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(71) Applicant(s):	QLM Technology Ltd Unit Dx, Albert Road, St. Philips, Bristol, BS2 0XJ, United Kingdom	(58) Field of Search:	INT CL G01N, G01S Other: WPI, EPODOC
(72) Inventor(s):	James Titchener Xiao Ai		
(74) Agent and/or Address for Service:	Lawrie IP Limited 310 St Vincent Street, GLASGOW, G2 5RG, United Kingdom		

(54) Title of the Invention: **Rapidly tuneable diode lidar**
Abstract Title: **Rapidly tuneable diode lidar**

(57) A lidar device 1 and method of operation comprises tuning a first emission wavelength 9 of a first output radiation 6 of a laser device 4 continuously within a first wavelength spectrum by modulating a drive current with a first drive current modulation with frequency of at least 100kHz. The first wavelength spectrum comprises a first spectral feature associated with at least part of a gas absorption spectrum of at least one gas 2, modulating the first output radiation of the laser device with a first output modulation 16 comprising a first plurality of binary pulses, scanning the first wavelength spectrum at a rate of at least 1µm per second, projecting the first output radiation towards a target area 18, receiving scattered radiation 20 from the first target area at detector 22, and processing the scattered radiation.

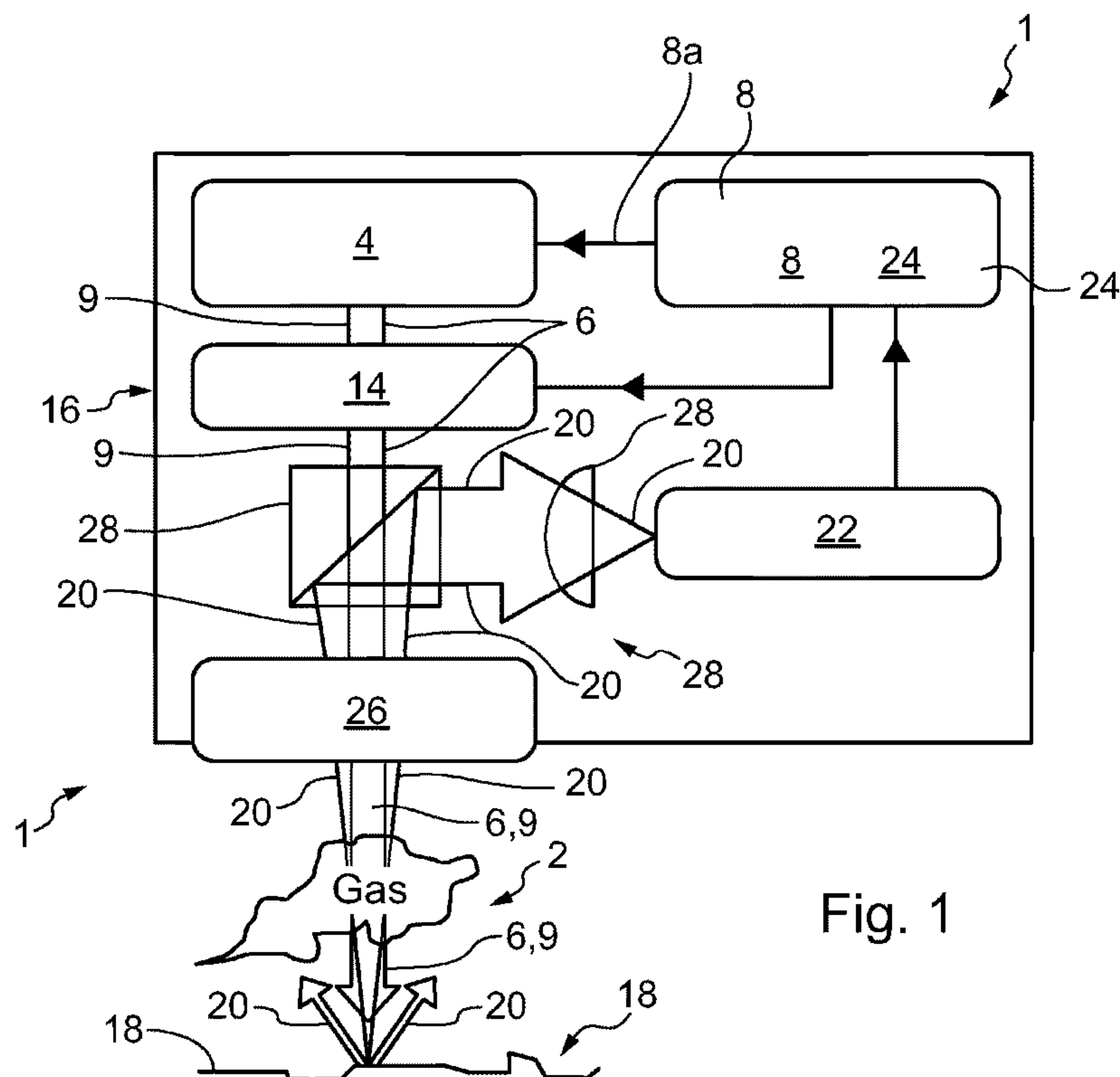
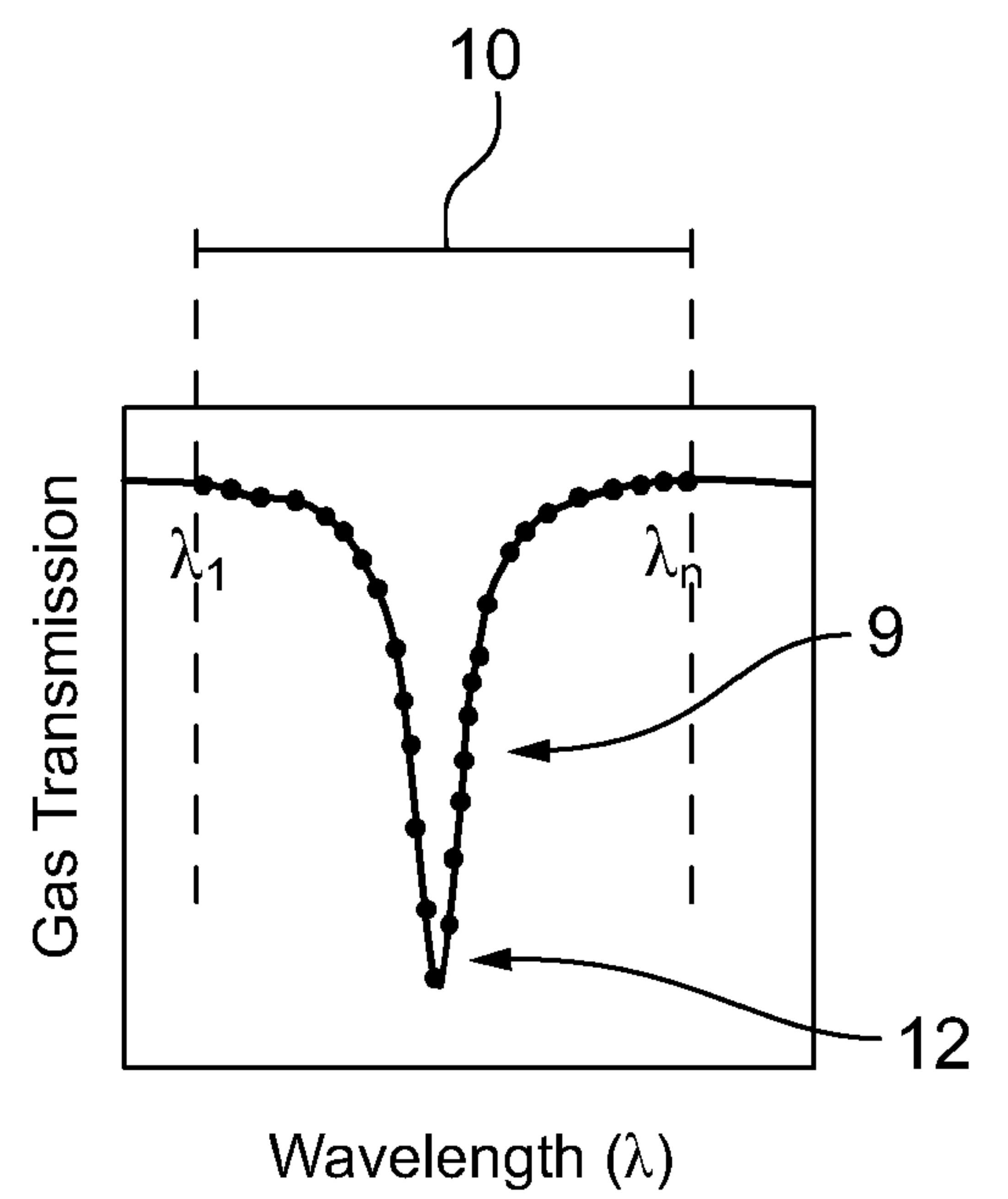
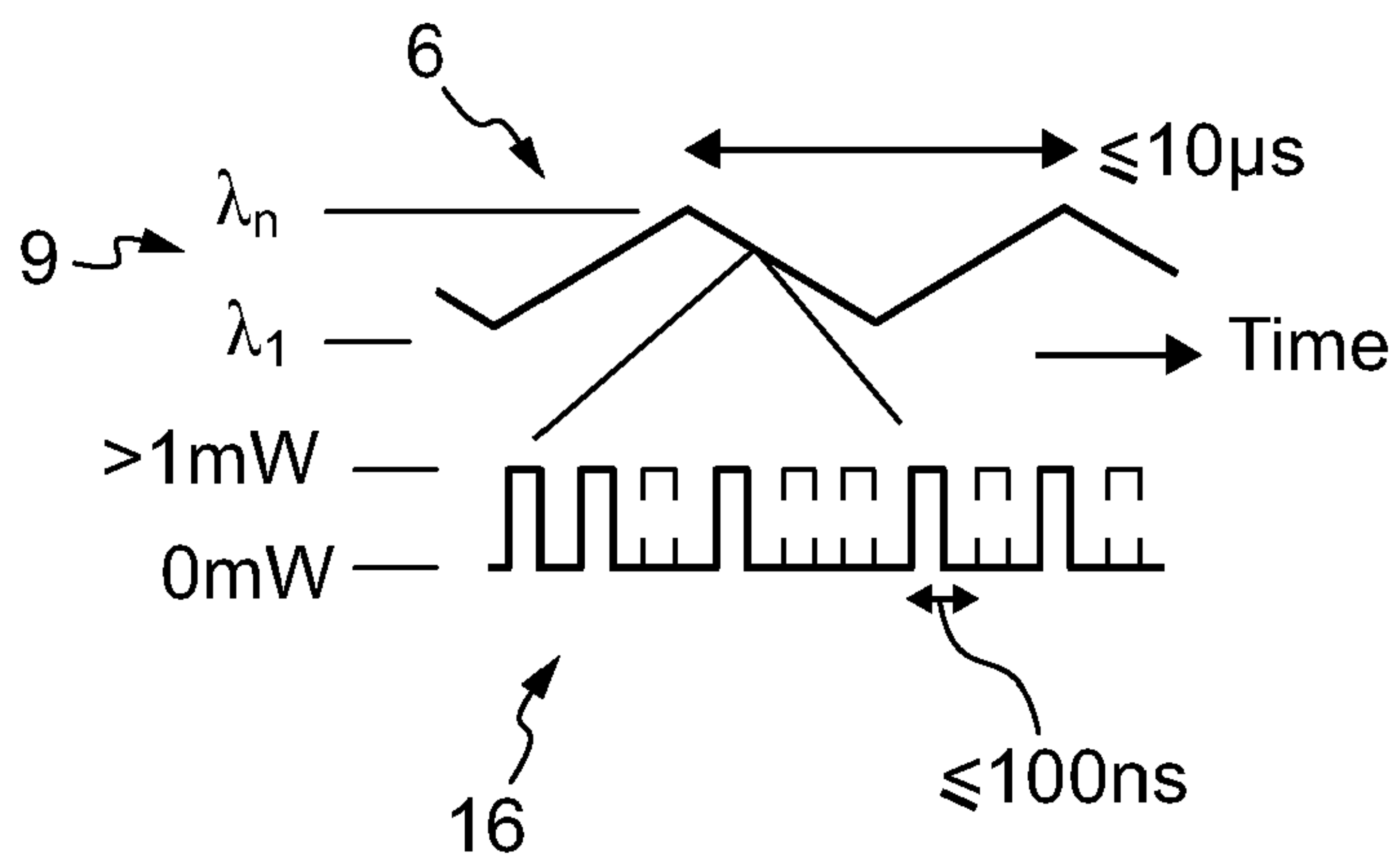
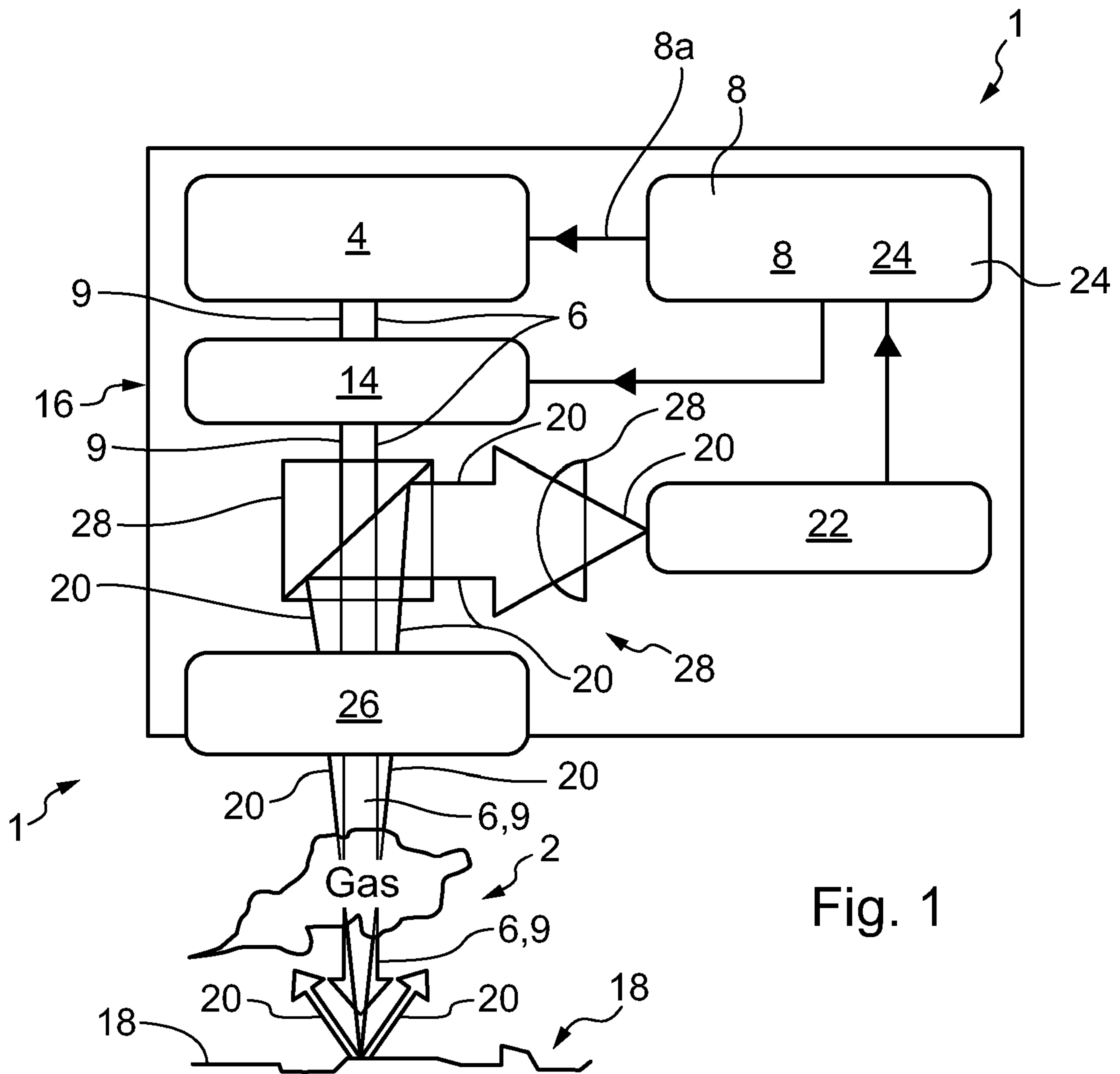
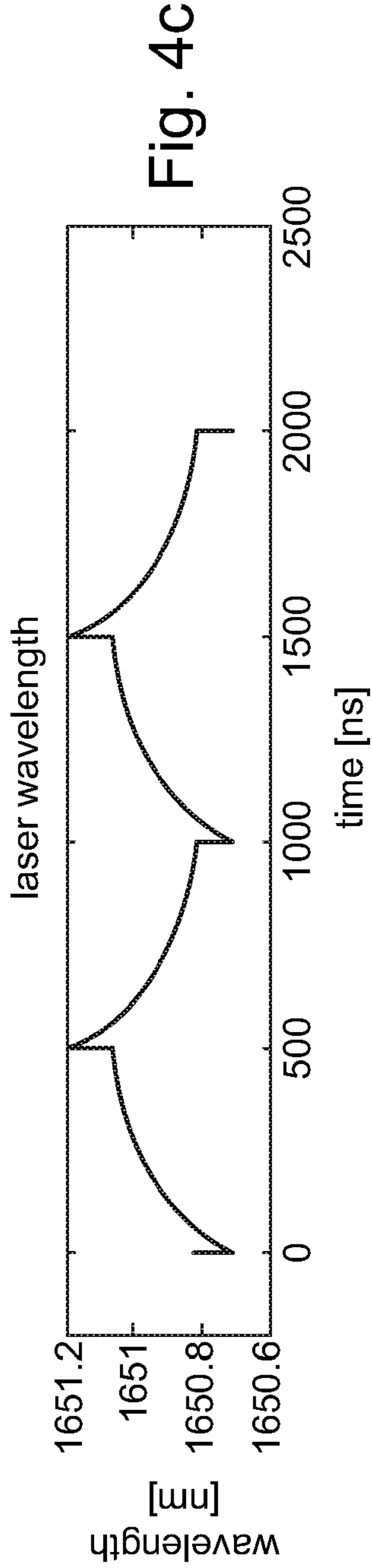
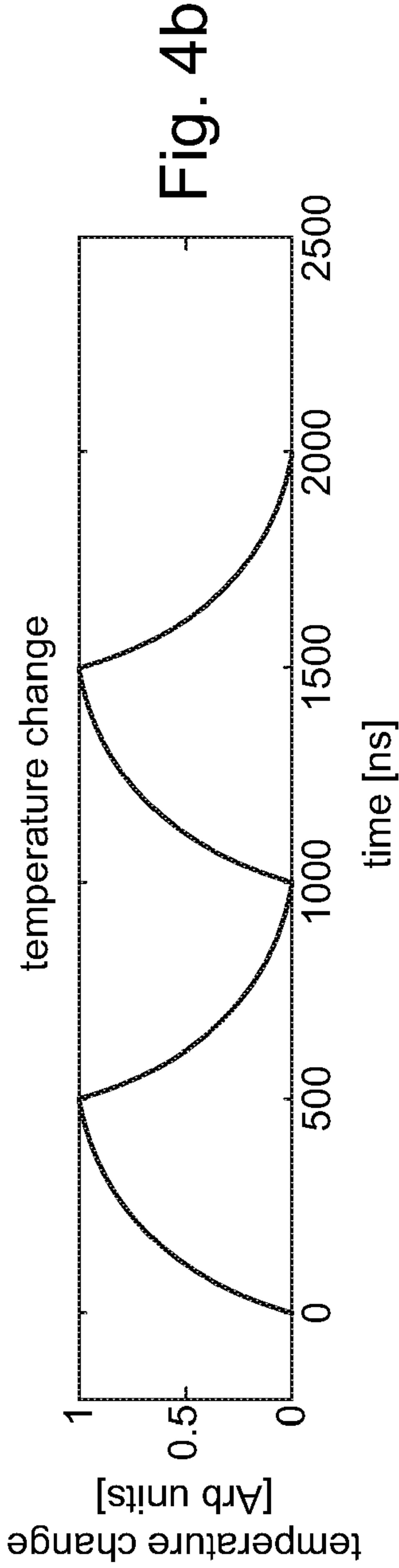
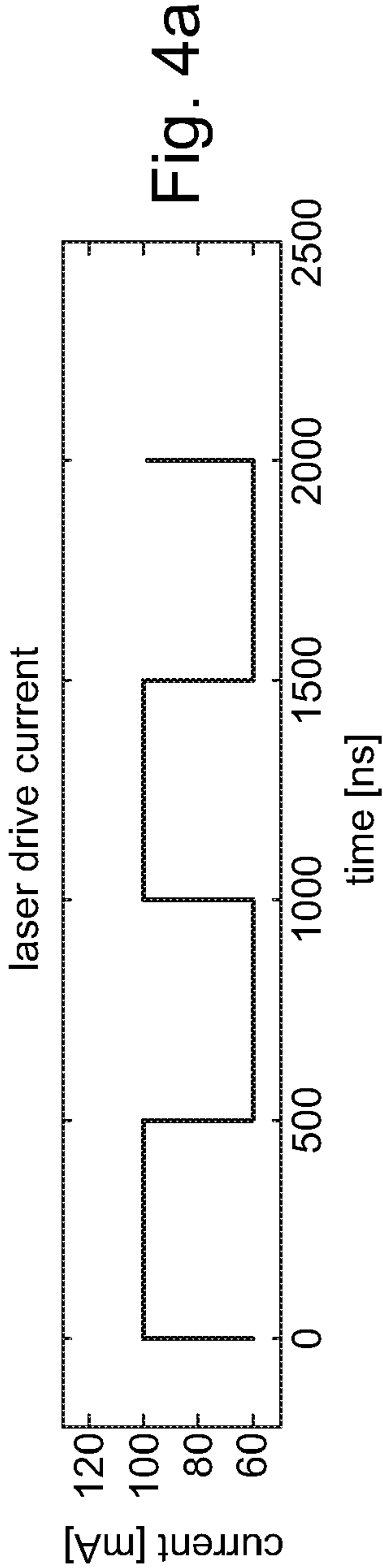


