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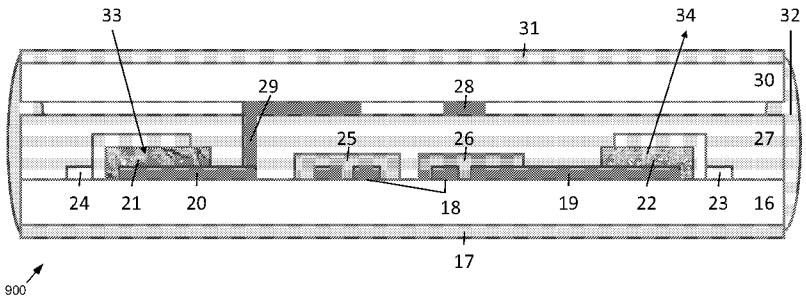


Figure 9a

(57) Abstract: We describe an integrated organic electronic imaging circuit, the circuit comprising a substrate onto which are integrated: at least one organic photosensor to detect an optical signal; an organic transistor circuit coupled to the organic photosensor, and configured to process information from the detected optical signal and to output a drive signal; and a display, coupled to receive said drive signal from said transistor circuit, to provide a display responsive to the processed detected optical signal. Embodiments of the invention use one or more arrays to compare colours and/or shapes, for example for a child's toy.

WO 2012/164259 A1

Electronic devices

FIELD OF THE INVENTION

This invention relates to integrated organic electronic devices, and in particular to smart imaging devices.

BACKGROUND TO THE INVENTION

Organic electronic devices present particular challenges and opportunities. For example, Thin Film Technologies Limited are looking to fabricate non-volatile memory based on ferroelectric polymers, whilst PolyIC GmbH have a number of patent applications relating to the fabrication of electronic circuits comprising organic components. There is also background prior art relating to colour sensing techniques (see, for example, WO2009/013718), and colour sensors using organic materials have been fabricated (see, for example, US7,586,528 and WO2008/038324). Further background prior art can be found in Organic Electronics, Vol 11, No 1, pp175-178, Renshaw C.K. et al; WO99/54936; US2006/273362; and GB2330451.

There is, nonetheless, much scope for improvement, particularly in the fabrication of relatively complex organic electronic devices.

SUMMARY OF THE INVENTION

According to the present invention there is therefore provided an integrated organic electronic device, the device having an integrated optoelectronic sensor and processing circuitry, the device comprising: a substrate bearing at least one organic semiconductor optosensor for light-sensing to provide a light-sensing signal, and organic semiconductor signal processing circuitry comprising a plurality of organic field effect transistors (OFETs), coupled to said optosensor to process said light sensing signal to provide a processed light detection signal output; a first, source-drain conducting layer; a gate dielectric layer; a first organic semiconductor layer between said first, source-drain conducting layer and said gate dielectric layer; wherein said

plurality of OFETs is formed in said first organic semiconductor layer, each said OFET having source and drain connections patterned in said first, source-drain conducting layer and a gate connection; a second, interconnection conducting layer; a third, transparent conducting layer; an optosensor organic semiconductor layer formed between said second, interconnection conducting layer and said third, transparent conducting layer, where said optosensor has a first optosensor electrode in said third, transparent conducting layer of dielectric and a second optosensor electrode coupled to said gate connection of at least one of said OFETs; and an electrical output from said signal processing circuitry to provide said processed light detection signal output.

Embodiments of the above described approach facilitate the integration of optoelectronic devices and their signal processing circuitry on a single substrate - in some preferred embodiments a flexible substrate - on which the sensor and processing circuitry is fabricated using solution deposition techniques. In embodiments the substrate is a plastic substrate, although other flexible substrates such as a thin metal, for example steel, substrate may also be employed.

Embodiments of the above described device thus facilitate reliable fabrication of complex organic electronic circuits in combination with optoelectronic components, in particular addressing some of the problems which occur in such circuits. These problems include constraints on fabrication (low temperature processes are desirable; a solvent deposited material should not dissolve the material underneath); problems relating to aging, which affects device characteristics; and problems relating to variation between the characteristics of organic electronic devices which, because of their relatively limited noise margin, can affect circuit operation. The integrated devices we describe have a structure which facilitates fabrication, addressing the first problem; which in embodiments employs matched optoelectronic devices and/or signal paths, which addresses the second problem; and which, in embodiments, employs combinatorial logic rather than register-based circuitry, which helps to address the third problem.

The OFETs may be either N-type or P-type but in some preferred implementations the processing circuitry includes both, complementary n_ and P-types of OFET. The OFET devices may have either a top-gate or a bottom-gate configuration.

Broadly speaking the sensor, which in embodiments is a photodiode (but may alternatively comprise, for example, a phototransistor) is connected to one or more gate connections of an input transistor of the processing circuitry. The photodiode may be fabricated, broadly speaking, in the same layer as the transistors, and the optosensor organic semiconductor layer may then be fabricated from the same semiconductor layer as used for a transistor. Then, where a top-gate transistor is employed as the input transistor, a via may connect from the second optosensor electrode (which may be fabricated in the source/drain metal layer) to the gate metal layer, which may be fabricated in the second, interconnection metal layer.

The skilled person will appreciate that where 'metal' is used herein, this term also encompasses conducting polymer metal.

Alternatively, with a bottom-gate input transistor, the second electrode of the photodiode may be formed from the same metal layer as used for the bottom-gate of this transistor.

In other arrangements the photodiode is formed in a separate semiconducting layer to that employed for the transistors, in which case the second optosensor electrode may be formed in the second, interconnection metal layer, and the same layer used to form the connection to the gate of an input transistor. In this case, where a top-gate input transistor is employed no via is needed between the second optosensor electrode of the photodiode and the gate of the input transistor. Nonetheless it can be advantageous, and preferable, to employ a via which, rather than connecting to conducting layers, terminates on the gate dielectric of the transistor: This enables a self-aligned gate (top-gate) transistor structure to be employed.

In general a source-drain metal layer provides the output connection for the circuitry. As described further later, in embodiments the integrated device includes an organic light emitting diode (OLED) device having an electrode coupled to this output source-drain metal layer. Where the OLED is fabricated with this electrode in the same layer as the output source-drain metal layer, no via is needed. However where, for example, the optosensor and OLED are fabricated in a second layer, broadly speaking above a layer comprising the organic electronic processing circuitry, a via connection may be

made between source-drain metal of a bottom-gate (or top-gate) device in a lower layer, to the layer comprising the optoelectronic sensor and OLED.

Optionally, where the OLED and optosensor are, broadly speaking, within a common optoelectronics layer (the signal processing circuitry being within a second, transistor layer) the OLED may incorporate an active layer comprising the optosensor organic semi-conducting layer.

More generally, in embodiments it is preferable for the third, transparent metal layer of the optosensor to also provide a transparent electrode for the OLED.

In a still further variant, the input optosensor may be located above the signal processing circuitry but the output optoelectronic indicator may be located in the same layer as the signal processing circuitry, provided the structure above the output optical device is substantially transparent.

The skilled person will appreciate that with more complex circuits there may be two or more source-drain metal layers, one of which provides the output connection, and two or more gate metal layers one of which provides the connection to the optosensor. As previously mentioned the organic semiconductor layer used to implement the optosensor may be the same layer used to form one or more of the transistors.

In embodiments the transparent metal layer is transparent (that is having a transmittance of at least 20%) at at least one wavelength in the range 300nm to 1500nm. Thus in this specification references to 'transparent' are to light which includes ultra violet and infra red light, as well as to visible light, - embodiments of the devices we describe may usefully operate using light outside the visible spectrum.

In embodiments the circuitry includes just a single interconnection metal layer, or has just two interconnection metal layers (broadly speaking one for connections in each of two orthoganol directions). This limits the number of vias needed.

Use of organic transistors facilitates the fabrication of circuits including resistors, by contrast with conventional silicon. Thus, in embodiments the signal processing circuitry includes analogue signal processing circuitry including one or more resistors fabricated

in an organic semiconductor layer of the device, for example a PEDOT-PSS layer. Such a resistor may comprise a load resistor for an OFET, and/or a resistor to offset a level of a comparator. In some preferred embodiments a resistor fabricated in an organic semiconductor layer of the device is configured to perform a current-to-voltage conversion to convert a photocurrent from the optosensor to a voltage for input to the signal processing circuitry.

In some preferred embodiments the device includes one or more matched pairs of organic semiconductor optosensors. Then, preferably, the signal processing circuitry includes two matched signal processing paths, one for each optosensor of a pair. In embodiments these matched signal processing paths are each coupled to common output stage circuitry implemented in combinatorial logic. This architecture helps to address aging effects within the device.

In embodiments the device includes a plurality of such matched pairs of organic optosensors, for exampled configured as an array to compare an object against a reference object and/or configured for colour matching. In embodiments of the latter approach two or three pairs of optosensors may be employed, either tuned to different wavelengths or, more preferably, all substantially the same with different coloured filters for each pair over the optosensors. There is a prejudice in the art against this latter approach because the maximum efficiency of the detector generally does not match with the spectral region transmitted by the filter. Nonetheless this approach is preferred in embodiments of the device we describe because fabricating all the optosensors in the same process effectively helps to design out process variability, and facilitates achieving a matched response from the photodiodes.

In embodiments of the device, as previously mentioned, the device includes at least a pair of optosensors, configured to receive light from a sensed object and from a reference object. Thus in embodiments the device is provided with a housing having a pair of windows beneath which the substrate bearing the optosensor resides.

In embodiments the device is configured to be brought adjacent to or into contact with the sensed and referenced object, and to illuminate these objects from within the housing - that is from behind the window or windows through which the optosensors view the objects.

In one approach, therefore, the housing includes a light conducting layer or region between the windows in the housing and the substrate to allow light to be input from an edge of the device. In an alternative approach a rear portion of the housing opposite the window or windows is transparent to allow illumination of the objections from behind the housing. In this latter case the optosensors are provided with a light blocking layer or region (which may comprise a thickened second electrode layer), to avoid direct illumination of the optosensors from behind. In some preferred embodiments the signal processing circuitry is screened from stray illumination by the light illuminating the sensed/reference objects.

One advantageous application of such a device is in a child's colour-matching and/or shape-matching toy. Other example toys in which such a smart imaging device may be incorporated include a book and a jigsaw.

There are many other applications of such a colour-matching device. For example in an industrial context the ability of a flexible substrate to conform to a sensed object and/or to fit around a rotating object is useful. Another example application is use in food packaging.

In a related aspect the invention provides an integrated organic electronic device, the device having an integrated optoelectronic sensor and processing circuitry, the device comprising: a substrate bearing at least one organic semiconductor optosensor for light-sensing to provide a light-sensing signal, and organic semiconductor signal processing circuitry comprising a plurality of organic field effect transistors (OFETs), coupled to said optosensor to process said light sensing signal to provide a processed light detection signal output; a first layer of organic semiconductor material in which said OFETs are fabricated; a second layer of organic semiconductor material in which said organic semiconductor optosensor is fabricated.

Broadly speaking in embodiments a lower level or region of the device (ir a level or region nearest the substrate) is used for the signal processing circuitry and a second, upper level or region is used for the optosensor(s), for example photodiode(s) and, where implemented, OLED(s). In some preferred embodiments top-gate transistors are employed and thus the gate dielectric lies above the organic semiconductor layer of the

transistors (with respect to the substrate). Preferably the gate dielectric then comprises an inert, cross-linked material to resist attack from solvent during fabrication of the upper, optoelectronic device(s). In such an arrangement preferably the metal interconnect layer(s) are above the gate dielectric and one or more vias is employed to connect between this layer and a source-drain drain layer of the transistors. In preferred embodiments the substrate is a flexible, in particular plastic, substrate and the integrated organic electronic device is fabricated by solution deposition techniques such as an inkjet or other printing process.

Embodiments of the above described integrated organic electronic device may also, conveniently, include a photovoltaic device for powering the circuitry, additionally or alternatively to an external power supply such as a battery. Such a photovoltaic device may employ, broadly speaking, a corresponding structure to a photodiode, and is thus straightforward to integrate.

In a further related aspect the invention provides an integrated organic electronic imaging circuit, the circuit comprising a substrate onto which are integrated: at least one organic photosensor to detect an optical signal; an organic transistor circuit coupled to the organic photosensor, and configured to process information from the detected optical signal and to output a drive signal; and a display, coupled to receive said drive signal from said transistor circuit, to provide a display responsive to the processed detected optical signal.

Thus we also describe a single-substrate/monolithically integrated smart imaging circuit comprising a substrate onto which are integrated: an array of photodiodes comprising at least one organic photodiode to detect an optical signal, an organic transistor circuit which processes the information deduced from the detected optical signal, and a display which receives a drive signal from the transistor circuit and displays an image which depends on the detected optical signal.

The substrate is preferably a flexible substrate, such as a flexible plastic substrate or a thin sheet of steel. Flexible substrates allow the realisation of such smart imaging devices in novel form factors. The device can simply be attached as a label to a non-planar surface and allows the integration of smart imaging functions into surfaces that are currently not suitable for integration of rigid devices made from inorganic

semiconductors. Plastic substrates also have the advantage of being substantially unbreakable, and this is an important attribute for certain of the applications discussed below, in particular toys, because the use of breakable substrates such as glass would risk doing harm to the user/child.

According to a first embodiment of this aspect of the invention the array of organic photodiodes comprises a first set of reference photodiodes to produce electrical signals that identify the colour of a reference object and a second set of photodiodes to produce electrical signals that identify the colour of the second object. The organic transistor circuit compares the electrical signals generated by the set of reference photodiodes with those generated by the second set of photodiodes and decides whether the colour of the second object is sufficiently similar to that of the reference object. It then sends a signal to the display which produces an image on the display indicating whether a colour match has been detected between the second object and the reference object or not.

The display preferably comprises an organic light-emitting diode, but other display elements such as a liquid crystal cell, an electrochromic or a reflective electrophoretic display medium may also be used. The display may comprise a single pixel or a number of pixels and can either be a simple directly driven, segmented display or an active or passive matrix-addressed display. The display may show a static image or may run through a predetermined set of images depending on whether a colour match has been achieved or not.

