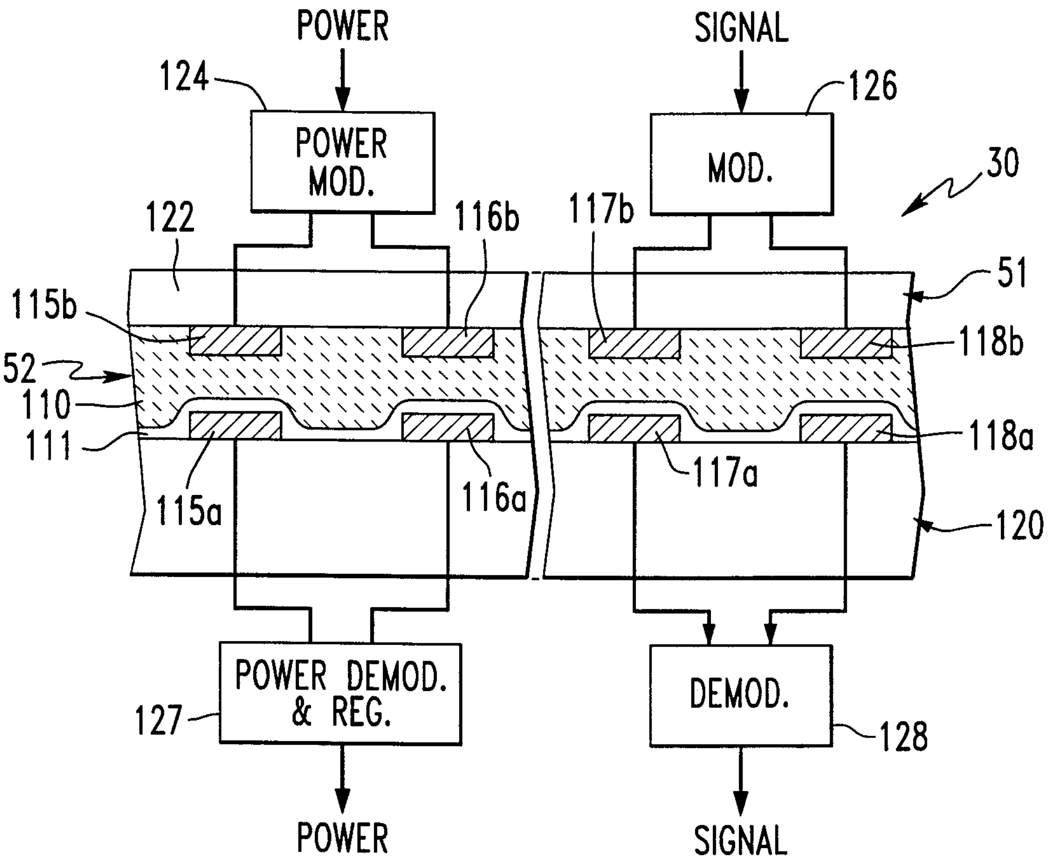
POWER
124
POWER MOD.
SIGNAL
126
MOD.
30
122
116b
117b
51
115b
118b
52
110
111
118a
117a
115a
116a
120
POWER DEMOD. & REG.
127
DEMOD.
128
POWER
SIGNAL

FIG. 7

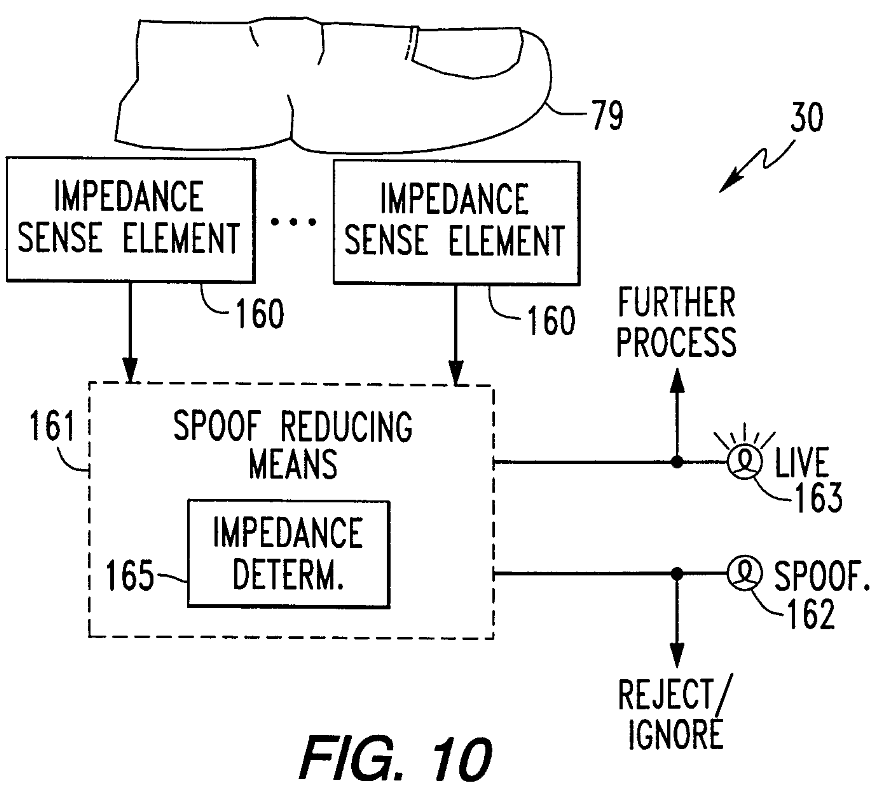
79
30
IMPEDANCE SENSE ELEMENT
IMPEDANCE SENSE ELEMENT
160
160
FURTHER PROCESS
161
SPOOF REDUCING MEANS
LIVE
163
IMPEDANCE DETERM.
165
SPOOF.
162
REJECT/ IGNORE