Fig. 1





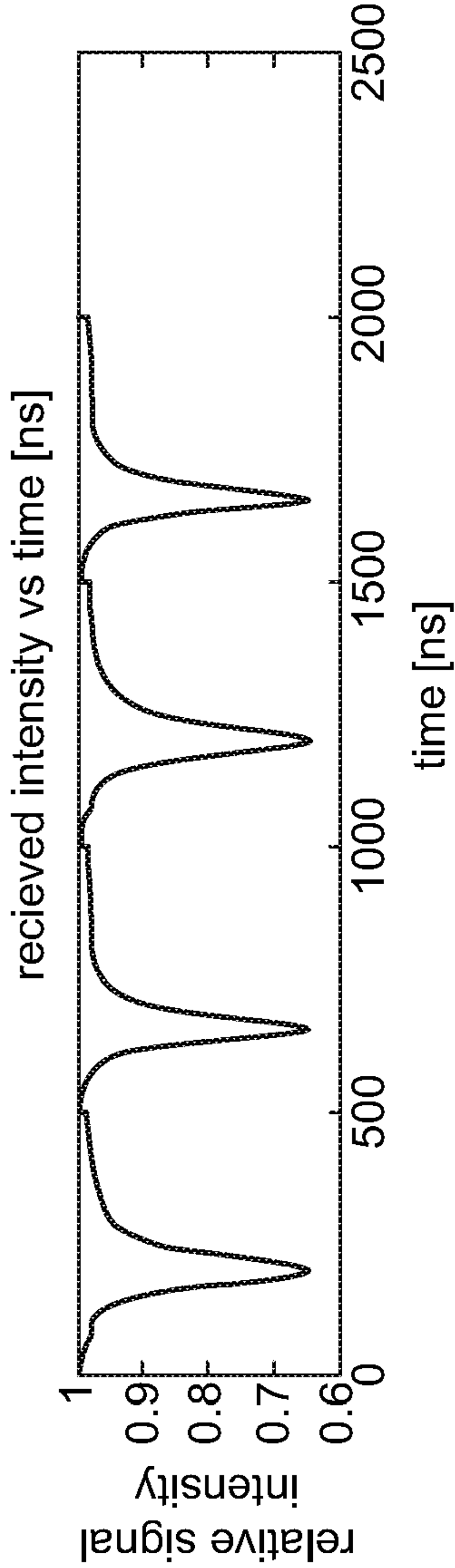


Fig. 4d

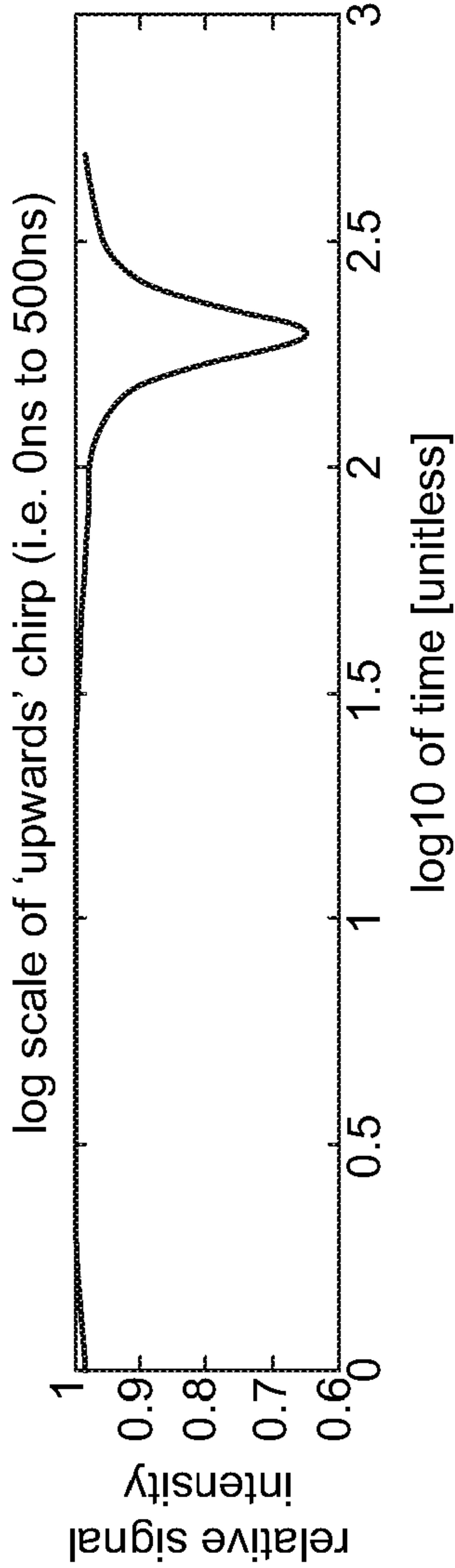


Fig. 4e

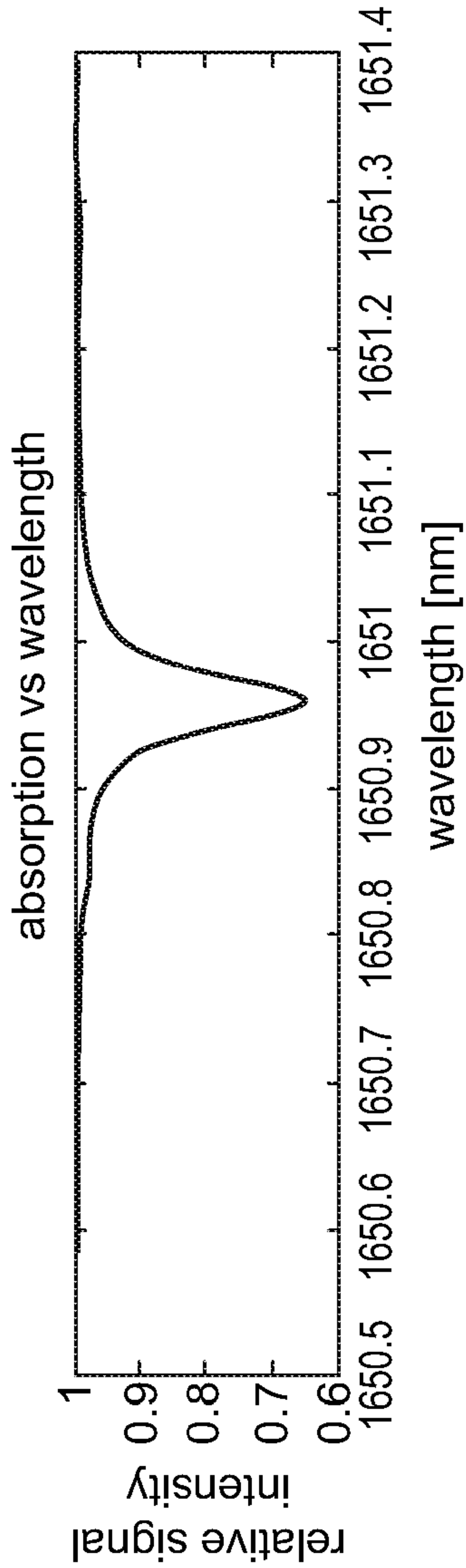


Fig. 4f

Rapidly Tuneable Diode Lidar

Field of the invention

5 The present invention relates particularly, but not exclusively, to an optical device and associated methods of use. The present invention also relates particularly, but not exclusively, to an optical device for detecting the presence or concentration of gas in the atmosphere, and to improvements in lidar-based devices and methods.

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Background to the invention

Optical devices, such as laser-based optical devices, are often used to detect a substance, such as an atmospheric gas. Typically, such optical
15 devices can be used to scan an area to determine the presence of a gas.

Some known optical devices, such as differential absorption lidar systems, typically work by outputting pulse radiation at an “on” wavelength (associated with a particular feature of a gas, such as the absorption
20 coefficient) and an “off” wavelength, relatively far removed from the “on” wavelength. However, such systems suffer from a number of drawbacks, such as the complex and, often, expensive components required to implement the “on” and “off” wavelength locking. Furthermore, the high peak power of such pulsed systems can damage the optical components
25 thereof. Moreover, such pulsed systems results in low wall-plug efficiencies, at least when using pulsed laser(s) to provide the “on” and “off” output radiation.

The inventors have appreciated the shortcomings in such known optical
30 devices.

According to a first aspect of the present invention there is provided an
5 optical device,

wherein the optical device is operable to output first output radiation, wherein the first output radiation comprises a continuous wave output;

wherein the optical device is operable to tune a first emission
10 wavelength of the first output radiation continuously within a first wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of a first substance;

wherein the optical device is operable to apply a first output modulation to the first output radiation;

15 wherein the optical device is operable to transmit the first output radiation towards a first target location and to collect or receive scattered radiation, the scattered radiation having been at least partially modified by the first substance in the first target location; and

wherein the optical device is operable to process the received
20 scattered radiation.

The optical device may be configured to detect one or more substances. The optical device may be configured to detect a plurality of substances. The optical device may be configured to detect the presence of one or
25 more substances in one or more target locations, or environments. The optical device may be configured to measure the concentration of one or more substances. The optical device may be configured to detect the presence, or concentration, of the, or each, substance in the atmosphere.

The optical device may be configured to detect the presence, or concentration, of the, or each, substance when the, or each, substance is located remote from the optical device. The optical device may be configured to detect the presence, or concentration, of the, or each, substance when the, or each, substance is located at a distance of up to approximately 200 km, optionally up to approximately 100 km, optionally up to approximately 100 metres from the optical device.

The first substance may be a gas. At least one of the substances may be a gas. The, or each, substance may be a gas. The, or each, substance may be one or more gases, liquids, solids and/or plasmas. The optical device may be configured to detect one or more gases. The optical device may be configured to detect one or more gases present in at least a part of the atmosphere. The, or each, substance may be at least one of: carbon dioxide (CO₂), nitrous oxide (N₂O), carbon monoxide (CO), ammonia (NH₃), ethylene (C₂H₄) and methane (CH₄).

The optical device may be operable to perform one or more scans of the first target location. The optical device may be operable to perform one or more scans of one or more target locations. The optical device may be operable to transmit the first output radiation to one or more target locations. The optical device may be operable to transmit the first output radiation to a plurality of target locations. At least two of the target locations may be adjacent to each other. The target locations may be remote from each other. The optical device may be operable to scan at least a part of the atmosphere. The optical device may be operable to perform one or more scans of one or more atmospheric target locations. In this arrangement, the optical device is operable to obtain measurement data associated with at least one substance in at least two dimensions of space, by scanning one or more target locations. The scan may include

one or more two-dimensional scans and/or one or more three-dimensional scans. The device may be movable to one or more target locations.

The optical device may be configured as a Lidar device. The optical
 5 device may be operable to perform one or more Lidar scans. The optical
 device may be operable to measure the distance between at least a part
 of the optical device and one or more targets, objects, substances, or the
 like. The optical device may be operable to measure the volume of one or
 more targets, objects, substances, or the like. The optical device may be
 10 operable to measure a cross-sectional area of one or more targets,
 objects, substances, or the like. The optical device may be operable to
 measure a trajectory of one or more targets, objects, substances, or the
 like. The optical device may be operable to locate, or detect, one or more
 sources of one or more targets, objects, substances, or the like. The
 15 source may be a source of one or more gases.

