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Laser diode driver circuits and methods of operating thereof

Abstract

A driver circuit includes a fly capacitor with a first end and a second end. The driver circuit includes a laser diode having an anode and a cathode. The driver circuit is configured to operate in first and second operating states. The anode is coupled to the first end of the fly capacitor. In the first operating state, the cathode is coupled to a first voltage supply node, the first end of the fly capacitor is coupled to a second voltage supply node, and the second end of the fly capacitor is coupled to a first reference terminal. In the second operating state, the cathode is coupled to a second reference terminal and decoupled from the first voltage supply node, the first end of the fly capacitor is decoupled from the second voltage supply node, and the second end of the fly capacitor is coupled to a third reference terminal.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a divisional application of U.S. application Ser. No. 16/774,889, filed on Jan. 28, 2020, which application is hereby incorporated herein by reference.

TECHNICAL FIELD

(1) The present invention relates generally to driver circuits, and particularly to laser diode driver circuits and methods of operating thereof.

BACKGROUND

(2) A growing number of technical applications utilize sub nanosecond pulses to drive laser diodes. Such applications include, but are not limited to, devices and methods related vertical cavity surface emitting lasers (VCSEL) for single photon avalanche diode (SPAD) based time-of-flight (TOF) sensors. Controlling the current through a diode in a system with short duration pulses can be problematic. It can also be difficult to limit optical tailing in VCSELs in these and other conditions.

SUMMARY

(3) In accordance with an embodiment of the present invention, a driver circuit includes a fly capacitor. The fly capacitor includes a first end and a second end. The driver circuit includes a laser diode that includes an anode and a cathode. The driver circuit is configured to operate in a first operating state and a second operating state. The anode is coupled to the first end of the fly capacitor. In the first operating state, the cathode is coupled to a first voltage supply node, the first end of the fly capacitor is coupled to a second voltage supply node, and the second end of the fly

capacitor is coupled to a first reference terminal. In the second operating state, the cathode is coupled to a second reference terminal and decoupled from the first voltage supply node, the first end of the fly capacitor is decoupled from the second voltage supply node, and the second end of the fly capacitor is coupled to a third reference terminal.

(4) In accordance with an embodiment of the present invention, a method of operating a laser diode includes having a driver circuit. The driver circuit includes a fly capacitor. The fly capacitor includes a first end and a second end. The driver circuit includes a laser diode that includes an anode and a cathode. The anode is coupled to the first end of the fly capacitor. The method includes charging the first end of the fly capacitor to a first potential. The method includes generating a current pulse by discharging the fly capacitor through the laser diode by driving the laser diode in forward bias. The method includes recharging the first end of the fly capacitor to the first potential and driving the laser diode in reverse bias.

(5) In accordance with an embodiment of the present invention, a driver circuit includes a current mirror coupled to a supply voltage node. The driver circuit includes a programmable current source coupled to a first path of the current mirror. The driver circuit includes a decoupling capacitor coupled to a second path of the current mirror. The driving circuit includes an output node coupled between the decoupling capacitor and the current mirror on the second path. The driver circuit includes a laser diode coupled to the output node. The driver circuit is configurable to provide a fixed current pulse through the laser diode by selecting the programmable current source.

(6) In accordance with an embodiment of the present invention a method for controlling current through a laser diode includes having a current mirror coupled to a supply voltage node with a programmable current source coupled to a first path of the current mirror and a decoupling capacitor coupled to a second path of the current mirror. The method includes having an output node coupled between the decoupling capacitor and the current mirror on the second path of the current mirror. The method include selecting a fixed current pulse for a laser diode by setting the programmable current source. The method includes charging the decoupling capacitor with a charging current on the second path of the current mirror, the charging current mirroring a programmable current set by the programmable current source. The method includes discharging the decoupling capacitor through the output node to provide the fixed current pulse through the laser diode.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

(2) FIG. 1 illustrates a schematic circuit of an embodiment of a reverse biasing laser diode driving circuit;

(3) FIG. 2 illustrates waveforms alternating states of an embodiment of the reverse biasing laser diode driving circuit depicted in FIG. 1.

(4) FIG. 3 illustrates the voltage across an embodiment of a fly capacitor of the circuit of FIG. 1.

(5) FIG. 4 illustrates the voltage across an embodiment of a laser diode of the circuit of FIG. 1.

(6) FIG. 5 illustrates a block diagram of a method of operating a laser diode in accordance with an embodiment of the present invention.

(7) FIG. 6 illustrates a schematic of a current controlled laser diode driving circuit in accordance with an embodiment of the present invention.

(8) FIG. 7 illustrates waveforms of gate signals that control operation of the switches of the current controlled laser diode driving circuit of FIG. 6 in accordance with an embodiment of the present

invention.

(9) FIG. **8** illustrates a block diagram of a method of operating a current controlled laser diode in accordance with an embodiment of the present invention.

(10) FIG. **9** illustrates a schematic of embodiments of a current controlled laser diode driving circuit.

(11) FIG. **10** illustrates a further schematic of a laser driver circuit.

(12) FIG. **11** illustrates an embodiment of a controller of a laser driver circuit.

(13) Corresponding numerals and symbols in the different figures generally refer to corresponding parts unless otherwise indicated. The figures are drawn to clearly illustrate the relevant aspects of the embodiments and are not necessarily drawn to scale.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

(14) The making and using of embodiments of this disclosure are discussed in detail below. It should be appreciated, however, that the concepts disclosed herein can be embodied in a wide variety of specific contexts, and that the specific embodiments discussed herein are merely illustrative and do not serve to limit the scope of the claims. Further, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of this disclosure as defined by the appended claims.

(15) Embodiments of the present application disclose circuits and methods for applying short duration pulses through laser diodes and with an ability to both forward and reverse bias the diodes. A laser diode operates by emitting photons when being subjected to a forward bias. However, in some user applications, the laser diodes are expected to operate for extremely short times, in other words, the laser diodes are expected to emit light in short pulses.

(16) In addition, during operation, laser diodes generate a large number of excited charge carriers, which recombine to produce photons. During forward bias, charge carriers are generated within the active region of the laser diode. Thus, when the laser diode current is modulated from a value above threshold to a sub-threshold (so that it is no longer in forward bias), the laser diodes may continue to emit a small intensity of photons as the remaining charge in the active region is slowly dissipated as photons even after the forward bias is removed. More specifically, the charge is dissipated at the rate of the spontaneous recombination lifetime which is on the order of a nanosecond. This is observed in conventional circuits as an optical tail—it is therefore a major limitation for the generation of fast sub-nanosecond pulses.

(17) Embodiments of the present application describe a laser diode driving circuit with reduced optical tailing by applying a short reverse bias to sweep the remaining charge carriers from the active region of the laser diode.

(18) Accordingly, embodiments of the present invention provide a laser diode driving circuit, where the laser diode is reverse biased between the current pulses that activate (forward bias) the diode. Thus, reverse biasing the laser diode limits optical tailing in a VCSEL laser diode. While embodiments of the present application are described, for clarity, using VCSEL laser diodes, embodiments of this disclosure are not limited to circuits that utilize VCSEL laser diodes, and they can be combined with other laser diodes known in the art.

