



(51) International Patent Classification:

A61B 5/00 (2006.01) A61B 5/01 (2006.01)  
H04B 10/80 (2013.01) A61B 5/0402 (2006.01)  
A61B 1/005 (2006.01) A61N 1/00 (2006.01)  
A61B 8/12 (2006.01) H04B 10/43 (2013.01)

(21) International Application Number:

PCT/IB2013/059794

(22) International Filing Date:

30 October 2013 (30.10.2013)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

61/723,853 8 November 2012 (08.11.2012) US

(71) Applicant: **KONINKLIJKE PHILIPS N.V.** [NL/NL];  
High Tech Campus 5, NL-5656 AE Eindhoven (NL).

(72) Inventors: **VAN DER MARK, Martinus Bernardus**; c/o  
High Tech Campus 5, NL-5656 AE Eindhoven (NL). **VAN  
DUSSCHOTEN, Anna Hendrika**; c/o High Tech Campus  
5, NL-5656 AE Eindhoven (NL).

(74) Agents: **STEFFEN, Thomas** et al.; High Tech Campus  
Building 5, NL-5656 AE Eindhoven (NL).

(81) Designated States (unless otherwise indicated, for every  
kind of national protection available): AE, AG, AL, AM,  
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,  
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, 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, KN, KP, KR,  
KZ, LA, LC, LK, LR, LS, LT, 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, 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).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: AN OPTICAL PROBE SYSTEM

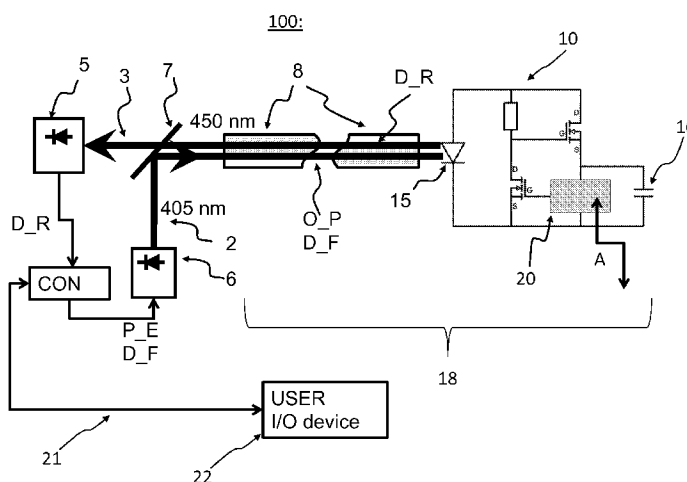


FIG. 1

(57) Abstract: The present invention relates to an optical probe system (100) comprising an optical probe (18) having an optical converter circuit (10) with an optoelectronic device (15). The optoelectronic device is arranged for converting a first radiation beam (2) from a radiation source (6) into electrical energy and for receiving first data comprised in said first radiation beam. The optical converter circuit (10) is powerable by said electric energy in the first radiation beam (2). The optoelectronic device is further arranged for emitting a second radiation beam (3) towards a photodetector (5), said emission being inducible by the incoming first radiation beam, the second radiation beam comprising second data. The invention is advantageous for obtaining an improved optical probe system capable of obtaining a higher data transmission and/or a relatively high power at the distal end of the optical probe system with relatively high efficiency and simultaneous at small size.

WO 2014/072891 A1

An optical probe system

## FIELD OF THE INVENTION

The present invention relates to an optical probe system, and more particularly relates to an optical probe system comprising an optoelectronic device being arranged for converting a first radiation beam into electrical energy, the invention relates to a  
5 corresponding optical probe, and the invention further relates to a corresponding method.

## BACKGROUND OF THE INVENTION

There is a clear and ongoing trend to replace conventional surgical procedures with minimally invasive (MI) interventions. Reduced trauma, shorter hospital stay and  
10 reduced cost are the most important drivers of the adoption of minimally invasive techniques. To enable further innovation in medical instrumentation – thus enabling more advanced and more challenging MI interventions – there is a need to integrate miniature sensors for in-body imaging and physiological measurement in instruments like catheters and guide wires.

Data and power delivery to the tip of long and thin devices such as a medical  
15 catheter or guide wire for imaging, sensing, sensitising or even ablation can be challenging. Including, on top of that, a high data rate return channel is even more problematic. This is due to several reasons.

Firstly, the combination of the small cross section (i.e. small diameter), necessary for the medical intervention, combined with the long length of a guide wire or  
20 catheter does severely limit the total number of electrical wires that can be integrated in such an instrument.

Secondly, the integration of (multiple) electrical wires compromises the flexibility of the instrument, while flexibility is a key property of this type of instruments.

Thirdly, for high data rate, such as e.g. required for an ultrasound transducer at  
25 the tip or sensitive measurements, one often requires coaxial cables which need even more space compared to single-core wires.

Fourthly, instruments with electrical wires typically are not compatible with the use of MRI due to resonances in/of the electric wiring leading to electromagnetic interference in the connected electronics and also possibly leading to tissue heating. And

furthermore, thin electrical cables typically cannot support a relatively high amount of power for use at the distal end of the catheter.

Also, because of their disposable use, catheters and guide wires must be manufactured in a relatively simple and cost effective way.

5 US patent 7,831,152 discloses an optical transceiver for detecting an incoming light beam and for transmitting an outgoing light beam along a common optical axis, the outgoing light beam may contain control or information signals. Such an optical transceiver provides a compact transceiver that is suitable for a wide variety of applications, for example a catheter or other kind of probes. In some embodiments, optical power is provided to an  
10 optical detector, which is converted into electrical energy for use at the distal end of an optical probe.

One disadvantage of this device is for example the use of a special multiple junction and/or stacked optoelectronic device. The device is furthermore GaAs/AlGaAs-based, hence it has a relatively low bandgap, and therefore the voltage produced is too low to  
15 power silicon-based electronics with only one junction. Further, the toxicity of As may be an issue for the use in medical devices.

The inventors of the present invention have appreciated that an improved optical probe system is of benefit, and have in consequence devised the present invention.

## 20 SUMMARY OF THE INVENTION

It would be advantageous to achieve an improved optical probe system. It would also be desirable to enable an optical probe system working faster and/or more accurate, particularly with a higher data transmission and/or a relatively higher power provided at the distal end of the probe. In general, the invention preferably seeks to mitigate,  
25 alleviate or eliminate one or more of the above-mentioned disadvantages singly or in any combination. In particular, it may be seen as an object of the present invention to provide a system and a method that solves the above mentioned problems, or other problems, of the prior art. Other problems may be efficiency and/or high power density to allow for a small optoelectronic device at the tip of a catheter/probe so that the invasive medical device  
30 remains relatively thin and so that tissue heating is avoided and/or minimized as well.

To better address one or more of these concerns, in a first aspect of the invention an optical probe system is provided, the system comprising:

a radiation source capable of emitting a first radiation beam, said first radiation beam comprising optical energy and first data,

a photodetector, the photodetector being arranged for detecting a second radiation beam, and

an optical probe, the optical probe being at its proximal end optically connected to the photodetector and the radiation source, the probe having an optical guide capable of connecting the distal end with the proximal end, the optical probe having at its distal end an optical converter circuit, said circuit comprising:

- an application device, the application device being arranged for monitoring and/or manipulation at the distal end of the probe, the application device being arranged for generating second data indicative of the functionality of the application device ,

and

- an optoelectronic device, the optoelectronic device being arranged for converting said first radiation beam into electrical energy and for receiving said first data, the first data being related to the functionality of the application device, the optoelectronic device further being arranged for emitting said second radiation beam towards the photodetector, the second radiation beam comprising the second data, the optoelectronic device further being arranged for:

- converting said first radiation beam into electrical energy and for receiving said first data, and

- emitting said second radiation beam towards the photodetector, said emission being inducible by the incoming first radiation beam, wherein the optical converter circuit is powerable by said electric energy in the first radiation beam.