FIG. 10

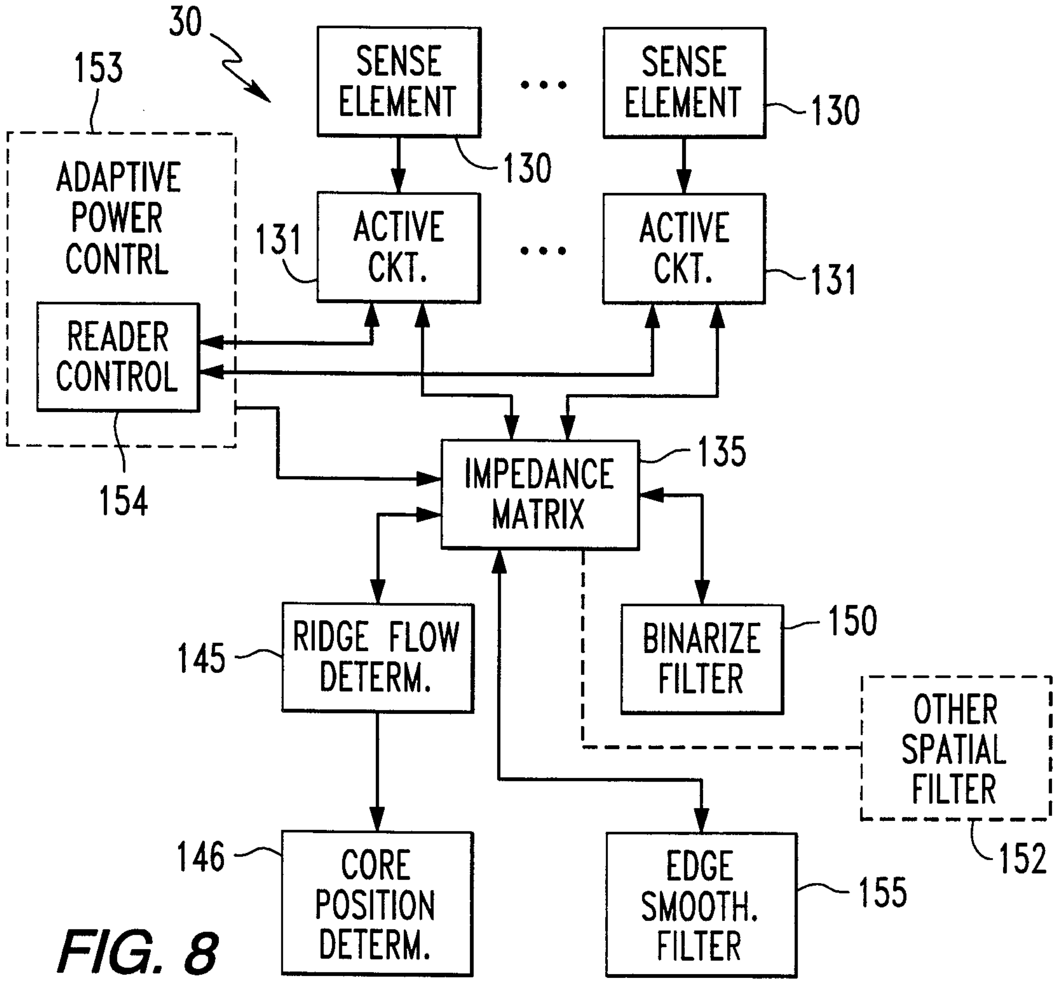
30
153
SENSE ELEMENT
SENSE ELEMENT
130
130
ADAPTIVE POWER CONTRL
ACTIVE CKT.
ACTIVE CKT.
131
131
READER CONTROL
154
IMPEDANCE MATRIX
135
RIDGE FLOW DETERM.
145
BINARIZE FILTER
150
OTHER SPATIAL FILTER
152
CORE POSITION DETERM.
146
EDGE SMOOTH. FILTER
155

