



(51) International Patent Classification:

A61B 5/1455 (2006.01) H01L 31/00 (2006.01)
A61B 6/00 (2006.01)

(21) International Application Number:

PCT/IL2017/050250

(22) International Filing Date:

28 February 2017 (28.02.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/300,848 28 February 2016 (28.02.2016) US
62/421,647 14 November 2016 (14.11.2016) US

(71) Applicant: **TECHNION RESEARCH & DEVELOPMENT FOUNDATION LIMITED** [IL/IL]; Senate Building, Technion City, 3200004 Haifa (IL).

(72) Inventor: **NEMIROVSKY, Yael**; 7 Golda St., 3498207 Haifa (IL).

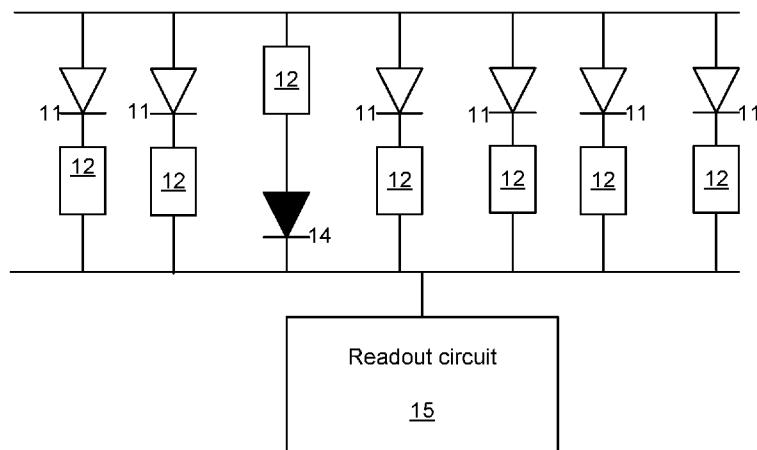
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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

Published:

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, — with international search report (Art. 21(3))

(54) Title: CMOS SPAD ARRAY, A METHOD AND DEVICE FOR MONITORING A LIVING BEING USING THE CMOS SPAD ARRAY



(57) Abstract: An integrated circuit, that includes an array of complementary metal-oxide-semiconductor (CMOS) single photon avalanche diodes (SPADs), at least one Silicon light emitting diode (LED), one or more quenching circuit and one or more readout circuit; wherein the at least one LED is integrated with the array of CMOS SPADs; wherein the readout circuit is configured to read at least one output signal outputted from the array of CMOS SPADs.

1 CMOS SPAD ARRAY, A METHOD AND DEVICE FOR MONITORING A LIVING
2 BEING USING THE CMOS SPAD ARRAY

3
4 CROSS REFERENCE TO RELATED APPLICATIONS

5 [001] This application claims the priority of US provisional patent serial number
6 62/300848 filing date 28 February 2016 and of US provisional patent serial number
7 62/421647 filing date 14 November 2016 – both provisional patents are incorporated
8 herein by reference in their entirety.

9
10 BACKGROUND OF THE INVENTION

11 [002] Single photon avalanche diodes SPADs (wikipedia.org)
12 are semiconductor devices based on a p-n junction reverse-biased at a voltage V_a that
13 exceeds breakdown voltage V_B of the junction. At this bias, the electric field is so
14 high [higher than 3×10^5 V/cm] that a single charge carrier injected into the depletion
15 layer can trigger a self-sustaining avalanche. The current rises swiftly [sub-
16 nanosecond rise-time] to a macroscopic steady level in the milliampere range. If the
17 primary carrier is photo-generated, the leading edge of the avalanche pulse marks
18 [with picosecond time jitter] the arrival time of the detected photon." The current
19 continues until the avalanche is quenched by lowering the bias voltage V_D down to or
20 below V_B : the lower electric field is no longer able to accelerate carriers to impact-
21 ionize with lattice atoms, therefore current ceases. In order to be able to detect another
22 photon, the bias voltage must be raised again above breakdown. This operation
23 requires a suitable circuit, which has to: (i) sense the leading edge of the avalanche
24 current; (ii) generate a standard output pulse synchronous with the avalanche build-
25 up; (iii) quench the avalanche by lowering the bias down to the breakdown voltage;
26 and (iv) restore the photodiode to the operative level. This circuit is usually referred to
27 as a quenching circuit.

28 [003] The cost of the packaging of a sensing device may be a substantial part of the
29 overall cost of the sensing device.

30 [004] There is a growing need to reduce the cost of the sensing device.

31 [005] In highly accurate sensing device it may be beneficial to reduce and even to
32 eliminate any relative movements between a sensing array and a light source.

33 [006] There is also a need to provide accurate and cost effective monitoring methods
34 for monitoring a person. For example- there is a growing need to provide an accurate

1 and cheap method for providing a Photoplethysmogram (PPG) – which is an optically
2 obtained plethysmogram, a volumetric measurement of an organ (wikipedia.org).

3 SUMMARY

4 [007] There may be provided an integrated circuit that may include an array of
5 complementary metal–oxide–semiconductor (CMOS) single photon avalanche diodes
6 (SPADs), at least one light emitting diode (LED), one or more quenching circuit and
7 one or more readout circuit; the at least one LED may be integrated with the array of
8 CMOS SPADs; the readout circuit may be configured to read at least one output signal
9 outputted from the array of CMOS SPADs.

10 [008] The LED may be a Silicon LED, may be a CMOS LED or any other LED.

11 [009] A group of CMOS SPADs of the array of CMOS SPADs may be coupled in
12 parallel to each other and output a single output signal that may be an analog sum of
13 currents that may be generated by the CMOS SPADs of the group.

14 [0010] The group of CMOS SPADs may include only part of the CMOS SPADs of the
15 array of CMOS SPADs.

16 [0011] The group of CMOS SPADs may be the array of CMOS SPADs.

17 [0012] A LED of the at least one LED may be surrounded by CMOS SPADs of the
18 array of CMOS SPADs.

19 [0013] A LED of the at least one LED may be not surrounded by CMOS SPADs of the
20 array of CMOS SPADs.

21 [0014] The integrated circuit may include a controller for calculating a distance
22 between the integrated circuit and an illuminated target or object (such as but not limited
23 to an organ).

24 [0015] The at least one LED may include an array of LEDs.

25 [0016] The array of LEDs may be arranged as a two-dimensional grid of LEDs.

26 [0017] There may be provided a method for monitoring a living being, the method may
27 include directing radiation towards the living being; detecting photons emitted from the
28 living being by an array of complementary metal–oxide–semiconductor (CMOS) single
29 photon avalanche diodes (SPADs) that may be coupled in parallel to each other;
30 determining times of flight of the photons emitted by the living being as a result of the
31 directing of the radiation; and determining a medical parameter related to the living
32 being based on at least times of flight of the photons emitted by the living being.

33 [0018] The determining of the medical parameter may include obtaining a
34 photoplethysmogram (PPG).

1 [0019] The method may include analog summing output currents that may be outputted
2 by the CMOS SPADs of the array of CMOS SPADs to provide an output signal
3 indicative of a number of photons that impinged on the array of CMOS SPADs.