The invention is particularly, but not exclusively, advantageous for obtaining an improved optical probe system capable of obtaining a higher data transmission and/or a relatively high power at the distal end of the optical probe system with relatively high efficiency.

Many simultaneous advantages may also come from using an optical guide, e.g. an optical fiber, directly connected to a bi-directional opto-electronic device at the tip of an elongated instrument. This may be true in particular in the medical domain for guide wires or catheters, though the present invention may also find application in other areas where optical probes may be beneficially used.

It is proposed to use an optical fiber linked to, at the distal end, a two-way opto-electronic device which is addressed and powered from the proximal end solely by light launched into and guided by the optical guide or optical fiber.

Typical examples of two-way opto-electronic devices may be semiconductor light emitters: they can be used as photodetectors as well. Two-way opto-electronic devices are, for example: LEDs, RCLEDs (resonant cavity light emitting diodes), semiconductor lasers or VCSELs (vertical-cavity surface-emitting lasers). Note that all those devices are made from direct band gap materials, though the present invention may also be implemented with indirect bandgap materials.

Another advantage may be seen from the facts that temperature increase of tissue near the distal end of the probe, and hence power load on the tissue should be limited. This is to prevent heating of the tissue to a temperature higher than the denaturation temperature of 42 °C. This may require, amongst other factors:

- efficient power conversion at the tip of a catheter or guide wire.
- and/or
- cooling of the tip by flow of water or another coolant through the catheter. This will allow much higher power to be delivered to the tip of the instrument in order to compensate for losses in the optoelectronics and/or electronics, within the catheter or on the interface between catheter and tissue. However, this solution may compromise the lateral space available in instrument.

It should be noted that, in the context of the present invention, lasers or power-LEDs are relatively ideal photovoltaic converters due to their low intrinsic series resistivity as well as for their optimization for a narrow wavelength band. Both LEDs and similar lasers typically produce substantial current when illuminated with light of preferably slightly shorter wavelength (for example 2-20%, such as 5-10%) than under their normal operating conditions when they produce light. It appears that a combination of a BluRay Disk violet laser at 405 nm works well with some high power blue LEDs from Philips Lumileds or Osram, normally operating at 440-450 nm. Currently, high power LEDs or lasers are particularly suitable for high-power and high power density photo voltaic conversion. It is conceivable that new, dedicated and even more optimal photovoltaic conversion devices will be designed in the future that may particularly be implemented when considering the general principle and teaching of the present invention.

Furthermore, it should be noted that when illuminating a LED (or Laser) it is possible to produce so-called photo-induced electroluminescence (PIEL), see for example F. Schubert, Q. Dai, J. Xu, J. K. Kim and F. Schubert, "Electroluminescence induced by photoluminescence excitation in GaInN/GaN light-emitting diodes", Applied Physics Letters, Volume 95, 191105 (2009), hereby incorporated by reference in its entirety. This reference

explains the physical principle behind photo-induced electroluminescence that may beneficially be applied in optical probes according to the present invention. The intensity of this PIEL luminescence typically depends on the electrical load on the LED device's terminals, and hence it can be modulated by the electronics at the distal end without the need for electrical power for the LED device, which would require a voltage higher than the bandgap to overcome resistive losses in the LED and driving circuit. In the situation sketched, the power comes directly from the laser or the radiation source at the proximal end and less resistive loss (with the associated drop in voltage) will normally occur. This provides an excellent way for a data return channel using a single device, that is, the present invention enables optical data multiplexing in a new and advantageous manner. In case of a power LED, such as the Philips Lumileds Luxeon Rebel, the bandwidth will be on the order of 1 MHz. In case a laser is used as 2-way optoelectronic device is at the distal end, the bandwidth is expected to be on the order of 400 MHz, or even higher.

An additional advantage of an optical link for data communication provided by the present application is its MRI compatibility and total electrical insulation of proximal and distal end. Note also that the electrical resistance of the body itself provides a natural lower bound on practical values of electrical insulation.

An extended application of the present invention may also exploit the combination of using a limited number (e.g. 2) of (thin, highly resistive) electrical wires to deliver a high-voltage for biasing (larger than a few volts, typically 100 Volt) to the sensor device at the tip (for example a CMUT ultrasound receiver or transducer), while the optical link is used for power and to program and control the sensor device (for example a data multiplexer) and transfer the data. In one embodiment, the electrical impedance of the high-voltage part of the electrical circuit can be large (i.e. a capacitor with a (quasi-)static bias voltage or a high-impedance resistor), in which case the resistance of the electrical wire can also be chosen large, which improves the MR-compatibility of this solution compared to an all-electrical solution. In a preferred embodiment, the highly resistive electrical connection can be an integral part of the coating of the optical fiber, or even the coating itself. A typical resistance would be  $1\text{M}\Omega$ .

The present invention may particularly be implemented together with optical shape sensing fibers for use in medical applications, or other similar applications. The optical shape sensing may be based on either Fiber Bragg Gratings (FBG) or Rayleigh backscattering in the optical guide or fiber.

In the context of the present application, it is to be understood that an optical probe may, but not exclusively, be considered as an elongated, or extended, shape with a proximal end and a distal end, the latter being used for monitoring and/or various applications, e.g. RF ablation and ultrasonic purposes.

5 In the context of the present application, it is to be understood that a radiation source may include any suitable transmitter of electromagnetic radiation, for example infrared light (IR), visible light, ultraviolet light (UV), X-Ray radiation, etc.

In an embodiment, the invention relates to an optical probe system wherein the optical guide is arranged for guiding said first radiation beam from the proximal end to the  
10 distal end, and further being arranged for guiding said second radiation beam from the distal end to the proximal end, the first radiation beam and the second radiation beam being arranged for being guided along the same optical path, or a parallel optical path, in said optical guide. A possible advantage of this embodiment may be that only a single guide is needed. In a particular embodiment, the optical guide may have one or more optical channels.  
15 In another possible embodiment, the optical guide may be arranged for allowing transmission of radiation in single mode. In another possible embodiment, the optical guide may be arranged for allowing transmission of radiation in multimode. In a possible embodiment, the optical guide may be manufactured in a single optical material. In a possible embodiment, the optical guide may have multiple cores, such as comprising a multicore fiber, wherein each  
20 core may be individually prepared as it is well-known to the skilled person in optics.

In another embodiment, the invention relates to an optical probe system wherein the optical guide comprises an optical fiber, the optical fiber comprising at least a part of the said optical path for the first radiation beam and the second radiation beam. In a particular embodiment, there is provided an optical guide comprising an optical fiber with  
25 separate optical cores.

In another embodiment, the invention relates to an optical probe system wherein the system further comprises a control unit (CON), the control unit being operably connected to the radiation source and arranged for controlling the optical energy and providing the first data thereto, the control unit further being operably connected to the  
30 photodetector and arranged for receiving the second data therefrom. This may be advantageous because an improved control system in a single unit is provided.

In another embodiment, the invention relates to an optical probe system wherein the control unit is configured for operating a control loop for controlling the optical energy (O\_P) and/or the first data (D\_F) based, at least partly, on the second data (D\_R).

This may be advantageous since feedback may be embedded in the second data, for example power deliver response of tissue to power delivered there to. This may be particularly important when used in humans because automatic control can avoid or minimize unintended damages.

5                    In another embodiment, the invention relates to an optical probe system wherein said second radiation beam is dependent upon an electrical load on the optoelectronic device. This may advantageously provide an efficient multiplexing data channel capable of providing high data transfer in both directions. In a specific embodiment, the effect of photo-induced electroluminescence (PIEL) is utilized.