FIG. 8

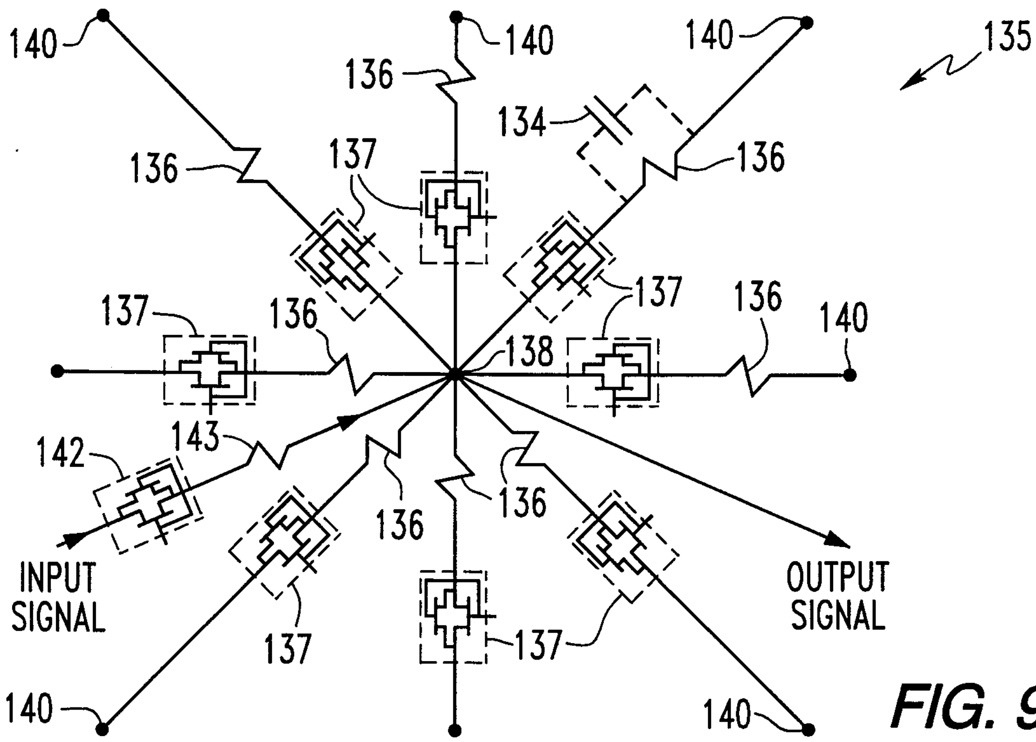
140
140
140
135
136
134
136
136
137
137
137
136
137
136
140
138
142
143
136
136
136
INPUT SIGNAL
OUTPUT SIGNAL
137
137
137
140
140

FIG. 9

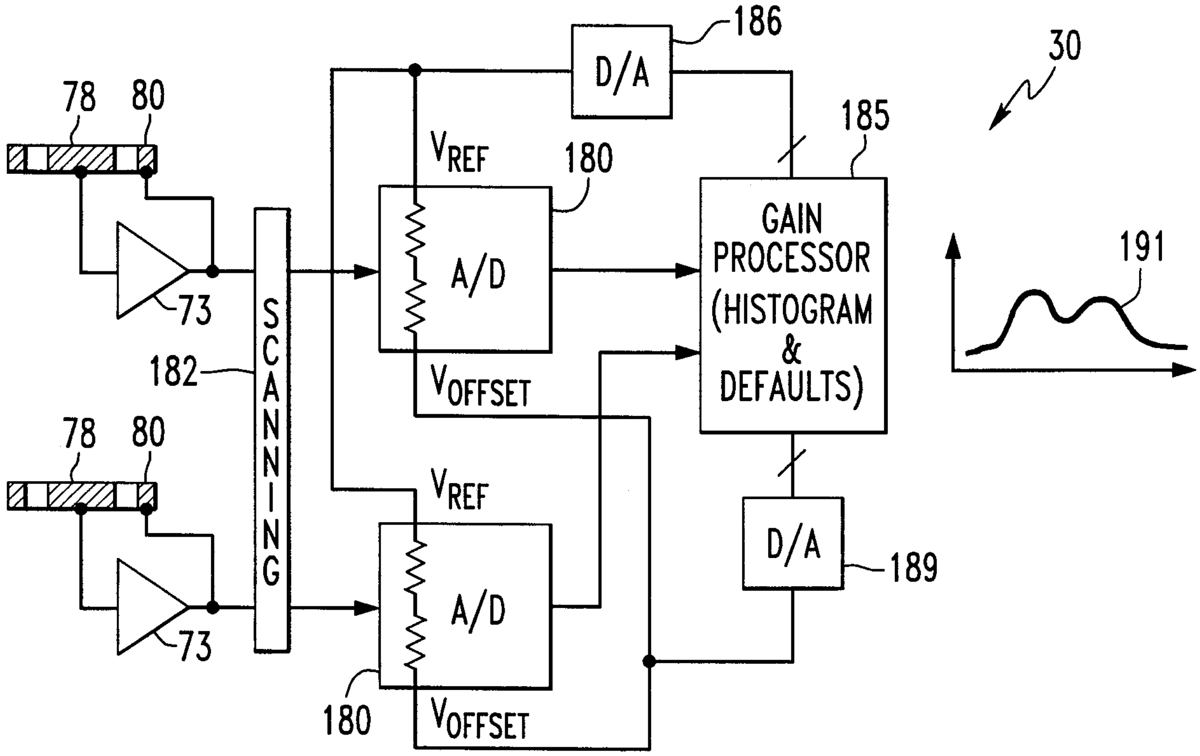
186
30
D/A
78 80
185
VREF
180
GAIN
PROCESSOR
(HISTOGRAM
&
DEFAULTS)
191
A/D
73
SCANNING
182
VOFFSET
78 80
VREF
A/D
D/A
189
73
180
VOFFSET