We also describe the use of colour matching devices according to the first embodiment as a children's toy, wherein the child is given a first coloured object and places it as a reference object in front of the first set of reference photodiodes and is then asked to look in its environment for second objects that have the same or a similar colour. When the child has identified a suitable second object it holds the second array of photodiodes in front of the second object and the display indicates to the child whether it has successfully matched the colour or whether the second object has a different colour to that of the reference object. The toy can be used with a sequence of reference objects of different colours, such as red, green, blue, pink, white or violet. In this way the toy is able to teach a young child recognition of colours, in an attractive and interactive manner.

The toy may also make use of an acoustic feedback in addition or in place of the display-based feedback. The toy will have a power source, which could either be an external battery or an integrated power source such as a printed battery or a solar cell integrated onto the same substrate. It may also include a suitable light source to illuminate the reference and second object, or alternatively it may be constructed such that it is able to use the natural illumination present in the environment in which it is used to illuminate the reference and the second object.

The colour matching toy may also be used to teach children how to mix colours. For example, the child is given three basic coloured inks or paints, such as cyan, magenta and yellow or red, green and blue and is shown a reference colour. It is then asked to mix the three basic colours in the right portions in order to achieve the reference colour. For examples, red can be made by mixing magenta and yellow in a ratio of 1:1. Or cyan colour can be made by mixing green and blue light with same intensity. The colour matching toy is then used to compare the mixed colour with the reference colour and the display indicates whether a colour match has been achieved.
It will be apparent to a person skilled in the art that many other ways in which a colour matching device according to an embodiment of the present invention can be used as a toy.

We also describe the use of colour matching devices according to the first embodiment of this aspect of the invention in industrial or consumer colour matching applications. The colour matching device may detect, for example, whether the colour of a product that is being manufactured is sufficiently close to a reference colour. The product may, for example, be a car the paint of which needs to match closely with the colour desired by the customer. Another example is a graphic arts proofing process where the colours in a printed document need to be adjusted to specific reference colours in order to achieve the most appealing appearance of the document. Alternatively, the device may detect through optical means and colour matching whether a machine that is equipped to accept consumable parts, such as a printer accepting ink cartridges, cleaning equipment accepting cleaning fluids, etc., is being fitted with the correct consumable. The device may also be able to indicate to the user which type of consumable is present in the machine in case multiple selections are possible, such as in the case of an air freshener with different scents. Yet another example involves the continuous

monitoring of the colour of an object in use in order to detect changes in colour that indicate that the product no longer meets required quality standards. This may involve, for example, food applications, where changes in the colour of the product can indicate perishing, or safety applications, where changes in the colour of an object can indicate a hazardous situation. For example, the smart imaging device can monitor continuously the abrasion of a coloured layer on a moving part and indicate an optical and/or acoustic alarm once a colour change is being detected. The device may also be used in consumer electronics applications and may indicate to the user whether a particular colour is being detected in his daily life without the user having to pay attention to detecting the colour. This may involve, for example, the matching of the colour of clothes in a shop with a set of reference colours of the user's favourite clothes at home.

According to a second embodiment of this aspect of the present invention the array of organic photodiodes comprises a first array of reference photodiodes to produce electrical signals that identify the shape or dimension of a reference object and a second set of photodiodes to produce electrical signals that identify the shape or dimension of a second object. The organic transistor circuit compares the electrical signals generated by the set of reference photodiodes with those generated by the second set of photodiodes. It then decides whether the shape or dimension of the second object is sufficiently similar to that of the reference object and sends a signal which produces an image on the display or an acoustic signal indicating to the user whether or not a shape or dimension match has been detected between the second object and the reference object.

We also describe the use of such monolithically integrated shape matching devices according to the second embodiment as a toy, wherein the child is first given a first object that has or displays a particular shape, for example a triangle, square or circle and places it as a reference object in front of the first set of reference photodiodes and is then asked to look in its environment for second objects that have the same or a similar shape. When the child has identified a suitable second object it holds the second array of photodiodes in front of the second object and the display indicates to the child whether it has successfully matched the shape or whether the second object has a different shape to that of the reference object. The toy would in this way teach a young child the recognition of shapes in an attractive and interactive manner.

The toy can be used with a sequence of reference objects of different shapes, such as triangle, squares, rectangles, lines, circles etc. The toy may also make use of an acoustic feedback in addition or in place of the display-based feedback. The toy will have a power source, which could either be an external battery or an integrated power source such as a printed battery or a solar cell integrated onto the same substrate. It may also include a suitable light source to illuminate the reference and second object, or alternatively it may be constructed such that it is able to use the natural illumination present in the environment in which it is used.

The toy may also be used to recognize the individual letters of the alphabet. The child is first shown a letter on a reference card and asked to place the letter on the reference card in front of the first set of photodiodes. It is then asked to identify the same letter again among a sample of letters and place it in front of the second set of photodiodes. If the child identifies the correct letter the display indicates that a match has been achieved. In this way the child will be taught the individual letters of the alphabet.

We also describe the use of a monolithically integrated shape matching device according to the second embodiment in industrial or consumer applications. The shape matching device may detect whether, for example, a linear dimension, size or general shape of an object that is being manufactured is equal to that of a reference object. If a deviation from the target dimension or shape is detected the manufacturing process may be halted in order to adjust the process conditions. Another example for the use of such a smart imaging device is the monitoring of the dimensions of an object in use in a machine. The device may continuously compare the size of the object to that of a reference object and indicate if the object begins to deform or elongate indicating that the object is about to fail requiring the machine to be halted to avoid damage.

According to a third embodiment of this aspect of the present invention the array of organic photodiodes generate electrical signals which are processed by the transistor circuit to detect an event occurring in time and determine an output signal that depends on whether an event has been detected. This output signal is then communicated to the user either using the display function, an acoustic feedback or stored in a memory integrated on the device.

A monolithically integrated smart imaging device according to the third embodiment may be used as an event counter. The array of photodiodes, or a single photodiode, as will be sufficient for many such applications, detects events, such as a shadow falling onto the photodiode because of an object or person passing the photodiode. These events are registered and counted by the transistor circuit. The display shows the updated number of events detected or alternatively the number of events could be stored in the internal memory and communicated to a host system through a wireless or wired communication interface.

Integrated smart imaging devices according to embodiments of the present invention may be equipped with wireless communication functions such that they can communicate with a host control system or even the internet. However, in some of the above applications, for example the toy applications, it is sufficient for the device to operate in a standalone manner and to communicate with the user through the integrated display or acoustic feedback function.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will now be further described, by way of example only, with reference to the accompanying figures, in which:

Fig. 1 shows a schematic diagram of a monolithically integrated smart imaging circuit according to an embodiment of the present invention.

Fig. 2 shows a schematic diagram of a monolithically integrated colour matching device according to an embodiment of the present invention.

Fig. 3 shows an exemplary circuit diagram for realising a monolithically integrated colour matching circuit with a small number of transistors, diodes and resistors.

Fig. 4 shows a schematic diagram of a toy which is used to indicate whether the colour of two objects is matched.

Fig. 5 shows a different possible illumination configuration for a monolithically integrated colour matching device.

Fig. 6 shows a schematic diagram of a monolithically integrated dimension matching device according to an embodiment of the present invention.

Fig. 7 shows a schematic diagram of a monolithically integrated shape matching device according to an embodiment of the present invention.

Fig. 8 shows a schematic diagram of a monolithically integrated event counter according to an embodiment of the present invention.

Fig. 9 (A-C) shows schematic diagrams for different device architectures for the monolithic integration of light sensing, information processing and display functions.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Organic semiconductors can be processed at low temperatures <100-150°C either by vacuum evaporation or by solution processing and are compatible with manufacturing on low-cost flexible substrates such as poly (ethylene terephtalate) (PET) and poly (ethylene naphtalate) (PEN). They enable embedding electronic or optoelectronic functions into environments and form factors that are not accessible with conventional inorganic semiconductors that require process temperatures > 200-300 °C. Solution-processible organic semiconductors enable new manufacturing methods, such as deposition by wet coating techniques as well as patterning by direct-write printing and microstructuring techniques. The performance of organic semiconductor based devices, such as organic light-emitting diodes (OLEDs), organic field-effect transistors (OFETs), organic photovoltaic cells (OPVs) and photodetectors (OPDs) has improved significantly over recent years, mainly as a result of focussed materials development. OLEDs with luminescence efficiencies > 50 lm/W, OFETs with field-effect mobilities > 1cm^2/Vs, OPVs with power conversion efficiency > 8% and OPDs with quantum efficiencies > 60-80 % achievable.

For applications such as OLED displays, OFET active-matrix flexible displays, OFET-based RFID tags and low-cost solar cells the specific molecular design requirements are subtly different. For example, active semiconductors for OLEDs require high photoluminescence efficiency while for OFETs semiconductors with high charge carrier mobility are desirable. Although optimised molecular structures for OLEDs, OFETs and OPDs are different, the processing characteristics as well as thermal and mechanical properties of most organic semiconductors are sufficiently similar that monolithic integration of these different device functions onto a common plastic substrate is easier in principle than it would be with inorganic semiconductors such as silicon and GaAs. Such monolithically integrated devices potentially offer a broad range of functionalities and these could be realised with the novel form factors and attributes of lightweight, flexibility and robustness that are enabled by the use of plastic substrates. However current first generation commercial applications of organic electronics, such as OLED displays and active matrix OTFT flexible displays do not involve integration of more than one type of organic device. This is at least partly a consequence of the complex information processing capability that is desired of such multifunctional devices to meet real application requirements. OTFT integrated circuits are currently limited in their ability to perform complex information processing tasks because it is challenging to print integrated circuits with more than a few hundred active and passive elements with a suitable yield and uniformity of characteristics, and integration organic (light) sensing and display elements with a silicon integrated circuit, which is feasible, would be complex and increase the manufacturing cost.

We will thus describe multifunctional organic electronic devices and their fabrication using all organic technology, at low manufacturing costs. More particularly we will describe organic smart imaging devices based on simple combinatorial logic architectures. In embodiments we provide an integrated optoelectronic circuit, which receives an input signal from its environment and which is able to switch its output between a finite number of possible states depending on the input signal received, without the use of a register or memory element. Here these are realised using light sensing OPD for input detection, OTFT circuits for information processing, a display element for indication of the output state, and potentially energy harvesting functions implemented with either thin film batteries or OPV cell, all integrated onto a common substrate. The smart imaging devices are configured for applications in toys, industrial processes and consumer electronics to achieve user requirements without requiring

highly complex information processing and may in some cases be realized with less than 100 active and passive elements.

Thus referring to Fig. 1, this shows the general configuration of a smart imaging circuit 100 according to an embodiment of the present invention which is integrated monolithically onto a common, flexible substrate. A light signal is detected by an array 102 of photodiodes. The photodiodes produce electrical signals that are a measure of the light intensity detected by each of the photodiodes. A transistor circuit 104 records these electrical signals and performs a series of analog and/or digital operations to analyse the detected light signals and determine whether a defined configuration/event has been detected by the photodiodes. The transistor circuit then also produces a drive signal 106 to address a display unit 108 to indicate to the user visually that the defined configuration/event has been detected. The device is powered by a power source 110, which can, for example, be an external battery or mains power source. However, preferably, the power source is a printed battery or a printed solar cell and is integrated onto the same substrate. The device may also have other functions, such as a loudspeaker 112 which provides an acoustic feedback to the user when the defined configuration/event has been detected. The device may also have an integrated memory 114 where information derived from the signals of the photodiodes is stored. This information is transmitted to a host system with more sophisticated information processing capability through a communications interface 116, which may be a wireless, radiofrequency (RF) transmitter or a simple electrical contact pad interface. The device may also be able to sense stimuli other than light, for example, it may have integrated chemical, biological or mechanical sensors 118 integrated together with the light sensors.

Fig. 2 shows a schematic diagram of a smart colour matching circuit 200 according to an embodiment of the present invention which is integrated monolithically onto a common, flexible substrate 202. This is a specific embodiment of the general smart imaging device shown in Fig. 1. In this case the array of photodiodes 204 is configured to detect whether the colour of a second object is matched to that of a reference object. In the specific configuration shown in Fig. 2 this function is implemented with three pairs of photodiodes (PD_i PD_i^{ref}). Each pair is configured to be sensitive to a particular wavelength range of the optical spectrum, for example PD_1 and PD_1^{Ref} are configured to be sensitive to the green portion of the spectrum, PD_2 and PD_2^{Ref} to the red portion

of the spectrum and PD_3 and PD_3^{Ref} to the blue portion of the spectrum. PD_1, PD_2 and PD_3 are exposed to light reflected from or transmitted through the second object, while PD_1^{Ref}, PD_2^{Ref} and PD_3^{Ref} are exposed to light reflected from or transmitted through the reference object. Each photodiode is connected to a resistor 206a-f or a more complex current-voltage converter, which converts the photocurrent generated in the PD as a result of light exposure into a voltage. The pair of PD_1 and PD_1^{Ref} is used to detect the difference in the amount of green light coming from the second object and the reference object. The pair of PD_2 and PD_2^{Ref} is used to detect the difference in the amount of red light coming from the second object and the reference object. The pair of PD_3 and PD_3^{Ref} is used to detect the difference in the amount of blue light coming from the second object and the reference object. The two photodiodes of each pair and the corresponding resistors are preferably very similar or identical in their configuration, size and light detecting characteristics, so that when the object and the reference object have the same colour the two photodiodes in each pair produce the same electrical signals.

The colour $\vec{Q}$ of an object can be uniquely determined by measuring the tristimulus values R,G,B of that colour with respect to three primary colours $\vec{R}$, $\vec{G}$, $\vec{B}$. In vector notation this can be written as $\vec{Q} = R\vec{R} + G\vec{G} + B\vec{B}$ (see for example, Wyszecki, Stiles, Colour Science, Wiley, 1967). Two colours that have the same R,G, B values appear identical, even if they do not have identical spectral energy distributions (in which case the two colours are called metameric colours). The R, G, B tristimulus values can be measured, for example, with three photodiodes of different spectral sensitivity. Although no man-made photodiode matches exactly the spectral sensitivity of the different cones in the human eye, it is generally sufficient to use photodiodes that have primary sensitivities in the red, green and blue part of the optical spectrum, respectively. The method of colour matching used in embodiments of the present invention is to detect whether the tristimulus values of the second object and the reference object detected by PD_1 and PD_1^{Ref}, PD_2 and PD_2^{Ref} and PD_3 and PD_3^{Ref}, respectively, are sufficiently close to each other that one can assume the colours of the second object and the reference object to be identical. However any set of primary colours other than R, G, B can alternatively be used.