10                   In another embodiment, the invention relates to an optical probe system wherein said control loop is arranged for optimizing the electrical load on the optoelectronic device. This may be beneficial because it is possible to find the maximum power point (MPP), where the maximum power point is the optimum point of operating the system, in particularly the optimum point of operating the optoelectronic device.

15                   In another embodiment, the invention relates to an optical probe system wherein the optoelectronic device comprises a photovoltaic converter, preferably the optoelectronic device comprises a solid-state laser, or a light emitting diode (LED). This may be beneficial because it might be possible to find the maximum power point (MPP), where the maximum power point is the optimum point of operating the system, in  
20 particularly the optoelectronic device. This is explained further in the detailed description of the invention.

                    In another embodiment, the invention relates to an optical probe system wherein the optoelectronic device is a direct band-gap device, preferably a single junction device where

25                   1) the converting of said first radiation beam into electrical energy and receiving said first data, and

                    2) the emitting of said second radiation beam towards the photodetector, said emission being inducible by the incoming first radiation beam, such as said emission being photo-inducible by the incoming first radiation beam, is arranged for taking place at said  
30 single junction. A junction may be broadly defined, but not necessarily limited to, an interface between two, or more, distinct materials which defines an active region capable of facilitating optical and/or opto-electrical phenomenons. The single junction may for example be a p-n junction in the optoelectronic device at which all conversion takes place: power, data and luminescence.

In another embodiment, the invention relates to an optical probe system wherein the optoelectronic device is capable of performing photo-induced electroluminescence (PIEL). This may be particularly advantageous because relatively fast two-way optical communication may be provided.

5 In another embodiment, the invention relates to an optical probe system wherein the optical probe, at its proximal end, comprises an optical element capable of separating the first and the second radiation beam, wherein the optical element may for instance be a semi-transparent or dichroic mirror.

10 In another embodiment, the invention relates to an optical probe system wherein the optical converter circuit is powerable solely by said electric energy from the optoelectronic device. This may be advantageous because electric wiring to the distal end may not be needed to the same extent, such as may be avoided or minimized.

15 In another embodiment, the invention relates to an optical probe system wherein the optical converter circuit is powerable directly by said electric energy from the optoelectronic device without any voltage up up-conversion. For example, the optical converter circuit may comprise a GaN based device such as a photodiode, LED or diode laser facilitating that the optoelectronic device is capable of driving silicon based electronics requiring approximately 2 Volt, hence no voltage up-conversion is necessary.

20 In another embodiment, the invention relates to an optical probe system wherein the application device is controllable in response to the first data.

In another embodiment, the invention relates to an optical probe system wherein the application device comprises any one of:

- a temperature sensor,
- a pressure sensor,
- 25 - a chemical sensor,
- an ultrasound transducer (CMUT),
- a camera,
- a sensor for ionizing radiation (alpha, beta and/or gamma),
- an electric field sensor for example for measuring an ECG (electrocardiogram),
- 30 and/or
- an electric stimulator or sensitizer.

In another embodiment, the optical probe system may be used for optical shape sensing.

The skilled person readily understands that other devices may be implemented in an optical probe system according to the present invention. It is noted that the probe system may be powered optically but the application device may be non-optically-based, for example by using ultrasound, voltammetry, strain gauges or other non-optical principles, techniques or modalities.

According to a second aspect, the invention relates to an optical probe, the optical probe being at its proximal end optically connectable to an associated photodetector and an associated radiation source, the probe having an optical guide capable of connecting the distal end with the proximal end, the optical probe having at its distal end an optical converter circuit, said circuit comprising:

- an application device, the application device being arranged for monitoring and/or manipulation at the distal end of the probe, the application device being arranged for generating second data indicative of the functionality of the application device, and
- an optoelectronic device, the optoelectronic device being arranged for converting a first radiation beam into electrical energy and for receiving first data, the first data being related to the functionality of the application device, the optoelectronic device further being arranged for emitting a second radiation beam towards the associated photodetector, the second radiation beam comprising the second data,

the optoelectronic device further having the capability of, upon receiving said first radiation beam:

- converting said first radiation beam into electrical energy and for receiving said first data, and
- emitting said second radiation beam towards the associated photodetector, said emission being inducible by the incoming first radiation beam,

wherein the optical converter circuit is powerable by said electric energy in the first radiation beam.

According to a third aspect, the invention relates to a method for supplying an optical probe with electrical energy and for sending and receiving data from the optical probe, the method comprising:

- providing an optical probe system, the system comprising:
  - a radiation source capable of emitting a first radiation beam, said first radiation beam comprising optical energy (O\_P) and first data (D\_F),
  - a photodetector, the photodetector being arranged for detecting a second radiation beam, and

an optical probe, the optical probe being at its proximal end optically connected to the photodetector and the radiation source, the probe having an optical guide capable of connecting the distal end with the proximal end, the optical probe having at its distal end an optical converter circuit, said circuit comprising:

- 5                   - an application device, the application device being arranged for monitoring and/or manipulation at the distal end of the probe, the application device being arranged for generating second data (D\_R) indicative of the functionality of the application device, and
- an optoelectronic device, the optoelectronic device being arranged for converting said first radiation beam into electrical energy and for receiving said first data, the
- 10                   first data being related to the functionality of the application device, the optoelectronic device further being arranged for emitting said second radiation beam towards the photodetector, the second radiation beam comprising the second data,

                    the optoelectronic device further being arranged for:

- converting said first radiation beam into electrical energy and for receiving
- 15                   said first data, and
- emitting said second radiation beam towards the photodetector, said emission being inducible by the incoming first radiation beam,

                    wherein the optical converter circuit is powerable by said electric energy in the first radiation beam,

20                   said method further comprising:

- emitting a first radiation beam from the radiation source, said first radiation beam comprising optical energy (O\_P) and first data (D\_F),
- converting at the optoelectronic device said first radiation beam into electrical energy and receiving said first data,
- 25                   - emitting said second radiation beam from the optoelectronic device towards the photodetector.

                    In general, the various aspects of the invention may be combined and coupled in any way possible within the scope of the invention. These and other aspects, features and/or advantages of the invention will be apparent from and elucidated with reference to the

30                   embodiments described hereinafter.

#### BRIEF DESCRIPTION OF THE DRAWINGS

                    Embodiments of the invention will be described, by way of example only, with reference to the drawings, in which

FIG. 1 shows a schematic embodiment of an optical probe system according to the present invention,

FIG. 2 shows a graph of power load curves (left axis) as a function of photo-induced (or photo-voltaic) current through the LED for 4 different currents through the driving laser according to the present invention. It also shows, on the right axis, the amount of photo-induced electroluminescence,

FIG. 3 shows a graph with laser power versus laser current (left axis). On the right axis, photo-luminescence and photo-induced electroluminescence of the laser-illuminated LED are given, for the corresponding laser power,

FIG. 4 shows another graph with load curves for two different LEDs, top curve: LD G5AP (OSRAM) with a surface area of  $0.4 \times 0.4 \text{ mm}^2$ , and bottom curve: Luxeon Rebel Royal Blue (LUMILEDS) with a surface area of  $1.0 \times 1.0 \text{ mm}^2$ , and

FIG. 5 shows a flow chart of a method according to the present invention.

## DESCRIPTION OF EMBODIMENTS

FIG. 1 shows a schematic embodiment of an optical probe system according to the present invention.

A radiation source 6 is capable of emitting a first radiation beam, said first radiation beam 2 comprising optical energy O\_P and first data D\_F. A photodetector 5, the photodetector is arranged for detecting a second radiation beam 3.

An optical probe is, at its proximal end, optically connected to the photodetector and the radiation source, the probe having an optical guide 8, for example an optical fiber as schematically illustrated in FIG. 1, capable of connecting the distal end with the proximal end, the optical probe having at its distal end an optical converter circuit 10, the circuit comprising:

An application device 20, the application device being arranged for monitoring and/or manipulation, e.g. the influencing surrounding tissue of a human with acoustic or electromagnetic radiation, at the distal end of the probe, the application device being arranged for generating second data D\_R indicative of the functionality of the application device.

