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(54) Title: ACTIVE PIXEL SENSOR AND ANALYTICAL DEVICE USING THE SAME

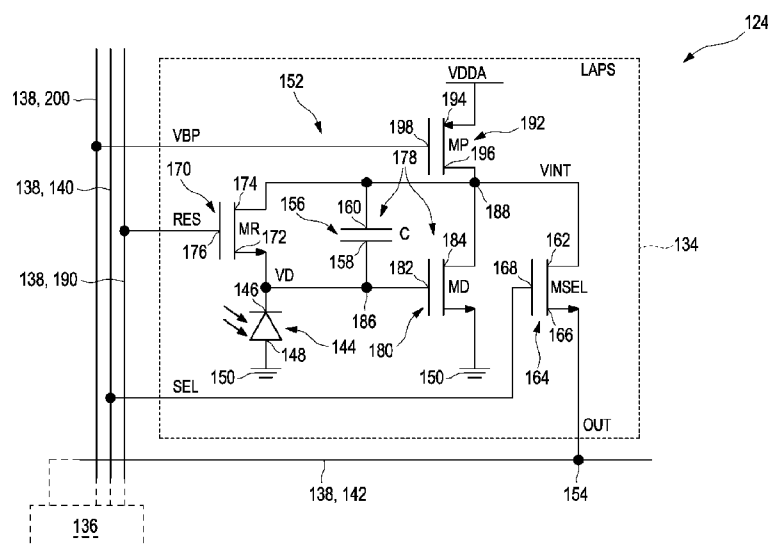


Fig. 3 A

(57) Abstract: An active pixel sensor (124) having at least one pixel (134) is disclosed. The pixel (134) comprises at least one photodiode (144) and at least one readout circuit (152). The readout circuit (152) comprises at least one integrating capacitor (156). The readout circuit (152) is adapted to accumulate electrical charges generated by the photodiode (144) during illuminating the photodiode (144) within the integrating capacitor (156). The readout circuit (152) further comprises at least one selector switch (164) adapted to read out the electrical charges from the integrating capacitor (156).



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Active pixel sensor and analytical device using the same

Field of the invention

The present invention refers to an active pixel sensor, an imaging device and an analytical device for detecting at least one property of a body fluid. The invention further refers to a method for detecting light, specifically by using the active pixel sensor. The active pixel sensor, the imaging device and the analytical device preferably may be used in the field of analytics, such as for qualitatively and/or quantitatively detecting at least one property of a body fluid, such as for detecting at least one analyte in the body fluid. In the following, the invention will mainly be disclosed in the context of blood glucose detection. However, other applications are possible. Further, applications outside the field of medical technology, such as in the general field of imaging devices, are possible, e.g. applications in the field of photography, environmental analytics, astronomy, scanning of documents or other fields.

Background of the invention

In the field of imaging technology, both for medical or analytical purposes and for applications in other technical fields, mainly, two types of imaging sensors are used. Thus, firstly, charge-coupled devices (CCDs) are used. Secondly, imaging devices based on complementary metal oxide semiconductor (CMOS) technology are used. Both technologies generally are suited for cameras or camera chips, both for linear arrays and for two-dimensional (2D) arrays.

Camera sensors using CMOS technology often are based on the use of a one-dimensional or two-dimensional array of so-called active pixel sensors (APS). Active pixel sensors are image sensors comprising an array of active pixels, wherein each pixel comprises, besides at least one photodiode, an integrated readout circuit comprising three or more transistors, such as MOS-FET transistors, which are integrated into the pixel. Active pixels allow for a pre-amplification of the signal generated by the photodiode, depending on the illumination

of the respective photodiode. The pre-amplification generally takes place using the junction capacitance of the photodiode, in which a charge-voltage-conversion takes place. By using a simple source follower circuit, the amplified signal may directly be read out as a voltage, as opposed to CCD technology in which the charges of the photodiodes are transferred pixel-by-pixel through the array, to an external amplifier. CMOS technology allows for reading out the pixels both by using a so-called rolling shutter mode and by using a global shutter mode. In the latter mode, the illumination of all pixels of the array takes place simultaneously, and the charges of the pixels, during the readout process, are stored in an additional storing capacitor within each pixel.

Active pixel sensors and CMOS technology, based on three or more metal oxide semiconducting field effect transistors (MOS-FET transistors), are generally known in the art. Thus, US 6,587,146 B1 discloses an active pixel sensor having a plurality of pixels with at least one pixel comprising: a photodetector operatively connected to a first electrical node; a pixel signal coupling capacitor having a first side connected to the first electrical node and a second side connected to a second electrical node; a reset transistor having a first source that is connected on the first electrical node and a second source that is connected to the second electrical node; a reset gate on the reset transistor connected to a reset control buss and a drain on the reset transistor connected to a voltage supply bus; an amplifier operatively connected to the second electrical node; and a select transistor operatively connected to the amplifier.

In Alireza Moini: Vision Chips or Seeing Silicon, The Centre for High Performance Integrated Technologies and Systems, Department of Electrical & Eletronics Engineering, The University of Adelaide, SA 5005, Australia, chapters 7.3.8 and 7.9 (available online under http://www.ohio.edu/people/starzykj/network/class/ee715/labs/systems/vision_chips.pdf), various setups for photocircuits are disclosed. Thus, as an example, in Figure 7.45 (c), a current read-out circuit is disclosed, having a photocircuit or detector circuit which, as a whole, is connected, via a sample switch, to a charge integrator for each column or for a whole chip.

Further, generally, the problem of the photodiode capacitance being dependent on an accumulated charge is a known problem. Thus, in G. Langfelder: "6. Pinned Photodiode and Correlated Double Sampling", Optoelectronics systems and digital imaging, April 27th, 2012, page 11, the problem of the linearity of the capacitance is discussed. For increasing the linearity, an additional capacitance is switched parallel to the junction capacitance of the photodiode.

Further, in W. Heering, Lichttechnisches Institut der Universität Karlsruhe, "Optoelektronik II", vol. 13, page 4 (available under http://www.lti.uni-karlsruhe.de/rd_download/Optoelektronik_II_13.pdf), a charge integration is discussed.

5 For this purpose, an address switch or video line switch is interposed in between a photodiode and an integrator. Immediately before addressing the respective pixel, a feedback capacitor of the integrator is discharged. By addressing the video line switch, the feedback capacitor of the integrator is charged up to a voltage corresponding to the photo charge which, previously and before addressing, had been accumulated within the photodiode,
10 during illumination.

The above-mentioned active pixel techniques, generally, even though significant advantages have been achieved, are based on the process of at least intermediately accumulating photo-induced charges within the photodiode itself. Still, since the capacitance C of
15 the photodiode itself depends on the charge, which is due to a charge-induced change of the space-charge region and, thus, a change in the effective charge distribution within the photodiode, the voltage of the photodiode U generally does not linearly depend on the charge Q . Since, however, the photodiode voltage generally is used as a measurement signal, a non-linear correlation between the illumination and the measurement signal may
20 occur. Further, a contribution to a non-linearity may arise from the internal source follower of the pixel and from the column amplifier. Even though the non-linearities and the deviations resulting thereof, in an optimized design, may generally be as low as a few percent, these deviations, in sensitive high-precision applications, may require an elaborate correction algorithm for correcting the non-linearities. Specifically in analytical applications for
25 medical purposes, these corrections may lead to an increased effort and expenditure as well as to an increased complexity of the evaluation devices. Furthermore, increased complexity can lead to increased risk of failure and errors. All of the above is generally undesirable, specifically in handheld applications.

30 Problem to be solved

It is therefore an objective of the present invention to provide an active pixel sensor, an imaging device, an analytical device and a method which, at least partially, avoid the above-mentioned problems of prior art devices and processes. Specifically, an active pixel
35 sensor shall be provided which, by using a simple electronic circuit within each pixel, avoids non-linearities at least to a large extent and which allows for a simple and cost-efficient setup.

Summary of the invention

This problem is solved by an active pixel sensor, an imaging device, an analytical device
5 and a method with the features of the independent claims. Preferred embodiments, which might be realized in an isolated fashion or in any combination, as the skilled person will recognize, are listed in the dependent claims.

As used in the following, the terms “have”, “comprise” or “include” or any arbitrary
10 grammatical variations thereof are used in a non-exclusive way. Thus, these terms may both refer to a situation in which, besides the feature introduced by these terms, no further features are present in the entity described in this context and to a situation in which one or more further features are present. As an example, the expressions “A has B”, “A comprises B” and “A includes B” may both refer to a situation in which, besides B, no other element
15 is present in A (i.e. a situation in which A solely and exclusively consists of B) and to a situation in which, besides B, one or more further elements are present in entity A, such as element C, elements C and D or even further elements.