The photodiodes can be configured to have spectral sensitivity in different parts of the optical spectrum in two ways. It is possible to select the band gap of the active organic semiconductor material of the OPDs such that the active light absorbing material of each of the three pairs of OPDs only absorbs light in a defined part of the optical spectrum (see Lanzani, Applied Physics Letters 90, 163509 2007). This provides, in principle, an elegant way to realize PDs with primary sensitivity in the red, green and blue part of the spectrum, respectively, simply by changing the molecular structure of the active semiconducting material. However, this uses deposition and integration of three different organic semiconductor materials onto the substrate and increases process complexity. A simpler method to achieve wavelength sensitivity is to deposit a colour filter on top of the photodiodes. In this case all six photodiodes can be realized with the same device architecture and active materials and the OPD is selected to have a high quantum efficiency over a broad portion of the visible spectrum. This can be achieved, for example, with a state-of-the-art materials system used in OPVs, for example, based on bulk heterojunctions of poly[N-900-hepta-decanyl-2,7-carbazole-alt-5,5-(40,70-di-2-thienyl-20,10,30-benzothiadiazole) (PCDTBT) with the fullerene derivative [6,6]-phenyl C70-butyric acid methyl ester (PC70BM) (Park, Nature Photonics 3, 297 (2009). This system has a high quantum efficiency of > 50% from 400-650 nm. If colour filters that transmit only red, green or blue light are placed on top, PD's for the individual primary colours can be realized. Only one active OPD semiconductor material needs to be integrated in this case and the realisation of a colour filter is potentially easier since the colour filter can be printed, for example on one of the encapsulation films on the device (see Figure 9C) or on the back of the substrate.

The integrated transistor circuit has parallel, matched analogue signal pathways 208a-c and in embodiments employs a combinatorial logic circuit output stage 210 without the need for a memory element. The circuit compares the signal from the two photodiodes in each pair and produces, for example, a logic LOW signal if the difference signal from the two photodiodes is larger than a threshold value and a logic HIGH signal if the difference signal from the two photodiodes is smaller than a threshold value, and amplifies the difference signal. A logic circuit then ensures that the output from the logic circuit enters a particular first state, only when the difference signal from each of the three pairs of photodiodes is smaller than a threshold value ((Match ? - Yes) condition).

As soon as one or more of the three difference signals is larger than the threshold value, the output from the logic circuit enters a second state ((Match ? - No) condition).

This output signal is then used to generate a drive signal 212 for the display 214. If all three pairs of photodiodes generate a difference signal less than the threshold value the display is made to display a first image (or sequence of images) indicating that the colours of the object and the reference object are matched. If one or more of the three difference signals is larger than the threshold value, the display is driven to display a second image (or sequence of images) indicating that the colour of the object and the reference object are not matched.

The display preferably comprises an organic light-emitting diode, but other display elements such as a liquid crystal cell, an electrochromic or a reflective electrophoretic display medium may also be used. The display may comprise a single pixel or a number of pixels and can either be a simple directly driven, segmented display or an active or passive matrix-addressed display. The display may show a static image or may run through a predetermined set of images depending on whether a colour match has been achieved or not.

Fig. 3 shows an exemplary circuit diagram with a small number of transistors, diodes and resistors for realising the monolithically integrated colour matching device of Fig. 2, in which like elements are indicated by like reference numerals. This is a specific exemplary implementation and alternative architectures and designs of individual blocks may be used.

Each photodiode is connected to two resistors whose functions are to perform the current-voltage conversion for the photodiode current and also to bias the resulting voltage output into the appropriate operating region of the following comparator circuit. Other combinations and topologies to perform the current-voltage conversion and the biasing are possible. For example, a resistor may be placed in series with the diode to perform the current-voltage conversion, and/or an additional resistor may be placed between the photodiode and the VSS or ground supply line to provide alternative biasing possibilities.

Two photodiodes are paired with two comparators in the exemplary circuit. The current outputs from the photodiodes having been converted to a voltage are then applied to the inputs of the two comparators. The two photodiodes are cross connected to two comparators in the manner shown in Fig. 3. A comparator is designed in such a way that one input is offset from the other input. In the exemplary circuit of Fig. 3 there is an offset resistor connected in series with the QP transistor. This will shift the switching threshold of the comparator by an amount equivalent to the voltage developed across the offset resistor. For example, if the photodiode and resistor network is expected to produce a voltage swing of 1 Volt, then the offset resistor may be chosen to produce an offset of one tenth of the photodiode output swing, 0.1 Volt. Other values of offset may be chosen depending upon the final desired specifications and sensitivities. The cross connection of the comparators together with the effect of the offset switching threshold result in an indication of approximate voltage match between the two photodiodes. In the exemplary circuit, if the currents of the two photodiodes are equivalent to each other within a threshold defined by the offset resistors, then the two outputs of the two comparators will be HIGH. In the case that one of the photodiode currents produce a voltage that is outside the threshold defined by the offset resistors, one of the comparator outputs will be LOW.

In the exemplary circuit of Fig. 3 three pairs of photodiodes are connected respectively to three pairs of comparators. Each pair of comparators produces two outputs so that there are a total of six outputs. These six outputs are connected to a six-input NAND gate. In the exemplary circuit, the six input NAND gate is implemented by six P-type transistors performing the pull-up function with a solitary N-type performing a static pull-down function. It is recognised that a person skilled in the art may implement other NAND gate designs including but not limited to alternative pull-up and pull-down designs. The output of the NAND gate will be LOW if each pair of photodiodes are approximately equal as described above. This situation represents an approximate colour match. If any photodiode produces a current which is significantly different from its paired photodiode then the output of the NAND gate will be HIGH. This presents a colour mis-match.

The output of the NAND gate may then be used to drive either directly or indirectly an LED or other device. The exemplary circuit shows that the NAND output is directly connected to an LED connected to VDD through a resistor. Other designs may include

but not limited to an LED connected through a resistor to VSS, or an intermediate driver stage which may increase current.

The exemplary circuit does not show the implementation of the bias voltage(s) employed for the comparators and the NAND gate. For example, this may be simply produced by a voltage divider constructed from resistors but other implementations are also possible. Also, the exemplary circuit does not show any hysteresis control on the output of the comparators. Hysteresis may be implemented by a transistor providing positive feedback on the comparator output. Once again, alternative hysteresis control circuits may be employed.

Fig. 4 illustrates the use of a monolithically integrated colour matching device in a children's toy 400. The toy may make use of the ability of the colour matching device 402 which is built on a flexible substrate to conform to and wrap around a non-planar surface, such as the surface of a cylinder. The child holds the toy in his hand using a suitable designed handle 404. The colour matching device is embedded in or fixed to the surface of the toy and the array of reference photodiodes 406 ($PD_{1\text{-}3}^{Ref}$) and second object photodiodes 408 ($PD_{1\text{-}3}$) are located in spatially separate areas on the surface of the toy. The child is asked to place a reference object 410 in front of the array of reference photodiodes and then asked to look in its environment for second objects 410 that are similar to or match the colour of the reference objects and place these objects in front of the photodiode array. A colour-match indication is shown on display 414. The toy may be powered by a battery 412 integrated into the housing or by an integrated solar cell or printed battery.

This configuration of the colour matching toy is merely exemplary. Other designs may be used. The toy may for example have the shape of a sheet or a credit or playing card onto which the reference object and the object are placed. The sheet or card may be flexible such that the child can bend it around the objects.

In order to allow accurate colour matching the two photodiodes in each pair should have similar light detection characteristics, and also the illumination of the reference object and object should be as similar as possible. Fig. 5 shows two examples of red, green, and blue illumination configurations for integrated organic optoelectronic devices 500, 550. In Fig. 5(A) the (red, green, and blue) reference photodiodes 8 and the

object photodiodes 9 on substrate 7 are embedded in an opaque housing 10. The reference object 13 and the second object 14 are separated from the photodiodes by an aperture 12 and a transparent spacer 11. The aperture 12 blocks light impinging onto the photodiodes from the areas of the front surface which are not covered by the reference object or the second object. The transparent spacer 11 allows light 15 from the environment to enter from the side, be reflected off the surface of the objects and then fall onto the photodiodes. In the configuration of Fig. 5(B) the housing 10 of the toy and the substrate 7 is transparent, such that light can enter from the back of the substrate. In this case it is important that the backside of the photodiodes itself is covered by an opaque material 10' such that the electrical signal generated by the photodiodes is not dominated by light 15' incident from the back that is not reflected off the objects. This opaque material may, for example, be a black paint coated onto the back of the substrate of the colour matching device, or may simply be provided by one of the electrodes of the photodiode being opaque. As discussed below OPDs (organic photodiodes) have generally one non-transparent metal electrode and this could provide the light blocking layer which is used to minimize backside exposure to light which does not come from the reference object or the object, respectively. Alternatively, a black matrix light blocking layer may be integrated onto the top or bottom side of the substrate 7, but leaving the peripheral area of the photodiodes transparent to light. Both configurations ensure that most of the light impinging onto the photodiodes is light that has been reflected of the surface of the objects (or been transmitted through the objects in case the objects are transmissive).

Fig. 6 shows a schematic diagram of a monolithically integrated dimension matching device 600 according to an embodiment of the present invention. The device is configured similarly to the colour matching device described above. An array of reference photodiodes 602 is configured to image the dimension/length of a reference object. A second array of photodiodes 604 is configured to image the dimension/length of a second object. However, in this case in order to compare the dimensions of the two objects with reasonable precision and also to accommodate different orientations and positions of the two objects the device uses a larger number of photodiodes in each of the two arrays and configures the photodiodes into a two-dimensional pixelated array. The number of pixels may be increased in order to achieve higher precision measurements of dimension differences. Integrated circuit 606 analyses the signals generated by the individual pixels and measures the targeted linear dimension of the

reference object and the second object, providing an output to display 608. The circuit configuration used for this may depend on the specific shape of the two objects and the nature of the dimensional measurement desired. In the case of measuring the length of a line with defined optical contrast/colour the measurement may simply consist of counting the number of pixels onto which the defined optical contrast/colour is being detected. For this the photodiodes may be configured such that they are most sensitive at the wavelengths that are emitted from the line of defined optical contrast or colour. For example, if the length of a red line on a green background is to be measured the array of photodiodes may only comprise photodiodes that have high sensitivity in the red part of the spectrum. This principle can be extended to more complex measurement tasks such as the determination of the area of an object of well defined optical contrast/colour. The integrated circuit then compares the dimensional measurements for the reference and the second object and generates a drive signal for the display which causes the display to indicate whether the dimensions of the reference object and the second object are identical within a defined tolerance or whether they are different. The signal processing may be analogue (with matched signal paths from the reference and test photodiodes), for example summing photodiode voltages or currents to perform the 'count', and then comparing the results as previously described.

Fig. 7 shows a schematic diagram of a monolithically integrated shape matching device 700 according to an embodiment of the present invention. The device is configured similarly to the dimension matching device described above. An array of reference photodiodes 702 is configured to image the shape of a reference object. A second array of photodiodes 704 is configured to image the shape of a second object. Integrated circuit 706 analyses the signals generated by the individual pixels of the two arrays and determines whether the reference object has the same geometrical shape as the second object. The reference object and the second object do not necessarily need to have the same size or orientation. The reference object and the second object preferably exhibits a clear optical contrast/colour against a background, such that the photodiodes can be configured such that they are most sensitive at the wavelengths that are emitted from the line of defined optical contrast or colour. For example, if the two objects are red on a green background the array of photodiodes may only comprise photodiodes that have high sensitivity in the red part of the spectrum. The integrated circuit determines the shape of the two objects, for example, by

measuring/counting the number of corners detected and/or measuring the angles at the boundaries of the objects by determining the number of pixels with object signal that have neighbouring pixels on which no object signal is being detected. The integrated circuit does not necessarily need to determine the absolute shape of the two objects, but may simply determine whether the two shapes are similar, i.e. have the same number of corners/angles. Again this may be performed in the digital and/or analogue domain, in the latter case again preferably employing matched signal paths. The integrated circuit then decides whether the two objects have the same shape or not and generates a corresponding drive signal for the display 708 (and/or a loudspeaker).

Fig. 8 shows a monolithically integrated event counter 800 according to an embodiment of the present invention. In this case a single photodiode 802 may be sufficient to detect events when a particular optical contact is being generated on the photodetector. This optical contrast may correspond, for example, to a shadow falling on the photodiode or a light pulse hitting the photodetector. More complex arrays of photodiodes may be configured to detect more complex events, for example, consisting of the coincidence of several individual events. Integrated circuit 804 registers the voltage pulse generated by the photodetector in each event and counts the number of events over a period of time. It outputs the current count onto an alphanumeric display 806 and/or an integrated memory (not shown). Again this may be performed in the digital logic and/or analogue domain (in the latter case, for example, accumulating charge on a capacitor and using a comparator(s) to detect count increment levels). The circuit may also incorporate a start and reset button.

Figure 9 shows schematic diagrams for different device architectures 900, 930, 960 for the monolithic integration of light sensing, information processing and display functions using organic/printable electronic materials. The device is fabricated on a lightweight, robust, flexible substrate 16, such as a PET or PEN plastic substrate or a steel substrate. In the case of a plastic substrate the substrate preferably has a suitable barrier film 17 protecting the device against exposure to harmful atmospheric species, such as moisture, penetrating into the layer stack from the bottom. In the configuration 900 of Figure 9(A) the transistors, photodiodes and display elements are fabricated on the same level directly on the surface of the substrate. The substrate may have suitable substrate planarization or substrate modification layers deposited on its surface prior to the deposition of electrodes and active layers. Figure 9(A) illustrates a

top-gate transistor architecture; an analogous structure applies to other architectures, such as bottom gate OFETs. For the top-gate structure a layer of transistor source-drain electrodes 18 and bottom electrodes 19 and 20 for the photodiode and the display element are defined on the surface of the substrate. Processes such as direct-write printing or photolithographic patterning may be used to structure these electrodes. Preferably, to simplify the process the electrodes 18, 19 and 20 are made from the same conducting material, for example an inorganic metal such as gold, copper or silver or a conducting polymer, such as PEDOT/PSS. However, there will generally be different requirements for achieving efficient charge injection/extraction in the different devices (OPD, OTFT, OLED and any other device functions integrated onto the same substrate, such as an OPV cell or printed battery). This may use different metals for the three electrodes or the local deposition of additional layers, such as self-assembled monolayers or conducting polymers, to modify the work function and charge injection/extraction properties of any of these electrodes.