(19) Disclosed herein are methods and devices for a reverse-biasing laser diode driving circuit. A first embodiment of a laser driver circuit will be discussed using FIG. **1**. Further embodiments will be described using FIGS. **6** and **9-10**. Methods of operating the laser driver circuits will be described using FIGS. **5** and **8**.

(20) FIG. **1** illustrates an embodiment of a reverse-biasing driver circuit **100** that allows reverse biasing of a laser diode. The reverse-biasing driver circuit **100** of the embodiment depicted in FIG. **1** comprises a fly capacitor **102** comprising a first end **104** and a second end **106**. In some embodiments, the fly capacitor **102** comprises a capacitor having a first plate at the first end **104** and a second plate at the second end **106**.

(21) As illustrated by FIG. **1**, embodiments also may comprise a laser diode **108** comprising an

anode no and a cathode **112**, the anode no being coupled with the first end **104** of the fly capacitor **102**. In some embodiments, the laser diode **108** comprises a vertical-cavity surface-emitting laser (VCSEL).

(22) The reverse-biasing driver circuit **100** has a first reference terminal **118** coupled to the second end **106** of the fly capacitor **102** and a second reference terminal **120** coupled to the third switch **128**.

(23) First, second, and third switches **124**, **126**, and **128** are configured to be switched between ON and OFF states (low resistance states and high resistance states) by the application of a control signal. It will be appreciated by one of ordinary skill in the art that first, second, and third switches **124**, **126**, and **128** may comprise different forms in different embodiments as will be discussed. The first switch **124** is coupled to a first voltage supply node **114** while the second switch **126** is coupled to a second voltage supply node **116**. The first voltage supply node **114** and the second voltage supply node **116** may be coupled to a same voltage supply node during operation in some embodiments.

(24) The reverse-biasing driver circuit **100** may be configured to operate in different states. In a first operating state, the laser diode **108** may be pulsed to cause it to become active while the second operating state may overlap with periods between pulses. FIG. 1 depicts an embodiment of the reverse-biasing driver circuit **100** configured to operate in a first operating state and a second operating state.

(25) In the embodiment depicted in FIG. 1, the first and second switches **124** and **126** are closed in the first operating state and open in the second operating state by applying a first control signal $\phi_{\text{sub.1}}$. On the other hand, the third switch **128** is open in the first operating state and closed in the second operating state by applying a second control signal $\phi_{\text{sub.2}}$.

(26) In some embodiments, like the one depicted in FIG. 1, in the first operating state of the reverse-biasing driver circuit **100**, first and second switches **124** and **126** are in the ON state (low resistance state). The cathode **112** is coupled to a first voltage supply node **114** and the first end **104** of the fly capacitor **102** is coupled to a second voltage supply node **116**. Also, in some embodiments, the second end **106** of the fly capacitor **102** is coupled to a first reference terminal **118**. Also in the first state, the third switch **128** is in the OFF state (high resistance state) so the cathode **112** is decoupled from a second reference terminal **120**. In one embodiment, the first reference terminal **118** and the second reference terminal **120** are coupled to a ground potential during operation.

(27) In this arrangement, the fly capacitor **102** is charged via the second voltage supply node **116**, and a voltage, e.g., coupled to supply voltage $V_{\text{sub.DD}}$ is applied to the cathode **112** of the laser diode **108**. As the fly capacitor **102** is charged the potential at the anode no will increase until it reaches the second voltage supply node **116** (minus the ON state voltage drop across the second switch **126**). Similarly, the potential at the cathode **112** is maintained at the first voltage supply node **114** (minus the ON state voltage drop across the first switch **124**). In various embodiments, the potential at the first voltage supply node **114**, the potential at the second voltage supply node **116** and the voltage drop across the first and second switches **124** and **126** are selected so that there is no potential across the laser diode **108** after the charging of the fly capacitor **102**. For example, this is accomplished if the first switch and second switch **124** and **126** are designed to have similar electrical device parametrics and the first voltage supply node **114** and the second voltage supply node **116** are coupled to the same potential node.

(28) In some embodiments, the first voltage supply node **114** is the second voltage supply node **116** may be coupled to a first and second voltage source, respectively

(29) Referring again to FIG. 1, in the second operating state of the reverse-biasing driver circuit **100**, the first and second switches **124** and **126** are turned off (OFF state). Additionally, the third switch **128** is now in the ON state and the cathode **112** is coupled to a second reference terminal **120** in the second state. Because the first switch **124** is now in the OFF state, the cathode **112** is

decoupled from the first voltage supply node **114**. The anode **110** is decoupled from the second voltage supply node **116** because the second switch **126** is the OFF state. Also because the second switch **126** is the OFF state, the first end **104** of the fly capacitor **102** is decoupled from the second voltage supply node **116**.

(30) As mentioned above, initially, in the first operating state in some embodiments of the present invention, the fly capacitor **102** is charged via the second voltage supply node **116**, e.g., to the supply voltage $V_{sub,DD}$. In such embodiments, as depicted in FIG. 1, at the end of the first operating state $V_{sub,fly}=V_{sub,DD}$ (assuming no other intervening voltage drop), where $V_{sub,fly}$ represents the voltage at the first end **104** of the fly capacitor **102**.

(31) During the second operating state, the laser diode **108** has been decoupled from second and first voltage supply nodes **116** and **114** at the anode no and the cathode **112** respectively. Meanwhile the cathode **112** has been coupled to the second reference terminal **120**. This puts the reverse-biasing driving circuit **100** in an arrangement that allows the fly capacitor **102** to discharge through the laser diode **108**. In particular, the laser diode **108** is now in forward bias as the anode no is at a higher positive potential than the cathode **112** and the laser diode **108** is able to conduct a current. Thus, charge stored at the fly capacitor **102** is discharged through the laser diode **108** as a current pulse, which causes the laser diode **108** to emit a light pulse.

(32) As the fly capacitor **102** is discharged the potential at the first end **104** of the fly capacitor **102** decreases in magnitude. The voltage in the fly capacitor **102** at the conclusion of the second operating state is described approximately by the following equation:

$V_{sub,fly}=V_{sub,DD}=I_{sub,peak} \cdot t_{sub,pw}/C_{sub,fly}$, where $I_{sub,peak}$ is the amplitude of the current pulse, $t_{sub,pw}$ is the pulse width, and $C_{sub,fly}$ is the capacitance of the fly capacitor **102**.

(33) Once the reverse-biasing driver circuit wo returns to the first operating state, the first switch **124** is turned into the ON state and the supply voltage $V_{sub,DD}$ is applied to the cathode **112** of the laser diode **108** via the first voltage supply node **114**. At the same time, the second switch **126** is also turned into the ON state again coupling the anode **110** and the first end **104** to the second voltage supply node **116**. Simultaneously, the third switch **128** is turned into the OFF state and the path from the cathode **112** to the second reference terminal **120** is interrupted.