Further, as used in the following, the terms "preferably", "more preferably", "particularly",
20 "more particularly", "specifically", "more specifically" or similar terms are used in conjunction with optional features, without restricting alternative possibilities. Thus, features introduced by these terms are optional features and are not intended to restrict the scope of the claims in any way. The invention may, as the skilled person will recognize, be performed by using alternative features. Similarly, features introduced by "in an embodiment
25 of the invention" or similar expressions are intended to be optional features, without any restriction regarding alternative embodiments of the invention, without any restrictions regarding the scope of the invention and without any restriction regarding the possibility of combining the features introduced in such way with other optional or non-optional features of the invention.

30 In a first aspect of the present invention, an active pixel sensor is disclosed. The active pixel sensor has at least one pixel, preferably a plurality of pixels, more preferably a plurality of pixels arranged in a one-dimensional or two-dimensional pixel matrix. As used herein and as defined above, an active pixel sensor generally refers to an image sensor having one
35 or more pixels, each pixel comprising at least one photodiode and at least one readout circuit, such as a readout circuit having an amplifier function for amplifying and/or pre-amplifying signals of the pixel. As further used herein, a pixel generally refers to a light-

sensitive element of the active pixel sensor, adapted for generating a signal in accordance with the illumination of the pixel.

Each pixel, as outlined above, comprises at least one photodiode and at least one readout
5 circuit. The readout circuit comprises at least one integrating capacitor. The integrating capacitor may be part of a charge integrator, as will be outlined in further detail below. As used herein, a charge integrator generally is an electronic device adapted for accumulating electrical charges. The at least one integrating capacitor generally may be an arbitrary capacitor which is capable of accumulating charges. The integrating capacitor specifically
10 may be embodied by using semiconductor technology, specifically by using CMOS technology. As will be outlined in further detail below, the at least one integrating capacitor preferably may be part of an integrator.

The readout circuit is adapted to accumulate electrical charges generated by the photodiode
15 during illuminating the photodiode within the integrating capacitor. Thus, generally, the readout circuit is adapted for transferring electrical charges generated during illuminating the photodiode onto the integrating capacitor. The readout circuit further comprises at least one selector switch adapted to read out the electrical charges from the integrating capacitor. As generally used herein, a selector switch is a switch, such as an electrical and/or
20 electromechanical switch, preferably a transistor switch, which is adapted for providing at least one signal indicating the electrical charges accumulated within the integrating capacitor to at least one readout port or output port. Thus, generally, the selector switch may be or may comprise a switch such as a transistor switch which is connected to the integrating capacitor and which connects or disconnects the integrating capacitor to at least one output
25 port of the readout circuit.

Thus, as an example, the photodiode, the integrating capacitor and the readout switch, in the given order, may be connected in a serial fashion. As an example, an anode of the photodiode may directly or indirectly be connected to ground, whereas a cathode of the photodiode may directly or indirectly be connected to a first port of the integrating capacitor. A
30 second, opposing port of the integrating capacitor may be connected to a first port of the selector switch, and a second port of the selector switch may be connected to an output port of the readout circuit. The cathode of the photodiode and the first port of the integrating capacitor may be connected in a direct fashion and/or in an indirect fashion, i.e. by interposing one or more additional elements in between these elements. Similarly, the second
35 port of the integrating capacitor may be connected to the first port of the selector

switch directly, without interposing additional elements, or indirectly, with one or more additional elements interposed in between these ports.

5 The readout circuit, by using the charge transfer onto the integrating capacitor, may be adapted to keep a voltage at the photodiode at a constant level during illumination, at least within a given intensity range of illumination, such as an intensity range below an overexposure threshold.

10 The readout circuit at least partially may be embodied as a CMOS circuit. Thus, the readout circuit may comprise one, two, three or more semiconductor devices embodied by using CMOS technology. Preferably, the readout circuit, as a whole, is designed as a CMOS circuit. As outlined above, each pixel may comprise a dedicated readout circuit, wherein the readout circuits of each pixel may be comprised in a common semiconductor device, including the respective photodiodes of the pixel.

15 As an example, the readout circuit may be embodied as a three-transistor readout circuit, such as a CMOS readout circuit having three CMOS transistors. Thus, the three-transistor readout circuit may comprise the above-mentioned selector switch, such as a transistor selector switch, and, additionally, as will be outlined in further detail below, a reset switch, such as a transistor reset switch, for resetting the integrating capacitor, and, additionally, an amplifier transistor. Thus, as an example, as outlined above, the photodiode, the integrating capacitor and the selector switch may be connected in a serial fashion. The reset switch, such as the reset transistor switch, may be connected to the first port and the second port of the integrating capacitor, thereby being positioned in a parallel fashion to the integrating capacitor. Additionally or alternatively, the amplifier, such as the amplifier transistor, may be connected to the integrating capacitor in a parallel fashion, such that the integrating capacitor is located in a feedback loop of the integrator. As an example, the integrating capacitor may be connected to the amplifier, such as the amplifier transistor, such that a first port of the capacitor is connected to an input port of the amplifier and a second port of the capacitor is connected to an output port of the amplifier. As an example, a first port of the integrating capacitor may be connected to a gate of an amplifying transistor, and a second port of the integrating capacitor may be connected to a source or a drain of the amplifying transistor. Still, other embodiments are feasible, such as four-transistor-setups.

35 As outlined above, the integrating capacitor may be serially connected to the photodiode. Thus, as an example, a first port of the integrating capacitor may be serially connected to a cathode of the photodiode. The anode of the photodiode may directly or indirectly be con-

nected to a ground level. A second port of the integrating capacitor may be connected to the selector switch. Thus, as an example, the integrating capacitor may be interposed in between the photodiode and the selector switch such that, during illumination, charges generated by the photodiode are permanently transferred onto the integrating capacitor and such that, by switching the selector switch, the charges accumulated within the integrating capacitor may be read out.

As outlined above, the readout circuit may comprise at least one integrator. The integrating capacitor may be part of the integrator, and the integrator further may comprise at least one amplifier. As used herein, an integrator generally is an electronic device adapted to perform the mathematical operation known as integration, such as adapted to perform an integration, such as a time integration, of electronic signals. Thus, generally, an integrator typically may comprise an amplifier having at least one input port and at least one output port, wherein a capacitor is interposed in a feedback loop connecting the input port and the output port. Thus, generally, in the setup proposed, the integrating capacitor may be connected to the amplifier of the integrator such that a first port of the integrating capacitor is connected to at least one input port of the amplifier, and at least one second port of the integrating capacitor is connected to an output port of the amplifier.

As used herein, generally, an amplifier is an electronic device adapted for amplifying electronic one or more signals, such as analogue signals, such as current and/or voltage signals, wherein the amplification of voltage signals is most common. As an example, a simple one-transistor amplifier may be used, such as a transistor comprising one field-effect transistor, such as a MOS-FET. By applying the signal to be amplified to a gate of the transistor, an electrical current through the transistor may be controlled, thereby transforming the gate signal into an appropriate amplified current or voltage signal. As outlined above, the integrating capacitor preferably may be interposed within the gate and one of a source and a drain of the transistor. Additionally and optionally, the optional reset switch may be disposed in between the first port and the second port of the integrating capacitor and, thus, in between the gate and one of the source and the drain of the transistor. Other setups of the integrator are feasible.

Thus, more complex setups of the amplifier of the integrator may be used. Specifically, setups having an amplifier with more than one transistor may be used. In any case, the amplifier may have at least one input port and at least one output port, wherein the integrating capacitor may be located in a connection between an input port and an output port of the amplifier.

As outlined above, the integrator may be serially connected to the photodiode. Thus, specifically, a cathode of the photodiode may directly or indirectly be connected to an input port of the amplifier. Further, on the input side, the integrator may be serially connected to the photodiode and, on the output side, the integrator may be serially connected to the selector switch. Thus, an input port of the amplifier of the integrator may directly or indirectly be serially connected to the photodiode, such as to a cathode of the photodiode, and an output port of the amplifier, directly or indirectly, may be connected to the selector switch.

As outlined above, the amplifier may comprise at least one transistor. Thus, the amplifier of the integrator may comprise at least one field-effect transistor, such as at least one metal oxide field effect transistor (MOS-FET), specifically embodied in CMOS technology.

The readout circuit generally may be adapted to transfer the electrical charges generated by illuminating the photodiode to the integrating capacitor. As outlined above, the active pixel sensor, specifically the readout circuit, may further comprise at least one reset switch adapted to reset one or both of the voltage of the integrating capacitor and the charge of the integrating capacitor to a reset level. Thus, as an example, the reset switch may be adapted to reset the voltage and/or the charge of the integrating capacitor to zero, by simply providing a short-circuit between both ports of the integrating capacitor. Alternatively, the reset switch may be adapted to reset the voltage and/or the charge of the integrating capacitor to a predetermined level other than zero, such as a predetermined level determined by the reset switch, e.g. a source-drain-voltage. As outlined above, the reset switch may comprise at least one transistor switch, such as a transistor switch comprising at least one field-effect transistor, specifically a MOS-FET, such as a MOS-FET embodied in CMOS technology.

As outlined above, the reset switch may be located in a branch of the readout circuit connecting a first port of the integrating capacitor and a second port of the integrating capacitor. Thus, the reset switch may directly or indirectly connect the first and the second ports of the integrating capacitor, in a switchable fashion.