The manufacturing process then involves deposition of the active semiconducting layers 21 of the photodiodes, 25/26 of the respective n-type and p-type OTFTs and 122 of the display element. Layer 22 may, for example, be an OLED emissive layer. Other active layers for other functional elements may also be deposited at this stage, for example the active layer of an OPV cell. The active semiconductor layers can be deposited onto the substrate by direct printing, such as inkjet printing or gravure printing, or as a continuous layer by a coating technique and then patterned by a subtractive process, such as photolithography (see, for example, Chang et al., Advanced Functional Materials 20, 2825 (2010)). If a subtractive process is used for the deposition of the different active semiconductor layers care should be taken to avoid dissolution and/or swelling of previously deposited layers. To address such issues, particularly when more than two active semiconducting layers are to be deposited, it is preferable, therefore, to deposit the different active layers by a direct-write printing process, such as inkjet printing, where the material is only deposited where it is needed.

The photodiode(s) 33 may be configured to have spectral sensitivity in different parts of the optical spectrum in two ways. It is possible to select the band gap of the active organic semiconductor material of the OPD such that the material only absorbs light in a defined part of the optical spectrum (see Lanzani, Applied Physics Letters 90,

163509 2007). This provides, in principle, an elegant way to realize PDs with primary sensitivity in the red, green and blue part of the spectrum, respectively, simply by changing the molecular structure of the active semiconducting material. However, this uses the deposition and integration of three different organic semiconductor materials. A simpler method to achieve wavelength sensitivity is to deposit a colour filter on top of the photodiodes. In this case all six photodiodes have the same device architecture and active materials. The PD is selected to have a high quantum efficiency over a broad portion of the visible spectrum. This can be achieved, for example, with a state-of-the-art materials system used in OPVs, for example, based on bulk heterojunctions of poly[N-900-hepta-decanyl-2,7-carbazole-alt-5,5-(40,70-di-2-thienyl-20,10,30-benzothiadiazole) (PCDTBT) with the fullerene derivative [6,6]-phenyl C70-butyric acid methyl ester (PC70BM) (Park, Nature Photonics 3, 297 (2009). This system has a high quantum efficiency of > 50% from 400-650 nm. If colour filters that transmit only red, green or blue light are placed on top, PD's for the individual primary colours can be realized. Only one active OPD semiconductor material needs to be integrated in this case and the realisation of a colour filter is potentially easier since the colour filter can be printed, for example on one of the encapsulation films on the device (see Figure 9C) or on the back of the substrate.

Apart from an OLED display or indicator the display element 34 may be realized by laminating onto electrode 19 a reflective, bistable display film, for example, a film of an electrophoretic display element. This choice offers lower power consumption than OLED and also has less stringent stability and encapsulation requirements than OLED. For integration of an electrophoretic display it is preferable to select an architecture where the electrode 19 remains exposed in a portion of the substrate at the end of the process. The electrophoretic film which typically contains a conducting lamination adhesive, the electrophoretic medium and a top transparent electrode on a plastic substrate may then simply be laminated at the end of the process.

At least one of the electrodes 24 of the photodiodes 24 and the electrode 23 of the display element should be transparent to light. In the architecture of Fig. 9A it is assumed that the top electrode is transparent. If the photodiodes are formed in a so-called "inverted" configuration the top electrode will be the hole extracting anode and may, for example, be formed from a PEDOT/PSS conducting polymer with good optical transparency. In order to achieve a higher conductivity without degrading quantum

efficiency significantly an additional fine metal grid may be printed on top of the PEDOT. The printed metal electrode (for example, silver) may also serve as an interconnection to any of the other electrodes to which the photodiode electrode is to be connected. In this inverted structure the bottom electrode may be formed from a non-transparent metal electrode of gold, silver copper or aluminium modified or a layer of indium tin oxide (ITO). However, the surface of this electrode should be modified with a surface layer that lowers the work function of the electrode, such as a layer of a metal oxide, such as zinc oxide (Vaynzof et al., Appl. Phys. Lett. 97, 033309 (2010)). In a first configuration the transparent electrode is the bottom, hole extracting electrode and can be fabricated from a transparent conducting polymer, such as PEDOT/PSS or a combination of PEDOT/PSS with a transparent ITO electrode or a grid of metal lines if higher conductivity is needed. The top electrode may be formed from an opaque film of a low work function metal film such as Al or Ba/Al or a printed metal such as silver. For this architecture it is often more important to ensure tight encapsulation in order to ensure adequate lifetime than for the more robust inverted architecture. If this configuration is used the light may enter the photodiode through the back of the substrate. Alternative configurations for the photodiode electrodes may also be used.

The desired functionality of the integrated circuit may employ CMOS integration of both n-type and p-type transistors, in order to achieve higher noise margins and integration density. In this case layer 25 comprises an organic semiconductor layer capable of high mobility n-type OFET operation, such as poly{[N,N9-bis(2-octyldodecyl)-naphthalene-1,4,5,8-bis(dicarboximide)-2,6-diyl]-alt-5,59-(2,29-bithiophene) (P(NDI2OD-T2)) (Yan et al., Nature 457, 679 (2009)) and layer 26 is an organic semiconductor layer capable of high mobility p-type OFET operation, such as poly(2,5-bis(3-tetradecylthiophen-2-yl) thieno[3,2-b]thiophene) (pBTTT) (McCulloch, Nat. Mat. 5, 328 (2006)). The substrate is then coated with a thin gate dielectric layer 27, such as a layer of polymethylmethacrylate (PMMA), which provides the electrical insulation between the active semiconducting layers of the transistors and the respective gate electrodes 28. In order to ensure a high quality interface between the organic semiconductor layers and the gate dielectric it is preferable that layers 25 and 26 are deposited immediately prior to the gate dielectric deposition, i.e. the fabrication steps for the OLED and the OPD, including the deposition of their top electrodes, preferably occur prior to the deposition of the transistor active layers 25 and 26.

In order to connect electrodes on the surface of the substrate to electrodes at the gate electrode level via-hole interconnections 29 are used. These may be fabricated, for example, by laser ablation, solvent etching (Kawase et al, 13, 1601 (2001)) or other techniques.

After completion of the fabrication of the active elements the device is covered with an optically transparent top film 30, which is preferably also equipped with a barrier/encapsulation film 31. An edge encapsulation 32 ensures that no ingress of moisture and other potentially damaging species can occur from the side. The transparent top film may also have formed on it an array of colour filters 37 in order to sensitize the individual photodiodes to different spectral regions (Figure 9C).

Many different device architectures and process sequences can alternatively be used to integrate these functions on the same substrate. The optimum choice will depend on the processing characteristics of the organic materials and the deposition and patterning techniques used. Fig. 9B illustrates an alternative architecture 930, where the photodiode 33 and the display element 34 are formed on the top of the surface of the gate dielectric. Fig. 9C illustrates a configuration, similar to that in Figure 9B, where the transistors have a self-aligned gate architecture. This is realized by depositing a first, thin gate dielectric material 27 onto the active semiconducting layers, and then depositing a thicker dielectric spacer layer 35, which is patterned such as to open up trenches just above the transistor channels, for example as described by Noh, Nat. Nano 2, 784 (2007).. With such self-aligned gate architectures the parasitic capacitances associated with otherwise large overlap capacitance between source-drain and gate electrode can be minimized. The gate dielectric layer 27 and the dielectric spacer layer 35, respectively, should be chosen to be inert during the subsequent processing steps of the photodiodes and the display element, in particular they should not be dissolved or swelled during any of the subsequent solution deposition steps; they may, for example, comprise a cross-linked polymer.

According to a preferred embodiment of the present invention the active semiconductor layers and dielectrics of the transistors, photodiodes and any OLEDs are preferably fabricated from solution-processible organic semiconductors, conjugated polymers and dielectrics in order to be compatible with low cost, low-temperature flexible substrates and to achieve low manufacturing cost. However, one or several of the active layers

can also be made from an organic semiconductor deposited from vacuum phase or an organic dielectric layer deposited by chemical vapour deposition, such as parylene. Also other carbon-based semiconductors and conductors, such as carbon nanotubes or graphene may be used as electrode materials or as active semiconductors.

Any of the devices may also contain low-temperature processible inorganic materials that are compatible with manufacturing on flexible substrates, such as sputtered or vacuum deposited amorphous metal oxide semiconductors as described, for example, in Banger et al. (Nat. Mat. 10, 45 (2011)), or other precursor or nanoparticle or nanowire based inorganic semiconductors.

The flexible circuits we describe have many advantages, as well as potentially low-cost fabrication. No doubt many effective alternatives will occur to the skilled person. It will be understood that the invention is not limited to the described embodiments and encompasses modifications apparent to those skilled in the art lying within the spirit and scope of the claims appended hereto.

CLAIMS:

1. An integrated organic electronic device, the device having an integrated optoelectronic sensor and processing circuitry, the device comprising:

a substrate bearing at least one organic semiconductor optosensor for light-sensing to provide a light-sensing signal, and organic semiconductor signal processing circuitry comprising a plurality of organic field effect transistors (OFETs), coupled to said optosensor to process said light sensing signal to provide a processed light detection signal output;

a first, source-drain conducting layer;

a gate dielectric layer;

a first organic semiconductor layer between said first, source-drain conducting layer and said gate dielectric layer;

wherein said plurality of OFETs is formed in said first organic semiconductor layer, each said OFET having source and drain connections patterned in said first, source-drain conducting layer and a gate connection;

a second, interconnection conducting layer;

a third, transparent conducting layer;

an optosensor organic semiconductor layer formed between said second, interconnection conducting layer and said third, transparent conducting layer, where said optosensor has a first optosensor electrode in said third, transparent conducting layer and a second optosensor electrode coupled to said gate connection of at least one of said OFETs; and

an electrical output from said signal processing circuitry to provide said processed light detection signal output.

2. An integrated organic electronic device as claimed in claim 1 wherein said second optosensor electrode is coupled to said gate connection of said at least one of said OFETs by said second, interconnection conducting layer.

3. An integrated organic electronic device as claimed in claim 1 or 2 wherein said electrical output is coupled to said first source-drain conducting layer.

4. An integrated organic electronic device as claimed in claim 1, 2 or 3 further comprising at least via connection connected to said second, interconnection

conducting layer, wherein an electrical connection between said second interconnection layer and one of: said source-drain metal layer, said electrical output, and said gate connection of said OFET coupled to said second optosensor electrode, includes said at least one via connection.

5. An integrated organic electronic device as claimed in any preceding claim wherein said second, interconnection conducting layer comprises a gate conducting layer of said OFETs.

6. An integrated organic electronic device as claimed in claim 5 when dependent on claim 4 wherein a said via connection forms said gate connection of said OFET coupled to said second optosensor electrode.

7. An integrated organic electronic device as claimed in any preceding claim wherein said optosensor organic semiconductor layer and said third, transparent conducting layer are both located between said first, source-drain conducting layer and said second, interconnection conducting layer, and wherein said second, interconnect conducting layer includes an opening above said optosensor.

8. An integrated organic electronic device as claimed in any preceding claim further comprising an optical display element integrated into said substrate having a drive input coupled to said electrical output from said signal processing circuitry, and wherein said processed light detection signal output provides an input signal to said optical display element.

9. An integrated organic electronic device as claimed in claim 8 wherein said optical display element comprises an electrophoretic display element laminated over said signal processing circuitry.

10. An integrated organic electronic device as claimed in claim 8 wherein said optical display element comprises an OLED display element having a first electrode coupled to said electrical output and a second electrode, wherein said second electrode is formed in said third, transparent conducting layer.

11. An integrated organic electronic device as claimed in any one of claims 1 to 10 wherein said second optosensor electrode is formed in said first, source-drain conducting layer.

12. An integrated organic electronic device as discussed in claim 11 when dependent on claim 4 wherein said at least one via connection is connected between said first, source-drain conducting layer and said second, interconnection conducting layer.

13. An integrated organic electronic device as claimed in any preceding claim wherein said second interconnection conducting layer is optically opaque and shields the optosensor from light exposure from one side of said substrate.

14. An integrated organic electronic device as claimed in any one of claims 1 to 10 wherein said second optosensor electrode is formed in said second, interconnect conducting layer, and wherein said second, interconnect conducting layer comprises a said gate connection of a said OFET.

15. An integrated organic electronic device as claimed in any one of claims 1 to 10 wherein a said OFET has a self-aligned gate architecture.

16. An integrated organic electronic device as claimed in any one of claims 1 to 15 wherein said organic semiconductor signal processing circuitry comprises both n-type and p-type OFETs.

17. An integrated organic electronic device as claimed in any one of claims 1 to 16 wherein said organic semiconductor signal processing circuitry comprises one or more resistors fabricated in an organic semiconductor layer of said device, wherein said one or more of said resistors is configured as one or more of: a load resistor for a said OFET, a comparator level offset resistor, and a current-to-voltage converter to convert a photocurrent from said optosensor to a voltage for said processing circuitry.

18. An integrated organic electronic device as claimed in any one of claims 1 to 17 comprising at least a pair of said organic semiconductor optosensors; and

wherein said signal processing circuitry includes analogue signal processing circuitry, wherein said analogue signal processing circuitry comprises at least two matched signal processing paths, one coupled to each of said optosensors, and wherein said signal processing circuitry further comprises a common output stage coupled to said output and having an input from each of said matched signal processing paths.

19. An integrated organic electronic device as claimed in claim 18 comprising a plurality of pairs of said optosensors each having a respective matched pair of signal processing paths.

20. An integrated organic electronic device as claimed in claim 18 of 19 wherein said common output stage comprises combinatorial logic.

21. An integrated organic electronic device as claimed in any preceding claim comprising at least a pair of said organic semiconductor optosensors, and wherein said signal processing circuitry is configured to compare signals from said optosensors to provide said light detection signal output.

22. An integrated organic electronic device as claimed in claim 21 further comprising a respective window for each said optosensor and a light-conducting layer between said windows to said optosensors extending to an edge of said substrate for illuminating an object to be sensed from behind a said window.

23. An integrated organic electronic device as claimed in claim 21 further comprising a respective window for each said optosensor, and a housing for said substrate, wherein a portion of said housing opposite said windows is substantially transparent for illuminating an object to be sensed from behind a said window, and further comprising a light block for a said optosensor located between the optosensor and said transparent portion of said housing, wherein said light block is provided by an optically opaque said second interconnection conducting layer.