4 [0020] The determining of the times of flight of the photons that may be emitted by the
5 living being may include determining the times of flight of ballistic photons emitted
6 from the living being.

7 [0021] The determining of the times of flight of the photons that may be emitted by the
8 living being may include ignoring the times of flight of non-ballistic photons emitted
9 from the living being.

10 [0022] The determining of the medical parameter may include finding a change in a
11 volume of a blood vessel of the living being over time.

12 [0023] The directing of the radiation towards the living being may include emitting
13 light by at least one light emitting diode (LED), the LED and the array of CMOS SPADs
14 belong to a same integrated circuit.

15 [0024] A LED of the at least one LED may be surrounded by CMOS SPADs of the
16 array of CMOS SPADs.

17 [0025] A LED of the at least one LED may be not surrounded by CMOS SPADs of the
18 array of CMOS SPADs.

19 [0026] The method may include detecting photons emitted from the living being by
20 multiple arrays of CMOS SPADs.

21 [0027] Each array of CMOS SPAD may include at least one light emitting diode (LED).

22 [0028] The arrays of CMOS SPADs may be positioned side by side.

23 [0029] The arrays of CMOS SPADs may be intertwined.

24 [0030] There may be provided a device for monitoring a living being, the device may
25 include an illumination source for directing radiation towards the living being; an array
26 of complementary metal–oxide–semiconductor (CMOS) single photon avalanche
27 diodes (SPADs) that are coupled in parallel to each other; the array of CMOS SPADs
28 is configured to detect photons emitted from the living being; and at least one circuit
29 that is configured to determine times of flight of the photons emitted by the living being
30 as a result of the directing of the radiation and determine a medical parameter related
31 to the living being based on at least times of flight of the photons emitted by the living
32 being.

33 [0031] The at least one circuit may be a processor.

[0032] The determining may be executed by the processor of the device, by another device or by a combination of the processor of the device and by another device

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features, and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanying drawings in which:

[0034] FIG. 1 is an example of a part of an array of CMOS SPADs and a LED;

[0035] FIG. 2 is an example of a part of an array of CMOS SPADs and a LED;

[0036] FIGs. 3-5 illustrates different arrangements of LEDs and CMOS SPADs;

[0037] FIG. 6 illustrates an example of a device and a hand of a person;

[0038] FIG. 7 illustrates a method; and

[0039] FIG. 8 illustrates an example of a device and a hand of a person.

DETAILED DESCRIPTION OF THE DRAWINGS

[0040] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, and components have not been described in detail so as not to obscure the present invention.

[0041] The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features, and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanying drawings.

[0042] It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements.

[0043] Because the illustrated embodiments of the present invention may for the most part, be implemented using electronic components and circuits known to those skilled in the art, details will not be explained in any greater extent than that considered

1 necessary as illustrated above, for the understanding and appreciation of the
2 underlying concepts of the present invention and in order not to obfuscate or distract
3 from the teachings of the present invention.

4 [0044] Any reference in the specification to a method should be applied mutatis
5 mutandis to a device capable of executing the method.

6 [0045] Any reference in the specification to a device should be applied mutatis
7 mutandis to a method that may be executed by the device.

8 [0046] The term “comprising” is synonymous with (*means the same thing*
9 *as*) “including,” “containing” or “having” and is inclusive or open-ended and
10 does not exclude additional, unrecited elements or method steps.

11 [0047] The term “consisting” is a closed (*only includes exactly what is stated*) and
12 excludes any additional, unrecited elements or method steps.

13 [0048] The term “consisting essentially of” limits the scope to specified materials or
14 steps and those that do not materially affect the basic and novel characteristics.

15 [0049] In the claims and specification any reference to the term “comprising” (or
16 “including” or “containing”) should be applied mutatis mutandis to the term
17 “consisting” and should be applied mutatis mutandis to the phrase “consisting
18 essentially of”.

19 [0050] In the claims and specification any reference to the term “consisting” should
20 be applied mutatis mutandis to the term “comprising” and should be applied mutatis
21 mutandis to the phrase “consisting essentially of”.

22 [0051] In the claims and specification any reference to the phrase “consisting
23 essentially of” should be applied mutatis mutandis to the term “comprising” and should
24 be applied mutatis mutandis to the term “consisting”.

25 [0052] There may be provided devices and method for monitoring a living being such
26 as but not limited to a person.

27 [0053] For simplicity of explanation the following text will refer to Silicon LEDS
28 although it is applicable mutatis mutandis to other types of LEDs.

29 [0054] For simplicity of explanation the following text will refer to a person although
30 it is applicable mutatis mutandis to any living being including humans, animals, and
31 any organism.

32 [0055] CMOS SPAD ARRAY WITH AN INTEGRATED LIGHT EMITTING
33 DIODE (LED)

1 [0056] Integrating a Silicon light emitting diode (LED) and an array of CMOS
2 SPADs may provide a compact device which will require a single and compact
3 packaging instead of having a separate packaging for the LED and a separate
4 packaging for the array of CMOS SPADs – which is more expensive and consumes
5 more volume.

6 [0057] A device may include a first chip that includes the array of CMOS SPADs and
7 also includes a second chip that include a LED. This device may allow relative
8 movements between the first chip and the second chip. The relative movements may
9 reduce the accuracy of measurements performed by the device.

10 [0058] For example – when the device calculates the time difference between the
11 emission of a photon by the LED and a reception of an emitted photon by the array of
12 CMOS SPADs – then relative movements between the first chip and the second chip
13 may bias the measurement.

14 [0059] In addition – having first and second chips may introduce more noise to the
15 LEDs and/or the array of CMOS SPADs. The LED and the array of CMOS SPADs
16 may be fed by different power sources and subjected to different noise and ambient
17 conditions.

18 [0060] There may be provided a CMOS chip that integrates an array of CMOS
19 SPADs with one or more Silicon LED.

20 [0061] This CMOS chip exhibits a reduced dimension, power, and cost.

21 [0062] This CMOS chip may include side by side arrays of CMOS SPADs and/or
22 intertwined arrays of CMOS SPADs. One or more (and even all) of the CMOS
23 SPADs may include one or more LEDs in addition to the CMOS SPADs.

24 [0063] The CMOS chip, using a Time-of-Flight (ToF) principle may provide high-
25 accuracy absolute-range measurements at a most competitive cost, footprint, low
26 power consumption as well as eye safety.

27 [0064] The CMOS chip may be attractive for Internet of things (IoT) applications and
28 a wide range of consumer electronics applications, including: industrial control,
29 distance measurement in any type of robots, domestic wares, on-board computer
30 control with gesture, proximity, and light detection as well as proximity sensing and
31 autofocus required in smartphones and tablets.

32 [0065] Each CMOS SPAD may include a p–n junction that operates biased at voltage
33 V_A above breakdown voltage V_B . At this bias, the electric field is so high that a single
34 charge carrier injected into the depletion layer can trigger a self-sustaining avalanche.