The selector switch generally may be positioned between the integrating capacitor and an output port of the pixel. Thus, a second port of the integrating capacitor may be connected to the selector switch, and the selector switch may be connected to the output port of the pixel, such as an output port of the readout circuit of the pixel.

As outlined above, the selector switch may comprise at least one transistor switch. As outlined above, the transistor switch may comprise at least one field-effect transistor, such as at least one MOS-FET, such as at least one MOS-FET embodied in CMOS technology.

5 The readout circuit may comprise one or more additional elements. Thus, as an example, the readout circuit may further comprise at least one current source. As used herein, a current source generally refers to an electrical element adapted to provide an electrical current in a controlled fashion. Thus, as an example, the electrical current source may comprise at least one transistor, such as a field-effect transistor, specifically a MOS-FET, such as a
10 MOS-FET embodied in CMOS technology, wherein at least one of a source and a drain of the transistor is connected to a driver-sided current- or voltage supply and wherein a gate of the transistor is connected to a driver line. An output port of the transistor, i.e. the other one of the source and the drain, may be connected to the integrating capacitor, such as to the above-mentioned second port of the integrating capacitor being connected to the output
15 port of the amplifier. Thus, an output port of the current source generally may be connected to an output port of the amplifier of the integrator. Thus, as an example, the amplifier of the integrator may comprise at least one transistor, wherein at least one of the source and the drain of the transistor may directly or indirectly be connected to ground and wherein the second one of the source and the drain may form an output port of the amplifier and
20 may be connected to the selector switch. The output port may be connected to the current source. As outlined above, the gate of the transistor of the amplifier may form an input port of the amplifier, and a first port of the integrating capacitor may be connected to this input port, whereas a second port of the integrating capacitor may be connected to the output port of the amplifier. Thus, generally, the integrating capacitor may be connected to the
25 selector switch, and the current source may be connected to at least one node in between the integrating capacitor and the selector switch. This at least one node, as an example, may be the output port of an amplifier of an integrator.

The active pixel sensor may comprise a plurality of the pixels, and the pixels may be arranged in at least one matrix, such as a one-dimensional or a two-dimensional matrix. In an
30 embodiment, the matrix has rows and columns. Thus, as an example, the matrix may be a rectangular matrix, wherein the columns are vertical lines of the rectangular matrix, and wherein the rows are horizontal lines of the rectangular matrix. Each pixel, thus, may be identified by a row number and a column number.

35 The active pixel sensor may further comprise a plurality of signal lines. These signal lines, as an example, may be connected to a driver of the active pixel sensor and/or to a driver which is part of an imaging device comprising the active pixel sensor. The plurality of sig-

nal lines may be adapted for selectively actuating the selector switches of the pixels. Thus, the signal lines may allow for selectively reading out the electrical charges of the integrating capacitors of the pixels, such as by reading out these charges as current signals and/or as voltage signals. The signal lines may comprise a plurality of selector lines and a plurality of output lines. Each of the selector lines may be a common line for the pixels of a respective row, and each of the output lines may be a common line for the pixels of a respective column. Thus, each row may have its own selector line, and each column may have its own output line. The number of selector lines therefore might correspond to the number of rows, and the number of output lines therefore might correspond to the number of columns of the matrix.

The signal lines may further comprise a plurality of reset lines for resetting the integrating capacitors. Thus, the selector lines may be connected to the selector switch, such as to a gate of a respective transistor of the selector switch of the respective pixels of a row. The output lines may be connected to an output port of the selector switch of all readout circuits of a column. The reset lines may be connected to the reset switches, such as to a gate of a transistor of the reset switches. The reset lines may be common lines for the pixels of a row. Thus, one and the same reset line may be connected to the reset switches of all readout circuits of the pixels of one row. Thus, the number of reset lines may correspond to the number of rows of the matrix.

The signal lines may further comprise a plurality of reference voltage lines for providing a reference voltage to the pixels. Each of the reference voltage lines may be a common line for the pixels of a row. Thus, the number of reference voltage lines may correspond to the number of the pixels of the matrix.

The active pixel sensor may further comprise at least one driving unit, also referred to as a driver. The driving unit may be connected to the signal lines, and the driving unit may be adapted to provide an electric driving pattern to the signal lines for repeatedly reading out each of the pixels. Thus, an electric driving pattern may be provided to the signal lines, having pre-defined sequences of voltage and/or current levels, in order to selectively and/or subsequently readout the pixels of the matrix, i.e. for subsequently and/or selectively readout the accumulated electrical charges of the respective integrating capacitors. Thus, as an example, the electric driving pattern may comprise a pulse resetting the integrating capacitor by addressing the respective reset switch and may comprise a pulse for reading out the accumulated charges from the respective integrating capacitor, by addressing the

respective selector switch. The pulses, as an example, may be rectangular pulses and, thus, the driving pattern may be a rectangular driving pattern.

In a further aspect of the present invention, an imaging device is disclosed. The imaging device comprises at least one active pixel sensor according to the present invention, such as according to any one of the embodiments disclosed above and/or according to any one of the embodiments disclosed in further detail below. As generally used herein, an imaging device is a device adapted for acquiring an image, preferably an electronic image and more preferably an image comprising a plurality of data values for each pixel of the image. Thus, generally, the imaging device may be a camera, such as a digital camera. Thus, the imaging device may comprise at least one active pixel sensor according to the present invention, wherein the active pixel sensor may have a plurality of pixels, such as a plurality of pixels arranged in a matrix. As an example, the imaging device may comprise at least 10 pixels, at least 100 pixels, or even at least 500 or at least 1000 pixels.

The imaging device, besides the at least one active pixel sensor, may comprise one or more additional elements, such as electronic elements and/or optical elements. Thus, as an example, the imaging device may further comprise at least one optical lens. Further, the imaging device may comprise one or more of a reflective element such as a mirror and/or a wavelength-selective element such as a filter.

In a further aspect of the present invention, an analytical device for detecting at least one property of a body fluid is disclosed. Generally, the at least one property may be an arbitrary property which may be detected by using optical means. As an example, the at least one property may be the presence and/or the concentration of at least one analyte in the body fluid. Thus, generally, the analytical device may be an analytical device for detecting at least one analyte in a body fluid, such as for determining a concentration of at least one analyte in the body fluid. The analyte, as an example, may be an analyte which is part of the metabolism of a human or animal user, such as a metabolite. As an example, the analyte may be selected from the group consisting of glucose, cholesterol, triglycerides, or lactate. Other embodiments are feasible. The at least one body fluid, as an example, may be selected from the group consisting of blood, preferably whole blood, serum, urine, saliva, stool or ocular fluid. As an example, the analytical device may be adapted for determining the concentration of glucose in blood, such as whole blood.

The analytical device has at least one imaging device according to the present invention, such as according to any one of the embodiments disclosed above or according to any one

of the embodiments disclosed in further detail below. The analytical device is further adapted for recording, by using the imaging device, at least one optically detectable change of at least one test field of a test element to which a sample of the body fluid is applied. Thus, the test field may comprise at least one detector or test chemical which, in the presence of an analyte to be detected and/or in accordance with the property of the body fluid, is adapted to perform a detectable test reaction or detection reaction, the progress of which may be optically detectable. Thus, as an example, the test field and/or the test chemical comprised therein may, due to the detection reaction, change at least one optical property selected from the group consisting of a color, a remission or a fluorescence. Other embodiments are feasible. Thus, the test chemical may comprise at least one enzyme adapted for performing an enzymatic reaction with an analyte to be detected, wherein, such as by using a dye, a progress of the enzymatic reaction may be detected by observing a color and/or a remission of a test field comprising the test chemical. As an example, the test field may be a coherent field of the test chemical which may directly or indirectly be applied to a test carrier of the test element, such as a strip-shaped or tape-shaped carrier.

The analytical device is adapted for determining the property of the body fluid by evaluating the recorded change. Thus, as an example, the analytical device may comprise at least one evaluation device, such as at least one processor, which, by applying one or more evaluation algorithms to data provided by the imaging device, is capable of calculating the concentration of the analyte and/or the property of the body fluid. Thus, the at least one change recorded by using the imaging device, such as in spatially resolved fashion, may be compared with at least one evaluation curve.

These analytical devices are generally known to the skilled person. Thus, as an example, the analytical device as used in WO 2012/010454 A1 and/or other analytical devices disclosed therein, having a spatially resolving optical imaging device, may be adapted according to the present invention, by using the imaging device of the present invention. Other embodiments are feasible.

In a further aspect of the present invention, a method for detecting light is disclosed. The method comprises the steps of providing at least one pixel, the pixel comprising at least one photodiode and at least one readout circuit. The readout circuit comprises at least one integrating capacitor which, as outlined above, may be part of a charge integrator. The readout circuit further comprises at least one selector switch allowing for reading out the electrical charges from the integrating capacitor. The method further comprises illuminating the photodiode with the light, whereby electrical charges are generated by the photodi-

ode. The electrical charges are accumulated by the readout circuit within the integrating capacitor during the illuminating of the photodiode with the light. The method further comprises switching the selector switch in order to read out the electrical charges from the integrating capacitor.