The optical device may be operable to output one or more different types
 of output radiation, wherein each output radiation comprises a continuous
 wave output. The optical device may be operable to output a plurality of
 20 different types of output radiation, wherein each output radiation
 comprises a continuous wave output. The optical device may be operable
 to receive one or more types of scattered radiation, the, or each, scattered
 radiation being associated with a type of output radiation. The optical
 device may be operable to receive a plurality of types of scattered
 25 radiation, each type of scattered radiation being associated with a type of
 output radiation. The optical device may be operable to receive a plurality
 of types of scattered radiation, the plurality of types of scattered radiation
 including at least one of: specular or diffuse, and each type of scattered
 radiation being associated with a type of output radiation.

The optical device may be operable to output first output radiation in the infrared, visible, ultraviolet, and/or the microwave region of the electromagnetic spectrum. The optical device may be operable to output first output radiation in the terahertz region of the electromagnetic spectrum. The optical device may be operable to output one or more types of output radiation in the infrared, visible, ultraviolet, and/or the microwave region of the electromagnetic spectrum. The optical device may be operable to output first output radiation having a wavelength of between approximately 1.65 μm and 1.652 μm , optionally between approximately 1.6506 μm and approximately 1.6512 μm .

The optical device may be operable to receive or collect scattered radiation in the infrared, visible, ultraviolet, and/or the microwave region of the electromagnetic spectrum. The optical device may be operable to receive or collect scattered radiation having a wavelength of between 1.65 μm and 1.652 μm , optionally between approximately 1.6506 μm and approximately 1.6512 μm .

The first output radiation comprises a continuous wave (CW) output and the optical device may be operable to apply a first output random or quasi-random modulation (RM) to the first output radiation. In this arrangement, the optical device is a CW-RM device. The first optical device may be configured to be a CW-RM Lidar device.

The first spectral feature may be associated with an electromagnetic transmission coefficient of the first substance. The first spectral feature may be associated with an electromagnetic absorption coefficient of the first substance. The first spectral feature may be associated with the absorption coefficient of at least one substance. The first spectral feature may be associated with the absorption coefficient of at least one gas. The

first spectral feature may be associated with the transmission coefficient of at least one gas.

5 The optical device may be operable to tune the first emission wavelength of the first output radiation continuously within a first wavelength spectrum, the first wavelength spectrum comprising one or more, or a plurality of, spectral features associated with one or more, or a plurality of, characteristics of at least one substance.

10 The optical device may be operable to tune a plurality of emission wavelengths of a plurality of output radiation continuously within a plurality of wavelength spectra. Each wavelength spectra may comprise one or more, or a plurality of, spectral features associated with one or more, or a plurality of, characteristics of one or more substances.

15 The optical device may be configured to process received scattered radiation and to fit the processed data to one or more measured absorption spectra to detect the presence, or concentration, of one or more substances.

20 The optical device may comprise one or more laser devices. The optical device may comprise a plurality of laser devices. The optical device may comprise a single laser device. The, or each, laser device may be operable to output the first output radiation. Each laser device may be
25 operable to output radiation in an associated wavelength spectrum. The optical device may comprise a plurality of laser devices, with each single laser device being associated with a unique wavelength spectrum, such that no two laser devices are configured to output the same wavelength spectrum.

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The optical device may comprise one or more laser devices, and the optical device may be operable to tune the emission wavelength of the, or each laser device continuously within a wavelength spectrum. Each wavelength spectrum of each laser device may comprise one or more spectral features associated with one or more characteristics of one or more substances.

The optical device may comprise one or more control elements. The optical device may comprise a plurality of control elements.

The optical device may comprise one or more modulators. The optical device may comprise a plurality of modulators. The optical device may comprise a single modulator. The, or each, modulator may be operable to apply the first output modulation to the first output radiation.

The optical device may comprise one or more optical transceiver systems. The optical device may comprise a plurality of optical transceiver systems. The optical device may comprise a single optical transceiver system. The optical transceiver system may be operable to transmit the first output radiation. The optical transceiver system may be operable to receive the scattered radiation. The optical transceiver system may be operable to transmit the first output radiation and to receive the scattered radiation. The optical device may comprise a single optical transceiver system and the single optical transceiver system may be operable to transmit the first output radiation and to receive the scattered radiation. The optical transceiver system may be operable to transmit the first output radiation to the first target location.

The optical transceiver system may be operable to transmit a plurality of types of output radiation. The optical transceiver system may be operable

to receive a plurality of scattered radiation. In this arrangement, the optical transceiver system is operable to transmit a plurality of types of output radiation having different wavelengths and to receive a plurality of corresponding scattered radiation having different wavelengths.

5

The optical transceiver system may comprise one or more transmitter modules and one or more receiver modules. The optical transceiver system may include a common transmitter and receiver module. The optical transceiver system may include a discrete transmitter module and a discrete receiver module. The transmitter module and the receiver module may be arranged to be coaxial. The transmitter module and the receiver module may be arranged to be confocal. The transmitter module and the receiver module may be integrally formed. The transmitter module and the receiver module may be configured as a single transceiver module.

15

The optical transceiver system may comprise one or more telescope devices. The transmitter module may comprise a telescope device. The receiver module may comprise a telescope device. The transmitter module and the receiver module may be formed by one or more telescope devices. The transmitter module and the receiver module may be formed from a single telescope device.

20

The optical device may comprise one or more detectors. The optical device may comprise a plurality of detectors. The optical device may comprise a single detector. The detector may be an optical detector. The detector may be a photodetector. The detector may be configured to receive electromagnetic radiation. The detector may be operable to receive the scattered radiation. The detector may be operable to receive the scattered radiation via the optical transceiver system.

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The optical device may comprise one or more processing elements. The optical device may comprise a plurality of processing elements. The, or each, processing element may be operable to process the received scattered radiation received or collected by the detector.

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The optical device may be configured to be mountable to a frame member, a vehicle, an aerial vehicle, an unmanned vehicle, an unmanned aerial vehicle, and/or a helicopter. The optical device may be mountable to a satellite apparatus. The optical device may be configured to be a portable
10 device. The optical device may be configured to be a lightweight device.

The optical device may include one or more optical guide elements. The optical guide elements may be configured to guide the received scattered radiation to the, or each, detector. The optical guide elements may be
15 configured to direct the received scattered radiation from the optical transceiver system to the detector. The optical guide elements may be configured to direct the received scattered radiation away from the modulator and/or the laser device.

20 The laser device may be a tuneable laser device. In this arrangement, the emission wavelength of the laser device is tuneable.

The drive current of the laser device may be configured to be adjustable. The laser device may be configured to output the first output radiation at
25 one or more drive currents. The emission wavelength of the first output radiation may be determined, at least in part, by the laser drive current. The laser device may be configured such that changing the laser drive current causes the temperature of the active region of the laser device to change.

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The laser device may be a semiconductor laser device. The laser device may be a diode laser device. The laser device may be a narrow-linewidth laser device. The laser device may be a distributed feedback (DFB) laser device. The laser device may be an indium phosphide laser device.

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The laser device may be operable to output first output radiation at one or more wavelengths. The laser device may be operable to output first output radiation at a plurality of wavelengths. The laser device may be operable to output first output radiation at one or more wavelengths in the infrared, visible, ultraviolet, and/or microwave regions of the electromagnetic spectrum. The laser device may be operable to output first radiation in the short-wave infrared region of the electromagnetic spectrum.

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15 The laser device may be operable to receive one or more signals from the control element. The laser device may be operable to receive one or more signals from the control element, and the laser device may be operable to adjust the laser drive current based, at least in part, on the signals received from the control element.

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The optical device may be operable to scan the first wavelength spectrum at a frequency of at least approximately 90 kHz, or at least approximately 100 kHz, or at least approximately 180 kHz, or at least approximately 200 kHz, or at least approximately 1 MHz, or at least approximately 2 MHz, or at least approximately 100 MHz, or at least approximately 200 MHz. The optical device may be operable to scan the first wavelength spectrum at a frequency of between approximately 90 kHz and approximately 200 MHz, optionally between approximately 100 kHz and approximately 100 MHz, optionally between approximately 100 kHz and approximately 2 MHz, optionally between approximately 100 kHz and approximately 1 MHz,

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optionally between approximately 200 kHz and approximately 1 MHz,
 optionally between approximately 200 kHz and approximately 2 MHz. In
 this arrangement, the optical device is operable to sweep the emission
 wavelength of the first output radiation continuously from the minimum
 5 wavelength of the first wavelength spectrum to the maximum wavelength
 of the first wavelength spectrum at a frequency of at least approximately
 90 kHz, or at least approximately 100 kHz, or at least approximately 180
 kHz, or at least approximately 200 kHz, or at least approximately 1MHz, or
 at least approximately 2 MHz, or at least approximately 100 MHz, or at
 10 least approximately 200 MHz.

The optical device may be operable to tune the emission wavelength of
 the first output radiation at a rate of at least 1 μm per second. The optical
 device may be operable to tune the emission wavelength of the first output
 15 radiation at a rate of at least 1 mm per second. The optical device may be
 operable to tune the emission wavelength of the first output radiation at a
 rate of at least 10 mm per second. The optical device may be operable to
 tune the emission wavelength of the first output radiation at a rate of at
 least 10 m per second.

20 The optical device may be operable to tune the emission wavelength of
 the first output radiation at a rate of between 1 μm per second and 10 m
 per second, optionally between 1 μm per second and 1 mm per second,
 optionally between 1 μm per second and 10 mm per second,
 25 optionally between 1 mm per second and 10 mm per second, optionally
 between 1 mm per second and 10 m per second.

The first wavelength spectrum may have a wavelength range of at least
 approximately 10 pm. The first wavelength spectrum may have a
 30 wavelength range of at least approximately 100 nm. The first wavelength

spectrum may have a wavelength range of between approximately 10 pm and approximately 100 nm.

5 The optical device may be operable to scan the first wavelength spectrum at a frequency of 100 kHz and the first wavelength spectrum may have a wavelength range of 10 pm. In this arrangement, the optical device is operable to scan the first wavelength spectrum at a rate of 1 μ m per second.

10 The optical device may be operable to scan the first wavelength spectrum at a frequency of 100 MHz and the first wavelength spectrum may have a wavelength range of 10 pm. In this arrangement, the optical device is operable to scan the first wavelength spectrum at a rate of 1 mm per second.

15 The optical device may be operable to scan the first wavelength spectrum at a frequency of 100 kHz and the first wavelength spectrum may have a wavelength range of 100 nm. In this arrangement, the optical device is operable to scan the first wavelength spectrum at a rate of 10 mm per
20 second.

The optical device may be operable to scan the first wavelength spectrum at a frequency of 100 MHz and the first wavelength spectrum may have a wavelength range of 100 nm. In this arrangement, the optical device is
25 operable to scan the first wavelength spectrum at a rate of 10 m per second.

The optical device may be operable to continuously tune the first emission wavelength within the first wavelength spectrum and to perform multiple
30 scans within the first wavelength spectrum. In this arrangement, the

optical device is operable to continuously scan the first wavelength spectrum.