24. A colour-matching toy comprising the integrated organic electronic device of any preceding claim.

25. An integrated organic electronic device, the device having an integrated optoelectronic sensor and processing circuitry, the device comprising:

a substrate bearing at least one organic semiconductor optosensor for light-sensing to provide a light-sensing signal, and organic semiconductor signal processing circuitry comprising a plurality of organic field effect transistors (OFETs), coupled to said optosensor to process said light sensing signal to provide a processed light detection signal output;

a first layer of organic semiconductor material in which said OFETs are fabricated;

a second layer of organic semiconductor material in which said organic semiconductor optosensor is fabricated.

26. An integrated organic electronic device as claimed in claim 25 comprising at least a pair of said organic semiconductor optosensors, wherein said signal processing circuitry includes analogue signal processing circuitry, wherein said analogue signal processing circuitry comprises at least two matched signal processing paths, one coupled to each of said optosensors, and wherein said signal processing circuitry further comprises a common output stage coupled to said output and having an input from each of said matched signal processing paths.

27. An integrated organic electronic device as claimed in claim 26 wherein said common output stage comprises combinatorial logic.

28. An integrated organic electronic device as claimed in claim 26 or 27 configured for colour matching, wherein the device comprises a plurality of pairs of said optosensors each having a respective matched pair of signal processing paths, and wherein each of said pairs of optosensors has a different coloured optical filter.

29. An integrated organic electronic device as claimed in claim 28 further comprising a respective window for each said optosensor, and wherein the device is configured for illuminating an object to be sensed from behind a said window.

30. An integrated organic electronic device as claimed in claim 28 or 29 in a colour-matching toy.

31. An integrated organic electronic imaging circuit, the circuit comprising a substrate onto which are integrated:

at least one organic photosensor to detect an optical signal;

an organic transistor circuit coupled to the organic photosensor, and configured to process information from the detected optical signal and to output a drive signal; and

a display, coupled to receive said drive signal from said transistor circuit, to provide a display responsive to the processed detected optical signal.

32. An integrated organic electronic imaging circuit, as claimed in claim 31 comprising an array of said organic photosensors coupled to said organic transistor circuit; wherein said array comprises a first set of reference photosensors to produce electrical signals that identify the colour of a reference object and a second set of photosensors to produce electrical signals that identify the colour of a second object; and wherein said display responsive to said processed detected optical signal indicates whether a colour match is detected between the second object and the reference object.

33. An integrated organic electronic imaging circuit, as claimed in claim 31 comprising two arrays of said organic photosensors coupled to said organic transistor circuit, a first array of reference photodiodes to produce first electrical signals that identify the shape or dimension of a reference object and a second set of photodiodes to produce second electrical signals that identify the shape or dimension of a second object; and wherein said organic transistor circuit is configured to compare said first and second electrical signals to determine whether one or both of a shape and a dimension of said second object matches that of said reference object to within a tolerance and to output said drive signal responsive to a result of said determination.

34. An integrated organic electronic imaging circuit, as claimed in claim 31 wherein said organic transistor circuit is configured to process said detected optical signal to detect an event and to output said drive signal responsive to said detection.

35. An integrated organic electronic imaging circuit, as claimed in claim 34 wherein said organic transistor circuit is configured to count said events

36. An integrated organic electronic imaging circuit, as claimed in claim 35 wherein said drive signal is configured to drive said display to indicate a count of said events.

37. An integrated organic electronic imaging circuit, as claimed in any one of claims 31 to 36 wherein said at least one organic semiconductor photosensor is configured to provide a light-sensing signal, wherein said organic transistor circuit comprises organic semiconductor signal processing circuitry comprising a plurality of organic field effect transistors (OFETs), coupled to said photosensor to process said light sensing signal to provide a processed light detection signal output; the integrated organic electronic imaging circuit further comprising:

a first, source-drain conducting layer;

a gate dielectric layer;

a first organic semiconductor layer between said first, source-drain conducting layer and said gate dielectric layer;

wherein said plurality of OFETs is formed in said first organic semiconductor layer, each said OFET having source and drain connections patterned in said first, source-drain conducting layer and a gate connection;

a second, interconnection conducting layer;

a third, transparent conducting layer;

an photosensor organic semiconductor layer formed between said second, interconnection conducting layer and said third, transparent conducting layer, where said photosensor has a first photosensor electrode in said third, transparent conducting layer of dielectric and a second photosensor electrode coupled to said gate connection of at least one of said OFETs; and

an electrical output from said signal processing circuitry to provide said processed light detection signal output.

38. An integrated organic electronic device as claimed in claim 37 wherein said second photosensor electrode is coupled to said gate connection of said at least one of said OFETs by said second, interconnection conducting layer.

39. An integrated organic electronic device as claimed in claim 37 or 38 wherein said electrical output is coupled to said first source-drain conducting layer.

40. An integrated organic electronic device as claimed in claim 37, 38 or 39 further comprising at least via connection connected to said second, interconnection conducting layer, wherein an electrical connection between said second interconnection layer and one of: said source-drain metal layer, said electrical output, and said gate connection of said OFET coupled to said second photosensor electrode, includes said at least one via connection.

41. An integrated organic electronic device as claimed in any one of claims 37 to 40 wherein said second, interconnection conducting layer comprises a gate conducting layer of said OFETs.

42. An integrated organic electronic device as claimed in claim 41 when dependent on claim 40 wherein a said via connection forms said gate connection of said OFET coupled to said second photosensor electrode.

43. An integrated organic electronic device as claimed in any one of claims 37 to 42 wherein said photosensor is organic semiconductor layer and said third, transparent conducting layer are both located between said first, source-drain conducting layer and said second, interconnection conducting layer, and wherein said second, interconnect conducting layer includes an opening above said photosensor.

44. An integrated organic electronic device as claimed in any one of claims 37 to 43 wherein said display comprises an optical display element integrated into said substrate having a drive input coupled to said electrical output from said signal processing circuitry, and wherein said processed light detection signal output provides an input signal to said optical display element.

45. An integrated organic electronic device as claimed in claim 44 wherein said optical display element comprises an electrophoretic display element laminated over said signal processing circuitry.

46. An integrated organic electronic device as claimed in claim 44 wherein said optical display element comprises an OLED display element having a first electrode coupled to said electrical output and a second electrode, wherein said second electrode is formed in said third, transparent conducting layer.

47. An integrated organic electronic device as claimed in any one of claims 37 to 46 wherein said second photosensor electrode is formed in said first, source-drain conducting layer.

48. An integrated organic electronic device as discussed in claim 47 when dependent on claim 40 wherein said at least one via connection is connected between said first, source-drain conducting layer and said second, interconnection conducting layer.

49. An integrated organic electronic device as claimed in claim 47 or 48 wherein said second interconnection conducting layer is optically opaque and shields the optosensor from light exposure from one side of said substrate.

50. An integrated organic electronic device as claimed in any one of claims 37 to 46 wherein said second photosensor electrode is formed in said second, interconnect conducting layer, and wherein said second, interconnect conducting layer comprises a said gate connection of a said OFET.

51. An integrated organic electronic device as claimed in any one of claims 37 to 46 wherein a said OFET has a self-aligned gate architecture.

52. An integrated organic electronic device as claimed in any one of claims 37 to 51 wherein said organic semiconductor signal processing circuitry comprises both n-type and p-type OFETs.

53. An integrated organic electronic device as claimed in any one of claims 37 to 52 wherein said organic semiconductor signal processing circuitry comprises one or more resistors fabricated in an organic semiconductor layer of said device, wherein said one or more of said resistors is configured as one or more of: a load resistor for a said

OFET, a comparator level offset resistor, and a current-to-voltage converter to convert a photocurrent from said photosensor to a voltage for said processing circuitry.

54. An integrated organic electronic device as claimed in any one of claims 37 to 53 comprising at least a pair of said organic semiconductor photosensors; and wherein said signal processing circuitry includes analogue signal processing circuitry, wherein said analogue signal processing circuitry comprises at least two matched signal processing paths, one coupled to each of said photosensors, and wherein said signal processing circuitry further comprises a common output stage coupled to said output and having an input from each of said matched signal processing paths.

55. An integrated organic electronic device as claimed in claim 54 comprising a plurality of pairs of said photosensors each having a respective matched pair of signal processing paths.

56. An integrated organic electronic device as claimed in claim 54 of 55 wherein said common output stage comprises combinatorial logic.

57. An integrated organic electronic device as claimed in any one of claims 37 to 56 comprising at least a pair of said organic semiconductor photosensors, and wherein said signal processing circuitry is configured to compare signals from said photosensors to provide said light detection signal output.

58. An integrated organic electronic device as claimed in claim 57 further comprising a respective window for each said photosensor and a light-conducting layer between said windows to said photosensors extending to an edge of said substrate for illuminating an object to be sensed from behind a said window.

59. An integrated organic electronic device as claimed in claim 57 further comprising a respective window for each said photosensor, and a housing for said substrate, wherein a portion of said housing opposite said windows is substantially transparent for illuminating an object to be sensed from behind a said window, and further comprising a light block for a said photosensor located between the photosensor and said transparent portion of said housing.

60. An integrated organic electronic imaging circuit, as claimed in any one of claims 31 to 59 wherein said display is configured to display one or more images.

61. An integrated organic electronic imaging circuit, as claimed in any one of claims 31 to 60, wherein said display comprises an OLED.

62. An integrated organic electronic imaging circuit, as claimed in any one of claims 31 to 61, wherein said display is replaced by an acoustic feedback device.

63. An integrated organic electronic imaging circuit, as claimed in any one of claims 31 to 62 further comprising a power source integrated onto said substrate.

64. An electronic toy comprising the integrated organic electronic imaging circuit of any one of claims 31 to 63.

65. An integrated organic electronic device or circuit as claimed in any preceding claim wherein said substrate is a flexible substrate.

66. An integrated organic electronic device or circuit as claimed in any preceding claim wherein a gate dielectric of said OFETs comprises a cross-linked material.

67. An integrated organic electronic device or circuit as claimed in any preceding claim wherein said integrated optoelectronic sensor and processing circuitry is fabricated by solution deposition techniques.

68. Use of an integrated organic electronic device as claimed in any one of claim 32 and claims 38 to 67 as dependent on claim 32, in a children's toy, wherein the use comprises giving the child a first coloured object to place as a reference object in front of the first set of reference photodiodes, asking the child to look in its environment for second objects that have the same or a similar colour, and placing such objects in front of the second array of photodiodes, and wherein the display subsequently indicates to the child whether it has successfully matched the colours of the reference and the second object or whether the second object has a different colour to that of the reference object.

69. Use of an integrated organic electronic device as claimed in claim 68 in a children's toy, wherein the toy is used with a sequence of reference objects of different colours.

70. Use of an integrated organic electronic device as claimed in claim 68 or 69 in a children's toy, where the device provides an acoustic feedback in addition to or in place of the display.

71. Use of an integrated organic electronic device as claimed in any one of claims 32, and 38 to 67 when dependent on claim 32, in an industrial or consumer colour matching tool, wherein the use comprises monitoring, using the tool, whether the colour of an object is sufficiently close to a reference colour to determine whether a quality of the object meets a required quality criterion.

72. Use of an integrated organic electronic device as claimed in any one of claims 33, and 38 to 44 when dependent on claim 33, as a children's toy, wherein the use comprises giving a child a first object that has or displays a particular shape or dimension; receiving the first object as a reference object in front of the first set of reference photodiodes, asking the child to look in its environment for second objects that have the same or a similar shape, and receiving a said second object in front of the second array of photodiodes, and displaying to the child whether it has successfully matched the shape or whether the second object has a different shape to that of the reference object.

73. Use of an integrated organic electronic device as claimed in claim 72 in a children's toy, where the device provides an acoustic feedback in addition to or in place of the display.

74. Use of an integrated organic electronic device as claimed in claim 72 or 73, where the toy is used to recognize the individual letters of an alphabet or set of characters.

75. Use of an integrated organic electronic device as claimed in any one of claims 33, and 38 to 44 when dependent on claim 33 as a shape matching tool in an industrial or consumer application, wherein the use comprises using the tool for monitoring

whether the shape of dimension of an object is the same as that of a reference object and using the monitoring to indicate whether a quality of the object meets a required quality criterion.

76. An integrated organic electronic imaging circuit as claimed in any one of claims 1 to 23, wherein integrated onto said substrate are:

said at least one organic semiconductor optosensor to detect an optical signal;

said organic semiconductor signal processing circuitry comprising said plurality of organic field effect transistors, wherein said transistor circuitry is coupled to said organic photosensor and configured to process information from the detected optical signal and to output a drive signal; and

a display, coupled to receive said drive signal from said transistor circuitry, to provide a display responsive to the processed detected optical signal.

77. An integrated organic electronic imaging circuit, as claimed in claim 76 comprising an array of said organic optosensors coupled to said organic transistor circuitry; wherein said array comprises a first set of reference optosensors to produce electrical signals that identify the colour of a reference object and a second set of optosensors to produce electrical signals that identify the colour of a second object; and wherein said display responsive to said processed detected optical signal indicates whether a colour match is detected between the second object and the reference object.

78. An integrated organic electronic imaging circuit, as claimed in claim 76 comprising two arrays of said organic optosensors coupled to said organic transistor circuitry, a first array of reference photodiodes to produce first electrical signals that identify the shape or dimension of a reference object and a second set of photodiodes to produce second electrical signals that identify the shape or dimension of a second object; and wherein said organic transistor circuitry is configured to compare said first and second electrical signals to determine whether one or both of a shape and a dimension of said second object matches that of said reference object to within a tolerance and to output said drive signal responsive to a result of said determination.

79. An integrated organic electronic imaging circuit, as claimed in claim 76 wherein said organic transistor circuitry is configured to process said detected optical signal to detect an event and to output said drive signal responsive to said detection.

80. An integrated organic electronic imaging circuit, as claimed in claim 79 wherein said organic transistor circuitry is configured to count said events

81. An integrated organic electronic imaging circuit, as claimed in claim 80 wherein said drive signal is configured to drive said display to indicate a count of said events.

82. An integrated organic electronic imaging circuit, as claimed in any one of claims 31 to 59 wherein said display is configured to display one or more images.