1 The current rises swiftly within sub nanosecond rise time to a macroscopic steady
2 level in the milliampere range. If the primary carrier is photo-generated, the leading
3 edge of the avalanche pulse marks the arrival time of the detected photon. The current
4 continues to flow until the avalanche can be quenched by lowering the bias voltage to
5 V_B or below. The bias voltage is then restored, in order to be able to detect another
6 photon.

7 [0066] Each CMOS SPAD is coupled to a suitable circuit that must (i) sense the
8 leading edge of the avalanche current, (ii) generate a standard output pulse that is well
9 synchronized to the avalanche rise, (iii) quench the avalanche by lowering the bias to
10 the breakdown voltage, (iv) restore the photodiode voltage to the operating level. This
11 circuit is usually referred to as the quenching circuit. A quenching circuit may be
12 passive or active. An example of a passive quenching circuit is a resistor.

13 [0067] The array of CMOS-SPADs may include one or more groups of CMOS
14 SPADs that are electrically coupled to each other in-parallel and may form a CMOS
15 Silicon Photomultiplier. A group of CMOS SPADs may be referred to as a pixel and
16 the CMOS SPADs that form the group may be referred to as sub-pixels.

17 [0068] An output signal of a group of CMOS SPADs is an (analog) sum of all output
18 signals of the CMOS SPADs of the group.

19 [0069] Each CMOS SPAD of the group may be electrically coupled to a single
20 quenching circuit. Each CMOS SPAD responds individually to a photon. This
21 arrangement offers fast high output signal with wide field of view. CMOS Silicon
22 photomultipliers are useful for diverse applications at photon-counting levels of very
23 low signal.

24 [0070] Similar to radar, ranges to objects may be accurately determined optically by
25 measuring the time difference between an emission of an emitted photon and the
26 absorption of a photon reflected or scattered from the object. This measured time is
27 known as time of flight.

28 [0071] The emitted photon may be emitted by a light source such as but not limited to
29 a light emitting diode (LED). The LED may or may not be positioned adjacent to one
30 or more of the Silicon photo-multipliers.

31 [0072] An array of CMOS SPADs that are integrated within one or more LEDs may
32 have any arrangement. For example – the one or more LEDs and the CMOS SPADs
33 may be arranged in an interleaved manner, in a non-interleaved manner, in an
34 interlaced manner, in a non-interlaced manner, and the like. A LED may or may not

1 be surrounded by CMOS SPADs. A LED may be partially surrounded by CMOS
2 SPADs. There may be a certain spacing between a LED and adjacent CMOS SPADs.
3 There may be no spacing between a LED and adjacent CMOS SPADs.

4 [0073] Figure 1 is an example of a part of an array of CMOS SPADs and a LED 14.

5 [0074] Figure 1 illustrates a group of CMOS SPADs, wherein the CMOS SPADs 11
6 are coupled in parallel to each other, each CMOS SPAD 11 is connected in serial to a
7 quenching circuit such as a resistor. The quenching circuit may be passive or active.

8 [0075] During a point in time each CMOS SPAD may detect up to a single photon
9 (either a photon impinges on the CMOS SPAD or not) and generates a CMOS SPAD
10 signal – such as a current signal. Due to the parallel coupling the currents of the
11 different CMOS SPADs of the group are added to each other- thereby providing an
12 indication of the number of photons that impinged on the group.

13 [0076] This output signal (sum of currents) may be fed to digital and/or analog
14 circuits such as a comparator, an analog to digital converter and the like. Figure 1
15 illustrates a readout circuit 15 (that belong to chip 10) that receives the output signals
16 and may generate a digital output signal indicative of the number of photons that
17 impinged on the array of CMOS SPADs.

18 [0077] When chip include multiple groups of CMOS SPADs- there may be provide
19 multiple readout circuits and/or a multiplexing or rousing circuits that selectively
20 reads the output signals of different CMOS SPADs groups.

21 [0078] The array of CMOS SPADs and the LED may be included in a CMOS chip
22 10.

23 [0079] Figure 2 is an example of a part of an array of CMOS SPADs and a LED 14.

24 [0080] In figure 2 there is a certain distance (for example tens of microns) between
25 the LED 14 and adjacent CMOS SPADs. This may assist in reducing crosstalk.

26 [0081] Figures 3-5 illustrates different arrangements of LEDs and CMOS SPADs. An
27 array of CMOS SPADs may include one or more LEDs.

28 [0082] When there are multiple LEDs – the LEDs may be arranged in various
29 manners – in rows, in columns, in a rectangular grid, in sets of any shape and/or size
30 or spaced apart from each other. A LED may be surrounded by CMOS SPADs, may
31 be partially surrounded (not from all sides) by CMOS SPADs or may not be
32 surrounded at all by CMOS SPADs.

33 [0083] Having more LEDs may facilitate a stronger illumination and/or may allow
34 illumination of an object from one or more angles.

[0084] Different LEDs may illuminate the same point of the object, partially overlapping points of the object or may illuminate different points of the object. Different LEDs may have the same optical characters (wavelength and/or strength) but may have different optical characters.

[0085] The CMOS SPADs and the one or more LEDs may be controlled by controller 18.

[0086] MONITORING A PERSON

[0087] With each cardiac cycle the heart pumps blood to the periphery. Even though this pressure pulse is somewhat damped by the time it reaches the skin, it is enough to distend the arteries and arterioles in the subcutaneous tissue. If the pulse oximeter is attached without compressing the skin, a pressure pulse can also be seen from the venous plexus, as a small secondary peak.

[0088] The change in volume caused by the pressure pulse is detected by illuminating the skin with the light from a light-emitting diode (LED) and then measuring the amount of light either transmitted or reflected to a photodiode. Each cardiac cycle appears as a peak, as seen in the figure. Because blood flow to the skin can be modulated by multiple other physiological systems, the PPG can also be used to monitor breathing, hypovolemia, and other circulatory conditions. Additionally, the shape of the PPG waveform differs from subject to subject, and varies with the location and manner in which the pulse oximeter is attached.

[0089] There is a growing need to provide an efficient and non-invasive device and method for measuring oxygen.

[0090] It has been found that PPG measurements can be performed using one or more CMOS Silicon light emitting diodes that are integrated with CMOS SPADs sensors array. The CMOS SPADs array may act as a Silicon photomultiplier.

[0091] An example of a CMOS SPADs array without an integrated LED is the FlightSense™ of ST microelectronics. The FlightSense radiation source is a Vertical Cavity Surface-Emitting Laser (VCSEL) light source.

[0092] The array of CMOS SPADs is highly sensitive and thus can easily detect the ballistic photons – the photons that are virtually directly reflected by the human tissue – and may separate (in the time domain) between these ballistic photons and other photons that may be scattered in the human tissue – or otherwise not be directly reflected – thereby providing accurate information about the concentration of the oxygen within the human tissue.

1 [0093] The array of CMOS SPADs may be preceded with filters for passing only
2 desired wavelengths.

3 [0094] The array of CMOS SPADs can sense single photons within picoseconds, has a
4 low energy consumption, is very small, requires only a small energy source and can be
5 a wearable device.

