Therapeutic light source

Description

The present invention relates to a therapeutic light source.

Photochemotherapy of cancer is often referred to as photodynamic therapy (PDT). In PDT, a photosensitizing agent is administered to a patient and is preferentially retained in tumour cells. The agent is irradiated with visible or near infrared light, the wavelength of which is chosen to match the absorption wavelength of the photosensitizing agent. The agent becomes excited and passes its energy to oxygen molecules within the cell to generate singlet oxygen and so cause cell necrosis.

The present invention seeks to provide an improved therapeutic light source.

According to the present invention there is provided a therapeutic light source comprising at least two laser diodes, means for causing the laser diodes to emit pulses of light substantially simultaneously and having intervals between pulses of less than 1 microsecond and means for coupling light emitted by the laser diodes into an optical fibre.

Thus, the light source can generate short pulses of light at high power which can be particular effective in therapies, such as PDT.

The therapeutic light source may comprise at least three laser diodes.

The therapeutic light source may comprise a first laser diode for emitting light at a first wavelength, a second laser diode for emitting light at a second wavelength and a third laser diode for emitting light at a third wavelength, wherein the first, second and third wavelengths are different.

The therapeutic light source may comprise at least two diodes for emitting light at the first wavelength, at least two diodes for emitting light at the second wavelength; and at least two diodes for emitting light at the third wavelength.

The first wavelength may be about 635 nm, the second wavelength may be about 1050 nm and the third wavelength may be about 1270 nm.

The laser diodes may be configured to output light having a combined power of at least 500 mW. The combined power may be at least 1 W.

The means for causing the laser diodes to emit pulses of light may comprise means for generating a pulse waveform and means for driving current through the laser diodes, wherein the generating means provides at least one pulse waveform to the current driving means.

The therapeutic light source may comprises at least two current driving means, each configured to drive a respective laser diode; wherein the generating means provides at least two pulse waveforms.

The pulse waveform generating means may be a processor and the current driving means comprises an amplifier circuit. The current driving means may include a means for switching current on and off and means for regulating current through a laser diode

The means for causing the laser diodes to emit pulses of light may be configured to cause the laser diodes to emit pulses having intervals between pulses of less than or equal to 100 ns or less than or equal to 10 ns.

According to the present invention there is provided at least two laser diodes, a circuit arranged to cause the laser diodes to emit pulses of light substantially simultaneously and having intervals between pulses of less than 1 microsecond and a coupler for channelling light emitted by the laser diodes into an optical fibre.

The circuit may be programmable.

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

Figure 1 is schematic block diagram of a therapeutic light source in accordance with the present invention;

Figure 2 is a timing diagram illustrating simultaneous output of pulsed light from laser diodes;

Figure 3 is a more detailed view of some of the blocks shown in Figure 1; and

Figure 4 illustrates in more detail a driver circuit shown in Figure 1.

Referring to Figure 1, a light source 1 for use in therapy, such as PDT, in accordance with the present invention is shown. As will be explained in more detail later, the power output of the light source 1 can exceed 500 mW and operate in pulse mode producing pulses of light having pulse intervals and/or pulse duration less than 1 microsecond. When used in PDT, such pulses of light at such high power can stimulate singlet oxygen production in tumour cells more efficiently.

The light source 1 includes a microprocessor 2 which provides a programmable signal generator 3. The microprocessor 2 is coupled to circuits 4 (or "drivers") for driving respective semiconductor laser diodes 5. In this example, the microprocessor 2 and the drivers 4 are supported on a motherboard (not shown).

There may be two or more laser diodes 5. For example, there may be up to about 20 laser diodes. Some or all of the laser diodes 5 may emit light at the same wavelength. In this and some embodiments of the invention, the laser diodes 5 include at least two sets of laser diodes, preferably three sets of diodes, each set of laser diodes 5 emitting light at a different wavelength. A set of laser diodes 5 may include one or more than one laser diode.