83. An integrated organic electronic imaging circuit, as claimed in any one of claims 76 to 82, wherein said display comprises an OLED.

84. An integrated organic electronic imaging circuit, as claimed in any one of claims 76 to 83, wherein said display is replaced by an acoustic feedback device.

85. An integrated organic electronic imaging circuit, as claimed in any one of claims 76 to 84 further comprising a power source integrated onto said substrate.

86. An electronic toy comprising the integrated organic electronic imaging circuit of any one of claims 76 to 85.

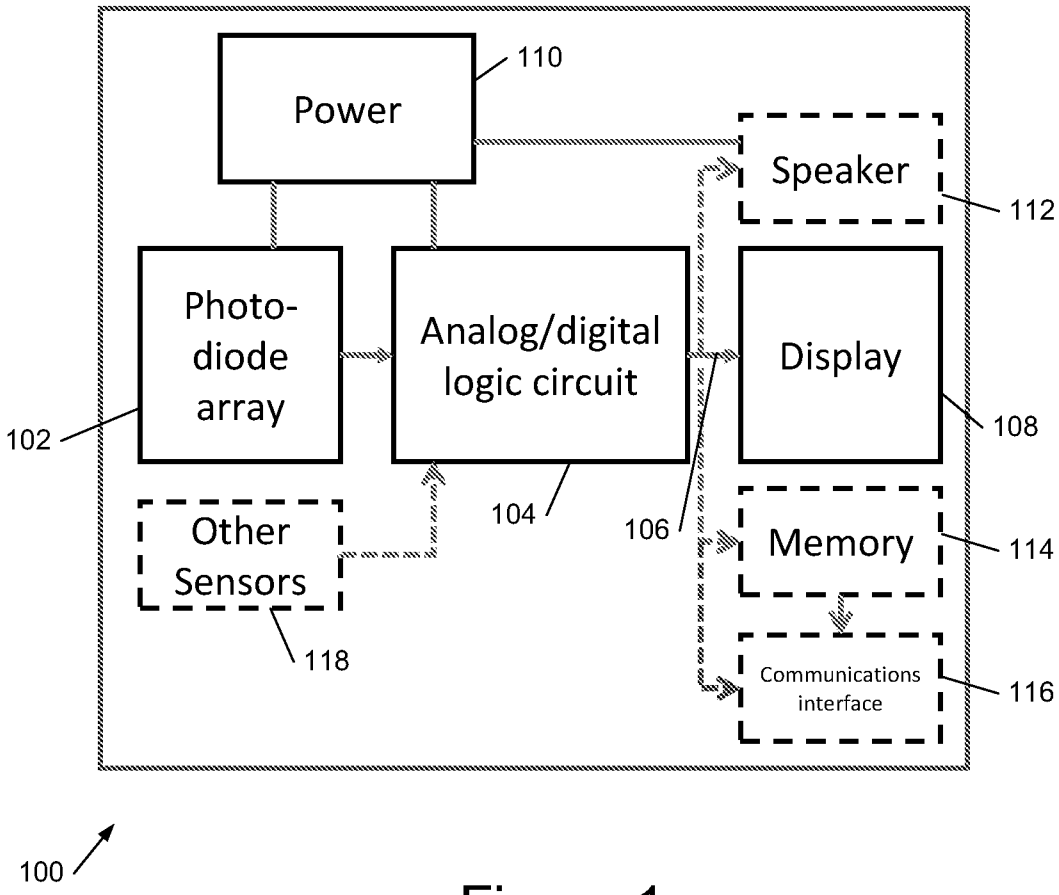

Power
110
Speaker
112
Photo-
diode
array
Analog/digital
logic circuit
Display
102
108
104
106
Other
Sensors
Memory
114
118
Communications
interface
116
100

Figure 1

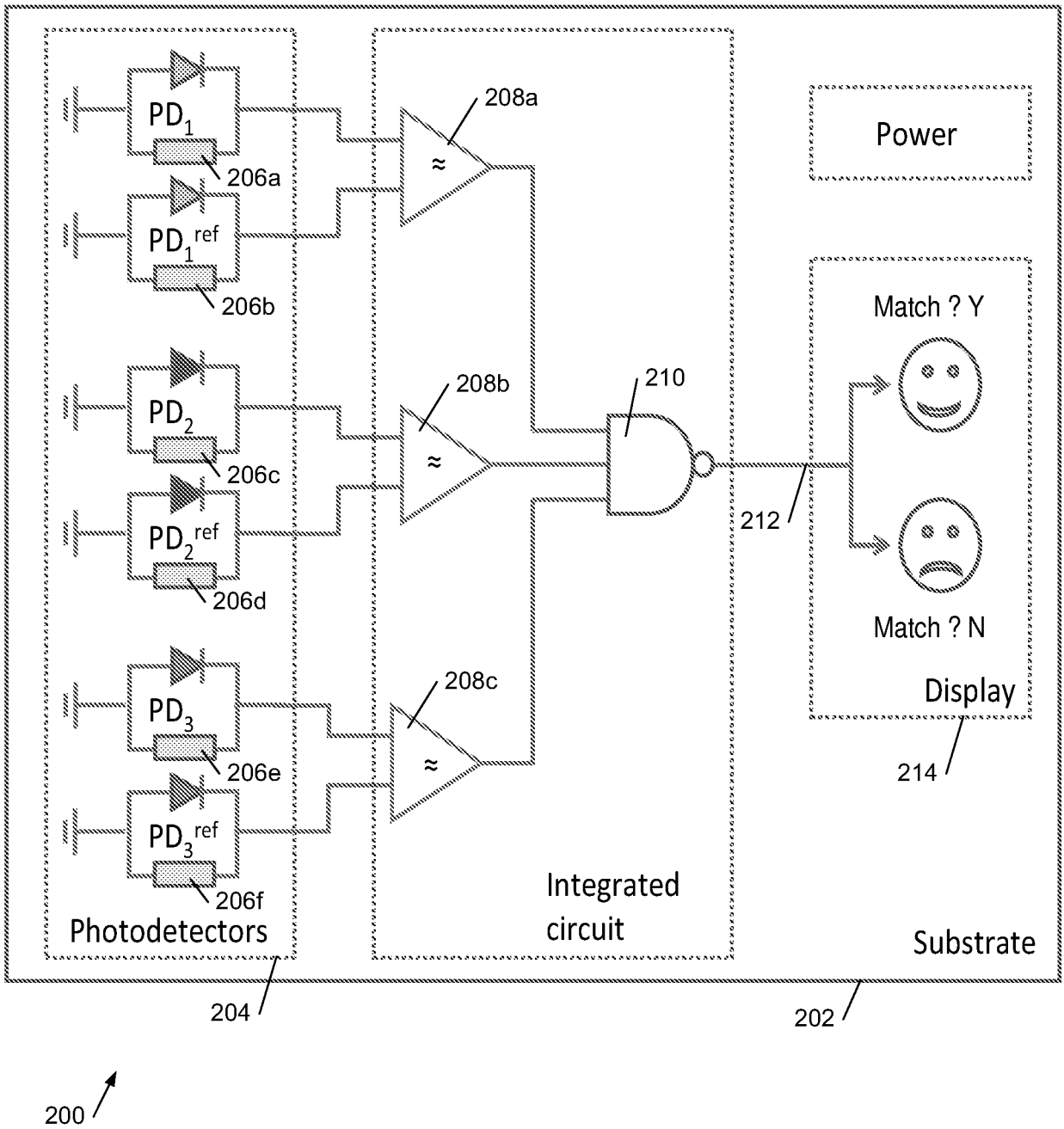

PD1
206a
PD1ref
206b
PD2
206c
PD2ref
206d
PD3
206e
PD3ref
206f
Photodetectors
204
208a
208b
208c
Integrated circuit
210
212
Power
Match ? Y
Match ? N
Display
214
Substrate
202
200

Figure 2

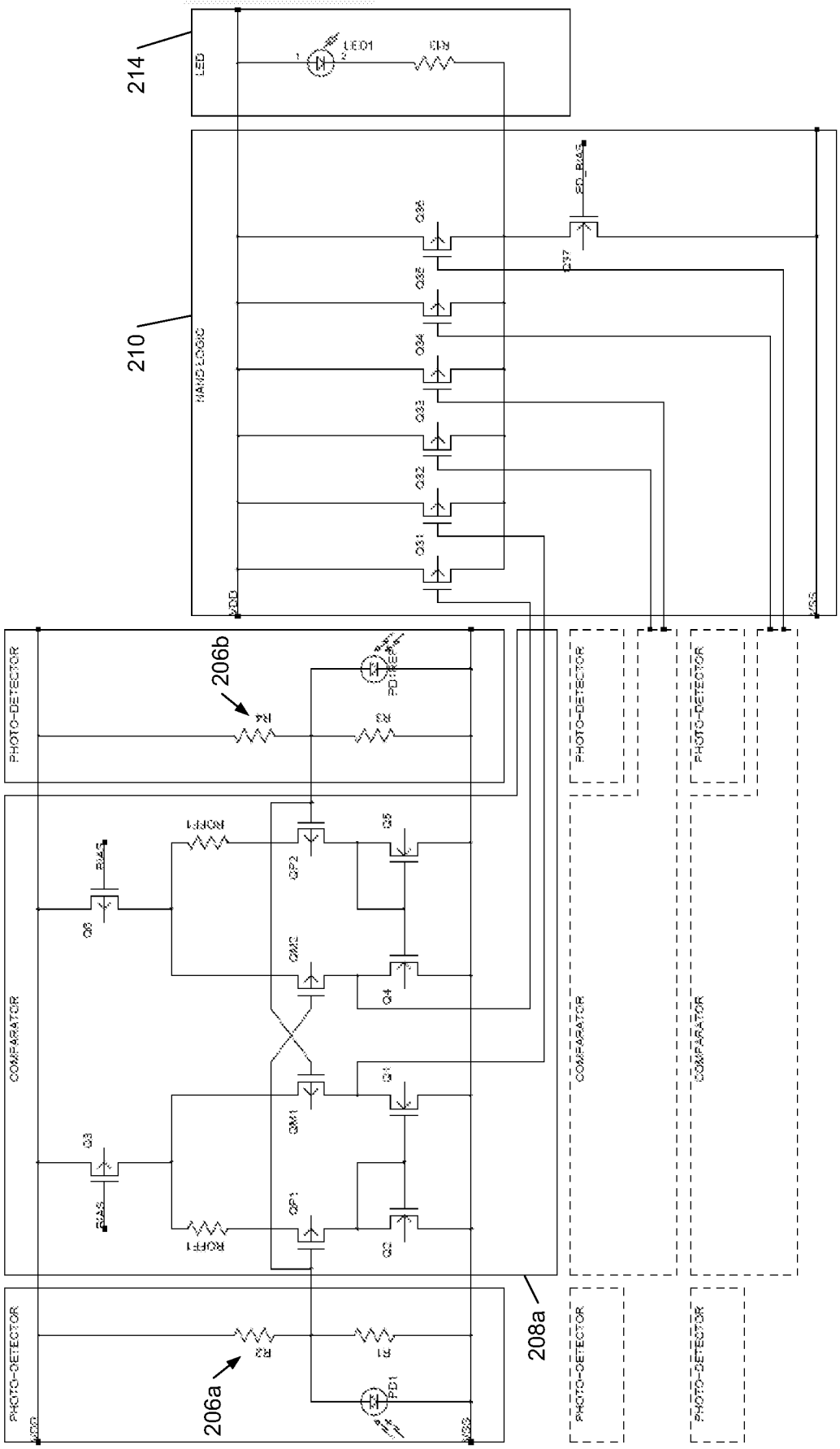

214
LED
LED1
R10
210
NAND LOGIC
Q36
Q35
Q34
Q33
Q32
Q31
ED_BIAS
Q37
VDD
VSS
206b
PHOTO-DETECTOR
PD_REF
R4
R3
COMPARATOR
ROFF1
Q5
Q2
Q6
BIAS
QM2
Q4
QM1
Q1
Q3
QP1
Q6
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206a
R2
R1
PD1
200