An optoelectronic device 15, the optoelectronic device being arranged for converting said first radiation beam 2 into electrical energy and for receiving said first data, the first data being related to the functionality of the application device, the optoelectronic

device further being arranged for emitting said second radiation beam 3 towards the photodetector, the second radiation beam comprising the second data, the optoelectronic device further being arranged for:

- converting said first radiation beam into electrical energy and for receiving said first data,
- 5 and
- emitting said second radiation beam towards the photodetector, said emission being inducible by the incoming first radiation beam,

wherein the optical converter circuit 10 is powerable by said electric energy in the first radiation beam 2. Thus, the optical energy  $O_P$ , originated from radiation source 6 being  
10 powered via controller CON delivering energy  $P_E$  to it, is radiated to the circuit 10 at the distal end and there converted into electrical energy useable in the circuit.

In this embodiment, optical power is delivered through the fiber 8 by a short-wavelength laser 6, positioned at the proximal end of the fiber, which is integrated in a medical device such as a catheter or guide wire 18. A high band-gap photovoltaic receiver  
15 may act as the optoelectronic device 15 and thereby provide power for at the tip (distal end) of the fiber.

An example of an embodiment of the power and data delivery system that can be integrated into a catheter or guide wire 18. Light of 405 nm BluRay disk laser 6 is launched into an optical fiber via a dichroic mirror 7. This light illuminates an LED with  
20 slightly lower band-gap which as a consequence produces a current in the circuit 10 attached to it. This circuit is designed so that it can influence the electrical impedance felt by the LED. In the example of this figure, it can essentially disconnect the diode by raising the impedance substantially, thereby also disconnecting its own power source. A capacitor 16 is used to  
25 bridge the time period without external supply. By disconnecting the diode, photo-induced electroluminescence (PIEL) will occur with a longer wavelength (for example 450 nm) than the absorbed light from the laser (for example 405 nm), and it is collected by the fiber and transported to a detector via the dichroic mirror 7. By this means the circuit 10 can send data  
30  $D_R$  back to the control unit CON, and in turn a user 22, e.g. an I/O device, via connection 21 (wireless or dedicated wire (s)).

The advantages of this embodiment, and more generally the present invention, results from one, or more, of the following elements:

- single junction optoelectronic device (not stacked, not arranged in series) with 3-way use: simultaneous data in, data out (transceiver for duplexing) and power input
- GaN/AlGaN based, with direct, high band gap typically supplying 2-2.5 Volts

- directly powering silicon based electronics (Voltage required  $>1.65$  Volt)
  - small, high power and power density capability  $> 1\text{W}/\text{mm}^2$  up to  $1\text{kW}/\text{mm}^2$  or even up to  $1\text{MW}/\text{mm}^2$
  - GaN is non-toxic, an advantage for in-body use
- 5
- PIEL is a signature of high efficiency, which in itself makes low heat load on tissue possible.
  - Feedback and control loop using PIEL, and/or
  - Data return using PIEL

In the embodiment of the power and data delivery system 100 that can be  
10 integrated into a catheter or guide wire 18 is shown in FIG. 1. By this means the circuit can send data. The input power from the laser can be changed to adjust to find the optimum working point for power efficiency (the Maximum Power Point, MPP). A feedback loop can be made in which the total luminescence (the sum of photoluminescence and photo-induced electroluminescence) is monitored to measure the load on the LED and from that to deduce  
15 the working point and power efficiency of the electronic circuit. This is illustrated in FIG. 2, which shows a graph with power load curves as a function of current through the LED for 4 different currents through the driving laser according to the present invention. Additionally, a data stream can modulate the input power on the laser to send data to the circuit. The circuit senses the associated modulation of the supply voltage within a given frequency band. This  
20 frequency band presumably lies at higher frequencies than that of the power adjustment control loop.

FIG. 2 shows a graph of power load curves as a function of current through the LED for 4 different currents through the driving laser according to the present invention; Measured data on an LED of type LD G5AP (OSRAM) with a surface area of  $0.4 \times 0.4 \text{ mm}^2$ .  
25 The graph shows power load curves as a function of current through the LED for 4 different currents through the driving laser. Clearly, the power that can be draw from the LED shows a maximum, this is the so-called maximum power point (MPP). The down-sloping lines belong to the right axis and correspond to the luminescence signal on a collecting photodetector, with the optics configured much like shown in Fig. 1, but with a lens replacing the optical  
30 fiber.

Comparing to FIG. 3 teaches us that the photovoltaic conversion efficiency in the MPP for this LED is approximately 10%. One can also see that the increase in output power is linear with input power; hence power density is not an issue at those power levels.

FIG. 3 shows a graph with laser power versus laser current. In FIG. 3, on the left axis, laser power versus laser current is shown; laser threshold is approximately 30 mA. The right axis gives the collected luminescent power from the OSRAM LED on the photodetector. Only a limited fraction of luminescence was collected. The power at closed circuit represents pure photoluminescence, the power at open circuit the total luminescence. The power was calculated using a photosensitivity of 0.234 A/W at 450 nm of the silicon detector and a load of 50 Ohm.

FIG. 4 shows another graph with load curves for two different LEDs. Thus, in FIG. 4, the load curve for two different LEDs is shown. The top curve shows the LD G5AP (OSRAM) with a surface area of  $0.4 \times 0.4 \text{ mm}^2$ , and the bottom curve the Luxeon Rebel Royal Blue (LUMILEDS) with a surface area of  $1.0 \times 1.0 \text{ mm}^2$ . Input power is 53 mW at a wavelength of 405 nm. The graph shows the maximum power points for each curve which correspond to 10% and 33% power efficiency respectively. With 33% conversion and 17.5 mW power, the LUMILEDS device seems rather suitable for power conversion.

It should be noted that the speed of modulation of a large area power LED is currently limited to the 100 kHz - 1 MHz range. Future developments may or may not change this. The use of a diode laser, such as used as light source for optical recording purposes may improve this to the 100 MHz - 1 GHz range. Alternatively, if a low modulation speed LED is used as power converter and receiver of the first data, a second device may be employed for transmitting the second data. For high speed communication, a VCSEL operating at for example 850 nm would do fine; the operating voltage and current are well within the scope of what has been described above and the data rate would increase to 10 Gb/s (Philips ULM Photonics makes such device and it is also relatively small). Again, the great disadvantage would be the position and alignment of the devices, the VCSEL and LED.

The optimum wavelength of power delivery depends on the band gap of the semiconductor. Roughly, the wavelength for power delivery should be about 5-20% shorter than the emission wavelength used for data transmission. The higher the band gap of the semiconductor, the shorter the emission and power-up wavelengths, and the higher the output voltage will be.

A high band gap (2.26 eV) semiconductor like Gallium phosphide (GaP) which emits at the green wavelength of 555 nm has optimum photovoltaic sensitivity at about 440 nm. Power delivery could be realized with, for example, a blue laser at 405 nm. Gallium nitride (GaN) has a band gap of 3.4 eV. Both GaP and GaN provide the potential to deliver power at directly useful voltages to drive Si-based electronics. Note that the maximum

voltage  $V$  that might be produced by the LED in photovoltaic mode is related to its emission wavelength  $\lambda$  by  $V = 1.24 \times 10^{-6} / \lambda$ . However, in practice this voltage will not be available, rather this equation gives the maximum voltage at 100% quantum efficiency (the inverse,  $S = V^{-1}$ , is called the photo sensitivity). There are at least three reasons why this voltage will not

5 be obtained in a practical situation:

- 1) Built-in potential (typically less favourable for materials with an indirect bandgap such as Si (1.12 eV), GaP (2.26 eV). Materials with a direct bandgap are for example GaAs (1.424 eV), InP (1.344 eV), GaN (3.4 eV), and also in particular  $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$  which is used for red emitting lasers (650 nm) and RCLEDs or VCSELs as well as the
- 10 high-energy junction on double and triple junction photovoltaic cells.
- 2) Photo absorption depth, this is directly related to the quantum efficiency. Typically, if one irradiates a photodiode at a wavelength just above the band gap, the absorption length in the material will be larger than the depletion depth, and hence many charge carriers will be lost, or, if total material thickness is small, the light will not be
- 15 absorbed at all
- 3) Forward leakage due to voltage built up and other losses in the diode (see below for an electronic model using the equivalent circuit).