6 [0095] A mapping between the number of ballistic photons reflected from the human
7 tissue and the oxygen level may be obtained (for example- by performing measurements
8 by using the array of CMOS SPADs and performing additional measurements – even
9 invasive measurements) – and the mapping may be used for further measurements – for
10 calibrating the measurement device using the array of CMOS SPADs.

11 [0096] Figures 6 and 8 illustrates devices and a hand of a person and figure 7 illustrates
12 a method.

13 [0097] Either one of these devices may include at least one circuit for reading and/or
14 processing the signals from the CMOS SPADs. The one or more circuits may be a
15 processor, a readout circuit, and the like.

16 [0098] In figure 6 the array of CMOS SPADs may be integrated in a device (300) that
17 may include at least some out of a controller (310) for controlling the device, an array
18 of CMOS SPADs (320), a readout circuit (330), optics (340), illumination source (350),
19 processor (360), communication module (370), power source (380) and memory
20 module (390).

21 [0099] In figure 8 the device includes an array of CMOS SPADs that includes one or
22 more LEDs (collectively denoted 333).

23 [00100] In both figures 6 and 8 the optics may include filters, lenses, and the like.

24 [00101] The power source may be a battery.

25 [00102] The memory module 390 may store detection signals from the readout
26 circuit.

27 [00103] Processor 360 may perform at least an initial processing of the detection
28 signals. It may count the number of photons, calculate distances, calculate a PPG, and
29 the like.

30 [00104] The power source 380 may be replaced by (or be coupled to) an input
31 port for receiving power.

32 [00105] The communication module 370 can wirelessly communicate with other
33 devices (for example using BLE or other low power standards – or any other

1 communication protocol). Additionally, or alternatively, the communication module
2 may communicate over a wired interface (such as a plug).

3 [00106] The device may be a bracelet, may be included in a bracelet, may be a
4 part of a shirt or any other wearable item, may be a necklace, may be included in a
5 necklace, may be a patch, may be included in a patch, and the like.

6 [00107] The device may include a man machine interface for receiving
7 instructions from a person, for outputting information to a person and the like. Any type
8 of man machine interface may be used (for example- touch screen, keyboard, one or
9 more light emitting elements, vibration element and the like).

10 [00108] A method (400) may be provided for monitoring a person. The method
11 may include directing (410) radiation towards a person. Detecting (420) by a device
12 that includes an array (for example a two-dimensional array) of CMOS SPADs photons
13 (especially ballistic photons) emitted from the person (because of the radiation directed
14 towards the person), and determining (430) a medical parameter related to the person
15 based on the detection signals.

16 [00109] The detecting may include reading detection signals from the CMOS
17 SPADs by a readout circuit. The detection signals may be stored and/or sent to another
18 device. The determining may be executed by a processor of the device, by another
19 device or by a combination of the processor of the device and by another device. The
20 method may include performing processing operations such as selecting detection
21 signals related to the ballistic photons (ignore or consider detection signals from non-
22 ballistic photons), signal to noise improvement steps (noise rejection, modulation,
23 filtering), and the like.

24 [00110] The ballistic photons travel the shortest way and thus are received before
25 other photos (that also scatter within the organ of the person) and provide the most
26 accurate estimate of the distance between the device and the blood vessel. Multiple
27 distance measurements over a period may provide information about the change in
28 volume of the blood vessel caused by the pressure pulse and thus provide highly
29 accurate PPG measurements. The device can detect the ballistic photons due to the fast
30 response of the array of CMOS SPADs and the capability of the array.

31 [00111] It is noted that PPG is merely a non-limiting example of a method for
32 monitoring person using the device that includes the CMOS SPADs.

33 [00112] Although the mentioned above examples discussed oxygen monitoring
34 (PPG) the method may be applied to other materials in the blood.

1 [00113] The illumination can be made in one or more wavelength ranges such as
2 but not limited to near infra-red (wavelength of less than 1 micron). Such light is highly
3 penetrating.

4 [00114] Another non-limiting example of the monitoring may include measuring
5 the oxygen in the brain (for example- for monitoring pilots during flight – especially in
6 high acceleration scenarios), monitoring the oxygen in the brain during surgery.

7 [00115] Another non-limiting example of the monitoring may include
8 measuring water in the lungs (which is an indication of heart failure).

9 [00116] Those skilled in the art will recognize that the boundaries between logic
10 blocks are merely illustrative and that alternative embodiments may merge logic
11 blocks or circuit elements or impose an alternate decomposition of functionality upon
12 various logic blocks or circuit elements. Thus, it is to be understood that the
13 architectures depicted herein are merely exemplary, and that in fact many other
14 architectures may be implemented which achieve the same functionality.

15 [00117] Any arrangement of components to achieve the same functionality is
16 effectively "associated" such that the desired functionality is achieved. Hence, any two
17 components herein combined to achieve a particular functionality may be seen as
18 "associated with" each other such that the desired functionality is achieved,
19 irrespective of architectures or intermedial components. Likewise, any two
20 components so associated can also be viewed as being "operably connected," or
21 "operably coupled," to each other to achieve the desired functionality.

22 [00118] Furthermore, those skilled in the art will recognize that boundaries
23 between the above described operations merely illustrative. The multiple operations
24 may be combined into a single operation; a single operation may be distributed in
25 additional operations and operations may be executed at least partially overlapping in
26 time. Moreover, alternative embodiments may include multiple instances of an
27 operation, and the order of operations may be altered in various other embodiments.

28 [00119] Also for example, in one embodiment, the illustrated examples may be
29 implemented as circuitry located on a single integrated circuit or within a same device.
30 Alternatively, the examples may be implemented as any number of separate integrated
31 circuits or separate devices interconnected with each other in a suitable manner.

32 [00120] Also for example, the examples, or portions thereof, may implemented
33 as soft or code representations of physical circuitry or of logical representations

1 convertible into physical circuitry, such as in a hardware description language of any
2 appropriate type.

3 [00121] However, other modifications, variations and alternatives are also
4 possible. The specifications and drawings are, accordingly, to be regarded in an
5 illustrative rather than in a restrictive sense.

6 [00122] In the claims, any reference signs placed between parentheses shall not
7 be construed as limiting the claim. The word 'comprising' does not exclude the
8 presence of other elements or steps than those listed in a claim. Furthermore, the terms
9 "a" or "an," as used herein, are defined as one or more than one. Also, the use of
10 introductory phrases such as "at least one" and "one or more" in the claims should not
11 be construed to imply that the introduction of another claim element by the indefinite
12 articles "a" or "an" limits any particular claim containing such introduced claim
13 element to inventions containing only one such element, even when the same claim
14 includes the introductory phrases "one or more" or "at least one" and indefinite articles
15 such as "a" or "an." The same holds true for the use of definite articles. Unless stated
16 otherwise, terms such as "first" and "second" are used to arbitrarily distinguish
17 between the elements such terms describe. Thus, these terms are not necessarily
18 intended to indicate temporal or other prioritization of such elements. The mere fact
19 that certain measures are recited in mutually different claims does not indicate that a
20 combination of these measures cannot be used to advantage.