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The method specifically may be performed such that a voltage at the photodiode is kept at a constant level during illumination, such as a voltage in between a cathode and an anode of the photodiode. This keeping the voltage at a constant level may be performed by transferring the electrical charges generated within the photodiode to the integrating capacitor.

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The method specifically may be performed by using the active pixel sensor according to the present invention, such as the active pixel sensor according to any one of the embodiments disclosed above and/or according to any one of the embodiments disclosed in further detail below. Thus, for further details of the method, reference may be made to the disclosure of the active pixel sensor. Still, other embodiments are feasible.

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In a further and final aspect of the present invention, a use of the active pixel sensor according to the present invention, such as according to any one of the embodiments disclosed above and/or according to any one of the embodiments disclosed in further detail below, for imaging at least one test field for detecting at least one property of a body fluid, such as for detecting at least one analyte in the body fluid, is disclosed.

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The active pixel sensor, the imaging device, the analytical device, the method and the use according to the present invention provide a large number of advantages as compared to conventional devices and methods. Thus, generally, the internal capacitor of the photodiode, which generally is part of every type of photodiode, may be combined with an integrator and/or an amplifier, such as a current amplifier, within the readout circuit. Thus, specifically by using an operational amplifier, such as an operational amplifier serially connected to the cathode of the photodiode and, more specifically, an operational amplifier being part of an integrator serially connected to a cathode of the photodiode, the photodiode may be driven at a constant voltage. Thus, charges generated within the photodiode may not lead to a change of a voltage at the photodiode, which generally may cause nonlinearities of the photodiode, and furthermore it generally may keep the voltage at the input port of capacitor at a constant value so that voltage at output port of summing capacitor (amplifier output port) can act as truly linear representation of accumulated photogenerated charges. Charges accumulated within the integrating capacitor may lead to a voltage at an output of the amplifier, wherein the voltage at the output port of the amplifier, such as the

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output port of the integrator, may linearly depend or linearly correlate to the charge generated by illuminating the photodiode. Thus, by using the setup according to the present invention, non-linearities in a range below 0.1 % may be achieved. These non-linearities, which are significantly smaller than non-linearities of typical optical CMOS devices and/or of typical active pixel sensors, significantly improve the precision of the active pixel sensor and, thus, of the analytical device using the active pixel sensor. Further, the active pixel sensor, the imaging device and the analytical device may be embodied in a more simple fashion as compared to conventional devices, since, typically, due to the small non-linearities provided by the present invention, a correction of the non-linearities may be omitted. Thus, generally, the active pixel sensor, the imaging device and the analytical device may be embodied without a non-linearity correction algorithm or correction device. Thus, generally speaking, imaging devices and analytical devices using the active pixel sensor according to the present invention may be embodied in a significantly simplified fashion, thereby reducing hardware requirements and cost as well as possible risk of failure or errors, by still providing a significant increase in precision and linearity.

Summarizing the findings of the present invention, the following embodiments are, inter alia, disclosed:

Embodiment 1: An active pixel sensor having at least one pixel, the pixel comprising at least one photodiode and at least one readout circuit, the readout circuit comprising at least one integrating capacitor, the readout circuit being adapted to accumulate electrical charges generated by the photodiode during illuminating the photodiode within the integrating capacitor, the readout circuit further comprising at least one selector switch adapted to read out the electrical charges from the integrating capacitor.

Embodiment 2: The active pixel sensor according to the preceding embodiment, wherein the readout circuit is adapted to keep a voltage at the photodiode at a constant level during illumination, by transferring the electrical charges generated within the photodiode to the integrating capacitor.

Embodiment 3: The active pixel sensor according to any one of the preceding embodiments, wherein the readout circuit at least partially is embodied as a CMOS circuit.

Embodiment 4: The active pixel sensor according to any one of the preceding embodiments, wherein the readout circuit is embodied as a three-transistor readout circuit.

Embodiment 5: The active pixel sensor according to any one of the preceding embodiments, wherein the integrating capacitor is serially connected to the photodiode.

5 Embodiment 6: The active pixel sensor according to the preceding embodiment, wherein a first port of the integrating capacitor is connected to the photodiode and wherein a second port of the integrating capacitor is connected to the selector switch.

10 Embodiment 7: The active pixel sensor according to any one of the preceding embodiments, the readout circuit comprising at least one integrator, wherein the integrating capacitor is part of the integrator, the integrator further comprising at least one amplifier.

15 Embodiment 8: The active pixel sensor according to the preceding embodiment, wherein the integrating capacitor is located in a connection between an input port and an output port of the amplifier.

Embodiment 9: The active pixel sensor according to any one of the two preceding embodiments, wherein the integrator is serially connected to the photodiode.

20 Embodiment 10: The active pixel sensor according to any one of the three preceding embodiments, wherein, on the input side, the integrator is serially connected to the photodiode, and wherein, on an output side, the integrator is serially connected to the selector switch.

25 Embodiment 11: The active pixel sensor according to any one of the four preceding embodiments, wherein the amplifier comprises at least one transistor.

Embodiment 12: The active pixel sensor according to the preceding embodiment, wherein the transistor is a field-effect transistor.

30 Embodiment 13: The active pixel sensor according to any one of the preceding embodiments, wherein the readout circuit is adapted to transfer the electrical charges generated by illuminating the photodiode to the integrating capacitor.

35 Embodiment 14: The active pixel sensor according to any one of the preceding embodiments, the active pixel sensor further comprising at least one reset switch adapted to reset one or both of a voltage of the integrating capacitor and a charge of the integrating capacitor to a reset level.

Embodiment 15: The active pixel sensor according to the preceding embodiment, wherein the reset switch is adapted to short-circuit the integrating capacitor.

- 5 Embodiment 16: The active pixel sensor according to any one of the two preceding embodiments, wherein the reset switch comprises at least one transistor switch.

Embodiment 17: The active pixel sensor according to the preceding embodiment, wherein the transistor switch comprises at least one field-effect transistor.

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Embodiment 18: The active pixel sensor according to any one of the four preceding embodiments, wherein the reset switch is located in a branch of the readout circuit connecting a first port of the integrating capacitor and a second port of the integrating capacitor.

- 15 Embodiment 19: The active pixel sensor according to any one of the preceding embodiments, wherein the selector switch is positioned between the integrating capacitor and an output port of the pixel.

- 20 Embodiment 20: The active pixel sensor according to any one of the preceding embodiments, the selector switch comprising at least one transistor switch.

Embodiment 21: The active pixel sensor according to the preceding embodiment, wherein the transistor switch comprises at least one field-effect transistor.

- 25 Embodiment 22: The active pixel sensor according to any one of the preceding embodiments, wherein the readout circuit further comprises at least one current source, the current source being connected to the integrating capacitor.

- 30 Embodiment 23: The active pixel sensor according to the preceding embodiment, wherein the integrating capacitor is connected to the selector switch, wherein the current source is connected to at least one node in between the integrating capacitor and the selector switch.

- 35 Embodiment 24: The active pixel sensor according to any one of the preceding embodiments, the active pixel sensor comprising a plurality of the pixels, wherein the pixels are arranged in at least one a matrix, the matrix having rows and columns.

Embodiment 25: The active pixel sensor according to the preceding embodiment, the active pixel sensor further comprising a plurality of signal lines, the plurality of signal lines allowing for selectively actuating the selector switches of the pixels and the signal lines allowing for selectively reading out the electrical charges of the integrating capacitors of the pixels.

Embodiment 26: The active pixel sensor according to the preceding embodiment, wherein the signal lines comprise a plurality of selector lines and a plurality of output lines.

Embodiment 27: The active pixel sensor according to the preceding embodiment, wherein each of the selector lines is a common line for the pixels of a row, and wherein each of the output lines is a common line for the pixels of a column.

Embodiment 28: The active pixel sensor according to any one of the three preceding embodiments, wherein the signal lines further comprise a plurality of reset lines for resetting the integrating capacitors.

Embodiment 29: The active pixel sensor according to the preceding embodiment, wherein each of the reset lines is a common line for the pixels of a row.

Embodiment 30: The active pixel sensor according to any one of the five preceding embodiments, wherein the signal lines further comprise a plurality of reference voltage lines for providing a reference voltage to the pixels.

Embodiment 31: The active pixel sensor according to the preceding embodiment, wherein each of the reference voltage lines is a common line for the pixels of a row.

Embodiment 32: The active pixel sensor according to any one of the seven preceding embodiments, the active pixel sensor further comprising at least one driving unit, the driving unit being connected to the signal lines, the driving unit being adapted to provide an electric driving pattern to the signal lines for repeatedly reading out each of the pixels.

Embodiment 33: An imaging device, the imaging device comprising the active pixel sensor according to any one of the preceding embodiments.