Figure 3

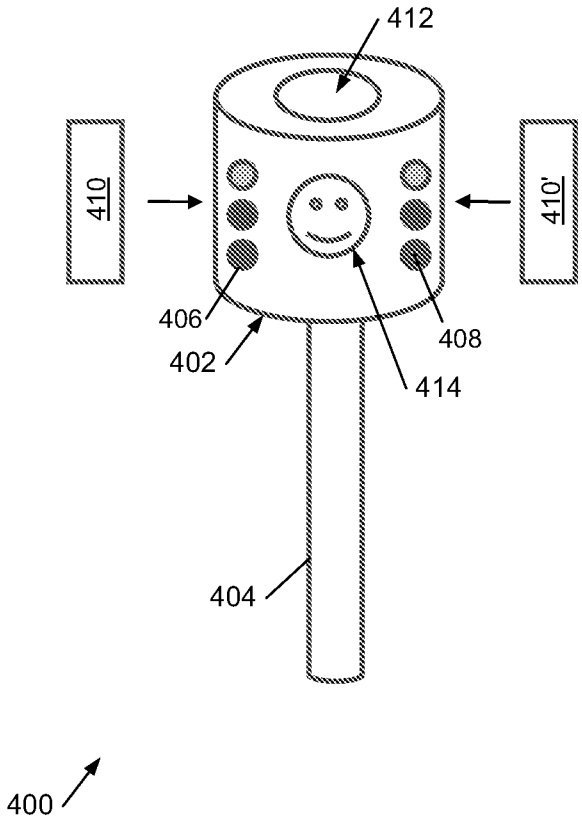


Figure 4

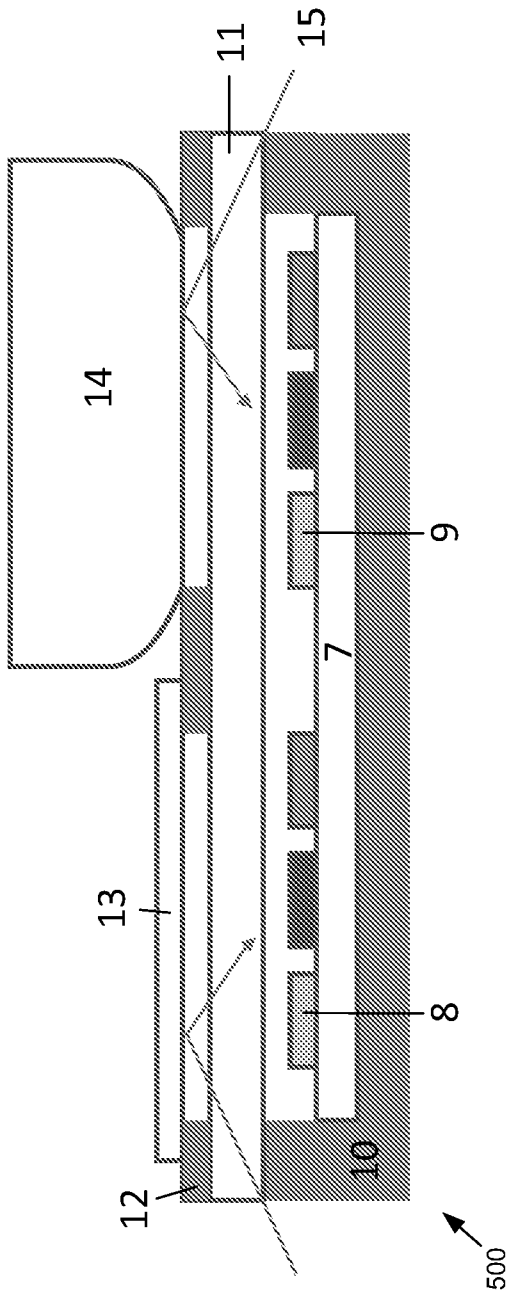


Figure 5a

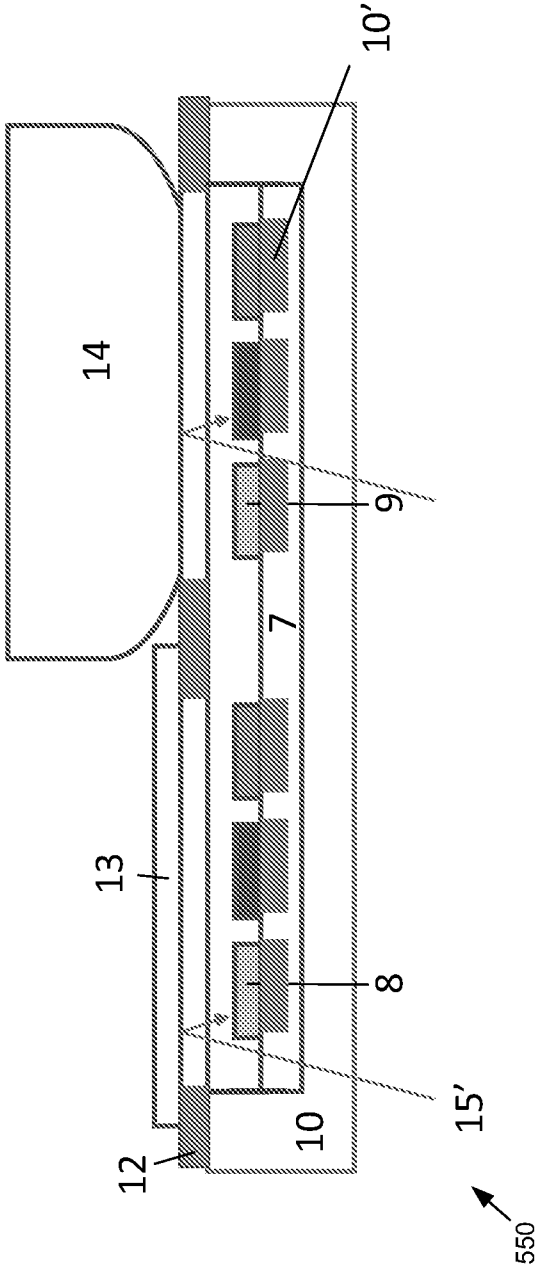


Figure 5b

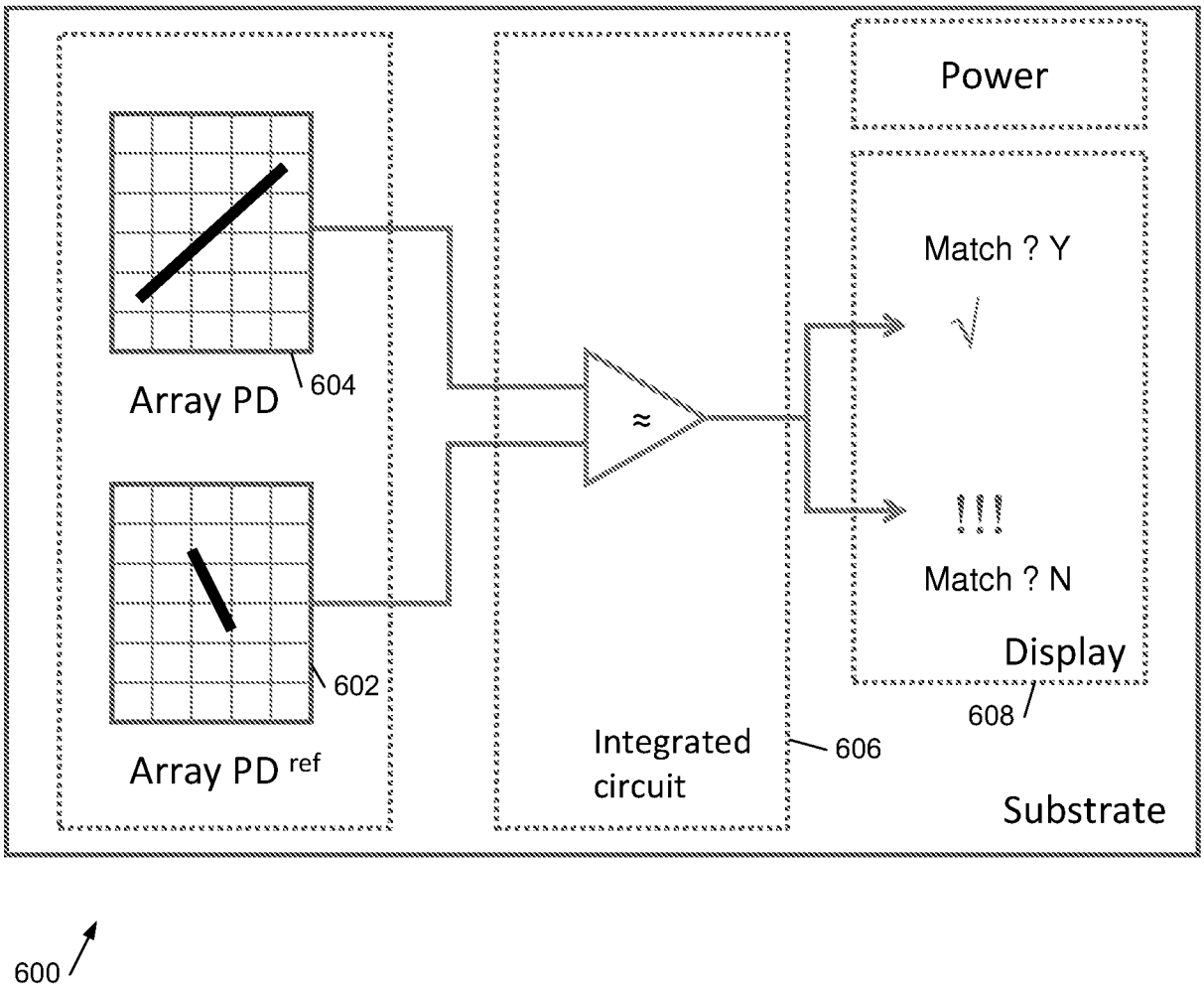

Power
Match ? Y
√
!!!
Match ? N
Display
608
Array PD
604
Array PD ref
602
≈
Integrated
circuit
606
Substrate
600

Figure 6

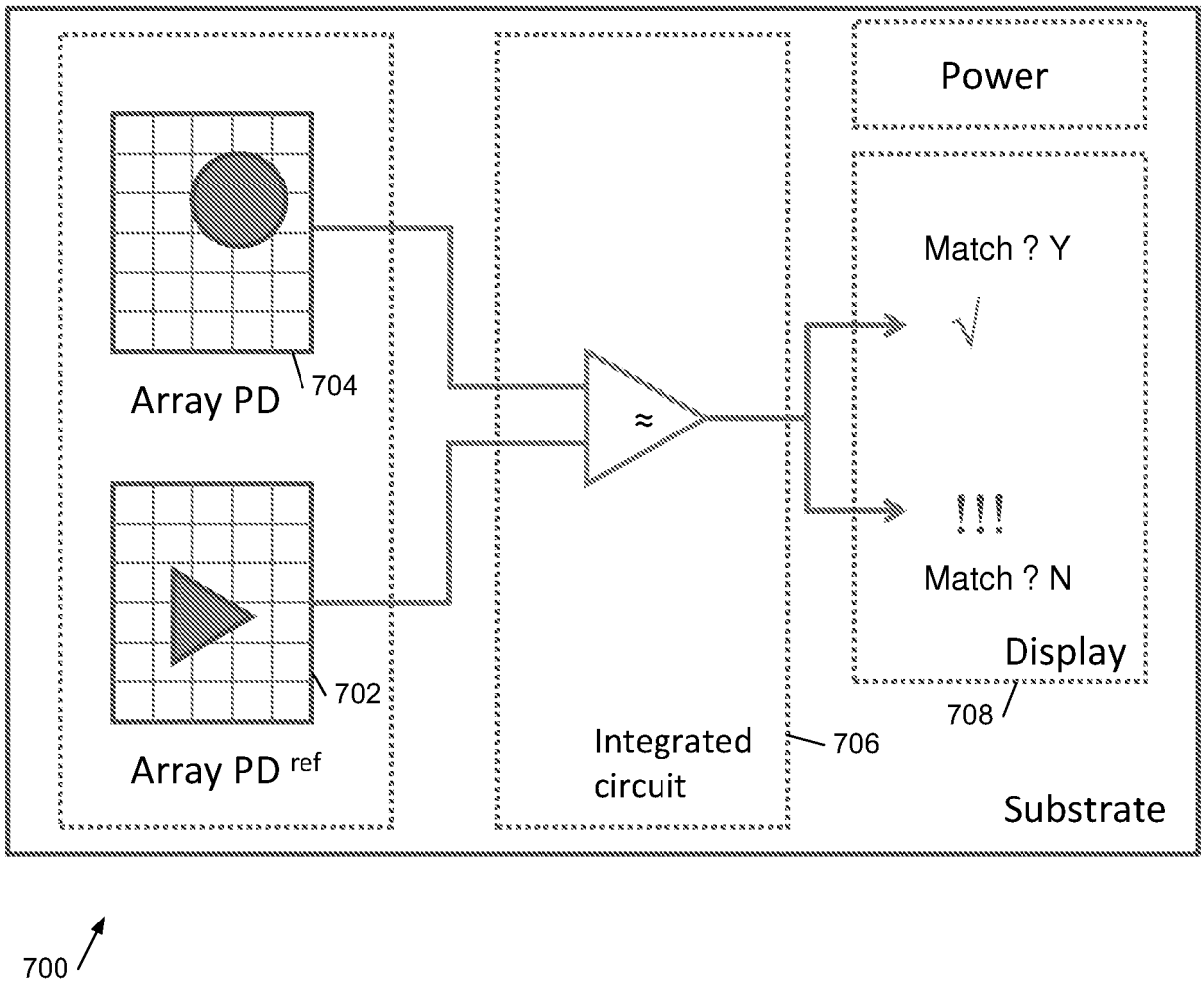

Power
Match ? Y
√
!!!
Match ? N
Display
708
Array PD
704
Array PD ref
702
Integrated
circuit
706
Substrate
≈
700

Figure 7

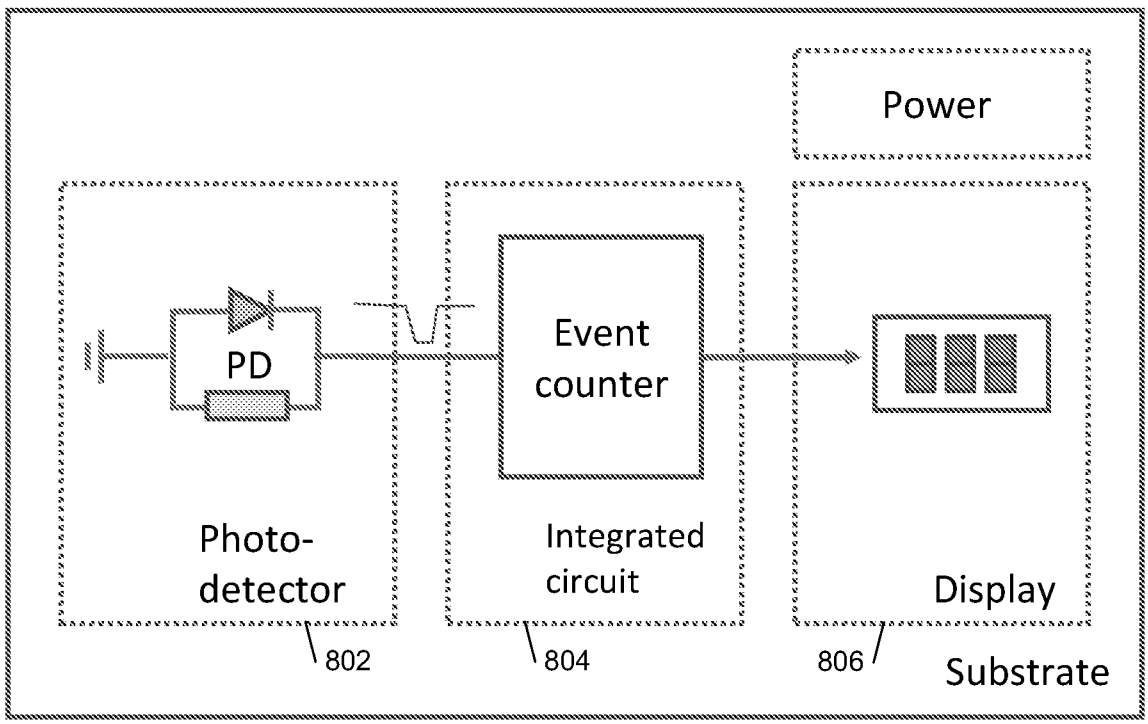

Power
PD
Event
counter
Photo-
detector
Integrated
circuit
Display
802
804
806
Substrate
800