Instead of using the indirect band-gap material like Si, or better, GaP (at 2.26 eV corresponding to 555 nm), it is possible and favourable to use the direct band-gap

20 material AlGaInP. Note that the latter has a transition to an indirect band gap at 555 nm. One finds that blue 470 nm LEDs made of GaInN/GaN seem to perform very well: the forward voltage (2.75 V at 1 mA) approaches the emission energy (2.64 eV) closely.

FIG.5 shows a flow chart of a method according to the present invention, more particularly the figure shows a method for supplying an optical probe with electrical energy and for sending and receiving data from the optical probe, the method comprising:

25 - providing (S1) an optical probe system according to the first aspect, said method further comprising:

- emitting (S2) a first radiation beam from the radiation source 6, said first radiation beam 2 comprising optical energy  $O_P$  and first data  $D_F$ ,

30 - converting (S3) at the optoelectronic device 15 said first radiation beam into electrical energy and receiving said first data,

- emitting (S4) said second radiation beam from the optoelectronic device 15 towards the photodetector.

To sum up, the present invention relates to an optical probe system 100 comprising an optical probe 18 having an optical converter circuit 10 with an optoelectronic device 15. The optoelectronic device is arranged for converting a first radiation beam 2 from a radiation source 6 into electrical energy and for receiving first data comprised in said first radiation beam. The optical converter circuit 10 is powerable by said electric energy in the first radiation beam 2. The optoelectronic device is further arranged for emitting a second radiation beam 3 towards a photodetector 5, said emission being inducible by the incoming first radiation beam, the second radiation beam comprising second data. The invention is advantageous for obtaining an improved optical probe system capable of obtaining a higher data transmission and/or a relatively high power at the distal end of the optical probe system with relatively high efficiency and simultaneous at small size.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfill the functions of several items recited in the claims.

The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. Any reference signs in the claims should not be construed as limiting the scope.

## CLAIMS:

1. An optical probe system (100), the system comprising:

- a radiation source (6) capable of emitting a first radiation beam, said first radiation beam (2) comprising optical energy (O\_P) and first data (D\_F),

5 - a photodetector (5), the photodetector being arranged for detecting a second radiation beam (3), and

- an optical probe (18), the optical probe being at its proximal end optically connected to the photodetector and the radiation source, the probe having an optical guide (8) capable of connecting the distal end with the proximal end, the optical probe having at its distal end an optical converter circuit (10), said circuit comprising:

10 - an application device (20), the application device being arranged for monitoring and/or manipulation at the distal end of the probe, the application device being arranged for generating second data (D\_R) indicative of the functionality of the application device, and

15 - an optoelectronic device (15), the optoelectronic device being arranged for converting said first radiation beam (2) into electrical energy and for receiving said first data, the first data being related to the functionality of the application device, the optoelectronic device further being arranged for emitting said second radiation beam (3) towards the photodetector, the second radiation beam comprising the second data, the optoelectronic device further being arranged for:

20 - converting said first radiation beam into electrical energy and for receiving said first data, and

- emitting said second radiation beam towards the photodetector, said emission being inducible by the incoming first radiation beam,

25 wherein the optical converter circuit (10) is powerable by said electric energy in the first radiation beam (2).

2. The system according to claim 1, wherein the optical guide (8) is arranged for guiding said first radiation beam (2) from the proximal end to the distal end, and further being arranged for guiding said second radiation beam (3) from the distal end to the proximal

end, the first radiation beam and the second radiation beam being arranged for being guided along the same optical path, or a parallel optical path, in said optical guide.

3. The system according to claim 2, wherein the optical guide comprises an  
5 optical fiber, the optical fiber comprising at least a part of the said optical path for the first radiation beam and the second radiation beam.
4. The system according to claim 1, wherein the system further comprises a  
10 control unit (CON), the control unit being operably connected to the radiation source and arranged for controlling the optical energy and providing the first data thereto, the control unit further being operably connected to the photodetector and arranged for receiving the second data therefrom.
5. The system according to claim 4, wherein the control unit is configured for  
15 operating a control loop for controlling the optical energy (O\_P) and/or the first data (D\_F) based, at least partly, on the second data (D\_F).
6. The system according to claim 1, wherein said second radiation beam (3) is  
20 dependent upon an electrical load on the optoelectronic device (15).
7. The system according to claim 4 and 6, wherein said control loop is arranged  
for optimizing the electrical load on the optoelectronic device (15).
8. The system according to claim 1, wherein the optoelectronic device (15)  
25 comprises a photovoltaic converter, preferably the optoelectronic device comprises a solid-state laser, or a light emitting diode (LED).
9. The system according to claim 1 or 8, wherein the optoelectronic device is a  
30 direct band-gap device, preferably a single junction device, where
- 1) the converting of said first radiation beam into electrical energy and receiving said first data, and
  - 2) the emitting of said second radiation beam towards the photodetector, said emission being inducible by the incoming first radiation beam, is arranged for taking place at said single junction.

10. The system according to claim 1, wherein the optoelectronic device is capable of performing photo-induced electroluminescence (PIEL).

5 11. The system according to claim 1, wherein the optical converter circuit is powerable solely by said electric energy from the optoelectronic device.

12. The system according to claim 1 or 11, wherein the optical converter circuit is powerable directly by said electric energy from the optoelectronic device without any voltage  
10 up up-conversion.

13. The system according to claim 1, wherein the application device comprises any one of:

- 15 - a temperature sensor,
- a pressure sensor,
- a chemical sensor,
- an ultrasound transducer (CMUT),
- a camera,
- a sensor for ionizing radiation (alpha, beta and/or gamma),
- 20 - an electric field sensor for example for measuring an ECG  
(electrocardiogram), and/or
- an electric stimulator or sensitizer.

14. An optical probe (18), the optical probe being at its proximal end optically  
25 connectable to an associated photodetector and an associated radiation source, the probe having an optical guide (8) capable of connecting the distal end with the proximal end, the optical probe having at its distal end an optical converter circuit (10), said circuit comprising:  
- an application device (20), the application device being arranged for monitoring and/or  
manipulation at the distal end of the probe, the application device being arranged for  
30 generating second data (D\_R) indicative of the functionality of the application device, and  
- an optoelectronic device (15), the optoelectronic device being arranged for converting a first radiation beam (2) into electrical energy and for receiving first data, the first data being related to the functionality of the application device, the optoelectronic device further being arranged for emitting a second radiation beam (3) towards the associated photodetector, the

second radiation beam comprising the second data,  
the optoelectronic device further having the capability of, upon receiving said first radiation  
beam:

- converting said first radiation beam into electrical energy and for receiving said first data,

5 and

- emitting said second radiation beam towards the associated photodetector, said emission  
being inducible by the incoming first radiation beam,

wherein the optical converter circuit (10) is powerable by said electric energy in the first  
radiation beam (2).

10

15. A method for supplying an optical probe with electrical energy and for  
sending and receiving data from the optical probe, the method comprising:

- providing (S1) an optical probe system according to any one of claims 1-13,  
said method further comprising:

15

- emitting (S2) a first radiation beam from the radiation source (6), said first  
radiation beam (2) comprising optical energy (O\_P) and first data (D\_F),

- converting (S3) at the optoelectronic device (15) said first radiation beam  
into electrical energy and receiving said first data,

20

- emitting (S4) said second radiation beam from the optoelectronic device (15)  
towards the photodetector.