Embodiment 34: The imaging device according to the preceding embodiment, the imaging device further comprising at least one optical lens.

Embodiment 35: An analytical device for detecting at least one property of a body fluid, specifically for detecting at least one analyte in the body fluid, the analytical device having at least one imaging device according to any one of the two preceding embodiments, the analytical device being adapted for recording, by using the imaging device, at least one optically detectable change of at least one test field of at least one test element to which a sample of the body fluid is applied, and wherein the analytical device is further adapted for determining the property of the body fluid by evaluating the recorded change.

Embodiment 36: A method for detecting light, the method comprising the steps of providing at least one pixel, the pixel comprising at least one photodiode and at least one readout circuit, the readout circuit comprising at least one integrating capacitor, the readout circuit further comprising at least one selector switch allowing for reading out the electrical charges from the integrating capacitor, the method further comprising illuminating the photodiode with the light, whereby electrical charges are generated by the photodiode, wherein the electrical charges are accumulated by the readout circuit within the integrating capacitor during the illuminating of the photodiode with the light, the method further comprising switching the selector switch in order to read out the electrical charges from the integrating capacitor.

Embodiment 37: The method according to the preceding embodiment, wherein a voltage at the photodiode is kept at a constant level during illumination, by transferring the electrical charges generated within the photodiode to the integrating capacitor.

Embodiment 38: The method according to any one of the two preceding embodiments, wherein the active pixel sensor according to any one of the preceding embodiments referring to an active pixel sensor is used.

Embodiment 39: A use of the active pixel sensor according to any one of the preceding embodiments referring to an active pixel sensor, for imaging at least one test field for detecting at least one property of a body fluid.

Short description of the Figures

Further optional features and embodiments of the invention will be disclosed in more detail in the subsequent description of preferred embodiments, preferably in conjunction with the dependent claims. Therein, the respective optional features may be realized in an isolated

fashion as well as in any arbitrary feasible combination, as the skilled person will realize. The scope of the invention is not restricted by the preferred embodiments. The embodiments are schematically depicted in the Figures. Therein, identical reference numbers in these Figures refer to identical or functionally comparable elements.

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In the Figures:

Figure 1 shows a schematic cross-sectional view of an analytical device and an imaging device according to the present invention;

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Figure 2 shows a partial view of a first embodiment of an active pixel sensor; and

Figures 3A and 3B show a partial view of a second embodiment of an active pixel sensor (Figure 3A) and of a driving pattern for driving the active pixel sensor (Figure 3B), according to a second embodiment of the present invention.

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Detailed description of the embodiments

In Figure 1, a simplified cross-sectional view of an embodiment of an analytical device 110 for detecting at least one property of a body fluid is disclosed. The analytical device 110 is adapted to interact with at least one test element 112, such as at least one test strip and/or at least one test tape. Other types of analytical test elements are feasible, such as test discs or other test devices. The test element 112, as shown in Figure 1, may be part of the analytical device 110 and/or may be handled as a separate test element.

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The test element may comprise at least one carrier element 114 and at least one test field 116 disposed thereon, to which, directly or indirectly, a sample of the body fluid may be applied. The analytical device 110 may comprise a housing 118 having a receptacle 120 for receiving the test element 112.

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The analytical device 110 further comprises at least one imaging device 122 having at least one active pixel sensor 124 adapted for observing at least one optically detectable property of the test field 116, specifically in a spatially resolved fashion, such as by taking one or more images of the test field 116 or of a part thereof, such as by taking one or more image sequences.

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The analytical device 110 may further comprise at least one evaluation device 126, such as at least one processor. The evaluation device 126 may be connected to the imaging device 122 and may be adapted for determining at least one property of the body fluid by evaluating at least one optically detectable change of the at least one test field 116, recorded by
5 using the imaging device 122.

The analytical device 110 may further comprise additional elements. Thus, as an example, the analytical device 110 may further comprise at least one display element 128 and/or may comprise at least one user interface 130, such as one or more push buttons, and/or
10 may comprise one or more electronic interfaces 132. Thus, generally, the analytical device 110 may be a handheld device. Other embodiments are feasible.

In Figure 2, a first embodiment of an active pixel sensor 124 according to the present invention is shown in a partial view. The active pixel sensor 124 comprises one or preferably
15 more than one pixels 134, such as a matrix of pixels 134, more preferably a rectangular matrix having rows and columns. The active pixel sensor 124 may further comprise at least one driving unit 136 adapted to provide an electric driving pattern to signal lines 138 of the active pixel sensor 124 and/or for reading out the signal lines 138. Thus, in the embodiment shown in Figure 2, the signal lines 138 comprise one or more selector lines 140, such
20 as a selector line for each row of the matrix of pixels 134. Further, the signal lines 138 may comprise one or more output lines 142, such as one output line for each column of the matrix of pixels 134.

Each pixel 134 comprises a photodiode 144 having a cathode 146 and an anode 148. As an
25 example, the anode 148 may directly or indirectly be connected to an electrical ground 150 and, thus, may be grounded.

Each pixel 134 further comprises at least one readout circuit 152. For each readout circuit 152, an output port 154 may be provided, which, as outlined above, may be connected to
30 the output line 142. Thus, as an example, the output ports 154 of all pixels of a column of the matrix may be connected to a common output line 138, thereby providing individual output lines 138 for each column of the matrix.

The readout circuit 152 comprises at least one integrating capacitor 156. In this embodiment, a first port 158 of the integrating capacitor 156 is connected to the cathode 146 of the
35 photodiode 144. A second port 160 of the integrating capacitor 156 is connected to a first port 162 of a selector switch 164, wherein the first port 162 may be one of a source and a

drain of a transistor of the selector switch 164, such as an FET, a MOS-FET, and, more preferably, a CMOS transistor. A second port 166 of the transistor of the selector switch 164, which may be the other one of the source and the drain of the transistor, may be connected directly or indirectly to the output port 154 of the readout circuit 152. A switching port 168, which may be the gate of the transistor of the selector switch 164, may be connected to the selector line 140.

The readout device 152 may further comprise at least one reset switch 170. The reset switch 170 may be adapted for short-circuiting the first and second ports 158, 160 of the integrating capacitor 156. Thus, a first port 172 of the reset switch 170 may be connected to the first port 158 of the integrating capacitor 156, and a second port 174 of the reset switch 170 may be connected to the second port 160 of the integrating capacitor 156. Further, which is not shown in detail in Figure 2, the reset switch 170 may comprise a switching port 176 for generating a switching action, i.e. for closing or opening the reset switch 170. Thus, as an example, the switching port 176 may be a gate of a transistor of the reset switch 170, and the first port 172 may be one of a source and a drain of the transistor, whereas the second port 174 may be the other one of the source and the drain of the transistor. The switching port 176 may be connected to a switching line being part of the signal lines 138, which is not shown in Figure 2.

The integrating capacitor 160 may be part of an integrator 178 of the readout circuit 152. The integrator 178, besides the integrating capacitor 156, may further comprise at least one amplifier 180 having an input port 182 and an output port 184. The input port 182 may be connected to or may be identical to an input port 186 of the integrator 178, and the output port 184 of the amplifier 180 may be connected to or identical with an output port 188 of the integrator 178. The integrating capacitor 156 is located in a feedback loop of the amplifier 180. Thus, the first port 158 of the integrating capacitor 156 is connected to the input port 182 of the amplifier 180, and the second port 160 of the integrating capacitor 156 is connected to the output port 184 of the amplifier 180. The output port 188 of the integrator 178 is connected to the first port 162 of the selector switch 164. Thus, the integrator 178 serially connects the cathode 146 of the photodiode 144 and the selector switch 164.

The setup shown in Figure 2 allows for integrating and/or accumulating of electrical charges generated when illuminating the photodiode 144. A charge-voltage-transformation may take place remote from the photodiode, in the integrating capacitor 156 and/or the integrator 178. The integrator 178 allows for an accumulation of the photo-generated electrical charges within the integrating capacitor 156. The photodiode 144 itself solely serves

as a current generator, wherein the electrical charges generated during illuminating the photodiode 144 are transferred from the photodiode onto the integrating capacitor 156.

5 In Figure 3, an alternative embodiment of an active pixel sensor 124 is shown in a partial view (Figure 3A), including an appropriate driving pattern for driving the active pixel sensor 124 (Figure 3B).

Firstly, with regard to many details, the setup shown in Figure 3A corresponds to the setup of Figure 2. Thus, each pixel 134 comprises a photodiode 144 and a readout circuit 152.
10 The readout circuit 152 comprises an integrating capacitor, which is part of an integrator 178 having, besides the integrating capacitor 156, an amplifier 180. The first port 158 of the integrating capacitor 156 and the input port 186 of the integrator 178, again, are serially connected to the cathode 146 of the photodiode 144. Further, the second port 160 of the integrating capacitor 156 is connected to the output port 184 of the amplifier 180 and, thus,
15 is connected to the output port 188 of the integrator 178. Further, as in Figure 2, a selector switch 164 is provided, connected to the output port 188 of the integrator 178, wherein a second port 166 of the selector switch 164 is connected to an output port 154 of the readout circuit 152. The output port 154 of the readout circuit 152 is connected to an output line 142, which, again, may be connected to one or more driving units 136 of the active pixel sensor 124. A switching port 168 of the selector switch 164 may be connected to a selector
20 line 140 of the signal lines 138.