21 [00123] While certain features of the invention have been illustrated and
22 described herein, many modifications, substitutions, changes, and equivalents will
23 now occur to those of ordinary skill in the art. It is, therefore, to be understood that the
24 appended claims are intended to cover all such modifications and changes as fall within
25 the true spirit of the invention.

26

27

1 WE CLAIM

2 1. An integrated circuit, comprising: an array of complementary metal–oxide–
3 semiconductor (CMOS) single photon avalanche diodes (SPADs), at least one light
4 emitting diode (LED), one or more quenching circuit and one or more readout circuit;
5 wherein the at least one LED is integrated with the array of CMOS SPADs; wherein
6 the readout circuit is configured to read at least one output signal outputted from the
7 array of CMOS SPADs.

8 2. The integrated circuit according to claim 1 wherein a group of CMOS SPADs
9 of the array of CMOS SPADs are coupled in parallel to each other and output a single
10 output signal that is an analog sum of currents that are generated by the CMOS SPADs
11 of the group.

12 3. The integrated circuit according to claim 2 wherein the group of CMOS SPADs
13 comprise only part of the CMOS SPADs of the array of CMOS SPADs.

14 4. The integrated circuit according to claim 2 wherein the group of CMOS SPADs
15 is the array of CMOS SPADs.

16 5. The integrated circuit according to claim 1 wherein a LED of the at least one
17 LED is surrounded by CMOS SPADs of the array of CMOS SPADs.

18 6. The integrated circuit according to claim 1 wherein a LED of the at least one
19 LED is not surrounded by CMOS SPADs of the array of CMOS SPADs.

20 7. The integrated circuit according to claim 1 comprising a controller for
21 calculating a distance between the integrated circuit and an illuminated target.

22 8. The integrated circuit according to claim 1 wherein the at least one Silicon LED
23 comprises an array of Silicon LEDs.

24 9. The integrated circuit according to claim 8 wherein the array of Silicon LEDs
25 is arranged as a two dimensional grid of LEDs.

26 10. A method for monitoring a living being, the method comprises:

27 directing radiation towards the living being;

28 detecting photons emitted from the living being by an array of complementary
29 metal–oxide–semiconductor (CMOS) single photon avalanche diodes (SPADs) that are
30 coupled in parallel to each other;

31 determining times of flight of the photons emitted by the living being as a result
32 of the directing of the radiation; and

33 determining a medical parameter related to the living being based on at least
34 times of flight of the photons emitted by the living being.

1 11. The method according to claim 10 wherein the determining of the medical
2 parameter comprises obtaining a photoplethysmogram (PPG).

3 12. The method according to claim 10 comprising analog summing output currents
4 that are outputted by the CMOS SPADs of the array of CMOS SPADs to provide an
5 output signal indicative of a number of photons that impinged on the array of CMOS
6 SPADs.

7 13. The method according to claim 10 wherein the determining of the times of flight
8 of the photons that are emitted by the living being comprises determining the times of
9 flight of ballistic photons emitted from the living being.

10 14. The method according to claim 10 wherein the determining of the times of flight
11 of the photons that are emitted by the living being comprises ignoring the times of flight
12 of non-ballistic photons emitted from the living being.

13 15. The method according to claim 10 wherein the determining the medical
14 parameter comprises finding a change in a volume of a blood vessel of the living being
15 over time.

16 16. The method according to claim 10 wherein the directing of the radiation towards
17 the living being comprises emitting light by at least one light emitting diode (LED),
18 wherein the LED and the array of CMOS SPADs belong to a same integrated circuit.

19 17. The method according to claim 16 wherein a LED of the at least one LED is
20 surrounded by CMOS SPADs of the array of CMOS SPADs.

21 18. The method according to claim 16 wherein a LED of the at least one LED is not
22 surrounded by CMOS SPADs of the array of CMOS SPADs.

23 19. The method according to claim 10 comprising detecting photons emitted from
24 the living being by multiple arrays of CMOS SPADs.

25 20. The method according to claim 19 wherein each array of CMOS SPAD
26 comprises at least one light emitting diode (LED).

27 21. The method according to claim 19 wherein the arrays of CMOS SPADs are
28 positioned side by side.

29 22. The method according to claim 19 wherein the arrays of CMOS SPADs are
30 intertwined.

31 23. A device for monitoring a living being, the device comprises:
32 an illumination source for directing radiation towards the living being;

an array of complementary metal–oxide–semiconductor (CMOS) single photon avalanche diodes (SPADs) that are coupled in parallel to each other; the array of CMOS SPADs is configured to detect photons emitted from the living being; and

at least one circuit that is configured to determine times of flight of the photons emitted by the living being as a result of the directing of the radiation and determine a medical parameter related to the living being based on at least times of flight of the photons emitted by the living being.

24. The device according to claim 23 wherein the at least one circuit is configured to obtain a photoplethysmogram (PPG).

25. The device according to claim 23 comprising a readout circuit that is configured to analog sum output currents that are outputted by the CMOS SPADs of the array of CMOS SPADs to provide an output signal indicative of a number of photons that impinged on the array of CMOS SPADs.

26. The device according to claim 23 wherein the at least one circuit is configured to determine the times of flight of ballistic photons emitted from the living being.

27. The device according to claim 23 wherein the at least one circuit is configured to ignore the times of flight of non-ballistic photons emitted from the living being.

28. The device according to claim 23 wherein the at least one circuit is configured to find a change in a volume of a blood vessel of the living being over time.

29. The device according to claim 23 wherein the illumination source comprises at least one light emitting diode (LED), wherein the at least one LED and the array of CMOS SPADs belong to a same integrated circuit.

30. The device according to claim 29 wherein a LED of the at least one LED is surrounded by CMOS SPADs of the array of CMOS SPADs.