(34) In some embodiments, the voltage across the laser diode **108**, at the beginning of the first operating state, is the difference between the potential at the first end **104** of the fly capacitor **102** $V_{sub,fly}$ and the potential of the first voltage supply node **114** ($V_{sub,DD}$ —assuming no other voltage drop). As previously noted, potential at the first end **104** of the fly capacitor **102** $V_{sub,fly}$ is lower than the potential at the second voltage supply node **116** because of the discharging of the fly capacitor **102** through the laser diode **108**. Thus, the voltage across the laser diode **108** may be described at this point approximately by the equation

$$(35) V_{laser} = V_{fly} - V_{DD} = -\frac{I_{peak} t_{pw}}{C_{fly}}.$$

This advantageously dynamically applies a reverse bias to the laser diode **108** until the potential at the first end **104** of the fly capacitor **102** is brought back up to the second voltage supply node **116** ($V_{sub,DD}$ —assuming no other voltage drop). During this duration, the laser diode **108** is under reverse bias, thus, for example, any remaining electrons in the n-type regions of the laser diode **108** are swept into the first voltage supply node **114**. This can also be explained as the discharge of the parasitic junction capacitance of the laser diode **108**. The quick removal of charge carriers from the active regions of the laser diode **108** prevents any further generation of photons and thus can limit optical tailing in embodiments.

(36) As previously described, the reverse bias is reduced as the fly capacitor **102** is charged back up to the second voltage supply node **116** and the laser diode **108** is subsequently maintained at zero bias. In other words, when the voltage at the first end **104** ($V_{sub,fly}$) reaches the second voltage supply node **116**, i.e., $V_{sub,fly}=V_{sub,DD}$, the potential at the anode no will be equal to the potential at the cathode **112** and the laser diode **108** will be at zero bias.

(37) The reverse-biasing driving circuit **wo** may then enter the second operating state again allowing the charged fly capacitor **102** to discharge through the laser diode **108**. This cycle can continue as long as needed.

(38) In some embodiments, the magnitude of the reverse voltage present across the laser diode **108** at the conclusion of the second operating state is tunable by the capacitance of the fly capacitor **102**. This can be seen from the equation

$$(39) V_{laser} = V_{fly} - V_{DD} = -\frac{I_{peak} t_{pw}}{C_{fly}}.$$

The capacitance, $C_{sub.fly}$, of the fly capacitor **102** appears in the denominator of the component defining the reverse bias. Keeping everything else equal, varying the capacitance can increase or decrease the magnitude of the reverse bias.

(40) The first, second, and third switches **124**, **126**, and **128** may comprise different forms in different embodiments. In some embodiments, some or all of the switches comprise field effect transistors such as MOSFETS. However, in other embodiments, some or all of the switches **124**, **126**, and **128** may comprise other types of electronic switches including, but not limited to bipolar transistors, power diodes, insulated gate bipolar transistors, silicon controlled rectifiers, and gate turn-off thyristors. However, for ease of design, the first and the second switches **124** and **126** are identical transistors.

(41) FIGS. **2-4** further illustrate the operation of embodiments of the reverse bias laser driving circuit of FIG. **1**. FIG. **2** illustrates examples of waveforms used as inputs for switches **124**, **126** and **128** to alternate some embodiments of the reverse biasing laser diode driving circuit like the one depicted in FIG. **1** between first and second operating states.

(42) As mentioned above, switches in FIG. **1** receiving first control signal $\phi_{sub.1}$ are closed in the first operating state and open in the second operating state while switches receiving second control signal $\phi_{sub.2}$ are open in the first operating state and closed in the second operating state. FIG. **2** depicts waveforms that can achieve this operation in some embodiments. However, it should be appreciated, that embodiments of the reverse-biasing driving circuit **100** utilizing different embodiments of the first, second, and third switches **124**, **126**, and **128** may achieve the appropriate operation by other waveform combinations.

(43) As illustrated in FIG. **2**, the first, second, and third switches **124**, **126**, **128** are controlled by a gate to source voltage $V_{sub.gs}$. The first control signal $\phi_{sub.1}$ has a first waveform for $V_{sub.gs}$ while the second control signal $\phi_{sub.2}$ has a second waveform for $V_{sub.gs}$. As illustrated, the first control signal $\phi_{sub.1}$ is in opposite in phase with the second control signal $\phi_{sub.2}$.

(44) In the first operating state reference as “I” in FIG. **2**, the first control signal $\phi_{sub.1}$ is high while the second control signal $\phi_{sub.2}$ is low. In the second operating state, the first control signal $\phi_{sub.1}$ is low while the second control signal $\phi_{sub.2}$ is high. In this illustration, a high $V_{sub.gs}$ state corresponds to a closed or ON state for a switch while a low $V_{sub.gs}$ state corresponds to an open or OFF state for the switch (e.g., assuming an enhancement mode NMOS FET). And, in corresponding to FIG. **1**, these waveforms will turn the first and second switches **124** and **126** into the ON state in the first operating state and switch the first and second switches **124** and **126** into the OFF state in the second operating state. The third switch **128** is turned into the ON state in the second operating state and into the OFF state in the first operating state. As can be appreciated, NMOS FET offer one embodiment of a switch corresponding to the waveforms presented in FIG. **2**. As known to a person having ordinary skill in the art, the waveforms for open and closed state would be opposite if a PMOS FET is used.

(45) FIG. **3** illustrates the voltage across the fly capacitor **102** in a specific illustrative embodiment of the reverse-biasing driving circuit **wo** from FIG. **1** to better understand the operation of the reverse-biasing driving circuit **100**.

(46) In the illustrative embodiment depicted in FIG. **3**, the fly capacitor **102** comprises has a capacitance of 180 pF. In the illustration, the voltage of the fly capacitor **102** is sketched during

repeating cycles of the first operating state (I) (time periods **301A**, **301B**, **301C**) and the second operating state (II) (time periods **303A**, **303B**, **303C**).

(47) The fly capacitor **102** is charged in the first operating state (time period **301A**) to a voltage of 2.5 V. Once the fly capacitor **102** is charged, the potential at the cathode **112** is approximately equal to the potential at the anode as described previously.

(48) In the second operating state, the fly capacitor **102** discharges triggering the laser diode **108**. This is depicted for the first time in FIG. **3** at **303A**. During this time period **303A**, the fly capacitor **102** loses its charge declining to approximately 2.175 V. When returned to the first operating state at **301B**, the fly capacitor **102** begins to charge and the voltage of the fly capacitor rises towards 2.5 V. A reverse bias will exist in the laser diode **108** for the short time during which the fly capacitor **102** is being charged until it reaches 2.5 volts. This charge and discharge cycle can continue indefinitely. It is noted that the values presented in FIG. **3** are for demonstrative purposes only. The capacitance, voltage, and duration of the first and second time periods may be varied in different embodiments.

(49) FIG. **4** illustrates the voltage across the laser diode **108** in first and second operating states in an embodiment. In the first operating state (time period **301A**) the voltage across the laser diode **108** remains at zero bias.

(50) In the second operating state, as the cathode **112** and anode no are decoupled from the first voltage supply node **114** and the second voltage supply node **116** respectively, the voltage across the laser diode rapidly increases, which generates a current pulse. This can be seen at **303A** in FIG. **4**.

(51) In the next cycle of the first operating state, the cathode **112** and the anode no are again coupled to the first voltage supply node **114** and the second voltage supply node **116**. However, due to the charge lost by the fly capacitor **102** during the pulse at time period **303A**, the potential at the cathode **112** is less than the potential at anode no so the laser diode **108** is reverse biased.