Further, as in Figure 2, a reset switch 170 may be provided, for resetting the integrating capacitor 156. The reset switch, again, may be embodied as a transistor, with the first port
25 172 of the reset switch 170 being one of a source and a drain of the transistor, and wherein the second port 174 of the reset switch 170 being the other one of the source and the drain of the transistor. The switching port 176 of the reset switch 170 may be the gate of the transistor. The transistor of the reset switch 170 is also referred to as MR in Figure 3A. The switching port 176 of the reset switch 170 may be connected to a reset line 190 of the signal
30 lines 138.

As outlined above, the amplifier 180 generally may comprise a transistor, which is also referred to as MD in Figure 3A. The gate of the transistor may form the input port 182 of the amplifier 180, and one of the source and the drain of the transistor MD may form an
35 output port 184 of the amplifier 180. The other one of the source and the drain, as shown in Figure 3A, may be connected to ground 150.

For driving the amplifier 180, the readout circuit 152 may further comprise an additional current source 192 interacting with the amplifier 180 and/or adapted for driving the amplifier 180. In the embodiment shown in Figure 3A, for this purpose, an additional transistor is provided, indicated by MP. Therein, a first port 194 of the current source 192, which may be one of a source and a drain of the current source 192, may be connected to a constant voltage VDDA provided e.g. by the driving unit 136. A second port 196 of the current source 192, which may be the other one of the source and the drain of the transistor MP, may be connected to the output port 188 of the integrator 178 and/or to the output port 184 of the amplifier 180. A control port 198 of the current source 192, which may be the gate of the transistor MP, may be connected to a reference voltage line 200 of the signal lines 138. The transistors MD and MP, in this embodiment, may provide an operational amplifier, in a common-source architecture. The transistor MR, as outlined above, provides the reset switch 170, and the transistor MSEL in Figure 3A provides the selector switch 164.

In Figure 3B, a driving pattern of the signals VDDA, RES (provided by the reset line 190), SEL (provided by the selector line 140), of the voltage VC, provided at the output port 188 and the voltage VD provided at cathode of photodiode 146 and so at input of integrating capacitor 186 is shown. Thus, firstly, up to t_0 , the reset voltage RES is at a high level, thereby resetting the integrating capacitor 156. Thus, during time span t_0 to t_1 , the integrator 180 is integrating and accumulating electrical charges, whereby the voltage VC at the integrating capacitor 156 is linearly increased and voltage VD at the input of integrating capacitor is kept constant, as long as the photodiode 144 is constantly illuminated, by using constant intensity. At time t_2 , the selector switch 164 is switched to a high level, and the voltage VC is read out by reading the output line 142. The SEL signal stays active during the reset phase (RESET signal at high level) so that the reset voltage level of pixel ($VC=VD$ voltage which is also equivalent to output voltage of pixel at no illumination and no dark current). This allows that correlated double sampling may be performed on the signal of output line. The SEL signals may also end to the time t_1 , a faster read out without the correlated double sampling would be then also possible.

The architecture of the active pixel sensor 124 shown in Figure 3A is also referred to as a linear active pixel sensor (LAPS) architecture. As outlined above, the driving of the pixel 134 is established generally by using three signals:

1. The signal RES:

This signal generates a reset of the integrator 178. By activating this signal, the integrating capacitor 156 is discharged, and an original, reset state, before the actual integration, is established. The integrating capacitor 156 is discharged, and the output voltage provided at the output port 188 of the integrator 178 corresponds to a reset level ($V_{INT}(t=t_0) = VR$), where VR represents reset level voltage which is equal to $VD(t=t_0)$. Therein, the reset level is dominated by the gate-source-voltage of transistor MD. During the low phase of the RES signal, i.e. at a low RES level, the integration takes place, and the photogenerated charge carriers provide the voltage at the output port 188 of the integrator 178. This output voltage may be calculated as follows:

$$VSIG = V_{INT}(t = T_{INT}) - V_{INT}(t = 0) = \int_0^{T_{INT}} \frac{I_{PD}}{C} dt = \frac{I_{PD} \cdot T_{INT}}{C} = \frac{(Npq + Ndq) \frac{q}{C}}{C} \quad (1),$$

$$G = \frac{q}{C} [V/e^-] \quad (2).$$

Therein,

- Npq denotes the number of photo-generated charge carriers,
- Ndq denotes the number of charges in the dark (without illumination),
- G denotes the gain of the pixel,
- TINT denotes the integration period (t_1-t_0 in Figure 3B), and
- q denotes electron charge value.

At the end of the integration period (interval t_0-t_1 in Figure 3B), a voltage level $VS = VR + V_{INT}(t = T_{INT}) = VR + VSIG = V_{INT}(t = t_1)$ occurs at the output port 184 of the amplifier 180, which is the actual desired signal or output signal indicating the illumination of the photodiode 144.

2. The signal SEL:

Via the selector signal SEL, a pixel of the matrix is selected, and the voltage VINT is provided, via the selector switch 164, at the output port 154 of the readout circuit 152 of the respective pixel 134.

3. The signal VBP:

The signal or voltage VBP denotes a reference voltage for transistor MP, which may be a resistor established in PMOS technology (PMOS: p-channel metal-oxide semiconductor), or through PMOS current mirroring. As outlined above, the transistor MP provides a current source 192.

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As discussed above, the signal lines VBP (reference voltage line 200), SEL (selector line 140) and RES (reset line 190) each may be common lines for a row of the matrix, the VBP may be even common for a column of matrix. Thus, one of the lines 200, one of the lines 140, and one of the lines 190 may be connected to the pixels of a specific row of the matrix. For each of the rows, one signal line 200, one signal line 140 and one signal line 190 may be provided, respectively. Similarly, a common output line 142 may be provided for all pixels of a specific column of the matrix, the output line 142 being connected to all pixels of the respective column. Thus, one output line 142 may be provided per column of the matrix. By addressing the respective signal lines 138, each pixel of the matrix may be addressed in a unique fashion, thereby allowing for a unique and unambiguous readout of each pixel of the matrix.

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Further, since the reset, as discussed above, leads to a complete discharge of the integrating capacitor 156, the setup disclosed in Figure 3A avoids an image lack.

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The output signal of the LAPS depicted in Figure 3A provides, similar to a three transistor APS (3T-APS), a difference between the voltages of the reset level (VR) and the signal level (VS), as is evident from eq. (1) above:

$$VSIG = VS - VR = VINT(t = TINT) - VINT(t = 0). \quad (3).$$

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Consequently, the setup acts as a column amplifier, in which the reset level and the signal level are subtracted from one another. Thus, the signal voltage, at least to a large extent, is freed from the offset of the amplifier 180 and the offset of the selector switch 164.

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As outlined above, the linearity of the signal output of the pixel 134, at least to a large extent, is not limited by the charges any longer. Generally, the integrating capacitor 156, in this embodiment or other embodiments of the present invention, may be realized in CMOS technology. CMOS technologies, specifically for providing capacitors, provide a high linearity, at least in case the integrating capacitor 156 is realized by using metal/metal technology and/or polysilicon/polysilicon technology. Thus, in this way, the remaining and dominant source of non-linearity is the amplifier 180. Since a gain A_0 of the amplifier 180, in

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reality, is limited, the voltage at the photodiode 144 may change, at least approximately, by dV_{INT}/A_0 . Still, however, even a small gain A_0 , such as a gain A_0 of 5 to 10, is sufficient in order to compensate for a voltage-dependent non-linearity of the photodiode 144.

- 5 Thus, the active pixel sensor 124 according to the present invention, both in the 3-T technology according to Figure 2 and in the technology according to Figure 3A, provides a simplified setup by which a calculational correction for non-linearities may be avoided. Thus, generally, even though the filling factor of the pixels 134, i.e. the ratio of the active area of the photodiode 144 and the overall area of the pixel 134, is reduced by implement-
- 10 ing the additional integrating capacitor 156, the overall setup may be simplified, and resources, specifically hardware and software resources, may be reduced. Further, it shall be noted that the overall the pixel gain and full well capacity of the pixel 134 may be adjusted and implemented irrespective of properties of the photodiode 144.