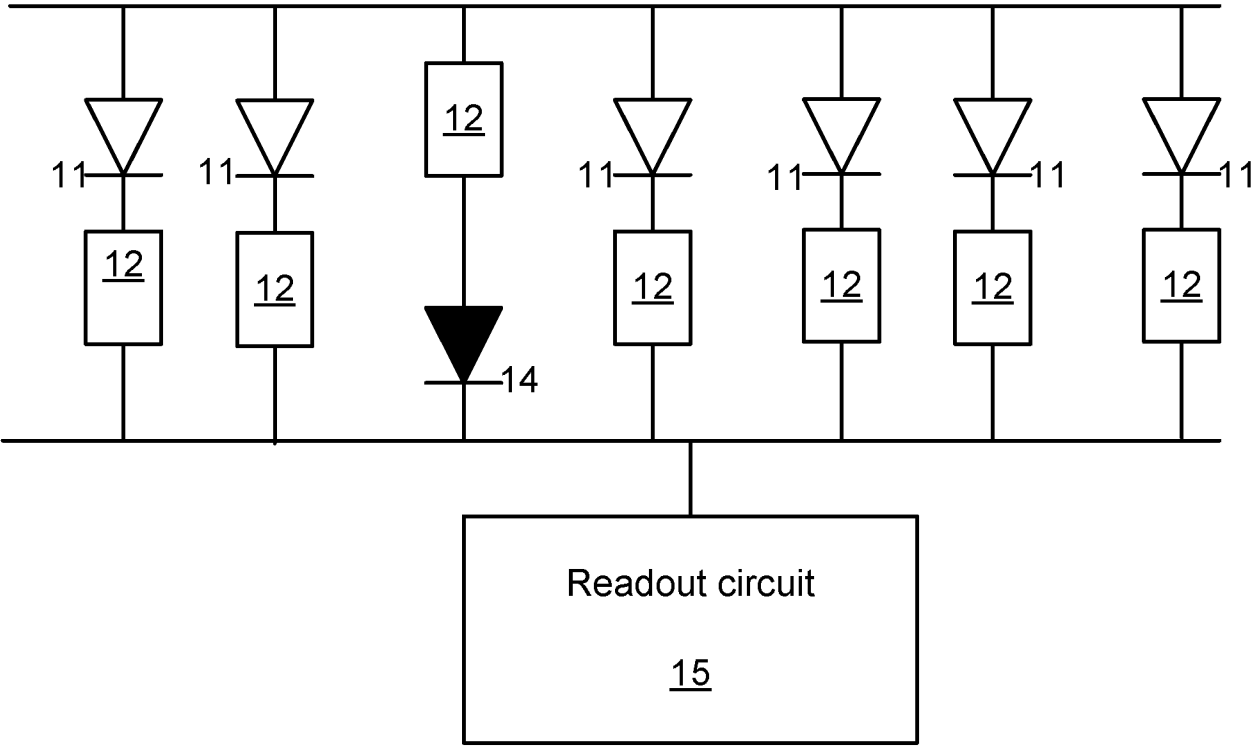
31. The device according to claim 29 wherein a LED of the at least one LED is not surrounded by CMOS SPADs of the array of CMOS SPADs.

32. The device according to claim 23 comprising multiple CMOS SPAD arrays that are configured to detect photons emitted from the living being.

33. The device according to claim 32 wherein each array of CMOS SPAD comprises at least one light emitting diode (LED).

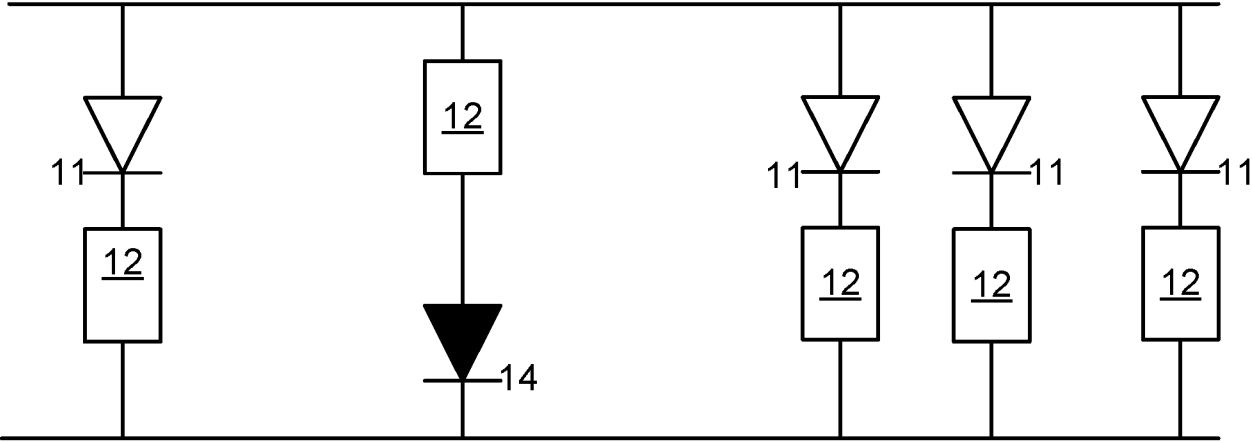
34. The device according to claim 32 wherein the arrays of CMOS SPADs are positioned side by side.

35. The device according to claim 32 wherein the arrays of CMOS SPADs are intertwined.



10

FIG. 1



10

FIG. 2

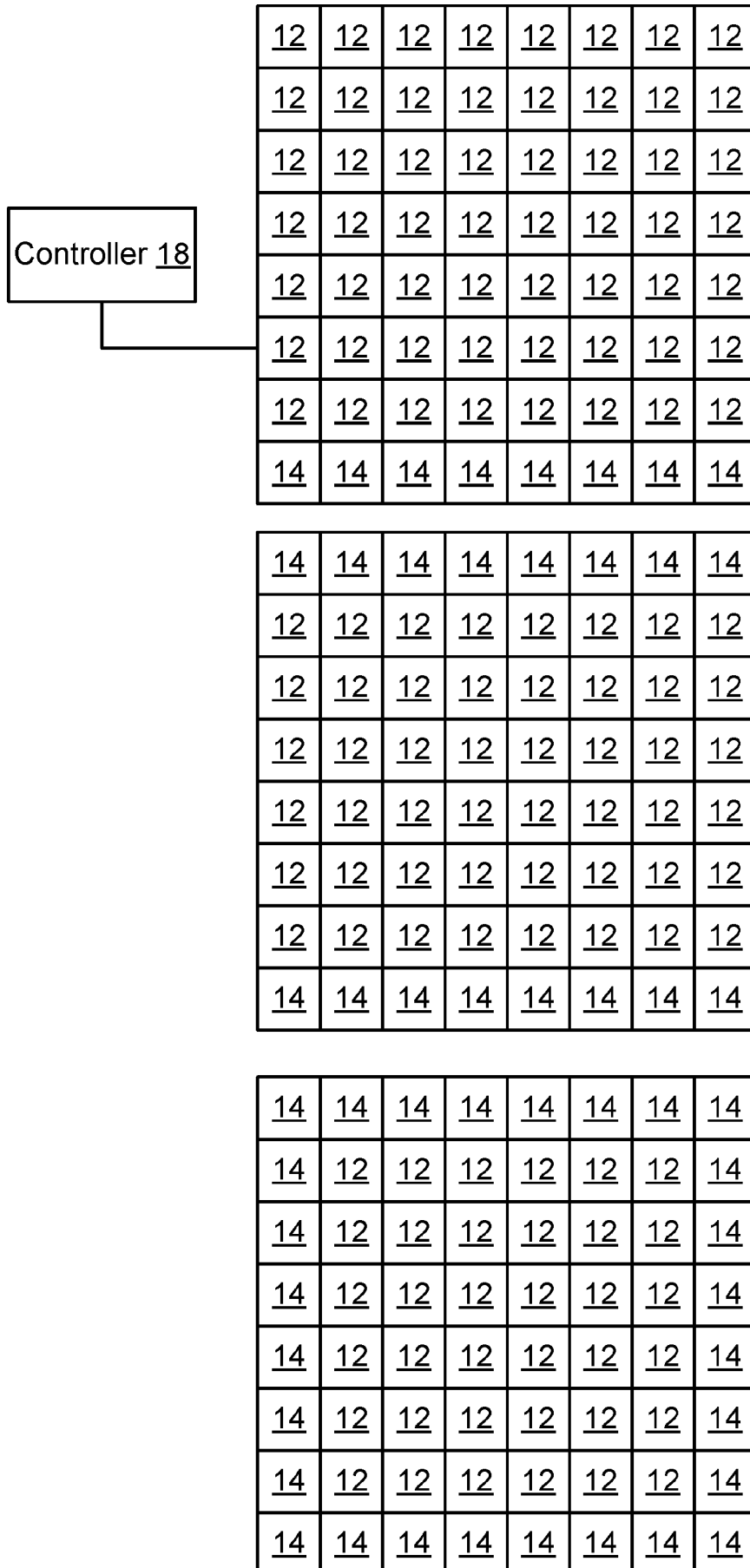


FIG. 3

<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>
<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>
<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>	<u>14</u>