(52) As demonstrated in FIG. **4**, the voltage across the laser diode **108** becomes reverse biased by an amount equal to

$$(53) -\frac{I_{peak} t_{pw}}{C_{fly}}$$

instantaneously when the reverse-biasing driver circuit **100** reenters the first operating state in the time period **301B**. As the fly capacitor **102** is recharged during the first operating state, the magnitude of the reverse biasing of the laser diode **108** declines until the potential at the cathode **112** is approximately equal to the potential at the anode no. At this point the voltage across the laser diode **108** is zero.

(54) When the reverse-biasing driving circuit **100** enters the second operating state once more at time period **303B**, the fly capacitor **102** is discharged again to produce another pulse. Charging and discharging of the fly capacitor **102** and pulsing of the laser diode **108** can then continue indefinitely as the reverse-biasing driving circuit **100** cycles between first and second operating states. FIG. **4** depicts a pulse width of 500 ps, however the pulse width may vary in different embodiments. Likewise, the peak current $I_{sub.peak}$, and the fly capacitance $C_{sub.fly}$ may vary in different embodiments.

(55) The value of the fly capacitance $C_{sub.fly}$ may be selected according to the specifications of the laser diode **108**. For example, in one or more embodiments, a value of 100 pF may be selected for a $I_{sub.peak}$ of approximately 100 mA with a $t_{sub.pw}$ of less than 1 ns. Or, in other embodiments, a value of 1 nF may be selected to achieve $I_{sub.peak}$ of 1 A and a $t_{sub.pw}$ greater than 1 ns.

(56) In some embodiments, the reverse-biasing driving circuit **100** may have more than two operating states. For example, the reverse-biasing driving circuit **100** may have a standby state, or intermediate operating states.

(57) In some embodiments, the first voltage supply node **114** and the second voltage supply node

116 may be coupled to the same voltage source. In some embodiments, the first voltage supply node **114** and the second voltage supply node **116** may be coupled to different voltage sources that have the same potential.

(58) In some embodiments, the laser diode **108** is reverse biased in the first operating state until the fly capacitor **102** is charged to a potential substantially equal to the potential at the first voltage supply node **114**.

(59) FIG. 5 illustrates a block diagram of a method of operating a laser diode. The method **500** comprising having a driver circuit comprising a fly capacitor comprising a first end and a second end, and a laser diode comprising an anode and a cathode, the anode being coupled to the first end of the fly capacitor. Examples of the fly capacitor of embodiments of this method **500** include, but are not limited to, fly capacitor **102** and fly capacitor **602** discussed in various embodiments above.

(60) As illustrated in FIG. 5, in embodiments the method **500** comprises charging the first end of the fly capacitor to a first potential node at **502**. The method further comprises generating a current pulse by discharging the fly capacitor through the laser diode by driving the laser diode in forward bias at **504**. Examples of the laser diode of embodiments of this method **500** include, but are not limited to, laser diode **108** and laser diode **608**. In embodiments, the method further comprises at **506** recharging the first end of the fly capacitor to the first potential node and driving the laser diode in reverse bias.

(61) In some embodiments, the method **500** further comprises coupling the cathode to an energy potential while the fly capacitor is recharging, the energy potential being substantially equal to the first potential node thereby reverse biasing the laser diode until the fly capacitor is recharged to the first potential node.

(62) In some embodiments, the method **500** further comprises decoupling the cathode from the energy potential by one or more switches when the laser diode is driven in forward bias.

(63) In some embodiments, the method **500** further comprises decoupling the first end of the fly capacitor and the anode from a charging energy source by one or more switches when the fly capacitor is discharging.

(64) In some embodiments, the method **500** further comprises determining the magnitude of the current pulse by setting a programmable current source of a current control driver that mirrors the charging current of a decoupling capacitor that is charged in parallel with the fly capacitor and discharged in series with the fly capacitor while the fly capacitor is discharged to generate the current pulse.

(65) In some embodiments, the method **500** further comprises toggling the decoupling capacitor and the fly capacitor between a parallel arrangement and serial arrangements with one or more switches.

(66) In some embodiments of the method **500**, determining the current pulse determines a peak current and an average current through the laser diode during the current pulse.

(67) In some embodiments of the method **500**, the peak current and the average current is each further determined by a duty cycle of the current pulse.

(68) FIG. 6 illustrates an embodiment of current controlled laser diode driving circuit **600**. The embodiments of the invention presented herein also include embodiments of a laser diode driving circuit with current control.

(69) The switches of some embodiments of the method **500** may include, but are not limited to, the switches **124**, **126**, **128**, **642**, **644**, **646**, and **647**, **648** and **650**. The current mirror of some embodiments of the method **500** may include, but is not limited to the current mirror **632**. The programmable current source of some embodiments of method **500** may include, but are not limited to **638**.

(70) In the embodiment discussed in FIG. 1, the total charge (therefore the current pulse) through the laser diode is determined by the charge of the energy storage To more accurately control the current pulse through the laser driver, embodiments of the invention provide an additional

decoupling capacitor having a larger capacitance than the charge storing capacity of the fly capacitor **102** to charge the fly capacitor **102**. The decoupling capacitor is charged through a current mirror circuit having a programmable current source to adjust the charging of the decoupling capacitor. Further details of this embodiment are explained in more detail below.

(71) As illustrated in FIG. **6**, in various embodiments, the current controlled laser diode driving circuit **600** comprises a current mirror **632** coupled to a current mirror voltage supply node **633**. Some embodiments of the current controlled laser diode driving circuit **600** further comprise a programmable current source **638** coupled to a first path **640** of the current mirror **632**. Some embodiments, like the one depicted in FIG. **6** also comprise a decoupling capacitor **626** coupled to a second path **634** of the current mirror **632**. An output node **654** is coupled between the decoupling capacitor **626** and the current mirror **632**, in some embodiments. A laser diode **608** can be coupled to the output node **654** where the current controlled laser diode driving circuit **600** is configurable to provide a fixed current pulse through the laser diode **608** by selecting the programmable current source **638**. In embodiments, laser diode **608** comprises a VCSEL.

(72) The current mirror **632** may be used to provide a current along a second path **634** that is determined from, or “mirrors” the current along a first path **640**. In some embodiments, the current along the second path **634** of the current mirror **632** may be a multiplied value of the current across the first path **640**. This ratio of current in the first path **640** to the second path **634** may be represented by notation 1:N where N is the multiplier.

(73) The architecture of embodiments of the current controlled laser diode driving circuit **600** of this disclosure, like the one depicted in FIG. **6**, allow a voltage $V_{sub.p}$ at the output node **654** to be adjusted by charges provided by the second path **634** of the current mirror **632**. The current along the second path **634** charges the decoupling capacitor **626**, and the charge stored by the decoupling capacitor **626** is a function of the current along the second path **634**. As mentioned above, the current along the second path **634** mirrors the current $I_{sub.R}$ along the first path **640**. The programmable current source **638** provides control over the current $I_{sub.R}$ in the first path **640**. And, the operation of the current mirror **632** allows the current along the second path **634**, and thus the charge stored by the decoupling capacitor **626**, to be determined at least by the selecting the programmable current source **638**.