List of reference numbers

110	analytical device
112	test element
114	carrier element
116	test field
118	housing
120	receptacle
122	imaging device
124	active pixel sensor
126	evaluation device
128	display element
130	user interface
132	electronic interface
134	pixel
136	driving unit
138	signal lines
140	selector line
142	output line
144	photodiode
146	cathode
148	anode
150	ground
152	readout circuit
154	output port of pixel/of readout circuit
156	integrating capacitor
158	first port of integrating capacitor
160	second port of integrating capacitor
162	first port of selector switch
164	selector switch
166	second port of selector switch
168	switching port of selector switch
170	reset switch
172	first port of reset switch
174	second port of reset switch
176	switching port of reset switch
178	integrator

180	amplifier
182	input port of amplifier
184	output port of amplifier
186	input port of integrator
188	output port of integrator
190	reset line
192	current source
194	first port of current source
196	second port of current source
198	control port of current source
200	reference voltage line

Claims

1. An active pixel sensor (124) having at least one pixel (134), the pixel (134) comprising at least one photodiode (144) and at least one readout circuit (152), the readout circuit (152) comprising at least one integrating capacitor (156), the readout circuit (152) being adapted to accumulate electrical charges generated by the photodiode (144) during illuminating the photodiode (144) within the integrating capacitor (156), the readout circuit (152) further comprising at least one selector switch (164) adapted to read out the electrical charges from the integrating capacitor (156).
2. The active pixel sensor (124) according to the preceding claim, wherein the readout circuit (152) is adapted to keep a voltage at the photodiode (144) at a constant level during illumination, by transferring the electrical charges generated within the photodiode (144) to the integrating capacitor (156).
3. The active pixel sensor (124) according to any one of the preceding claims, wherein the readout circuit (152) at least partially is embodied as a CMOS circuit.
4. The active pixel sensor (124) according to any one of the preceding claims, wherein the integrating capacitor (156) is serially connected to the photodiode (144).
5. The active pixel sensor (124) according to the preceding claim, wherein a first port (158) of the integrating capacitor (156) is connected to the photodiode (144) and wherein a second port (160) of the integrating capacitor (156) is connected to the selector switch (164).
6. The active pixel sensor (124) according to any one of the preceding claims, the readout circuit (152) comprising at least one integrator (178), wherein the integrating capacitor (156) is part of the integrator (178), the integrator (178) further comprising at least one amplifier (180).
7. The active pixel sensor (124) according to the preceding claim, wherein the integrating capacitor (156) is located in a connection between an input port (182) and an output port (184) of the amplifier (180).

8. The active pixel sensor (124) according to any one of the preceding claims, the active pixel sensor (124) further comprising at least one reset switch (170) adapted to reset one or both of a voltage of the integrating capacitor (156) and a charge of the integrating capacitor (156) to a reset level.
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9. The active pixel sensor (124) according to any one of the preceding claims, wherein the selector switch (164) is positioned between the integrating capacitor (156) and an output port (154) of the pixel (134).
- 10
10. The active pixel sensor (124) according to any one of the preceding claims, wherein the readout circuit (152) further comprises at least one current source (192), the current source (192) being connected to the integrating capacitor (156).
11. The active pixel sensor (124) according to any one of the preceding claims, the active pixel sensor (124) comprising a plurality of the pixels (134), wherein the pixels (134) are arranged in at least one matrix, the matrix having rows and columns, the active pixel sensor (124) further comprising a plurality of signal lines (138), the plurality of signal lines allowing for selectively actuating the selector switches (164) of the pixels (134) and the signal lines allowing for selectively reading out the electrical charges of the integrating capacitors (156) of the pixels (134).
- 15
- 20
12. An imaging device (122), the imaging device (122) comprising the active pixel sensor (124) according to any one of the preceding claims.
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13. An analytical device (110) for detecting at least one property of a body fluid, the analytical device (110) having at least one imaging device (122) according to the preceding claim, the analytical device (110) being adapted for recording, by using the imaging device (122), at least one optically detectable change of at least one test field (116) of at least one test element (112) to which a sample of the body fluid is applied, and wherein the analytical device (110) is further adapted for determining the property of the body fluid by evaluating the recorded change.
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14. A method for detecting light, the method comprising the steps of providing at least one pixel (134), the pixel (134) comprising at least one photodiode (144) and at least one readout circuit (152), the readout circuit (152) comprising at least one integrating capacitor (156), the readout circuit (152) further comprising at least one selector
- 35

switch (164) allowing for reading out the electrical charges from the integrating capacitor (156), the method further comprising illuminating the photodiode (144) with the light, whereby electrical charges are generated by the photodiode (144), wherein the electrical charges are accumulated by the readout circuit (152) within the integrating capacitor (156) during the illuminating of the photodiode (144) with the light, the method further comprising switching the selector switch (164) in order to read out the electrical charges from the integrating capacitor (156).

15. A use of the active pixel sensor (124) according to any one of the preceding claims referring to an active pixel sensor (124), for imaging at least one test field (116) for detecting at least one property of a body fluid.

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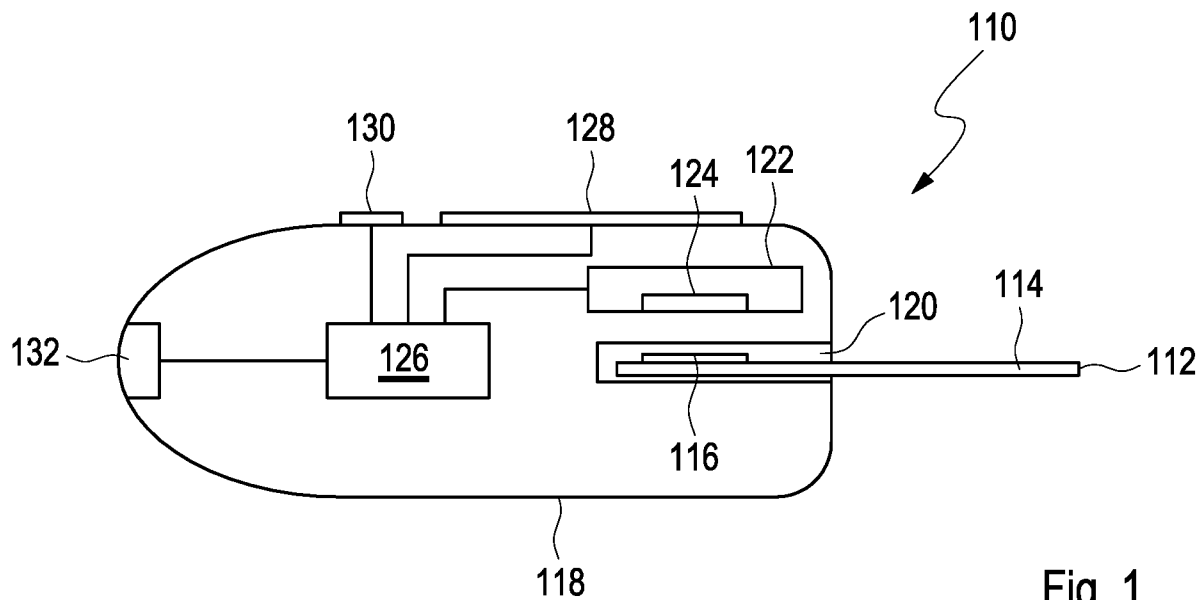