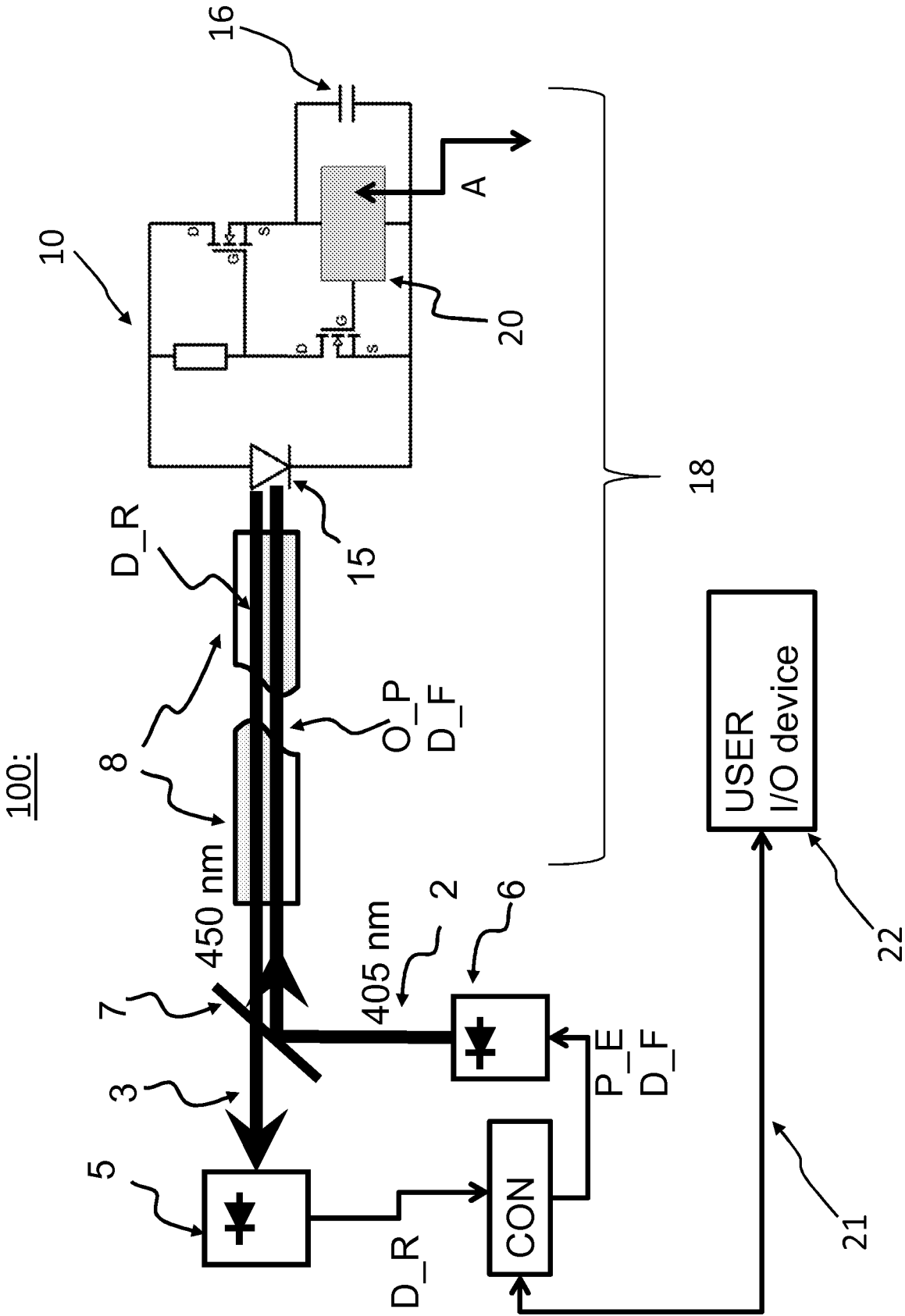


FIG. 1

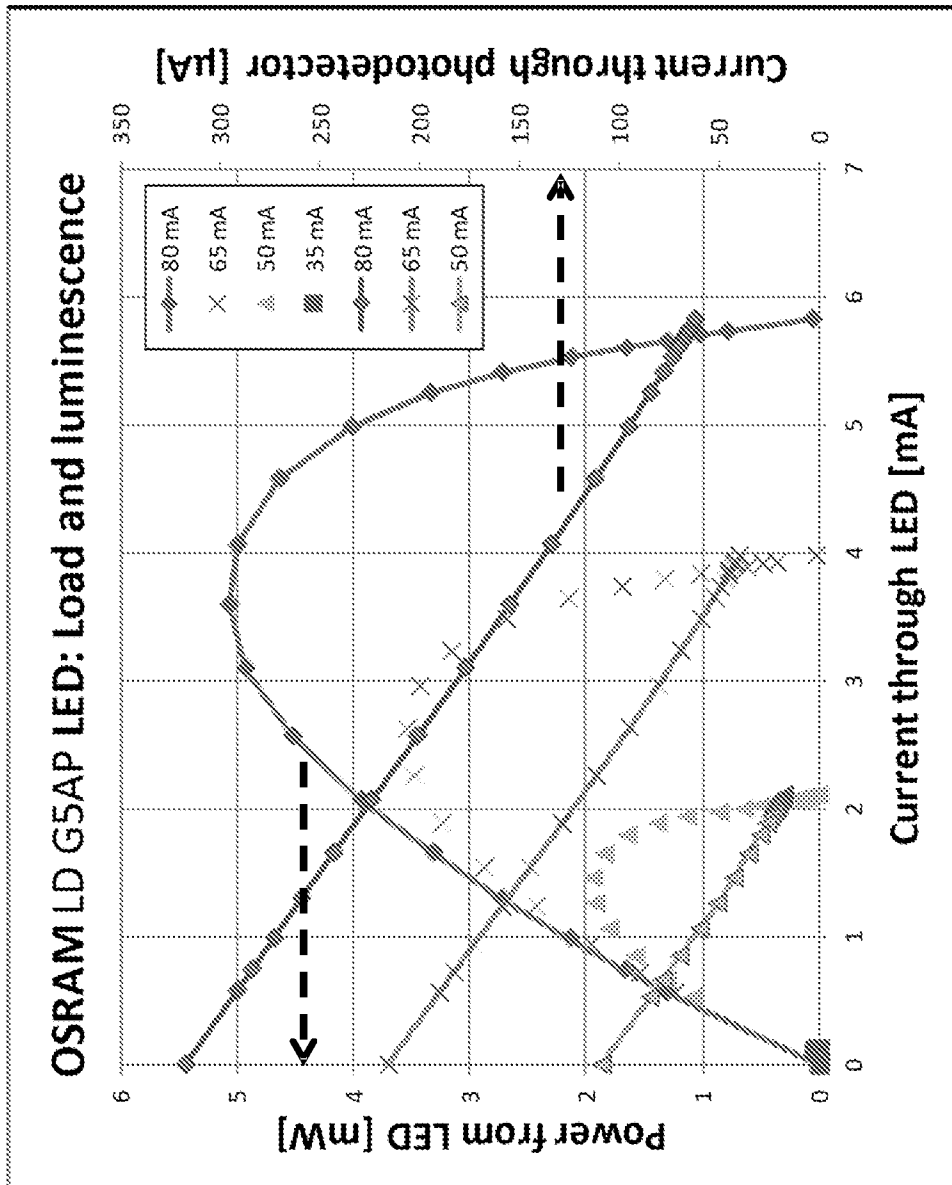


FIG. 2

OSRAM LD G5AP

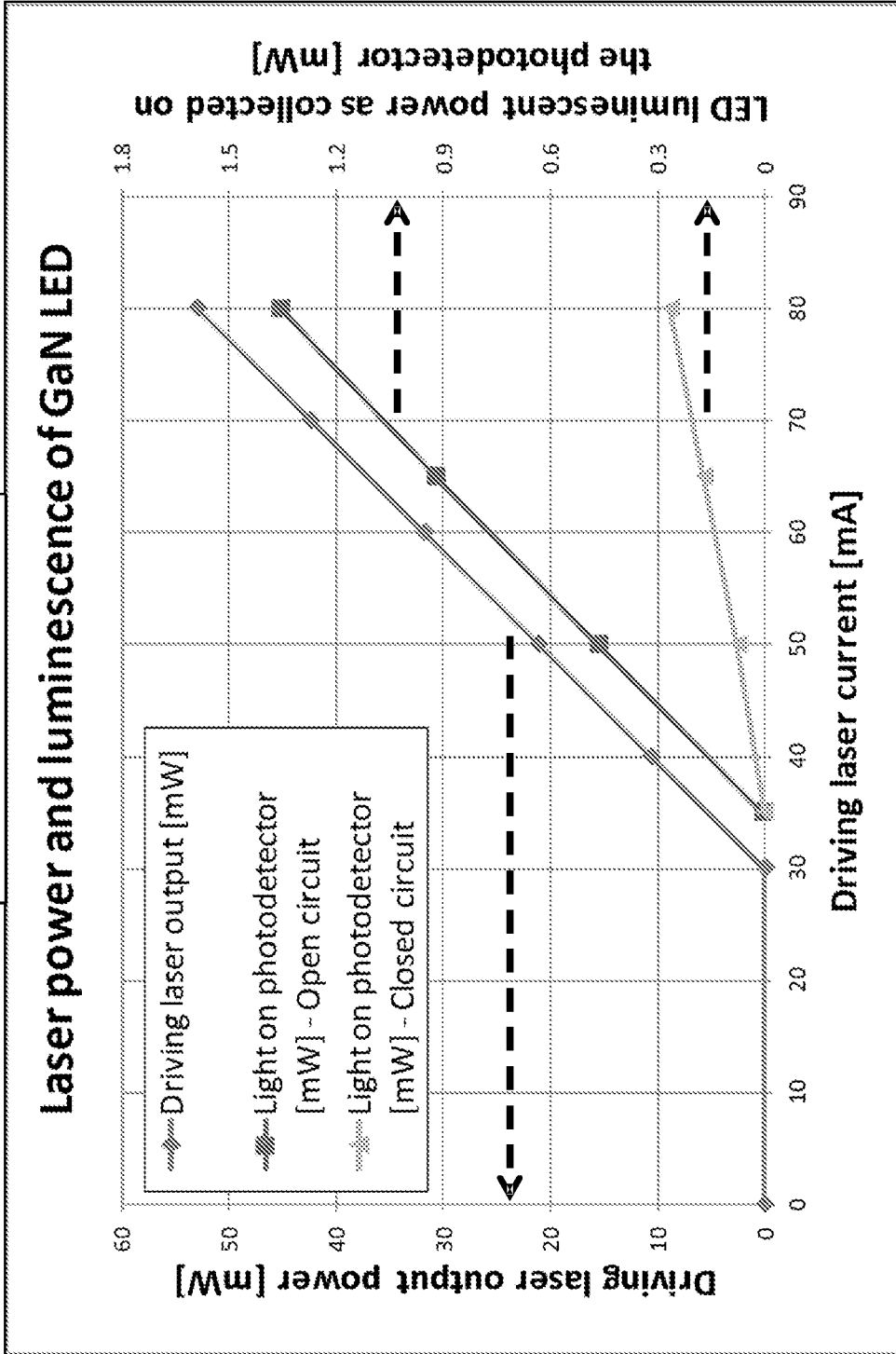


FIG. 3

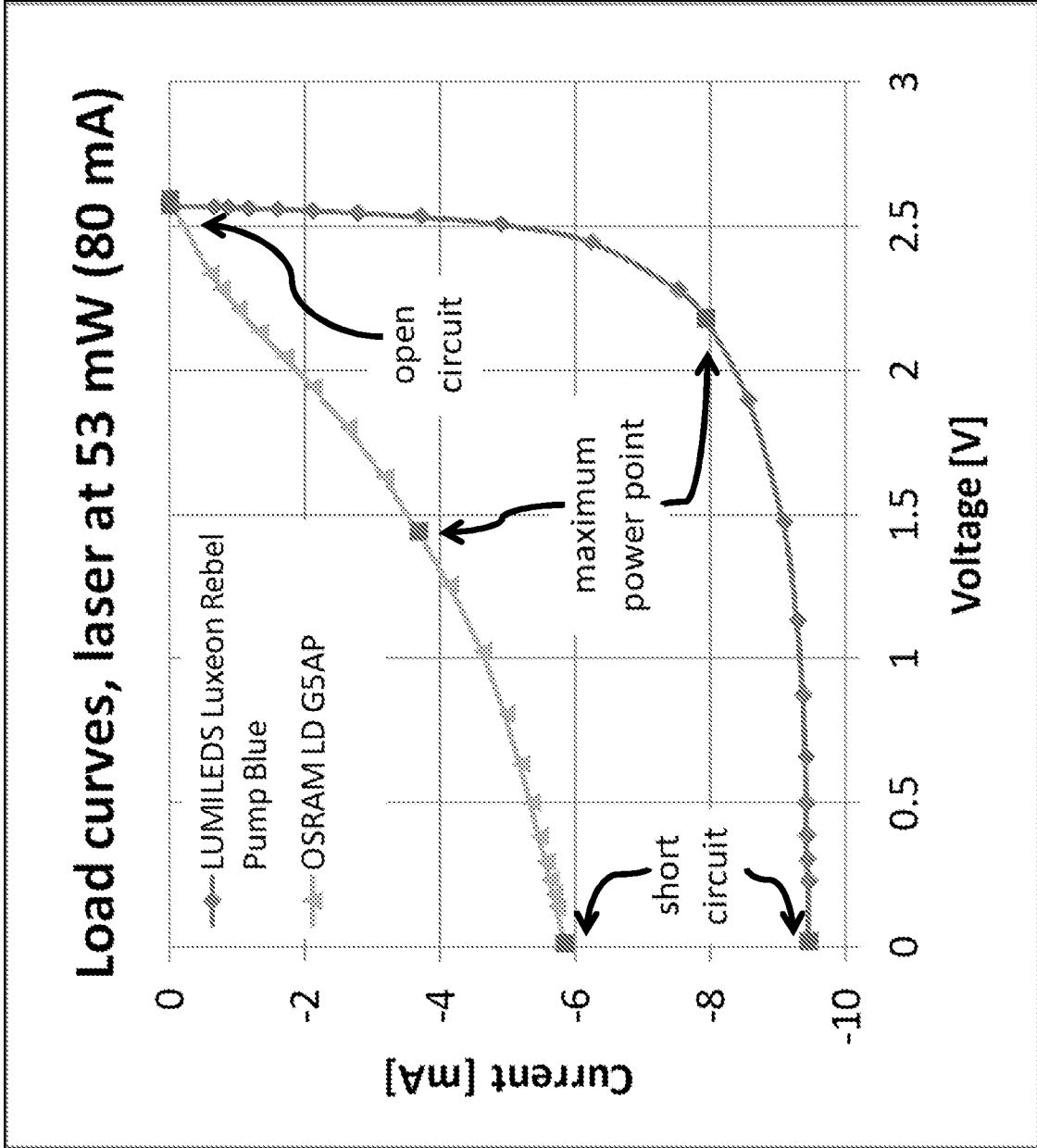


FIG. 4

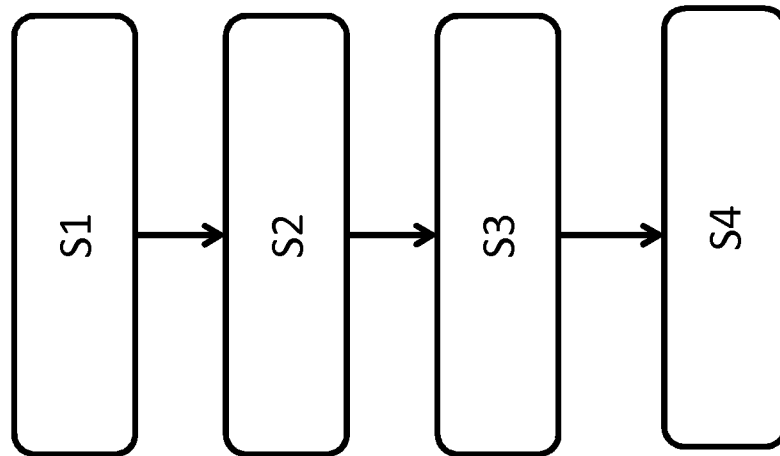


FIG. 5

# INTERNATIONAL SEARCH REPORT

International application No PCT/IB2013/059794
---

**A. CLASSIFICATION OF SUBJECT MATTER**  
 INV. A61B5/00 H04B10/80  
 ADD. A61B1/005 A61B8/12 A61B5/01 A61B5/0402 A61N1/00  
 H04B10/43

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)  
 H04B A61B

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, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 453 866 A (GROSS WALTER [DE]) 26 September 1995 (1995-09-26) column 1, lines 31, 32 column 3, line 58 - column 5, line 52 figure 1	1-15
X	US 2009/110148 A1 (ZHANG HONGXUAN [US] ET AL) 30 April 2009 (2009-04-30) paragraphs [0038] - [0040]; figure 3	1-15
X	US 5 528 409 A (CUCCI GERALD R [US] ET AL) 18 June 1996 (1996-06-18) column 3, line 10 - column 4, line 44; figure 1	1-15
X	US 2002/161309 A1 (MARRO DOMINIC P [US]) 31 October 2002 (2002-10-31) paragraphs [0015] - [0018]; figures 1-3	1-15
	-/--	

Further documents are listed in the continuation of Box C.       See patent family annex.

\* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"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</p> <p>"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</p> <p>"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</p> <p>"&amp;" document member of the same patent family</p>
---	---

Date of the actual completion of the international search  <b>11 March 2014</b>	Date of mailing of the international search report  <b>27/03/2014</b>