(74) Current mirror **632** may further comprise PMOS FETs **635** and **637** in some embodiments. Current controlled laser diode driving circuit **600** may also comprise PMOS FET **639** and inductor (LS) **607** in some embodiments.

(75) The current controlled laser diode driving circuit **600** may further comprise: a first switch **642** between the second end **606** of the fly capacitor **602** and the first and second reference terminal **618**; a second switch **644** between the second end **606** and output node **654**; a third switch **646** between the first voltage supply node **614** and the cathode **612**; a fourth switch **647** between the cathode **612** and the first and second reference terminal **618**; and a fifth switch **648** between the first end **604** of the fly capacitor **602** and a third voltage supply node **624**. In some embodiments, the third voltage supply node **624** is the output node **654** as depicted in FIG. **6**.

(76) In various embodiments, the various switches of the current controlled laser diode driving circuit **600** are configured to be activated/deactivated (switched ON/OFF) by control signals. In the embodiment depicted in FIG. **6**, first switch **642**, decoupling switch **650**, and third switch **646** are closed or in an ON state in a first operating state of the current controlled laser diode driving circuit **600**. The first switch **642**, decoupling switch **650**, and third switch **646** are open or in an OFF state in a second operating state of the current controlled laser diode driving circuit **600**. On the other hand, the second and fourth switches **644** and **647** are closed or in an ON state in the second operating state and open or in the OFF state in the first operating state. Additionally, the fifth switch **648** is closed or in an ON state, in the first operating state of the current controlled laser diode driving circuit **600** and open or in an OFF state in the second operating state. In one embodiment, the fifth switch **648** is a NMOS FET with its source coupled to the fly capacitor **602**

and the drain coupled to the output node **654**. One of ordinary skill in the art will appreciate that in different embodiments switches **642**, **644**, **646**, **647**, **648** and **650** may comprise different types of switches known in the art and used with different control signal waveforms to achieve the operation described above.

(77) Table I below illustrates the operational state of the various switches within the current controlled laser diode driving circuit **600** when the current controlled laser diode driving circuit **600** is the first operating state and the second operating state.

(78) TABLE-US-00001

| TABLE I | First Operating | Second Operating | Switch | State | State |
|---------|-----------------|------------------|--------|-------|-------|
| 642 | Enable | Disable | | | |
| 644 | Disable | Enable | | | |
| 646 | Enable | Disable | | | |
| 647 | Disable | Enable | | | |
| 648 | Enable | Disable | | | |
| 650 | Enable | Disable | | | |

(79) In Table 1, the switches are described as being enabled when they are conducting (low resistance state) and disabled when they are not conducting (high resistance state).

(80) Accordingly, in various embodiments, the output node **654** and the decoupling capacitor **626** are coupled with the current mirror **632** while the decoupling capacitor **626** is charged. In some embodiments, the output node **654** and the decoupling capacitor are decoupled from the current mirror **632** and the decoupling capacitor **626** during laser-diode pulses. In such embodiments, the decoupling capacitor **626** discharges through the laser diode **608** generating the current pulse through the laser diode **608**. The current pulse through the laser diode **608** being determined at least by the programmable current source **638**. This allows control of the current through the laser diode **608** by controlling the voltage in the decoupling capacitor **626** rather than controlling the current directly by a programmable current source.

(81) In some embodiments, the fixed current pulse through the laser diode **608** may comprise an average current through the laser diode **608**. The average current through the laser diode **608** may be approximately described by the following equation:

$$(82) \bar{I}_{LD} = \frac{NI_R}{2} \cdot \text{Math.} (1 - \alpha)$$

where \bar{I}_{LD} is the average current, I_R is the current selected by the programmable current source **638**, N defines ratio of the current along the first current path **640** to the second current path **634**, and α is the duty cycle of the laser diode **608**.

(83) In some embodiments, the peak current through the laser diode may be approximately described by the following equation:

$$(84) I_{LD} = \frac{NI_R}{2} \cdot \frac{T_{\phi 1}}{T_{\phi 2}}$$

where I_{LD} is the peak current, $T_{\phi 2}$ is the period of the current pulse through the diode, and $T_{\phi 1}$ is the time period of charging the decoupling capacitor. In such embodiments the peak and average currents through the laser diode is further determined by the duty cycle of the laser diode.

(85) The decoupling capacitor **626** and the output node **654** may be coupled and decoupled from the second path **634** by a decoupling switch **650** in some embodiments. FIG. 6 illustrates the decoupling switch **650** as a PMOS FET, but the current controlled laser diode driving circuit **600** may utilize other switches known in the art. Some examples include but are not limited to NMOS FET, bipolar transistors, power diodes, insulated gate bipolar transistors, silicon controlled rectifiers, and gate turn-off thyristors.

(86) The current mirror **632** depicted in FIG. 6 comprises first and second PMOS FETs M_{P0} and M_{P1} . Other embodiments may employ other types of current mirrors **632** including, but not limited to embodiments of current mirrors utilizing bipolar junction transistors.

(87) The current controlled laser diode driving circuit **600** may also comprise a voltage doubler in some embodiments. As depicted in FIG. 6, the current control laser diode driving circuit **600** can comprise a fly capacitor **602**. The fly capacitor **602** may be arranged in series with the decoupling capacitor **626** between the laser diode **608**. In some embodiments, the fly capacitor **602** and the decoupling capacitor **626** may discharge to provide a current pulse to the laser diode **608**. The

combined voltage of the fly capacitor **602** and the decoupling capacitor **626** may be approximately double the voltage of the decoupling capacitor **626**. The fly capacitor **602** may comprise a fly capacitor. The capacitance of the decoupling capacitor **626** may be much larger than the capacitance of the fly capacitor **602**, in some embodiments.

(88) As shown in FIG. **6**, the fly capacitor **602** may comprise a first end **604** and a second end **606** and similar to the fly capacitor **102** in FIG. **1**. The laser diode **608** may comprise an anode **610** and a cathode **612** and similar to the laser diode **108** described in FIG. **1**.

(89) FIG. **6** depicts some of the aforementioned switches as MOSFETS, however, in some embodiments, some or all of the aforementioned switches may comprise other types of electronic switches including, but not limited to bipolar transistors, power diodes, insulated gate bipolar transistors, silicon controlled rectifiers, and gate turn-off thyristors.

(90) FIG. **7** depicts waveforms of gate signals that can control operation of the switches described above in accordance with one embodiment of invention. As shown in FIG. **7**, the waveform corresponding to the first control signal $\phi_{\text{sub.1}}$ is high in the first operating state. The waveform corresponding to the second control signal $\phi_{\text{sub.2}}$ is high in the second operating state. Note that the waveforms corresponding to the first control signal $\phi_{\text{sub.1}}$ and the second control signal $\phi_{\text{sub.2}}$ are independent of the transistor type, High $|V_{\text{gs}}|$ corresponds to a closed gate and low $|V_{\text{gs}}|$ corresponds to an open gate.