Fig. 1

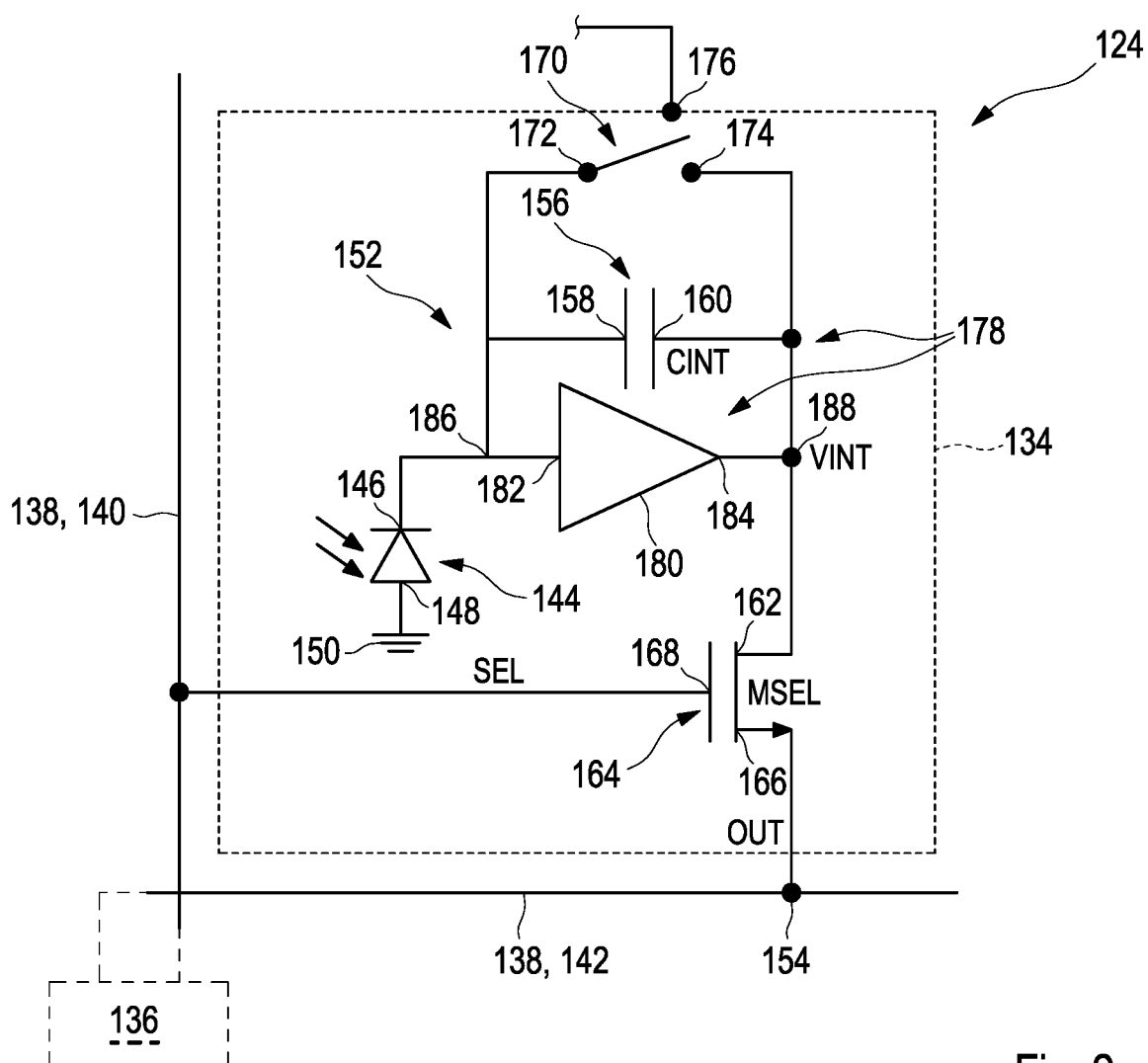


Fig. 2

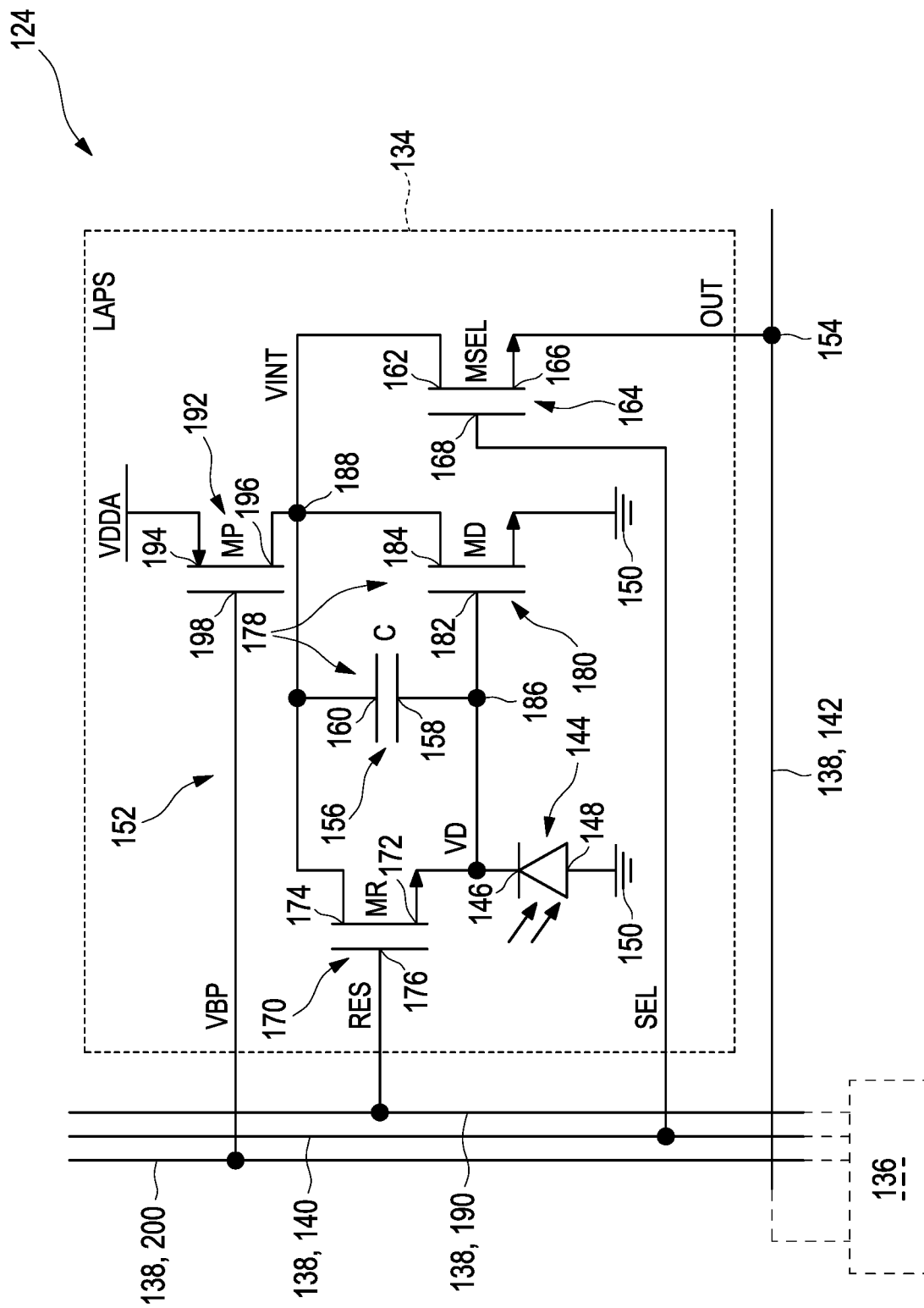


Fig. 3 A

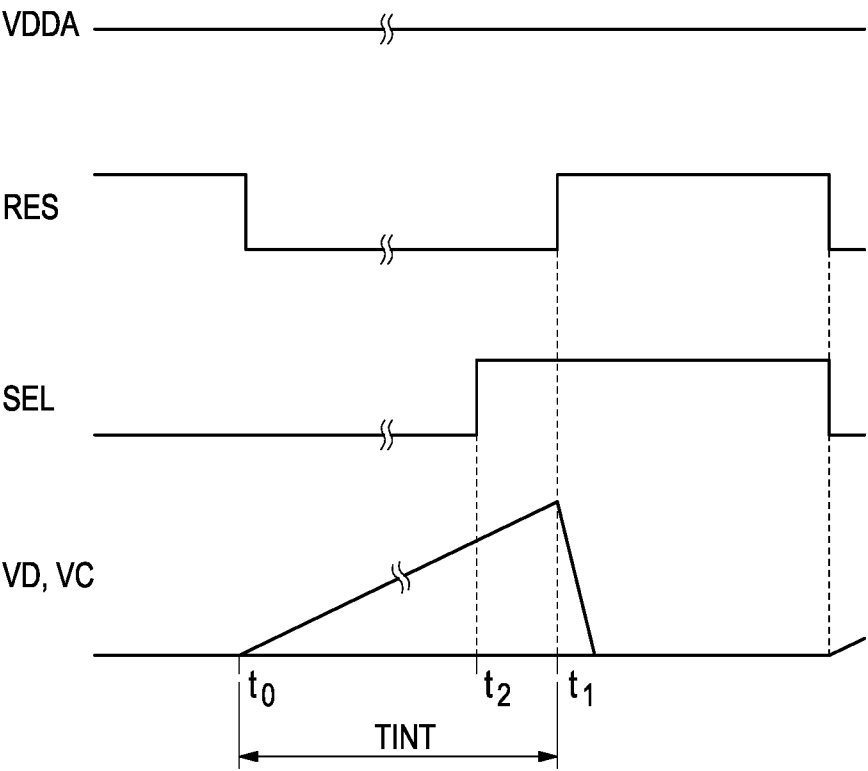


Fig. 3 B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/075265

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N5/3745
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)
H04N

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

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X	US 5 322 994 A (UNO MASAYUKI [JP]) 21 June 1994 (1994-06-21)	1-12,14
Y	column 3, lines 48-68; figures 4, 5 column 4, line 34 - line 36 -----	13,15
X	JP H05 215602 A (FUJI ELECTRIC CO LTD) 24 August 1993 (1993-08-24)	1-12,14
Y	abstract -----	13,15
X	US 2009/268070 A1 (HOSIER PAUL A [US]) 29 October 2009 (2009-10-29)	1-12,14
Y	sentence 1, paragraph 13 - sentence 9; figure 1 -----	13,15
X	US 2003/034433 A1 (FOWLER BOYD [US]) 20 February 2003 (2003-02-20)	1-12,14
Y	paragraph [0012]; figure 2 -----	13,15
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Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

9 December 2014

Date of mailing of the international search report

17/12/2014

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/075265

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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Y	WO 2012/010454 A1 (HOFFMANN LA ROCHE [CH]; ROCHE DIAGNOSTICS GMBH [DE]; PETRICH WOLFGANG) 26 January 2012 (2012-01-26) cited in the application page 7, line 20 - line 35 -----	13,15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/075265

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