Figure 8

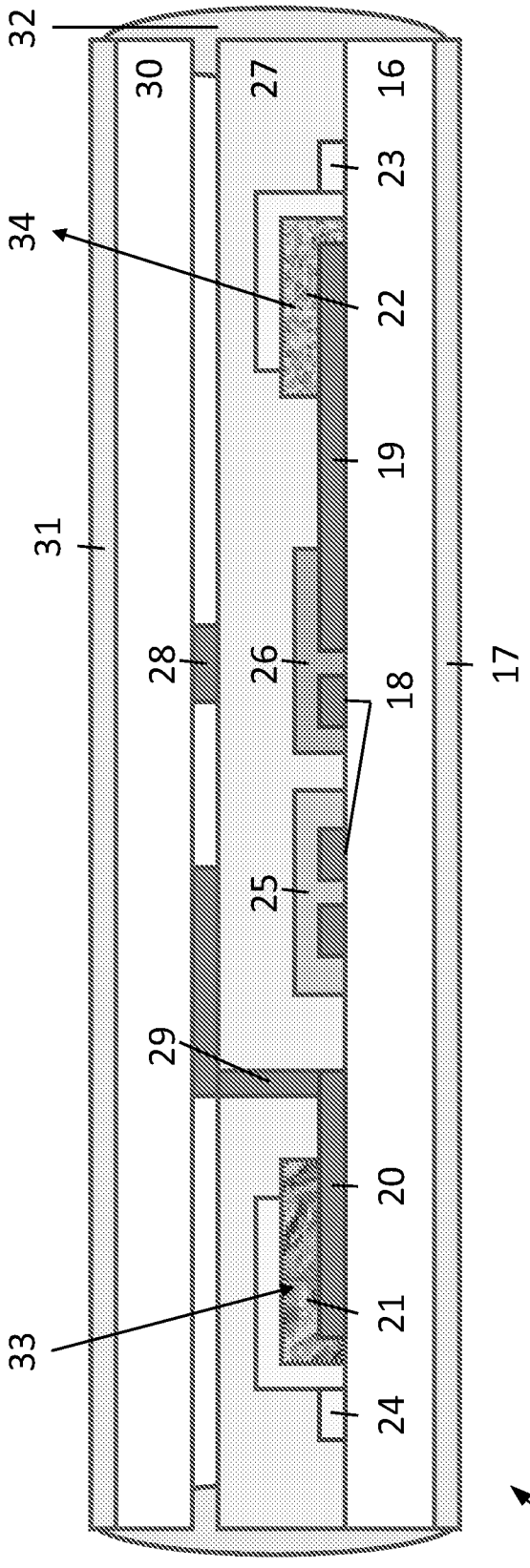


Figure 9a

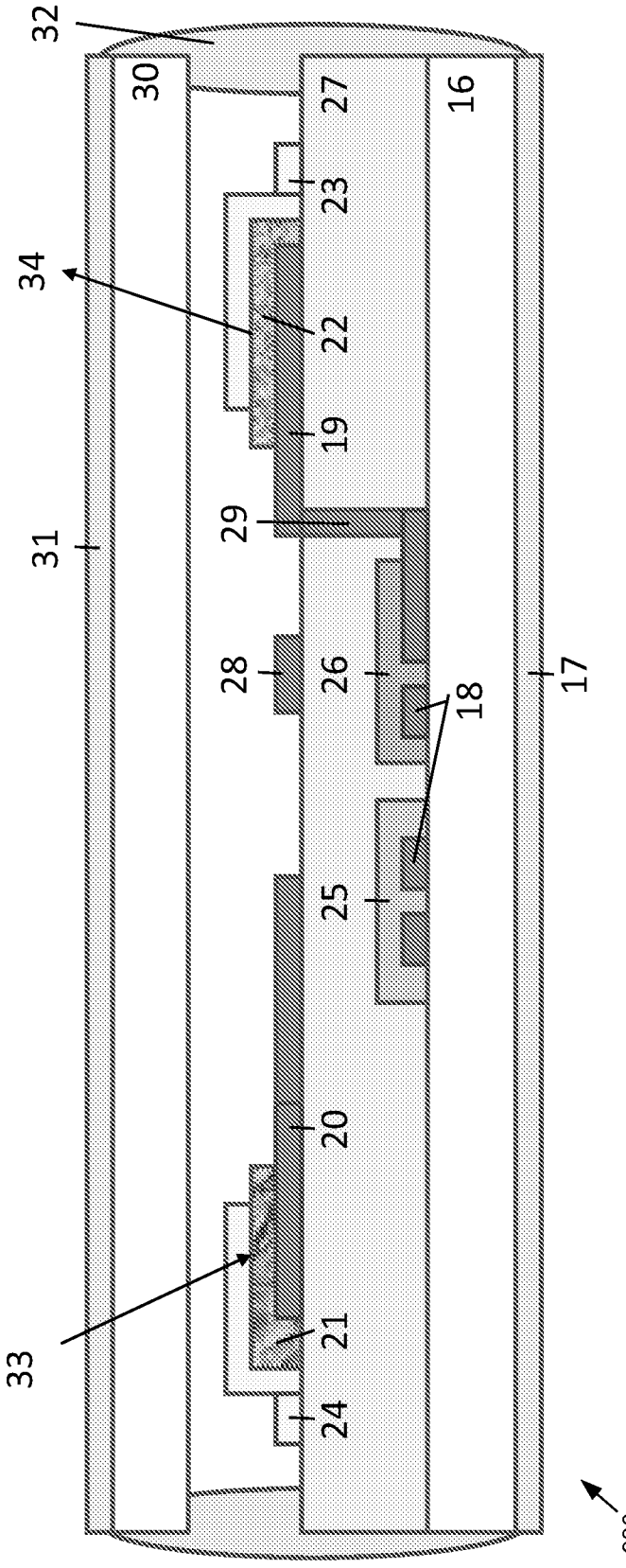


Figure 9b

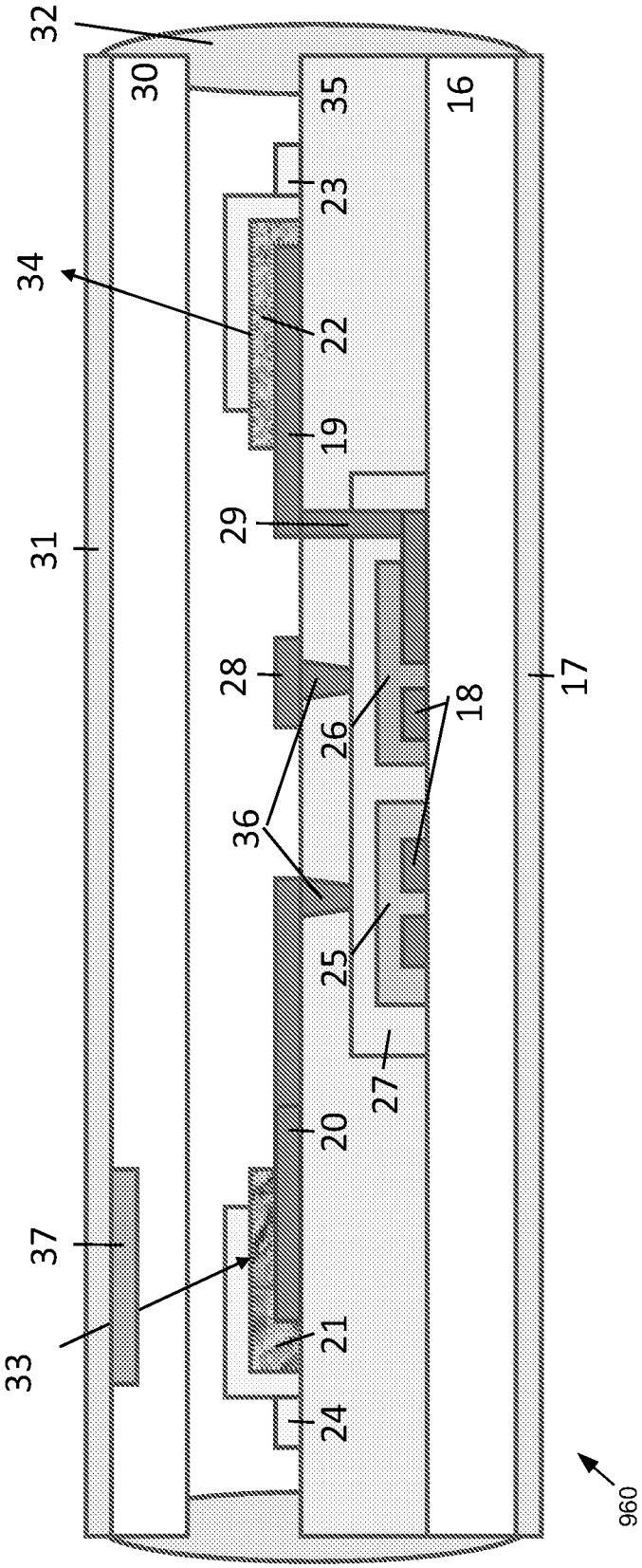


Figure 9c

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2012/051158

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L27/30
ADD.

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)
H01L G01C 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 practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/049489 A1 (FORREST STEPHEN R [US] ET AL) 3 March 2011 (2011-03-03)	1,3,4,7, 9,11-13, 15,16,84
Y	paragraph [0045] - paragraph [0063] figure 2	2,5,6,8, 10,14, 17-23, 76-81, 83,85,86

X	US 2008/277650 A1 (CHANG TZU-YUEH [TW] ET AL) 13 November 2008 (2008-11-13) paragraph [0041] - paragraph [0051] figure 3	1,11,13

Y	US 2002/056810 A1 (KOBAYASHI ISAO [JP] ET AL) 16 May 2002 (2002-05-16) figure 7	2,5,6,14

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[X] Further documents are listed in the continuation of Box C.

[X] 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 application or patent 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
13 November 2012	21/11/2012

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, Fax: (+31-70) 340-3016	Bernabé Prieto, A

2

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2012/051158

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

1-24, 31-86

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-24, 76-81(completely); 83-86(partially)

   Electronic device having an organic photosensor and a plurality of OFETs, the photosensor and the OFETs having a certain structure of the layers.

   ---

2. claims: 25-30

   Electronic device having at least a pair of organic photosensors and a plurality of OFETs and signal processing means for comparing the output of the photosensors.

   ---

3. claims: 31-75, 82(completely); 83-86(partially)

   Electronic device having an organic photosensor, an organic transistor circuit and a display coupled to the signal from the organic transistor circuit.

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 2008/203311 A1 (WATANABE MINORU [JP] ET AL) 28 August 2008 (2008-08-28) abstract	2,5,6,14
Y	US 2002/079512 A1 (YAMAZAKI SHUNPEI [JP] ET AL) 27 June 2002 (2002-06-27) figure 4	8,10,22, 23,76, 77, 79-81, 83,85,86
Y	US 4 004 852 A (PENTECOST EUGENE E) 25 January 1977 (1977-01-25) figures 1-2	17-21, 24,77-80
Y	US 2010/246892 A1 (HIRASAWA TAKU [JP] ET AL) 30 September 2010 (2010-09-30) figures 1-2	17-21, 24,77-80
A	US 7 573 037 B1 (KAMESHIMA TOSHIO [JP] ET AL) 11 August 2009 (2009-08-11) figure 3	1
X	US 2007/152290 A1 (CORNELL ROBERT L [US]) 5 July 2007 (2007-07-05)	31
Y	paragraph [0013] - paragraph [0016]; figures 1,3	32-67, 71,75,82
Y	US 2010/165090 A1 (SWEENEY LATANYA A [US] ET AL) 1 July 2010 (2010-07-01) abstract; figure 2	32-36
Y	WO 99/54936 A1 (CAMBRIDGE DISPLAY TECH [GB]; FRIEND RICHARD HENRY [GB]; SIRRINGHAUS HE) 28 October 1999 (1999-10-28) page 20, paragraph 2; figure 14	37-67, 71,75,82
A	WO 2005/111916 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; RENSEN WOUTER [FR]; HENDRIKS ROBE) 24 November 2005 (2005-11-24) figure 4	32,33

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2012/051158

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011049489 A1	03-03-2011	NONE	
US 2008277650 A1	13-11-2008	TW 200845447 A	16-11-2008
		US 2008277650 A1	13-11-2008
US 2002056810 A1	16-05-2002	JP 11307756 A	05-11-1999
		US 2002056810 A1	16-05-2002
		US 2003020020 A1	30-01-2003
		US 2004251421 A1	16-12-2004
		US 2005206764 A1	22-09-2005
US 2008203311 A1	28-08-2008	US 2008203311 A1	28-08-2008
		US 2009302229 A1	10-12-2009
US 2002079512 A1	27-06-2002	US 2002079512 A1	27-06-2002
		US 2004174324 A1	09-09-2004
		US 2011006305 A1	13-01-2011
		US 2012113058 A1	10-05-2012
US 4004852 A	25-01-1977	NONE	
US 2010246892 A1	30-09-2010	CN 101548154 A	30-09-2009
		JP 4246258 B2	02-04-2009
		US 2010246892 A1	30-09-2010
		WO 2009013866 A1	29-01-2009
US 7573037 B1	11-08-2009	JP 4773768 B2	14-09-2011
		JP 2007050053 A	01-03-2007
		US 7573037 B1	11-08-2009
US 2007152290 A1	05-07-2007	NONE	
US 2010165090 A1	01-07-2010	NONE	
WO 9954936 A1	28-10-1999	AU 766162 B2	09-10-2003
		AU 3614399 A	08-11-1999
		BR 9909580 A	19-12-2000
		CA 2328094 A1	28-10-1999
		CN 1301400 A	27-06-2001
		EP 1074048 A1	07-02-2001
		EP 2154718 A2	17-02-2010
		JP 4260368 B2	30-04-2009
		JP 2002512451 A	23-04-2002
		JP 2008227517 A	25-09-2008
		TW 498395 B	11-08-2002
		US 6603139 B1	05-08-2003
		WO 9954936 A1	28-10-1999
WO 2005111916 A1	24-11-2005	CN 1954330 A	25-04-2007
		EP 1751691 A1	14-02-2007
		JP 2007537526 A	20-12-2007
		KR 20070015198 A	01-02-2007
		US 2008285812 A1	20-11-2008
		WO 2005111916 A1	24-11-2005