(91) The waveform controlling the fifth switch **648** is shown as CP.sub.aux. The fifth switch **648** is depicted as an NMOS FET and the signal for CP.sub.aux is high in the first operating state so the fifth switch **648** in the ON state in the first operating state and in the OFF state in the second operating state. In one embodiment, the NMOS FET may be bootstrapped with the control signal CP.sub.aux switching between twice the voltage at the output node **654** and the voltage at the output node **654** (VP). In embodiments, CP.sub.aux may be generated from the voltage at the output node **654**. As one of ordinary skill in the art will appreciate, $2 \times \text{VP}$ may be generated from the voltage at the output node **654** using a level shifter structure.

(92) FIG. **8** depicts a block diagram of a method of operating a current controlled laser driver circuit. A method **800** for controlling current through a laser diode comprises having a current mirror coupled to a supply voltage node with a programmable current source coupled to a first path of the current mirror and a decoupling capacitor coupled to a second path of the current mirror, and an output node coupled between the decoupling capacitor and the current mirror on the second path of the current mirror. The method **800** further comprising at **802** selecting a fixed current pulse for a laser diode by setting the programmable current source; and at **804** charging the decoupling capacitor with a charging current on the second path of the current mirror, the charging current mirroring a programmable current set by the programmable current source. In embodiments, the method **800**, further comprises at **606** discharging the decoupling capacitor through the output node to provide the fixed current pulse through the laser diode.

(93) In some embodiments of the method **800**, the fixed current pulse comprises an average current and a peak current and wherein the fixed current pulse is further determined by a duty cycle of the laser diode.

(94) In some embodiments, the method **800** further comprises decoupling the output node and the decoupling capacitor from the second path of the current mirror while the decoupling capacitor is discharging.

(95) In some embodiments of the method **800** charging the decoupling capacitor substantially coincides with charging a fly capacitor coupled at a first end to an anode of the laser diode and discharging the decoupling capacitor substantially coincides with discharging the fly capacitor further wherein the first end of the fly capacitor is coupled with the output node while charging and a second end of the fly capacitor is coupled with the output node while discharging.

(96) The programmable current source of some embodiments of method **800** may include, but are not limited to **638**. Examples of the laser diode of embodiments of this method **800** include, but are

not limited to, **108** and **608**. Examples of the fly capacitor of embodiments of this method **800** include, but are not limited to, **102** and **602**. Examples of the decoupling capacitor of the method **800** include but are not limited to **626**.

(97) FIG. **9** illustrates the switching architecture for embodiments of the current controlled laser diode driving circuit **600**. The numbering from FIG. **6** has been carried over to FIG. **9**. FIG. **9** is a specific embodiment of the embodiment described in FIG. **6**.

(98) As depicted in FIG. **9**, the second switch **644A** comprises a PMOS transistor with an input tied to the first control signal $\phi_{\text{sub.1}}$. The second switch **644A** will be in the ON state in the second operating state and in the OFF state in the first operating state.

(99) As depicted in FIG. **9**, the first switch **642A** comprises a NMOS transistor with an input tied to the first control signal $\phi_{\text{sub.1}}$. The first switch **642A** is in the ON state in the first operating state and in the OFF state in the second operating state.

(100) As depicted in FIG. **9**, the third switch **646A** comprises a PMOS transistor with an input tied to the second control signal $\phi_{\text{sub.2}}$. The third switch **646A** is in the ON state in the first operating state and in the OFF state in the second operating state.

(101) As depicted in FIG. **9**, the fourth switch **647A** comprises a NMOS transistor with an input tied to the second control signal $\phi_{\text{sub.2}}$. As a result, the fourth switch **647A** is in the ON state in the second operating state and in the OFF state in the first operating state. Other embodiments may utilize other types of switches and other arrangements known in the art.

(102) Returning to FIG. **6**, in some embodiments the third voltage supply node **624** is coupled with the first voltage supply node **614** and coupled with the second voltage supply node **616** wherein a first end **628** of a decoupling capacitor **626** is coupled with the third voltage supply node **624** and a second end **630** of the decoupling capacitor **626** is coupled with a third reference terminal **622**.

(103) In some embodiments, the third voltage supply node **624** is coupled with the current mirror **632** in the first operating state and decoupled from the current mirror **632** in the second operating state, the decoupling capacitor **626** being on the second path **634** of the current mirror **632** in the first operating state and a current through the decoupling capacitor **626** in the first operating state being determined by the programmable current source **638** coupled to a first path **640** of the current mirror **632**. The current through the second path **634** charges the decoupling capacitor **626** in the first operating state in this arrangement.

(104) In some embodiments, the second end **606** of the fly capacitor **602** is configured to be coupled to the first and second reference terminal **618** in the first operating state by a first switch **642** that is closed in the first operating state and open in the second operating state and configured to be coupled to the third reference terminal **622** via the third voltage supply node **624** in the second operating state by a second switch **644** that is open in the first operating state and closed in the second operating state so the decoupling capacitor **626** is in series with the fly capacitor **602** and the laser diode in the second operating state.

(105) In second operating state the decoupling capacitor **626** may also be decoupled from the second path **634** and the decoupling capacitor **626** discharges in series with the fly capacitor **602** to substantially double the voltage applied to the anode **610** of the laser diode **608** during a pulse.

(106) In some embodiments, the fixed current pulse is further determined by a duty cycle of the laser diode **608** and the fixed current pulse comprises a peak current and an average current.

(107) In some embodiments, the first end **604** of the fly capacitor **602** is coupled to the anode **610** of the laser diode **608** in the first operating state in a parallel arrangement with decoupling capacitor **626** by operation of switches described above. In this state, fly capacitor **602** and the decoupling capacitor **626** will be charged in parallel as shown in FIG. **6**.

(108) In the second operating state, operation of the switches described above will place the fly capacitor **602** in a serial arrangement with the decoupling capacitor **626**, as shown in FIG. **6** allowing the fly capacitor **602** and the decoupling capacitor **626** to discharge through the laser diode **608** and provide the fixed current pulse. In some such embodiments, the voltage applied to

the anode **610** of the laser diode **608** to generate the fixed pulse may substantially double the voltage at the output node **654**.

(109) In some embodiments, the second end **606** of the fly capacitor **602** is coupled with the first and second reference terminal **618** in the parallel arrangement and the second end **606** of the fly capacitor **602** is coupled with the output node **654** in the serial arrangement.

(110) In some embodiments, the first end **604** of the fly capacitor **602** is coupled to the output node **654** in the parallel arrangement and wherein the second end **606** of the fly capacitor **602** is coupled with the output node **654** in the serial arrangement by.

(111) In some embodiments, the cathode **612** of the laser diode **608** is coupled to the output node **654** in the parallel arrangement and the cathode **612** of the laser diode **608** is coupled to the first and second reference terminal **618** in the serial arrangement.

(112) In some embodiments, the output node **654** and the decoupling capacitor **626** are decoupled from the current mirror **632** in the serial arrangement.

(113) In some embodiments, in the parallel arrangement, the cathode **612** of the laser diode **608** is coupled to a first voltage supply node **614** at a potential substantially equal to a potential at the output node **654** to provide a reverse bias to the laser diode **608** until the fly capacitor **602** is charged.

(114) In some embodiments, the output node **654** may be coupled with the first voltage supply node **114** of the embodiment of the driver circuit depicted in FIG. **1**. In some embodiments, the output node **654** may be coupled with the second voltage supply node **116** of the embodiment of the driver circuit depicted in FIG. **1**.