---	---

Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  <b>Mecking, Nikolai</b>
--	---

## INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2013/059794

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 4 417 140 A (ADOLFSSON MORGAN [SE] ET AL) 22 November 1983 (1983-11-22) column 2, line 42 - column 3, line 8; figure 1 -----	1-15
A	US 6 575 965 B1 (FITCH JOSEPH P [US] ET AL) 10 June 2003 (2003-06-10) column 9, line 1 - column 10, line 67; figures 10-14 -----	1-15
A	US 2011/044694 A1 (SCHERER AXEL [US] ET AL) 24 February 2011 (2011-02-24) paragraphs [0022] - [0026], [0045] - [0049]; figures 1,7 -----	1-15
A	JP S60 209717 A (OLYMPUS OPTICAL CO) 22 October 1985 (1985-10-22) abstract; figure 1 -----	1-15
A	SCHUBERT MARTIN ET AL: "Electroluminescence induced by photoluminescence excitation in GaInN/GaN light-emitting diodes", APPLIED PHYSICS LETTERS, AMERICAN INSTITUTE OF PHYSICS, US, vol. 95, no. 19, 10 November 2009 (2009-11-10), pages 191105-191105, XP012126380, ISSN: 0003-6951, DOI: 10.1063/1.3258488 cited in the application the whole document -----	1-15

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/IB2013/059794
---

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5453866	A	26-09-1995	AT 154716 T 15-07-1997 CA 2150814 A1 09-06-1994 DE 4240721 A1 16-06-1994 EP 0672284 A1 20-09-1995 JP H076288 A 10-01-1995 US 5453866 A 26-09-1995 WO 9412960 A1 09-06-1994
US 2009110148	A1	30-04-2009	US 2009110148 A1 30-04-2009 US 2012197094 A1 02-08-2012
US 5528409	A	18-06-1996	BR 9509304 A 23-12-1997 CA 2201894 A1 25-04-1996 DE 69520371 D1 19-04-2001 DE 69520371 T2 27-09-2001 EP 0801854 A1 22-10-1997 JP H10507602 A 21-07-1998 US 5528409 A 18-06-1996 WO 9612357 A1 25-04-1996