The first wavelength spectrum may include one or more spectral features associated with one or more characteristics of the first substance. The optical device may be operable to tune the first emission wavelength of the first output radiation to be at an emission wavelength that is not associated with the, or each, spectral feature, and to tune the first emission wavelength of the first output radiation to be at an emission wavelength that is associated with at least one of the spectral features. In this arrangement, the optical device is operable to output first output radiation at one or more “off” wavelengths and one or more “on” wavelengths. The optical device is operable to continuously tune the first emission wavelength between the one or more “off” wavelengths and the one or more “on” wavelengths.

The control element may be operable to tune the first emission wavelength of the first output radiation continuously within the first wavelength spectrum. The control element may be operable to cause the laser device to tune the first emission wavelength of the first output radiation continuously within the first wavelength spectrum. In this arrangement, the control element is operable to continuously tune the emission wavelength within the first wavelength spectrum, such that the emission wavelength varies continuously over time.

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The control element may be configured to tune the emission wavelength of the first output radiation in a non-linear manner over time.

The control element may be an electronic control element, module, or the like. The, or each, control element may be operable to tune the first

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emission wavelength of the first output radiation continuously within a first wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of the first substance. The control element may be configured to control at least one operating
 5 parameter of the, or each, laser device. The control element may be configured to tune the first drive current of the laser device. The control element may be configured to adjust the first drive current of the laser device between a plurality of discrete drive current values.

- 10 The control element may be configured to tune the drive current of the laser device at a frequency of at least approximately 90 kHz, or at least approximately 100 kHz, or at least approximately 200 kHz, or at least approximately 100 MHz, or at least approximately 200 MHz. The optical
 15 device may be operable to scan the first wavelength spectrum at a frequency of between approximately 90 kHz and approximately 200 MHz, optionally between approximately 100 kHz and approximately 100 MHz, optionally between approximately 100 kHz and approximately 2 MHz, optionally between approximately 100 kHz and approximately 1 MHz, optionally between approximately 200 kHz and approximately 1 MHz,
 20 optionally between approximately 200 kHz and approximately 2 MHz. The control element may be operable to tune the drive current of the laser device using a square wave signal. The square wave signal may have a duty cycle of approximately 50 %. The control element may be operable to tune the drive current of the laser device between approximately 80 mA
 25 and approximately 120 mA, optionally between approximately 60 mA and approximately 100 mA, optionally between approximately 60 mA and approximately 120 mA.

The control element may be operable to provide control data to the
 30 modulator. The modulator may be configured to apply the first output

modulation to the first output radiation based, at least in part, on the control data received from the control element.

5 The modulator may include one or more optical amplifiers, electro-optic modulators, acousto-optic modulators and/or semiconductor optical amplifiers (SOA). The modulator may be configured to output the modulated first output radiation.

10 The first output modulation may include a random or quasi-random modulation element. The first output modulation may include a binary modulation element. The first output modulation may comprise a first plurality of binary pulses. The first output modulation may include a digital modulation element. The first output modulation may include an on/off modulation element. The first output modulation may include a
15 substantially square-wave modulation element.

The first output modulation may comprise a plurality of pulses. the first plurality of pulses may comprise at least one of: a plurality of pulses in a random pulse sequence; a plurality of pulses in a pseudo-random
20 sequence; or a plurality of pulses in a predefined sequence.

The first output modulation may include a modulation frequency of at least approximately 10 MHz, optionally at least approximately 33 MHz. The first output modulation may include a substantially square-wave modulation
25 element having a duty cycle of approximately 50%.

The optical device may be operable to apply the first output modulation to the first output radiation using an amplitude modulation process. The optical device may be operable to apply the first output modulation to the

first output radiation by adjusting the power level of the first output radiation.

The detector may be an electronic detector. The detector may include one
5 or more semiconductor-based detector devices. The detector may include one or more single-photon detector devices. The detector may include one or more single-photon avalanche diodes (SPADs). The, or each, SPAD may be configured to operate in Geiger mode. The detector may include one or more avalanche photodiodes (APDs). The detector may
10 include one or more linear-mode APDs. The detector may include one or more silicon-based detector devices. The detector may include one or more indium gallium arsenide-based detector devices.

The detector may include one or more CMOS devices. In this
15 arrangement, at least a part of the detector is manufactured using a CMOS manufacturing process.

The detector may be operable to receive the scattered electromagnetic radiation received by the optical device. The detector may be arranged to
20 collect at least some of the scattered electromagnetic radiation received by the optical device. The detector may be operable to receive the scattered electromagnetic radiation in the infrared region of the electromagnetic spectrum.

25 The detector may be configured to send detector data to the processing element. The detector data may be associated with at least one property of the received electromagnetic radiation. The detector may be operable to receive scattered electromagnetic radiation and to provide one or more signals indicative of the properties of the received scattered radiation to
30 the processing element.

The processing element may include an electronic processing element.
 The processing element may be operable to receive and process detector data from the detector. The processing element may be operable to apply
 5 random or quasi-random modulation continuous wave (RM-CW) analysis to the detector data to determine the presence of, or concentration of, one or more substances in the first target area. The processing element may be operable to convert detector data into information regarding the presence or concentration of one or more substances in the first target
 10 area. The processing element may be operable to use a random or quasi-random modulation continuous wave Lidar gas absorption detection technique to process the detector data.

The optical device may be operable to correlate received scattered
 15 radiation with the transmitted first output radiation using one or more correlation techniques. The processing element may be operable to correlate received scattered radiation with the transmitted first output radiation using one or more correlation techniques.

20 The optical device may be operable to process and/or display data associated with the received scattered radiation in the time domain.

According to a second aspect of the present invention there is provided a method of operating an optical device, the method comprising the steps of:

25 tuning a first emission wavelength of a first output radiation of a laser device continuously within a first wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of a first substance;
 modulating the first output radiation of the laser device with a first
 30 output modulation;

projecting the first output radiation towards a first target area;
 receiving scattered radiation from the first target area; and
 processing the scattered radiation.

5 Embodiments of the second aspect of the present invention may include one or more features of the first aspect of the present invention or its embodiments. Similarly, embodiments of the first aspect of the present invention may include one or more features of the second aspect of the present invention or its embodiments.

10

According to a third aspect of the present invention there is provided a method of transmitting electromagnetic radiation, the method comprising the steps of:

15 tuning a first emission wavelength of a first output radiation of an electromagnetic radiation source continuously within a first wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of a first substance;
 modulating the first output radiation of the electromagnetic radiation source with a first output modulation; and
 20 projecting the first output radiation towards a first target area.

The electromagnetic radiation source may comprise one or more laser devices.

25 Embodiments of the third aspect of the present invention may include one or more features of the first and/or second aspects of the present invention or their embodiments. Similarly, embodiments of the first and/or second aspects of the present invention may include one or more features of the third aspect of the present invention or its embodiments.

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According to a fourth aspect of the present invention there is provided a method of receiving electromagnetic radiation, the method comprising the steps of:

- 5 receiving scattered electromagnetic radiation from a first target area, wherein the scattered electromagnetic radiation is provided by:
 - 10 tuning a first emission wavelength of a first output radiation of an electromagnetic radiation source continuously within a first wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of a first substance;
 - modulating the first output radiation of the electromagnetic radiation source with a first output modulation; and
 - projecting the first output radiation towards a first target area;
 - 15 and
 - processing the scattered radiation.

The electromagnetic radiation source may comprise one or more laser devices.

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Embodiments of the fourth aspect of the present invention may include one or more features of the first, second and/or third aspects of the present invention or their embodiments. Similarly, embodiments of the first, second, and/or third aspects of the present invention may include one
 25 or more features of the fourth aspect of the present invention or its embodiments.

According to a fifth aspect of the present invention there is provided a method of transmitting and receiving electromagnetic radiation, the
 30 method comprising the steps of:

tuning a first emission wavelength of a first output radiation of an electromagnetic radiation source continuously within a first wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of a first substance;

5 modulating the first output radiation of the electromagnetic radiation source with a first output modulation;

projecting the first output radiation towards a first target area;

receiving scattered radiation from the first target area; and

processing the scattered radiation.

10

The electromagnetic radiation source may comprise one or more laser devices.

Embodiments of the fifth aspect of the present invention may include one
15 or more features of the first, second, third and/or fourth aspects of the present invention or their embodiments. Similarly, embodiments of the first, second, third and/or fourth aspects of the present invention may include one or more features of the fifth aspect of the present invention or its embodiments.

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According to a sixth aspect of the present invention there is provided a computer program product comprising machine-readable instructions that, when run, are configured to implement the method of the first aspect of the invention.

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Embodiments of the sixth aspect of the present invention may include one or more features of the first, second, third, fourth and/or fifth aspects of the present invention or their embodiments. Similarly, embodiments of the first, second, third, fourth and/or fifth aspects of the present invention may

include one or more features of the sixth aspect of the present invention or its embodiments.

According to a seventh aspect of the present invention there is provided a
5 gas detection device, comprising:

a laser device operable to output first output radiation, wherein the first output radiation comprises a continuous wave output;

wherein the optical device is operable to tune a first emission
wavelength of the first output radiation continuously within a first
10 wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of a first gas;

wherein the optical device is operable to apply a first output modulation to the first output radiation;

wherein the optical device is operable to transmit the first output
15 radiation towards a first target location and to collect/receive scattered radiation, the scattered radiation having been at least partially modified by the first gas in the first target location; and

wherein the optical device is operable to process the received scattered radiation.

20

Embodiments of the seventh aspect of the present invention may include one or more features of the first, second, third, fourth, fifth and/or sixth aspects of the present invention or their embodiments. Similarly, embodiments of the first, second, third, fourth, fifth and/or sixth aspects of
25 the present invention may include one or more features of the seventh aspect of the present invention or its embodiments.

According to an eighth aspect of the present invention there is provided an optical device, comprising:

a laser device operable to output first output radiation, wherein the first output radiation comprises a continuous wave output;

wherein the optical device is operable to tune a first emission wavelength of the first output radiation continuously within a first wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of a first substance;

wherein the optical device is operable to apply a first output modulation to the first output radiation; and

wherein the optical device is operable to transmit the first output radiation towards a first target location.

Embodiments of the eighth aspect of the present invention may include one or more features of the first, second, third, fourth, fifth, sixth and/or seventh aspects of the present invention or their embodiments. Similarly, embodiments of the first, second, third, fourth, fifth, sixth and/or seventh aspects of the present invention may include one or more features of the eighth aspect of the present invention or its embodiments.

According to a ninth aspect of the present invention there is provided an optical device, wherein the optical device is operable to receive scattered radiation, the scattered radiation having been at least partially modified by a first substance in a first target location, the radiation being transmitted by:

a laser device operable to output first output radiation, wherein the first output radiation comprises a continuous wave output;

wherein the optical device is operable to tune a first emission wavelength of the first output radiation continuously within a first wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of a first substance;

wherein the optical device is operable to apply a first output modulation to the first output radiation;

wherein the optical device is operable to transmit the first output radiation towards the first target location; and

5 wherein the optical device is operable to process the received scattered radiation.

Embodiments of the ninth aspect of the present invention may include one or more features of the first, second, third, fourth, fifth, sixth, seventh,
10 and/or eighth aspects of the present invention or their embodiments. Similarly, embodiments of the first, second, third, fourth, fifth, sixth, seventh and/or eighth aspects of the present invention may include one or more features of the ninth aspect of the present invention or its
15 embodiments.