<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>14</u>	<u>14</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>14</u>	<u>14</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>

<u>14</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>14</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>14</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>14</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>14</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>14</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>14</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>14</u>

FIG. 4

<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	14	<u>12</u>
<u>12</u>	14	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	14	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	14	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	14	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	14
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	14	<u>12</u>	<u>12</u>	<u>12</u>
14	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>

<u>12</u>	<u>12</u>	<u>12</u>	14	14	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	14	14	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
14	14	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
14	14	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	14	14
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	14	14

14	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
14	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
14	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
14	<u>12</u>	<u>12</u>	14	14	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	14	14	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>
<u>12</u>	<u>12</u>	<u>12</u>	<u>12</u>	14	14	14	14

FIG. 5

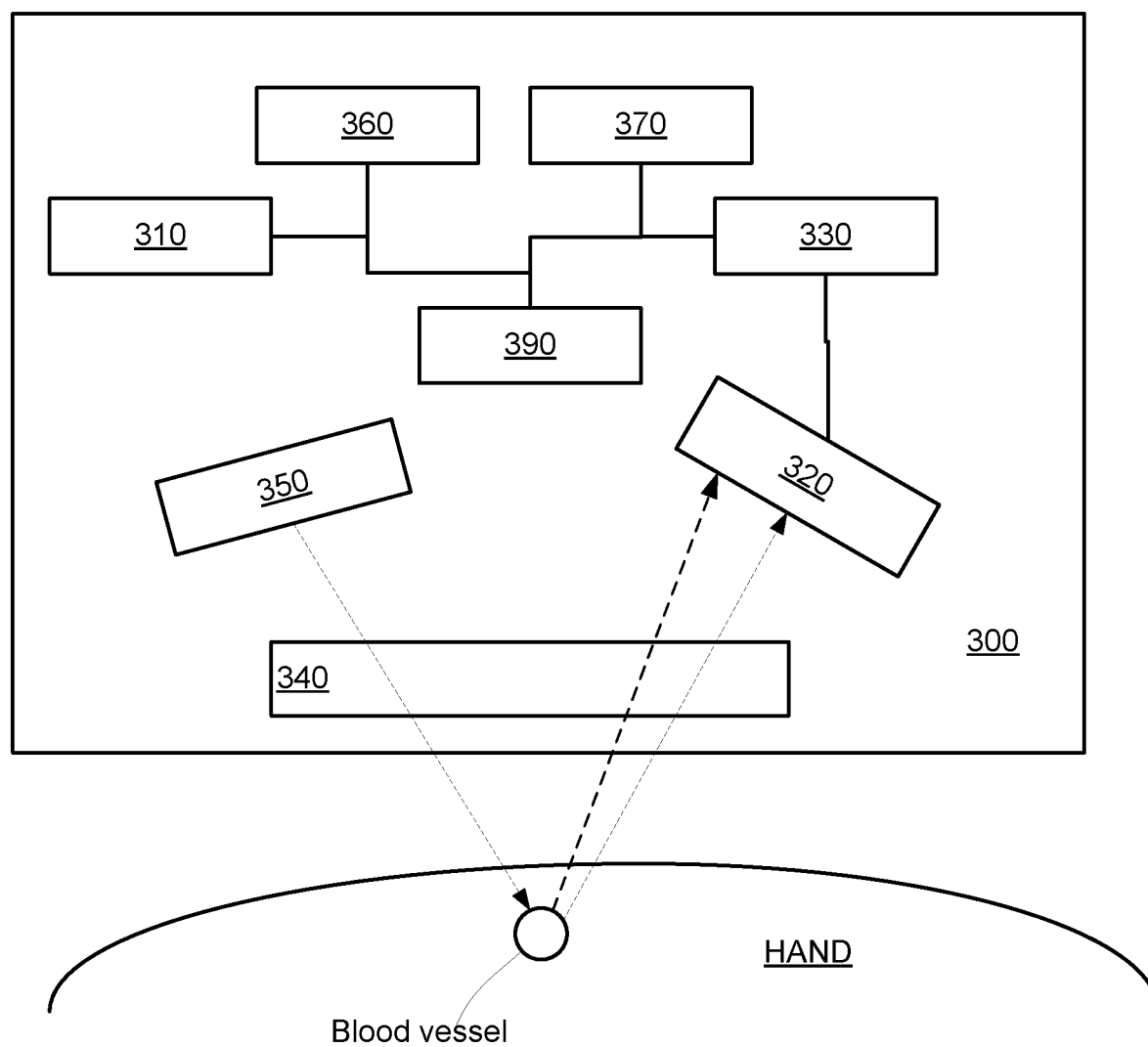


FIG. 6

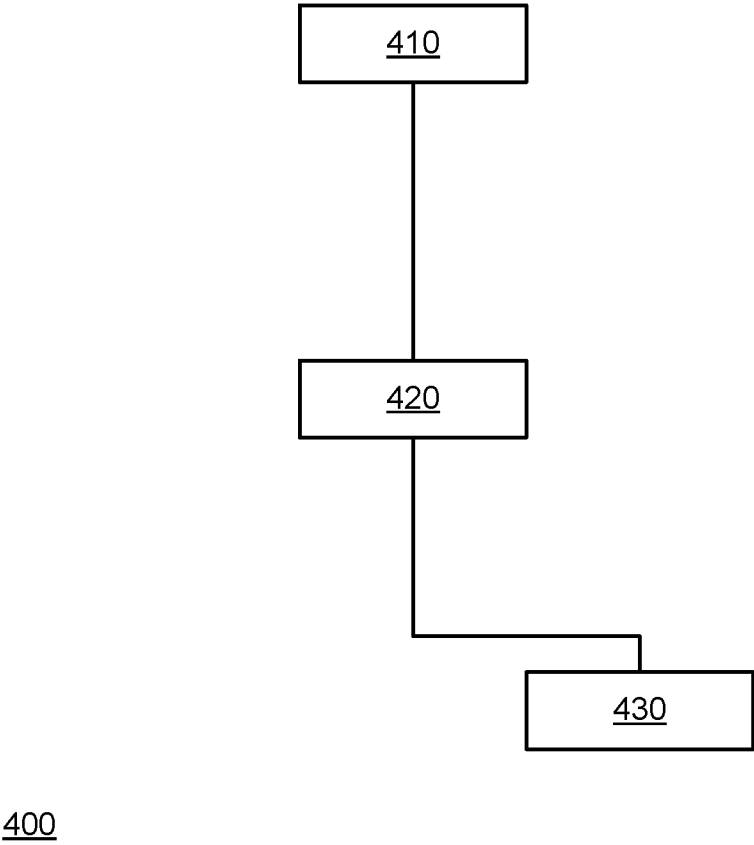


FIG. 7

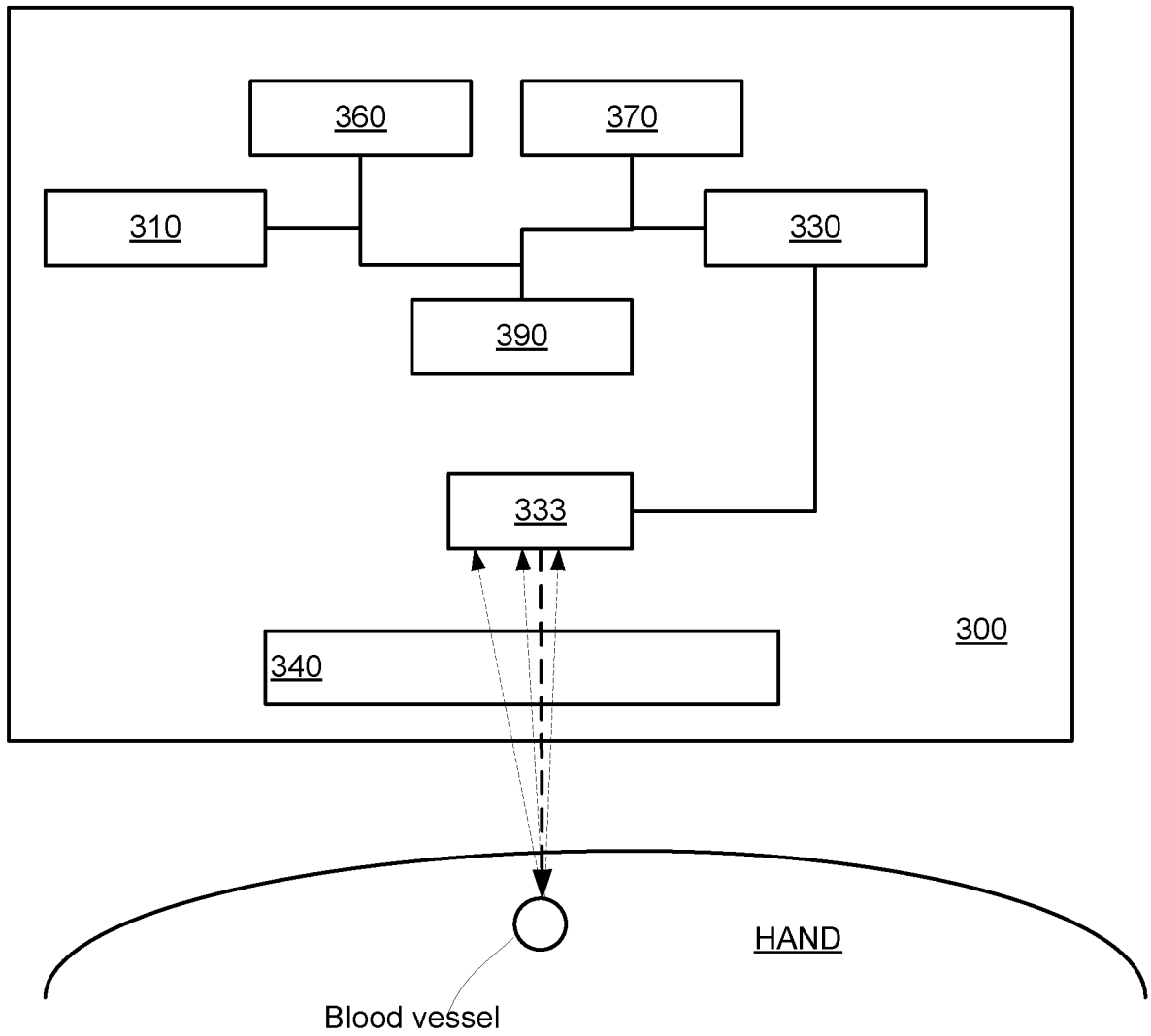


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL2017/050250