(115) In some embodiments the decoupling capacitor **626** comprises a large capacitance. In some embodiments, the capacitance of the decoupling capacitor **626** is approximately 1 nF. In embodiments where the fly capacitor **602** comprises a fly capacitor, the capacitance of the fly capacitor is approximately 180 pF.

(116) FIG. **10** illustrates a further schematic of a laser driver circuit in accordance with an embodiment of the present invention.

(117) Referring to FIG. **10**, in this embodiment, the laser driver circuit of FIG. **1** at the first end **104** of the fly capacitor **102** has been coupled to the output node **654** (e.g., as described in FIG. **6**). Consequently, this embodiment, does not have the voltage doubler, and the fly capacitor **102** may be the decoupling capacitor **626** described in FIG. **6** so that a separate fly capacitor (such as fly capacitor **602**) can be avoided. First and second control signals $\phi_{\text{sub.1}}$ and $\phi_{\text{sub.2}}$ may comprise control signals as explained elsewhere in this specification with reference to FIGS. **2** and **7**.

(118) FIG. **11** illustrates a schematic of a controller for a laser driver in accordance with embodiments of the present invention. As one of ordinary skill in the art will appreciate, a first control signal $\phi_{\text{sub.1}}$ may be generated by a controller **1101** and coupled to one more switches. Similarly controller **1101** may generate a second control signal $\phi_{\text{sub.2}}$ and coupled to one more switches. In the embodiment depicted in FIG. **11**, the first control signal $\phi_{\text{sub.1}}$ is coupled to switches **126** and **124**, while the second control signal $\phi_{\text{sub.2}}$ is coupled to switch **128**. However, as one of ordinary skill will appreciate, the first control signal $\phi_{\text{sub.1}}$ may be coupled with any switch in any embodiment of this disclosure controlled by the first control signal $\phi_{\text{sub.1}}$. Similarly, the second control signal $\phi_{\text{sub.2}}$ may be coupled with any switch in any embodiment of this disclosure denoted as receiving the second control signal $\phi_{\text{sub.2}}$.

Example 1

(119) A driver circuit including: a fly capacitor including a first end and a second end; a laser diode including an anode and a cathode, where the driver circuit is configured to operate in a first operating state and a second operating state, the anode being coupled to the first end of the fly capacitor, where, in the first operating state, the cathode is coupled to a first voltage supply node, the first end of the fly capacitor is coupled to a second voltage supply node, the second end of the fly capacitor is coupled to a first reference terminal; and where, in the second operating state, the

cathode is coupled to a second reference terminal and decoupled from the first voltage supply node, the first end of the fly capacitor is decoupled from the second voltage supply node, the second end of the fly capacitor is coupled to a third reference terminal.

Example 2

(120) The driver circuit of example 1 further including a third voltage supply node coupled with the first voltage supply node and coupled with the second voltage supply node, where a first end of a decoupling capacitor is coupled with the third voltage supply node and a second end of the decoupling capacitor is coupled with the third reference terminal.

Example 3

(121) The driver circuit of one of examples 1 or 2, where the third voltage supply node is coupled with a current mirror in the first operating state and decoupled from the current mirror in the second operating state, the decoupling capacitor being on a second path of the current mirror in the first operating state and a current through the decoupling capacitor in the first operating state being determined by a programmable current source coupled to a first path of the current mirror.

Example 4

(122) The driver circuit of one of examples 1 to 3, where the first reference terminal is the second reference terminal, and where the second end of the fly capacitor is configured to be coupled to the first reference terminal in the first operating state by a first switch that is closed in the first operating state and open in the second operating state and configured to be coupled to the third reference terminal via the third voltage supply node in the second operating state by a second switch that is open in the first operating state and closed in the second operating state so the decoupling capacitor is in series with the fly capacitor and the laser diode in the second operating state.

Example 5

(123) The driver circuit of one of examples 1 to 4, where the second reference terminal is the third reference terminal.

Example 6

(124) The driver circuit of one of examples 1 to 5, where the first voltage supply node is the second voltage supply node.

Example 7

(125) The driver circuit of one of examples 1 to 6, where the laser diode is reverse biased in the first operating state until the fly capacitor is charged to a potential substantially equal to the potential at the first voltage supply node.

Example 8

(126) The driver circuit of one of examples 1 to 7, where the first end of the fly capacitor is coupled to the second voltage supply node in the first operating state by a first switch that is closed in the first operating state and open in the second operating state.

Example 9

(127) The driver circuit of one of examples 1 to 8, where the cathode is coupled to the first voltage supply node in the first operating state by a switch that is closed in the first operating state and open in the second operating state.

Example 10

(128) The driver circuit of one of examples 1 to 9, where the cathode is coupled to the second reference terminal in the second operating state by a switch that is open in the first operating state and closed in the second operating state.

Example 11

(129) A method of operating a laser diode, the method including: having a driver circuit including an fly capacitor including a first end and a second end, and a laser diode including an anode and a cathode, the anode being coupled to the first end of the fly capacitor; charging the first end of the fly capacitor to a first potential; generating a current pulse by discharging the fly capacitor through

the laser diode by driving the laser diode in forward bias; and recharging the first end of the fly capacitor to the first potential and driving the laser diode in reverse bias.

Example 12

(130) The method of example 11 further including coupling the cathode to a supply voltage while the fly capacitor is recharging, the supply voltage being substantially equal to the first potential so as to reverse bias the laser diode until the fly capacitor is recharged to the first potential.

Example 13

(131) The method of one of examples 11 or 12 further including decoupling the cathode from the supply voltage by one or more switches when the laser diode is driven in forward bias.

Example 14

(132) The method of one of examples 11 to 13, where the first end of the fly capacitor and the anode are decoupled from a charging energy source by one or more switches when the fly capacitor is discharging.

Example 15

(133) The method of one of examples 11 to 14 further including determining the magnitude of the current pulse by setting a programmable current source of a current control driver that mirrors a charging current of a decoupling capacitor that is charged in parallel with the fly capacitor and discharged in series with the fly capacitor while the fly capacitor is discharged to generate the current pulse.

Example 16

(134) The method of one of examples 11 to 15 further including toggling the decoupling capacitor and the fly capacitor between a parallel arrangement and a serial arrangements with one or more switches.

Example 17

(135) The method of one of examples 11 to 16, where determining the current pulse determines a peak current and an average current through the laser diode during the current pulse.

Example 18

(136) The method of one of examples 11 to 17, where a peak current and an average current is each further determined by a duty cycle of the current pulse.

Example 19

(137) A driver circuit including: a current mirror coupled to a supply voltage node; a programmable current source coupled to a first path of the current mirror; a decoupling capacitor coupled to a second path of the current mirror; an output node coupled between the decoupling capacitor and the current mirror on the second path; and a laser diode coupled to the output node, where the driver circuit is configurable to provide a fixed current pulse through the laser diode by selecting the programmable current source.

Example 20

(138) The driver circuit of example 19, where the fixed current pulse is further determined by a duty cycle of the laser diode and the fixed current pulse includes a peak current and an average current.