According to a tenth aspect of the present invention, there is provided a device for transmitting electromagnetic radiation, comprising:

an electromagnetic radiation source operable to output first output radiation, wherein the first output radiation comprises a continuous wave
20 output;

wherein the device is operable to tune a first emission wavelength of the first output radiation continuously within a first wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of a first substance;

25 wherein the device is operable to apply a first output modulation to the first output radiation;

wherein the device is operable to transmit the first output radiation towards a first target location.

The device may be operable to collect or receive scattered radiation, the scattered radiation having been at least partially modified by the first substance in the first target location.

- 5 The device may be operable to process the received scattered radiation.

Embodiments of the tenth aspect of the present invention may include one or more features of the first, second, third, fourth, fifth, sixth, seventh, eighth and/or ninth aspects of the present invention or their embodiments.

- 10 Similarly, embodiments of the first, second, third, fourth, fifth, sixth, seventh, eighth and/or ninth aspects of the present invention may include one or more features of the tenth aspect of the present invention or its embodiments.

- 15 According to an eleventh aspect of the present invention there is provided a device for receiving electromagnetic radiation, wherein the device is operable to receive scattered radiation, the scattered radiation having been at least partially modified by a first substance in a first target location, the radiation being transmitted by:

- 20 an electromagnetic radiation source operable to output first output radiation, wherein the first output radiation comprises a continuous wave output;

- wherein the device is operable to tune a first emission wavelength of the first output radiation continuously within a first wavelength spectrum, the first wavelength spectrum comprising a first spectral feature associated with a first characteristic of a first substance;
- 25

wherein the device is operable to apply a first output modulation to the first output radiation;

- wherein the device is operable to transmit the first output radiation towards the first target location; and
- 30

wherein the device is operable to process the received scattered radiation.

Embodiments of the eleventh aspect of the present invention may include
5 one or more features of the first, second, third, fourth, fifth, sixth, seventh, eighth, ninth and/or tenth aspects of the present invention or their embodiments. Similarly, embodiments of the first, second, third, fourth, fifth, sixth, seventh, eighth, ninth and/or tenth aspects of the present invention may include one or more features of the eleventh aspect of the
10 present invention or its embodiments.

According to a twelfth aspect of the present invention there is provided use of a signal, wherein the signal has been generated, created, transmitted and/or received using the method and/or apparatus of any one of the
15 aspects of the present invention.

Embodiments of the twelfth aspect of the present invention may include one or more features of the first, second, third, fourth, fifth, sixth, seventh, eighth, ninth, tenth and/or eleventh aspects of the present invention or
20 their embodiments. Similarly, embodiments of the first, second, third, fourth, fifth, sixth, seventh, eighth, ninth, tenth and/or eleventh aspects of the present invention may include one or more features of the twelfth aspect of the present invention or its embodiments.

25 According to a thirteenth aspect of the present invention there is provided a method of operating an optical device, the method comprising:
tuning a first emission wavelength of a first output radiation of a laser device continuously within a first wavelength spectrum by modulating a drive current thereof with a first drive current modulation having a
30 frequency of at least 100 kHz, the first wavelength spectrum comprising a

first spectral feature associated with at least part of a gas absorption
 spectrum of at least one gas;
 modulating the first output radiation of the laser device with a first output
 modulation, the first output modulation comprising a first plurality of binary
 5 pulses;
 scanning the first wavelength spectrum at a rate of at least 1 μm per
 second;
 projecting the first output radiation towards a first target area;
 receiving scattered radiation from the first target area; and
 10 processing the scattered radiation.

Embodiments of the thirteenth aspect of the present invention may include
 one or more features of the first, second, third, fourth, fifth, sixth, seventh,
 eighth, ninth, tenth, eleventh and/or twelfth aspects of the present
 15 invention or their embodiments. Similarly, embodiments of the first,
 second, third, fourth, fifth, sixth, seventh, eighth, ninth, tenth, eleventh
 and/or twelfth aspects of the present invention may include one or more
 features of the thirteenth aspect of the present invention or its
 embodiments.

20

According to a fourteenth aspect of the present invention there is provided
 a gas detection device, comprising:

a laser device operable to output first output radiation,
 wherein the first output radiation comprises a continuous wave output;
 25 a control element operable to tune a first emission
 wavelength of the first output radiation continuously within a first
 wavelength spectrum at a rate of at least 1 μm per second by modulating
 a drive current of the laser device with a first drive current modulation
 having a frequency of at least 100 kHz, the first wavelength spectrum

comprising a first spectral feature associated with at least part of a gas absorption spectrum of at least one gas to be detected;

a modulator operable to apply a first output modulation to the first output radiation, the first output modulation comprising a first plurality
5 of binary pulses;

an optical transceiver system operable to transmit the first output radiation towards a first target location and to collect scattered radiation, the scattered radiation having been at least partially modified by the, or each, gas in the first target location;

10 a detector operable to receive the scattered radiation collected by the optical transceiver system; and

a processing element operable to process the received scattered radiation.

15 Embodiments of the fourteenth aspect of the present invention may include one or more features of the first, second, third, fourth, fifth, sixth, seventh, eighth, ninth, tenth, eleventh, twelfth and/or thirteenth aspects of the present invention or their embodiments. Similarly, embodiments of the first, second, third, fourth, fifth, sixth, seventh, eighth, ninth, tenth,
20 eleventh, twelfth and/or thirteenth aspects of the present invention may include one or more features of the fourteenth aspect of the present invention or its embodiments.

Brief description of the drawings

25

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

Fig. 1 shows a schematic of an optical device according to an embodiment of the present invention;

Fig. 2 shows example waveforms of the operation of the optical device of Fig. 1;

Fig. 3 shows an example wavelength spectrum of the optical device of Fig. 1; and

5 Figs. 4a to 4f show example waveforms of the operation of the optical device of Fig. 1.

Description of preferred embodiments

10 With reference to Figs. 1 to 4f an optical device 1 and associated waveforms of operation are shown.

As shown in Fig. 1, the optical device 1 is a gas detection device configured to detect the presence or concentration of at least one gas 2
15 (an example of a substance). It should be appreciated that the optical device 1 could be used to detect other substances.

The optical device 1 includes a laser device 4 operable to output first output radiation 6 having a continuous wave output. The optical device 1
20 includes a control element 8 operable to tune a first emission wavelength 9 of the first output radiation 6 continuously within a first wavelength spectrum 10. That is, the control element 8 is operable to continuously tune the emission wavelength 9 between the minimum and maximum wavelengths of the first wavelength spectrum 10. Continuously tuning the
25 emission wavelength 9 of the laser device 4 allows for fast scanning of an environment whilst reducing the spectral coherence of the transmitted radiation of the optical device 1.

The control element 8 is operable to continuously tune the first emission
30 wavelength 9 within the first wavelength spectrum 10 and to perform

multiple scans within the first wavelength spectrum 10. In this arrangement, the optical device 1 is operable to continuously scan the first wavelength spectrum 10, such that the emission wavelength 9 varies continuously over time.

5

As shown in Fig. 3, the first wavelength spectrum 10 comprises a first spectral feature 12 associated with a first characteristic of the gas 2 to be detected, which in this embodiment is a minimum value of the gas transmission spectrum of the gas 2 to be detected. It will be appreciated that the gas absorption spectrum of the gas 2 could also be used. Furthermore, other spectral features of a substance could be used.

10

15

As shown in Figs. 1 and 2, the optical device 1 includes a modulator 14 operable to apply a first output modulation 16 to the first output radiation 6.

The optical device 1 includes an optical transceiver system 26 operable to transmit the first output radiation 6 towards a first target location 18 and to collect/receive scattered radiation 20, the scattered radiation 20 having been at least partially modified by the gas 2 present in the first target location 18.

20

The optical device 1 includes a detector 22 configured to receive the scattered radiation 20 and a processing element 24 operable to process the received scattered radiation 20.

25

In the embodiments illustrated and described here, the optical device 1 is configured to detect the presence, or concentration, of the gas 2 in the atmosphere. However, it should be appreciated that the optical device 1 could be used to detect gas 2 in a chamber, a vessel, or the like.

30

Furthermore, the optical device 1 could comprise an internal substance

receptacle, vessel or the like, which could be used to test for the presence of one or more substances. It will be understood that in some embodiments, the optical device 1 could include a calibration element, which could include one or more gases, and used to calibrate the
5 operation of the optical device 1.

In the embodiments illustrated and described here, the optical device 1 is configured to detect the presence, or concentration, of the gas 2 when located remote from the optical device 1, at a distance of up to
10 approximately 100 metres. However, it should be appreciated that the optical device 1 could be configured to detect the gas 2 at other distances. For example, the optical device 1 could be mounted to a satellite and configured to operate at distances of up to 100 km or more. Furthermore, the optical device could be configured to detect gas located within the
15 optical device 1.

The optical device 1 is configured to detect methane (CH_4), although the optical device 1 could be configured to detect one or more gases. For example, the optical device 1 could be configured to detect at least one of:
20 carbon dioxide (CO_2), nitrous oxide (N_2O), carbon monoxide (CO), ammonia (NH_3), ethylene (C_2H_4) and methane (CH_4), by, for example, changing the first wavelength spectrum 10 and/or including a plurality of laser devices 4 within the optical device 1, each laser device 4 being configured to tune its emission wavelength 9 around a spectral feature 12
25 of a gas 2 of interest.

In use, the optical device 1 is operable to perform one or more scans of the first target location 18. In this arrangement, the optical device 1 is operable to obtain measurement data associated with at least one
30 substance in at least two dimensions of space, by scanning one or more

target locations. To achieve this, the optical device 1 could be movable (e.g. by mounting on a vehicle) and/or the optical device 1 could include a scanning module configured to direct the transmitted radiation across an area to be scanned (and to collect the scattered radiation 20).

5

As shown in Fig. 1, the optical device 1 is configured as a Lidar device.

In the embodiments illustrated and described here, the optical device 1 is operable to output the first output radiation 6 in the infrared region of the electromagnetic spectrum, specifically at a wavelength of between approximately 1.6506 μm and 1.6512 μm . However, in other
10
embodiments the optical device 1 could be operable to output the first output radiation 6 in one or more regions of the electromagnetic spectrum.

15 The first output radiation 6 comprises a continuous wave (CW) output and the modulator 14 is operable to apply a first output random or quasi-random modulation (RM) (an example of first output modulation 16) to the first output radiation 6. In this arrangement, the optical device 1 is a CW-RM device.

20

As shown in Fig. 1, the optical device 1 comprises a single laser device 4, and the emission wavelength 9 is continuously tuned within the wavelength spectrum 10, such that this single laser device 4 is used to generate both the “on” wavelength(s) and the “off” wavelength(s). That is,
25
in this embodiment the optical device 1 does not require a plurality of laser devices 4 to scan the wavelength spectrum 10. It will be appreciated that in other embodiments, the optical device 1 could comprise a plurality of laser devices 4, used to scan multiple wavelength spectra 10 or, in some embodiments, to use more than one laser device 4 to scan within a
30
particular wavelength spectrum 10 (e.g. using one laser device 4 to emit

an “off” wavelength and another laser device 4 to emit an “on” wavelength).

In the embodiments illustrated and described here, the optical device 1
5 includes a single optical transceiver system 26 operable to transmit the first output radiation 6 and to receive the scattered radiation 20, and the optical device 1 is configured to be mountable to a frame member, a vehicle, an aerial vehicle, and/or an unmanned vehicle, an unmanned aerial vehicle, and/or a helicopter. The optical device 1 is configured to be
10 a lightweight and portable device.