A. CLASSIFICATION OF SUBJECT MATTER IPC (2017.01) A61B 5/145500, A61B 6/00, H01L 31/00 According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC (2017.01) A61B 5/145500, A61B 6/00, H01L 31/00 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) Databases consulted: Esp@cenet, Google Patents, Google Scholar, FamPat database Search terms used: spad , spads , single photon avalanche diode , led , cmos ,quenching circuit		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Monolithic Integration of LEDs and SPADs in Standard CMOS Technology for Optical Joystick Application, October 2012 [retrieved on 22-05-2017]. Retrieved from < https:// repository.tudelft.nl/islandora/object/uuid:44bafde8-51be-4da3-becc1-c753c2e3df9d? collection=education>. Nupur Lodha 23 Oct 2012 (2012/10/23) entire document	1-6,8,9
A	WO 2015052523 A1 THE UNIVERSITY COURT OF THE UNIVERSITY OF GLASGOW 16 Apr 2015 (2015/04/16) entire document	1-35
A	US 8749765 B2 STMicroelectronics (Research &Development) Limited, 10 Jun 2014 (2014/06/10) entire document	1-35
A	US 2006192086 A1 Ecole Polytechnique Federale de Lausanne EPFL, 31 Aug 2006 (2006/08/31) entire document	1-35
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier 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 01 Jun 2017		Date of mailing of the international search report 01 Jun 2017
Name and mailing address of the ISA: Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Facsimile No. 972-2-5651616		Authorized officer COHAY Mattan Telephone No. 972-2-5651611

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL2017/050250

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012184831 A1 Radiation Monitoring Devices, Inc. 19 Jul 2012 (2012/07/19) entire document	1-35

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IL2017/050250

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
WO 2015052523 A1	16 Apr 2015	WO 2015052523 A1	16 Apr 2015
		EP 3054832 A1	17 Aug 2016
		GB 201317968 D0	27 Nov 2013
US 8749765 B2	10 Jun 2014	US 2012133921 A1	31 May 2012
		US 8749765 B2	10 Jun 2014
		GB 201020275 D0	12 Jan 2011
		GB 2485993 A	06 Jun 2012
US 2006192086 A1	31 Aug 2006	US 2006192086 A1	31 Aug 2006
		US 7262402 B2	28 Aug 2007
		US 2006202121 A1	14 Sep 2006
		US 7501628 B2	10 Mar 2009
		US 2006202129 A1	14 Sep 2006
		US 7547872 B2	16 Jun 2009
		US 2010127160 A1	27 May 2010
		US 8168934 B2	01 May 2012
US 2012184831 A1	19 Jul 2012	US 2012184831 A1	19 Jul 2012
		EP 2665418 A2	27 Nov 2013
		EP 2665418 A4	09 Mar 2016
		US 2014323879 A1	30 Oct 2014
		WO 2012099917 A2	26 Jul 2012
		WO 2012099917 A3	10 Apr 2014