In this and some embodiments of the invention, the laser diodes 5 include a first set of diodes 5_1 which emit light at a first wavelength λ_1, in this case 635 nm, a second set of laser diodes 5_2 which emit light at a second, different wavelength λ_2 ($\lambda_2 \neq \lambda_1$), in this example 1050 nm, and a third set of laser diodes 5_3 which emit light at a third, different wavelength λ_3 ($\lambda_3 \neq \lambda_2 \neq \lambda_1$), in this case 1270 nm. The wavelengths

can be chosen to match the absorption wavelength or wavelengths of a particular photosensitizing agent and may be chosen, for example, from visible or near infrared wavelengths. Usually for PDT, the wavelength(s) is chosen to excite an activated molecule into a triplet state, which produces singlet oxygen. Suitable laser diodes 5 can be obtained from LDX Optronics, Inc., 1729 Triangle Park Drive, Maryville, TN 37801, USA.

The laser diodes 5 form part of an optical system 6. The laser diodes 5 are attached via respective optical fibres 7 to an optical junction 8 (or "node" or "coupler") which is attached to one end of an optical fibre 9 having a diameter, in this example, of about 200 to 400μm. The optical junction 8 focuses light into the fibre 9.

The optical junction 8 includes a dense, polished semicylindrical prism (not shown) and a gradient lens (not shown) which gathers scattered photons and focuses them into the optical fibre 7. The light source 1 is housed in a casing (not shown).

By combining light from more than one laser diode 5 using the optical junction 8, high power densities can be achieved. Furthermore, the light source 1 is cheap to produce, compared with conventional dedicated high-power lasers since laser diodes 5 are inexpensive.

The laser diodes 5 are mounted and rigidly fixed onto the motherboard (not shown) which includes a cooling system (not shown) comprising fans and/or heat sinks.

As shown in Figure 1, the light source 1 also includes a power supply unit 11, control panel 12, display 13 and memory 14.

In some embodiments, the control panel 12 and display 13 are combined in the form of a touch screen display.

The control panel 12 includes actuators, e.g. push buttons, switches or selectable regions on a touch display, for switching power on and off, starting and stopping light output, setting output power, resetting, switching between pulse and

continuous modes, setting the duration of flashes and/or pauses and setting the brightness of an aiming beam. Power output can be selected, for example, in a range 100 mW to 1 W, in increments of 100 mW. If multiple wavelengths are used, the control panel 12 may include an actuator for switching between wavelengths.

The display 13 indicates operation and other settings, such as whether power is one or off, output power (W), pulse/continuous mode, indicator 'ready', flash duration (in nanoseconds), duration of pause (in nanoseconds) and flash counter.

In this example, there are six laser diodes 5 and the total output power of the laser diodes is about 1W. However, depending on the power of each laser diode 5 and the number of laser diodes, the total power can be lower or higher.

The light source 1 can be operated in continuous or pulse mode.

Referring also to Figure 2, in pulse mode, the light source 1 can generate pulses of light having duration, T_W, of the order of 1 or 10 nanoseconds, e.g. about 5 – 10 nanoseconds, and/or separated by intervals, T_i, of the order of 1 or 10 nanoseconds, e.g. about 5 – 10 nanoseconds. Thus, the light source 1 is beneficial for PDT and convenient for use with biological systems.

In pulse mode, the laser diodes 5 are arranged to emit pulses of light substantially simultaneously. However, the laser diodes 5 can work with a delay.

As will be explained in more detail later, the microprocessor 2 and drivers 4 can be used instead of a conventional (dedicated) high-frequency driver which is complex and costly. This can help reduce power consumption and heat production.

The light source 1 can also be used as part of an integrated unit (or "array") (not shown). The array (not shown) includes the light source 1 and a fluoroscopy camera (not shown) for monitoring the quantity of singlet oxygen produced during therapy (usually referred to as the "yield of singlet oxygen"). The life time of singlet oxygen is short and usually lasts no more than 50 nanoseconds.

Referring to Figure 3, circuitry 15 of the light source 1 shown in more detail.

The microprocessor 2 is operatively connected to the drivers 4 using digital-to-analogue converters (DACs) 16_1, 16_2, 16_3.

As shown in Figure 3, the digital-to-analogue converters 16_1, 16_2, 16_3 may be provided internally by the microprocessor 2 and/or externally as separate units. The microprocessor 2 can provide signals to an external digital-to-analogue converter via a bus 17, such as Inter-Integrated Circuit (I2C) bus having serial data (SDA) and serial clock (SCL) lines 17_1, 17_2. The bus 17 can be used to control more than one digital-to-analogue converter.