As shown in Fig. 1, the optical device 1 includes one or more optical guide elements 28 configured to guide the received scattered radiation 20 to the, or each, detector 22.

15

The laser device 4 is a tuneable laser device 4. In the embodiment illustrated in Fig. 1, the first emission wavelength 9 of the laser device 4 is tuneable by adjusting, or modulating, the drive current of the laser device 4, which in this embodiment is controlled by the control element 8 sending
20 a drive current modulation 8a to the laser device 4. It will be appreciated that in some embodiments, the laser drive current could be provided directly from the control element 8, or via ancillary drive circuitry.

As shown in Figs. 4a, to 4c the laser device 4 is configured to output the
25 first output radiation 6 at one or more drive currents. Fig. 4a shows the drive current of the laser device 4 being adjusted by approximately 40 mA (between drive current values of 60 mA and 100 mA) using a square wave modulation having a duty cycle of 50 % and a frequency of 1 MHz (that is, the frequency of the square wave signal is 1 MHz). That is, the drive
30 current of the laser device 4 is increased by 40 mA for a period of 500 ns

and is then decreased by 40 mA for 500 ns. This causes the temperature of the active region of the laser device 4 to decrease (for an increase in laser drive current), shown in Fig. 4b. This in turn causes the emission wavelength 9 of the laser device 4 to increase, as shown in Fig. 4c. Thus, modulating the laser drive current using a square wave signal, causes the emission wavelength 9 to change in a non-linear manner. This makes the processing of the received scattered radiation 20 more complex, as fitting the received data to the transmitted wavelength is not thought to be as straightforward as for a linear change in emission wavelength 9 (which is common for devices which use a step change to adjust the emission wavelength 9). It will be apparent from Figs. 4a to 4c that a single scan of the first wavelength spectrum 10 is achieved in 500 ns (from the minimum wavelength to the maximum wavelength). Thus, a single scan is achieved at a frequency of 2 MHz and, in this embodiment, at a scan rate of 0.8 μm per second. It will be appreciated that other scan rates, and drive currents could be used.

Scanning the wavelength spectrum 10 thus involves varying the emission wavelength 9 from the minimum value to the maximum value, and then from the maximum value to the minimum value, repeatedly. A relatively large number of data points can be gathered using this technique and at the possible scan frequencies outlined herein, even when moving the optical device 1 at high speed across an area to be scanned.

In the embodiments illustrated and described here, the emission wavelength 9 of the first output radiation 6 is determined, at least in part, by the laser drive current. It should be appreciated that other parameters could be taken into account when determining the desired emission wavelength 9, either alone or in combination with the laser drive current, such as the ambient temperature, the range to the target, the properties of

the environment (particularly the electromagnetic properties, such as the ambient light level) and/or the substance(s) to be detected.

In this embodiment, the laser device 4 is a diode laser device 4. However,
5 it should be appreciated that the laser device 4 could be at least one of: a narrow-linewidth laser device, a distributed feedback (DFB) laser device and/or an indium phosphide laser device.

As shown in Fig. 3, the optical device 1 is operable to tune the first
10 emission wavelength 9 of the first output radiation 6 to be at an emission wavelength 9 that is not associated with the, or each, spectral feature 12, and to tune the first emission wavelength 9 of the first output radiation 6 to be at an emission wavelength 9 that is associated with at least one of the spectral features 12. In this arrangement, the optical device 1 is operable
15 to output first output radiation 6 at one or more “off” wavelengths and one or more “on” wavelengths. The optical device 1 is operable to continuously tune the first emission wavelength 9 between the one or more “off” wavelengths and the one or more “on” wavelengths, such that there is no step change between the “on” and “off” wavelengths, rather
20 there is a smooth transition therebetween.

The control element 8 is an electronic control element 8 configured to control at least one operating parameter of the, or each, laser device 4 and the modulator 14. The control element 8 is operable to provide
25 control data to the modulator 14 and the modulator 14 is configured to apply the first output modulation 16 to the first output radiation 6 based, at least in part, on the control data received from the control element 8.

In the embodiments illustrated and described here, the modulator 14 includes a semiconductor optical amplifier (SOA) configured to output the modulated first output radiation 6.

5 As shown in Fig. 2, the first output modulation 16 includes a random sequence of square-wave, binary pulses, applied to the first output radiation 6 using amplitude modulation. In this embodiment, the first output radiation 6 is modulated between essentially 0 mW of output power to greater than 1 mW of output power. The first output modulation 14 is
10 applied with a frequency of at least 10 MHz. That is, the period of time between two pulses is at least 100 ns. The first output modulation 16 allows for matching of the received scattered radiation 20 with the corresponding transmitted radiation, particularly the wavelength thereof. It should be understood that whilst the output radiation 6 is modulated, the
15 laser device 4 is continuously tuned. That is, the tuning of the laser device 4 is not interrupted while the modulation is applied to the output radiation 6 of the laser device 4.

In the embodiments illustrated and described here, the detector 22 is a
20 single-photon avalanche diode (SPAD). Fig. 4d shows a signal determined, at least in part, on the received scattered radiation 20 over time.

Fig. 4e shows a corrected plot used to account for the non-linear variation
25 of the emission wavelength 9 of the laser device 4. Fig. 4e represents the period of 0 ns to 500 ns shown in Figs. 4a to 4d.

Fig. 4f shows the resultant plot of received intensity of the scattered radiation versus the emission wavelength 9 of the laser device 4, and thus
30 shows absorption/transmission with respect to the emission wavelength 9.

The detector 22 is configured to send detector data to the processing element 24 and the detector data is associated with at least one property of the received electromagnetic radiation 20. Thus, the detector 22 is
5 operable to receive scattered electromagnetic radiation 20 and to provide one or more signals indicative of the properties of the received scattered radiation 20 to the processing element 24.

The optical device 1 is configured to process received scattered radiation
10 20 and to fit the processed data to one or more measured absorption spectra to detect the presence, or concentration, of the gas 2 to be detected.

The processing element 24 is an electronic processing element 24, which
15 in this embodiment is embedded with the control element 8. It will be understood that in other embodiments, the processing element 24 and the control element 8 could be entirely separate.

The processing element 24 is operable to receive and process detector
20 data from the detector 22 and is operable to apply random or quasi-random modulation continuous wave (RM-CW) analysis to the detector data to determine the presence of, or concentration of, one or more substances in the first target location 18.

25 An example of how the present invention is used will now be provided, with reference to the embodiment illustrated in Figs. 1 to 4f.

Initially, a first wavelength spectrum 10 will be selected by configuring the optical device 1 through component selection (e.g. by the selection of a
30 suitable laser device and a suitable optical transceiver system 26) and by

component configuration (e.g. selecting the appropriate drive current values to be used during a scan, such as 60 mA to 100 mA). The laser device 4 is then used to output first output radiation 6, typically at the minimum wavelength of the wavelength spectrum 10, although the
 5 maximum wavelength, or another initial wavelength value could be used as the starting value.

Next, the control element 8 is used to continuously tune the laser device 4 by adjusting the drive current thereof. This results in the emission
 10 wavelength 9 being swept, or scanned, through the wavelength spectrum 10.

Whilst the laser device 4 is continuously scanned, output modulation 16 is applied to the output radiation 6 to produce a modulated output radiation
 15 6, which is then projected to the target location 18 via the optical transceiver system 26. The output radiation 6 passes through the atmosphere and is attenuated by the gas 2 to be detected. The output radiation is then scattered by an object, such as the ground (an example of a first target location 18). At least some of the scattered radiation 20 is
 20 then received or collected by the same optical transceiver system 26.

The received scattered radiation 20 is then directed to the detector 22 via the optical guide elements 28, and the processing element 24 is then used to process the detector data.

25

When at least one scan of the wavelength spectrum 10 has been completed, the optical device 1 is then typically moved spatially to build up a two-dimensional or three-dimensional scan of an area. It will be appreciated that when the wavelength spectrum 10 is scanned relatively
 30 quickly (such as scanning at frequencies of at least 90 kHz), multiple data

sets can be obtained for a fixed spatial point, depending on how fast the optical device 1 is moved.

Modifications and improvements may be made to the foregoing
5 embodiment without departing from the scope of the invention.

For example, in other embodiments, the optical device 1 could be operable to scan the first wavelength spectrum 10 at a frequency of at least approximately 90 kHz, or at least approximately 100 kHz, or at least
10 approximately 180 kHz, or at least approximately 200 kHz, or at least approximately 1 MHz, or at least approximately 2 MHz, or at least approximately 100 MHz, or at least approximately 200 MHz. The optical device could be operable to scan the first wavelength spectrum at a frequency of between approximately 90 kHz and approximately 200 MHz,
15 optionally between approximately 100 kHz and approximately 100 MHz. In this arrangement, the optical device 1 is operable to sweep the emission wavelength of the first output radiation continuously from the minimum wavelength of the first wavelength spectrum 10 to the maximum wavelength of the first wavelength spectrum 10 at a frequency of at least
20 approximately 90 kHz, or at least approximately 100 kHz, or at least approximately 180 kHz, or at least approximately 200 kHz, or at least approximately 1 MHz, or at least approximately 2 MHz, or at least approximately 100 MHz, or at least approximately 200 MHz.

25 Furthermore, in other embodiments the first wavelength spectrum could have a wavelength range of between 10 pm and 100 nm. It will be understood that in other embodiments the first wavelength spectrum could have other suitable ranges of wavelengths.

CLAIMS

1. A method of operating an optical device, the method comprising:
 - 5 tuning a first emission wavelength of a first output radiation of a laser device continuously within a first wavelength spectrum by modulating a drive current thereof with a first drive current modulation having a frequency of at least 100 kHz, the first wavelength spectrum comprising a first spectral feature associated with at least part of a gas absorption spectrum of at least one gas;
 - 10 modulating the first output radiation of the laser device with a first output modulation, the first output modulation comprising a first plurality of binary pulses;
 - scanning the first wavelength spectrum at a rate of at least 1 μm per second;
 - 15 projecting the first output radiation towards a first target area;
 - receiving scattered radiation from the first target area; and
 - processing the scattered radiation.
2. A method according to claim 1, wherein the step of scanning the first wavelength spectrum is carried out at a rate of between 1 μm per second and 10 m per second.
3. A method according to claim 1 or claim 2, wherein the first drive current modulation has a frequency of between 100 kHz and 100 MHz.
4. A method according to any preceding claim, wherein the first wavelength spectrum has a wavelength range of between 10 pm and 100 nm.
5. A method according to any preceding claim, wherein the first plurality of pulses comprises one of: a plurality of pulses in a random pulse sequence; a plurality of pulses in a pseudo-random sequence; or a plurality of pulses in a predefined sequence.