US 2002161309	A1	31-10-2002	AU 1241201 A 08-05-2001 US 2002161309 A1 31-10-2002 WO 0130232 A2 03-05-2001
US 4417140	A	22-11-1983	CA 1163458 A1 13-03-1984 DE 3173291 D1 06-02-1986 EP 0043929 A2 20-01-1982 JP H03680 B2 08-01-1991 JP S5729009 A 16-02-1982 SE 422111 B 15-02-1982 US 4417140 A 22-11-1983
US 6575965	B1	10-06-2003	NONE
US 2011044694	A1	24-02-2011	EP 2467881 A2 27-06-2012 US 2011044694 A1 24-02-2011 WO 2011022690 A2 24-02-2011
JP S60209717	A	22-10-1985	NONE

专利名称(译)	光学探针系统		
公开(公告)号	<a href="#">EP2916720A1</a>	公开(公告)日	2015-09-16
申请号	EP2013815577	申请日	2013-10-30
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦N.V.		
当前申请(专利权)人(译)	皇家飞利浦N.V.		
[标]发明人	VAN DER MARK MARTINUS BERNARDUS VAN DUSSCHOTEN ANNA HENDRIKA		
发明人	VAN DER MARK, MARTINUS BERNARDUS VAN DUSSCHOTEN, ANNA HENDRIKA		
IPC分类号	A61B5/00 H04B10/80 A61B1/005 A61B8/12 A61B5/01 A61B5/0402 A61N1/00 H04B10/43		
CPC分类号	A61B1/00029 A61B1/005 A61B5/01 A61B5/0402 A61B5/04282 A61B5/6851 A61B5/6852 A61B6/425 A61B8/12 A61B2560/0214 H04B10/2589 H04B10/40 H04B10/807 A61B1/00006 A61B1/00126 A61B1 /045 A61B1/051 A61B1/063 A61B1/0684 A61B1/07 A61B5/02055 A61B5/036 A61B5/1473 A61B6/00		
代理机构(译)	STEFFEN , THOMAS		
优先权	61/723853 2012-11-08 US		
外部链接	<a href="#">Espacenet</a>		

#### 摘要(译)

光学探针系统技术领域本发明涉及一种光学探针系统 ( 100 ) , 其包括光学探针 ( 18 ) , 该光学探针 ( 18 ) 具有带有光电子器件 ( 15 ) 的光学转换器电路 ( 10 ) 。光电子器件被布置用于将来自辐射源 ( 6 ) 的第一辐射束 ( 2 ) 转换成电能并用于接收包含在所述第一辐射束中的第一数据。光学转换器电路 ( 10 ) 可通过第一辐射束 ( 2 ) 中的所述电能供电。光电子器件还被布置用于朝向光电检测器 ( 5 ) 发射第二辐射束 ( 3 ) , 所述发射可由进入的第一辐射束诱导, 第二辐射束包括第二数据。本发明有利于获得一种改进的光学探针系统, 该光学探针系统能够以相对高的效率同时在小尺寸下在光学探针系统的远端获得更高的数据传输和/或相对高的功率。