The microprocessor 2 is provided with RAM 14_1 and with flash memory 14_2 for storing BIOS and control software. A foot-operated treadle 18 can also be used to control operation of the light source 1.

The microprocessor 2 generates a programmable waveform using its internal clock (not shown).

Referring to Figure 4, the circuitry of a driver 4 is shown in more detail.

The driver 4 is configured to drive the laser diode 5 using a constant current source.

The laser diode 4 is connected in series between positive supply 19 and ground 20 via a Darlington transistor 21, power field-effect transistor 22 and sensing resistance 23.

A signal from the DAC 16 is fed into a first input 24 of a differential amplifier 25. In this example, the first input 24 is a non-inverting input. The output 26 of the differential amplifier 25 is connected to a first resistor 27 (in this example, R_1 is about 2kΩ) which in turn is connected to the base 28 of the Darlington transistor 21. The laser diode 5 is connected between the supply 19 and the collector 29 of

the Darlington transistor 21. The emitter 30 of the Darlington transistor 21 is connected to the drain 31 of the power field-effect transistor 22. In this example, the differential amplifier 25 is arranged to provide full gain swing between the supply rails.

Thus, a signal from the DAC 16 provides control (e.g. 'high' and 'low' signal) for switching the diode 5 on and off. The differential amplifier 25 provides a high gain signal for switching the Darlington transistor 21 on and off, which in turn switches the laser diode 5 on and off.

Current through the laser diode 5 is regulated by the power field-effect transistor 22 which is controlled by a voltage comparator 32 which compares the voltage across the sensing resistance 23 taken at a sensing point 33 between the source 34 of the power field-effect transistor 22 and the sensing resistance 23.

The sensing point 33 is connected to a second resistor 35 (in this example, R_2 is about 10 kΩ) which is connected in series to a first variable resistor 36 (in this example, R_{v1} is about 10 kΩ) which in turn is connected to ground 37 thereby forming a potential divider. A tapping point 38 (also often refereed to as a "wiper") of the first variable resistor 36 is connected into a first input 39 of the voltage comparator 32. In this example, the first input 39 is a non-inverting input. A reference voltage is applied to a second input 40 of the voltage comparator 32. The output 41 of the voltage comparator 32 is fed back to the first input 39 of the voltage comparator 32 via third resistor 42 (in this example, R_3 is about 1 MΩ). The output 41 is also connected to the gate 43 of the power field-effect transistor 22. The gate 43 is also connected to positive supply 44 via a fourth resistor 45 (in this example, R_4 is about 4.7kΩ).

The reference voltage is provided using a positive voltage 46 (e.g. +5V), regulated by a fifth resistor 47 (in this example, R_5 is about 510 Ω) and a Zener diode 48, and set using a sixth resistor 49 (in this example, R_6 is about 10 kΩ), a second variable resistor 50 and first capacitor 51 (in this example, C_1 is about 0.1 μF). The sixth

resistor 49 is arranged in series with a parallel arrangement of the second variable resistor 50 (in this example, R_{v2} is about 10 kΩ) and first capacitor 51. However, one terminal 52 of the first capacitor 51 is connected to both an end terminal 53 and a tapping terminal 54 of the second variable resistor 50.

The sensing node 33 is also connected to a second capacitor 55 (in this example, C_2 is about 0.1 μF) which is connected to ground 56. The sensing node 33 is also connected to a seventh resistor 57 (in this example, R_6 is about 10 kΩ) which is connected to a first end terminal 58 and a tap terminal 59 of a third variable resistor 60 (in this example, R_{v3} is about 15 kΩ). A second end terminal 61 of the third variable resistor 60 is connected to a second input 62 of the differential amplifier 25 and to an eighth resistor 63 (in this example, R_8 is about 10 kΩ) which, in turn, is connected to ground 64. The first input 24 of the differential amplifier 25 is connected to the DAC 16 (Figure 3) and also to a ninth resistor 65 (in this example, R_9 is about 10 kΩ) connected to ground 66.