FIG. 12

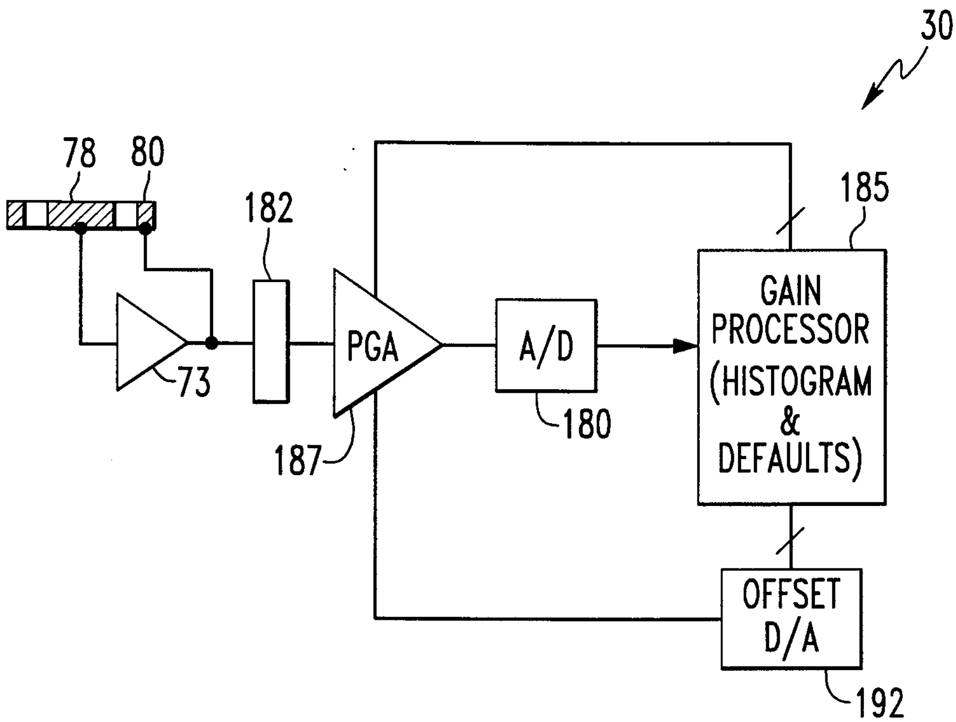
30
78 80
185
182
GAIN
PROCESSOR
(HISTOGRAM
&
DEFAULTS)
PGA
A/D
73
180
187
OFFSET
D/A
192

FIG. 13

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/09204

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G06K9/20 A61B5/117

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)
IPC 6 G06K

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 practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 353 056 A (TSIKOS CONSTANTINE) 5 October 1982 cited in the application ---	
A	US 5 325 442 A (KNAPP ALAN G) 28 June 1994 cited in the application ---	
A	US 3 781 855 A (KILLEN D) 25 December 1973 ---	
A	TARTAGNI M ET AL: "A 390 dpi live fingerprint imager based on feedback capacitive sensing scheme" 1997 IEEE INTERNATIONAL SOLID-STATE CIRCUITS CONFERENCE. DIGEST OF TECHNICAL PAPERS. ISSCC. SAN FRANCISCO, CA, USA, 6-8 FEBRUARY 1997, pages 200-201, 456, XP002077718 ISBN 0-7803-3721-2, 1997, New York -----	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"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
16 September 1998	28/09/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Sonius, M

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 98/09204

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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