6. A method according to any preceding claim, wherein the first output modulation comprises a modulation frequency of at least 10MHz.
- 5 7. A method according to any preceding claim, wherein the step of processing the scattered radiation comprises using a random or quasi-random modulation continuous wave Lidar gas absorption detection technique.
- 10 8. A method according to any preceding claim, wherein the method comprises a step of performing multiple scans within the first wavelength spectrum, each scan including one or more “on” wavelengths associated with one or more spectral features of the first substance to be detected and one or more “off” wavelengths that are not associated with the one or more spectral features of the first substance, the optical device being operable to continuously tune the first emission wavelength during each scan.
- 15 9. A method according to any preceding claim, wherein the method comprises the step of continuously scanning a plurality of wavelength spectra and/or detecting a plurality of gases.
- 20 10. A method according to any preceding claim, wherein the method comprises the step of continuously tuning the first emission wavelength of the laser device in a non-linear manner over time.
- 25 11. A gas detection device, comprising:
 - a laser device operable to output first output radiation, wherein the first output radiation comprises a continuous wave output;
 - a control element operable to tune a first emission wavelength of the first output radiation continuously within a first wavelength spectrum at a rate of at least 1 μm per second by modulating a drive current of the laser
 - 30 device with a first drive current modulation having a frequency of at least 100 kHz, the first wavelength spectrum comprising a first spectral feature associated with at least part of a gas absorption spectrum of at least one gas to be detected;

a modulator operable to apply a first output modulation to the first output radiation, the first output modulation comprising a first plurality of binary pulses;

5 an optical transceiver system operable to transmit the first output radiation towards a first target location and to collect scattered radiation, the scattered radiation having been at least partially modified by the, or each, gas in the first target location;

a detector operable to receive the scattered radiation collected by the optical transceiver system; and

10 a processing element operable to process the received scattered radiation.

12. A gas detection device according to claim 11, wherein the control element is operable to scan the first wavelength spectrum at a rate of between 1 μ m per second and 10 m per second.

15

13. A gas detection device according to claim 11 or claim 12, wherein the first drive current modulation has a frequency of between 100 kHz and 100 MHz.

20

14. A gas detection device according to any of claims 11 to 13, wherein the first wavelength spectrum has a wavelength range of between 10 μ m and 100 nm.

25 15. A gas detection device according to claim 14, wherein the first plurality of pulses comprises one of: a plurality of pulses in a random pulse sequence; a plurality of pulses in a pseudo-random sequence; or a plurality of pulses in a predefined sequence.

30 16. A method according to any of claims 11 to 15, wherein the first output modulation comprises a modulation frequency of at least 10 MHz.

17. A gas detection device according to any of claims 11 to 16, wherein the processing element is operable to use a random or quasi-random modulation continuous wave Lidar gas absorption detection technique.
- 5 18. A gas detection device according to any of claims 11 to 17, wherein the detector comprises one of: a single photon avalanche diode element; an avalanche photodiode; or a linear mode avalanche photodiode.
- 10 19. A gas detection device according to any of claims 11 to 18, wherein the gas detection device comprises a single optical transceiver system operable to transmit the output radiation and to receive the scattered radiation.
- 15 20. A gas detection device according to any of claims 11 to 19, wherein the gas detection device is operable to perform multiple scans within the first wavelength spectrum, each scan including one or more “on” wavelengths associated with one or more spectral features of the gas to be detected and one or more “off” wavelengths that are not associated with the one or more spectral features of the gas to be detected, the gas detection device being operable to continuously tune the first emission wavelength during each scan.
- 20 21. A gas detection device according to any of claims 11 to 20, wherein the gas detection device is operable to continuously scan a plurality of wavelength spectra and/or wherein the gas detection device is operable to detect a plurality of gases.
- 25 22. A gas detection device according to any of claims 11 to 21, wherein the control element is operable to continuously tune the first emission wavelength of the laser device in a non-linear manner over time.
- 30 23. A gas detection device according to any of claims 11 to 22, wherein the modulator comprises a semiconductor optical amplifier configured to modulate the first output radiation and to output the modulated first output radiation.

24. An optical device,
wherein the optical device is operable to output first output radiation,
wherein the first output radiation comprises a continuous wave output;
5 wherein the optical device is operable to tune a first emission wavelength of
the first output radiation continuously within a first wavelength spectrum, the
first wavelength spectrum comprising a first spectral feature associated with
a first characteristic of a first substance;
wherein the optical device is operable to apply a first output modulation to
10 the first output radiation;
wherein the optical device is operable to transmit the first output radiation
towards a first target location and to receive scattered radiation, the
scattered radiation having been at least partially modified by the first
substance in the first target location; and
15 wherein the optical device is operable to process the received scattered
radiation.
25. The optical device of claim 24, wherein the optical device is operable to
tune the first emission wavelength at a rate of at least 1 μm per second.

CLAIMS

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1. A method of operating an optical device, the method comprising:
tuning a first emission wavelength of a first output radiation of a laser
device continuously within a first wavelength spectrum by modulating a
drive current thereof with a first drive current modulation having a frequency
of at least 100 kHz, the first wavelength spectrum comprising a first spectral
feature associated with at least part of a gas absorption spectrum of at least
one gas;
modulating the first output radiation of the laser device with a first
output modulation, the first output modulation comprising a first plurality of
binary pulses;
scanning the first wavelength spectrum at a rate of at least 1 μm per
second;
projecting the first output radiation towards a first target area;
receiving scattered radiation from the first target area; and
processing the scattered radiation.
 2. A method according to claim 1, wherein the step of scanning the first
wavelength spectrum is carried out at a rate of between 1 μm per second
and 10 m per second.
 3. A method according to claim 1 or claim 2, wherein the first drive current
modulation has a frequency of between 100 kHz and 100 MHz.
 4. A method according to any preceding claim, wherein the first wavelength
spectrum has a wavelength range of between 10 pm and 100 nm.
 5. A method according to any preceding claim, wherein the first plurality of
pulses comprises one of: a plurality of pulses in a random pulse sequence;
a plurality of pulses in a pseudo-random sequence; or a plurality of pulses
in a predefined sequence.

6. A method according to any preceding claim, wherein the first output modulation comprises a modulation frequency of at least 10MHz.
7. A method according to any preceding claim, wherein the step of processing the scattered radiation comprises using a random or quasi-random modulation continuous wave Lidar gas absorption detection technique.
8. A method according to any preceding claim, wherein the method comprises a step of performing multiple scans within the first wavelength spectrum, each scan including one or more “on” wavelengths associated with one or more spectral features of the first substance to be detected and one or more “off” wavelengths that are not associated with the one or more spectral features of the first substance, the optical device being operable to continuously tune the first emission wavelength during each scan.
9. A method according to any preceding claim, wherein the method comprises the step of continuously scanning a plurality of wavelength spectra and/or detecting a plurality of gases.
10. A method according to any preceding claim, wherein the method comprises the step of continuously tuning the first emission wavelength of the laser device in a non-linear manner over time.
11. A gas detection device, comprising:
 - a laser device operable to output first output radiation, wherein the first output radiation comprises a continuous wave output;
 - a control element operable to tune a first emission wavelength of the first output radiation continuously within a first wavelength spectrum at a rate of at least 1 μm per second by modulating a drive current of the laser device with a first drive current modulation having a frequency of at least 100 kHz, the first wavelength spectrum comprising a first spectral feature associated with at least part of a gas absorption spectrum of at least one gas to be detected;

a modulator operable to apply a first output modulation to the first output radiation, the first output modulation comprising a first plurality of binary pulses;

an optical transceiver system operable to transmit the first output radiation towards a first target location and to collect scattered radiation, the scattered radiation having been at least partially modified by the, or each, gas in the first target location;

a detector operable to receive the scattered radiation collected by the optical transceiver system; and

a processing element operable to process the received scattered radiation.

12. A gas detection device according to claim 11, wherein the control element is operable to scan the first wavelength spectrum at a rate of between 1 μ m per second and 10 m per second.

13. A gas detection device according to claim 11 or claim 12, wherein the first drive current modulation has a frequency of between 100 kHz and 100 MHz.

14. A gas detection device according to any of claims 11 to 13, wherein the first wavelength spectrum has a wavelength range of between 10 μ m and 100 nm.

15. A gas detection device according to claim 14, wherein the first plurality of pulses comprises one of: a plurality of pulses in a random pulse sequence; a plurality of pulses in a pseudo-random sequence; or a plurality of pulses in a predefined sequence.

16. A gas detection device according to any of claims 11 to 15, wherein the first output modulation comprises a modulation frequency of at least 10 MHz.

17. A gas detection device according to any of claims 11 to 16, wherein the processing element is operable to use a random or quasi-random modulation continuous wave Lidar gas absorption detection technique.
- 5 18. A gas detection device according to any of claims 11 to 17, wherein the detector comprises one of: a single photon avalanche diode element; an avalanche photodiode; or a linear mode avalanche photodiode.
- 10 19. A gas detection device according to any of claims 11 to 18, wherein the gas detection device comprises a single optical transceiver system operable to transmit the output radiation and to receive the scattered radiation.
- 15 20. A gas detection device according to any of claims 11 to 19, wherein the gas detection device is operable to perform multiple scans within the first wavelength spectrum, each scan including one or more “on” wavelengths associated with one or more spectral features of the gas to be detected and one or more “off” wavelengths that are not associated with the one or more spectral features of the gas to be detected, the gas detection device being operable to continuously tune the first emission wavelength during each scan.
- 20 21. A gas detection device according to any of claims 11 to 20, wherein the gas detection device is operable to continuously scan a plurality of wavelength spectra and/or wherein the gas detection device is operable to detect a plurality of gases.
- 25 22. A gas detection device according to any of claims 11 to 21, wherein the control element is operable to continuously tune the first emission wavelength of the laser device in a non-linear manner over time.
- 30 23. A gas detection device according to any of claims 11 to 22, wherein the modulator comprises a semiconductor optical amplifier configured to modulate the first output radiation and to output the modulated first output radiation.

24. An optical device,
wherein the optical device is operable to output first output radiation,
wherein the first output radiation comprises a continuous wave output;
5 wherein the optical device is operable to tune a first emission wavelength of
the first output radiation continuously within a first wavelength spectrum at a
rate of at least 1 μm per second by modulating a drive current of the laser
device with a first drive current modulation having a frequency of at least
100 kHz, the first wavelength spectrum comprising a first spectral feature
10 associated with a first characteristic of a first substance;
wherein the optical device is operable to apply a first output modulation to
the first output radiation;
wherein the optical device is operable to transmit the first output radiation
towards a first target location and to receive scattered radiation, the
15 scattered radiation having been at least partially modified by the first
substance in the first target location; and
wherein the optical device is operable to process the received scattered
radiation.



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Claims searched: 1-25

Date of search: 24 January 2020

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-25	WO2019/013698 A1 (NEOLUND) Whole document, Figures 1 & 3 and related description in particular
X	1-25	WO2005/047871 A2 (ITT MFG ENTERPRISES) Figure 4 and related description; paragraphs 140, 141; claims 1, 2
X	1-25	US2003/030001 A1 (COOPER) Figure 1; paragraphs 39-47, 59; claim 27
X	1-25	US2018/058935 A1 (YU) Figures 1 & 3; paragraphs 45-63
X	1-25	US2016/334507 A1 (HANGAUER) Figures 1 & 2 and related description; paragraphs 6, 17-27

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X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

G01N; G01S

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC



International Classification:

Subclass	Subgroup	Valid From
G01N	0021/3504	01/01/2014
G01N	0021/3581	01/01/2014
G01N	0021/39	01/01/2006
G01N	0021/49	01/01/2006
G01S	0017/88	01/01/2006