In this example, the sensing resistance 23 is formed by a parallel arrangement of tenth and eleventh resistors 67, 68 (in this example, R_{10} is about 3.9 Ω and R_{11} is about 0.56 Ω).

In this and some embodiments of the invention, the differential amplifier 25 is an AD 626 (Analogue Devices), the Darlington transistor 21 is a KT 829, the voltage comparator32is an LM211 (National Semiconductor), the Zener diode is KC 107, and the power field-effect transistor is an IRFZ44N (International Rectifier). Other components having similar parameters may be used. Values of resistances and capacitances may vary.

The driver 4 illustrated in Figure 4 can allow the laser diode 5 to be switched quickly, e.g. having pulse durations and/or pulse widths of the order of 1, 10 or 100 ns, while also delivering high currents, e.g. currents of the order of 1A.
The microcontroller 2 (Figure 3) can select which drivers 4 to use, thereby selecting wavelength and power. The microcontroller 2 supplies the same waveform or

synchronised waveforms to the selected drivers 4, thereby allowing high power pulses of light to be generated.

It will be understood that the present invention has been described above by way of example only. For example, it will be appreciated that an alternative control circuit, for example using a different configuration, may be used instead of the control circuit including the differential amplifier 19 and the Darlington pair 21. Similarly, it will be appreciated that an alternative current regulation circuit, for example, using a different configuration, may be used instead of the current regulation circuit including the power transistor 22 and voltage comparator 32. The examples are not intended to limit the scope of the invention. Various modifications and embodiments can be made without departing from the scope and spirit of the invention, which is defined by the following claims only.

Claims

1. A therapeutic light source comprising:
at least two laser diodes;
means for causing the laser diodes to emit pulses of light substantially simultaneously and having intervals between pulses of less than 1 microsecond; and
means for coupling light emitted by the laser diodes into an optical fibre.

2. A therapeutic light source according to claim 1, comprising:
at least three laser diodes.

3. A therapeutic light source according to claim 2, including:
a first laser diode for emitting light at a first wavelength;
a second laser diode for emitting light at a second wavelength; and
a third laser diode for emitting light at a third wavelength;
wherein the first, second and third wavelengths are different.

4. A therapeutic light source according to claim 3, comprising:
at least two diodes for emitting light at the first wavelength;
at least two diodes for emitting light at the second wavelength; and
at least two diodes for emitting light at the third wavelength.

5. A therapeutic light source according to claim 3 or 4, wherein the first wavelength is about 635 nm, the second wavelength is about 1050 nm and the third wavelength is about 1270 nm.

6. A therapeutic light source according to any preceding claim, wherein the laser diodes are configured to output light having a combined power of at least 500 mW.

7. A therapeutic light source according to claim 6, wherein the combined power is at least 1 W.

8. A therapeutic light source according to any preceding claim, wherein the means for causing the laser diodes to emit pulses of light comprises:

means for generating a pulse waveform; and

means for driving current through the laser diodes,

wherein the generating means provides at least one pulse waveform to the current driving means.

9. A therapeutic light source according to claim 8, comprising:

at least two current driving means, each configured to drive a respective laser diode;

wherein the generating means provides at least two pulse waveforms.

10. A therapeutic light source according to claim 8 or 9, wherein:

the pulse waveform means is a processor; and

the current driving means comprises an amplifier circuit.

11. A therapeutic light source according to any one of claims 8 to 10, wherein the current driving means includes a means for switching current on and off and means for regulating current through a laser diode.

12. A therapeutic light source according to any preceding claim, wherein the means for causing the laser diodes to emit pulses of light is configured to cause the laser diodes to emit pulses having intervals between pulses of less than or equal to 100 ns.

13. A therapeutic light source according to any preceding claim, wherein the means for causing the laser diodes to emit pulses of light is configured to cause the laser diodes to emit pulses having intervals between pulses of less than or equal to 10 ns.

14. A therapeutic light source comprising:

at least two laser diodes;

a circuit arranged to cause the laser diodes to emit pulses of light

substantially simultaneously and having intervals between pulses of less than 1 microsecond; and

a coupler for channelling light emitted by the laser diodes into an optical fibre.

15. A therapeutic light source according to claim 14, wherein the circuit is programmable.