Example 21

(139) The driver circuit of one of examples 19 or 20, further including a fly capacitor including a first end coupled to an anode of the laser diode and where the decoupling capacitor and the fly capacitor are charged in a parallel arrangement and discharged in a serial arrangement to provide the fixed current pulse.

Example 22

(140) The driver circuit of one of examples 19 to 21, where a second end of the fly capacitor is coupled with a first reference terminal in the serial arrangement and where the second end of the fly capacitor is coupled with the output node in the parallel arrangement.

Example 23

(141) The driver circuit of one of examples 19 to 22, where the first end of the fly capacitor is coupled to the output node in the parallel arrangement and where a second end of the fly capacitor is coupled to the output node in the serial arrangement.

Example 24

(142) The driver circuit of one of examples 19 to 23, where the fly capacitor and decoupling capacitor may be toggled between the parallel arrangement and the serial arrangement by one or more switches.

Example 25

(143) The driver circuit of one of examples 19 to 24, where a cathode of the laser diode is coupled to the output node in the parallel arrangement and the cathode of the laser diode is coupled to a first reference terminal in the serial arrangement.

Example 26

(144) The driver circuit of one of examples 19 to 25, where the output node and the decoupling capacitor are decoupled from the current mirror in the serial arrangement.

Example 27

(145) The driver circuit of one of examples 19 to 26, where, in the parallel arrangement, a cathode of the laser diode is coupled to a voltage supply node at a potential substantially equal to a potential at the output node to provide a reverse bias to the laser diode until the fly capacitor is charged.

Example 28

(146) A method for controlling current through a laser diode including: having a current mirror coupled to a supply voltage node with a programmable current source coupled to a first path of the current mirror and a decoupling capacitor coupled to a second path of the current mirror, and an output node coupled between the decoupling capacitor and the current mirror on the second path of the current mirror; selecting a fixed current pulse for a laser diode by setting the programmable current source; charging the decoupling capacitor with a charging current on the second path of the current mirror, the charging current mirroring a programmable current set by the programmable current source; and discharging the decoupling capacitor through the output node to provide the fixed current pulse through the laser diode.

Example 29

(147) The method of example 28, where the fixed current pulse includes an average current and a peak current and where the fixed current pulse is further determined by a duty cycle of the laser diode.

Example 30

(148) The method of one of examples 28 or 29, where the output node and the decoupling capacitor are decoupled from the second path of the current mirror while the decoupling capacitor is discharging.

Example 31

(149) The method of one of examples 28 to 30, where charging the decoupling capacitor substantially coincides with charging a fly capacitor coupled at a first end to an anode of the laser diode and discharging the decoupling capacitor substantially coincides with discharging the fly capacitor further where the first end of the fly capacitor is coupled with the output node while charging and a second end of the fly capacitor is coupled with the output node while discharging.

Example 32

(150) The method of one of examples 28 to 31, where a cathode of the laser diode is coupled with the output node while the decoupling capacitor is charging and the cathode is coupled to a reference terminal while the decoupling capacitor is discharging.

Example 33

(151) The method of one of examples 28 to 32, where, while the fly capacitor is charging, a cathode of the laser diode is coupled to a voltage supply node providing a potential substantially equal to the potential at the output node thereby reverse biasing the laser diode until the fly

capacitor is charged.

(152) While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments, as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to the description. It is therefore intended that the appended claims encompass any such modifications or embodiments.

Claims

1. A circuit comprising: a fly capacitor comprising a first end and a second end; a laser diode comprising an anode and a cathode, wherein the circuit is configured to operate in a first operating state and a second, light emitting, operating state, the anode being coupled to the first end of the fly capacitor, wherein, in the first operating state, the cathode is coupled to a first voltage supply node to reverse bias the laser diode, the first end of the fly capacitor is coupled to a second voltage supply node, the second end of the fly capacitor is coupled to a first reference terminal; wherein, in the second operating state, the cathode is coupled to a second reference terminal and decoupled from the first voltage supply node, the first end of the fly capacitor is decoupled from the second voltage supply node, the second end of the fly capacitor is coupled to a third reference terminal; and a third voltage supply node coupled with the first voltage supply node and coupled with the second voltage supply node, wherein a first end of a decoupling capacitor is coupled with the third voltage supply node and a second end of the decoupling capacitor is coupled with the third reference terminal.
2. The circuit of claim 1, wherein, in the first operating state, the first end of the fly capacitor is positively charged with respect to the first reference terminal, and wherein, in the second operating state, the fly capacitor is discharged through the laser diode operating in forward bias.
3. The circuit of claim 1, wherein the third voltage supply node is coupled with a current mirror in the first operating state and decoupled from the current mirror in the second operating state, the decoupling capacitor being on a second path of the current mirror in the first operating state and a current through the decoupling capacitor in the first operating state being determined by a programmable current source coupled to a first path of the current mirror.
4. The circuit of claim 3, wherein the second end of the fly capacitor is configured to be coupled to the first reference terminal in the first operating state by a first switch that is closed in the first operating state and open in the second operating state and configured to be coupled to the third reference terminal via the third voltage supply node in the second operating state by a second switch that is open in the first operating state and closed in the second operating state so the decoupling capacitor is in series with the fly capacitor and the laser diode in the second operating state.
5. The circuit of claim 1, wherein the laser diode is reverse biased in the first operating state until the fly capacitor is charged to a potential substantially equal to the potential at the first voltage supply node.
6. The circuit of claim 1, wherein the first end of the fly capacitor is coupled to the second voltage supply node in the first operating state by a first switch that is closed in the first operating state and open in the second operating state.
7. The circuit of claim 1, wherein the cathode is coupled to the first voltage supply node in the first operating state by a first switch that is closed in the first operating state and open in the second operating state, wherein the cathode is coupled to the second reference terminal in the second operating state by a second switch that is open in the first operating state and closed in the second operating state.
8. A method of operating a laser diode, the method comprising: having a circuit comprising a fly capacitor comprising a first end and a second end, and the laser diode comprising an anode and a

cathode, the anode being coupled to the first end of the fly capacitor; charging the first end of the fly capacitor to a first potential; generating a current pulse by discharging the fly capacitor through the laser diode by driving the laser diode in forward bias; determining a magnitude of the current pulse by setting a programmable current source of a current control driver that mirrors a charging current of a decoupling capacitor that is charged in parallel with the fly capacitor and discharged in series with the fly capacitor while the fly capacitor is discharged to generate the current pulse; and recharging the first end of the fly capacitor to the first potential and driving the laser diode in reverse bias.

9. The method of claim 8, further comprising coupling the cathode to a supply voltage while the fly capacitor is recharging, the supply voltage being substantially equal to the first potential so as to reverse bias the laser diode until the fly capacitor is recharged to the first potential.

10. The method of claim 9, further comprising decoupling the cathode from the supply voltage by one or more switches when the laser diode is driven in forward bias.

11. The method of claim 8, wherein the first end of the fly capacitor and the anode are decoupled from a supply voltage by one or more switches when the fly capacitor is discharging.

12. The method of claim 8, further comprising toggling the decoupling capacitor and the fly capacitor between a parallel arrangement and a serial arrangement with one or more switches.

13. The method of claim 8, wherein determining the current pulse determines a peak current and an average current through the laser diode during the current pulse, wherein the peak current and the average current are each further determined by a duty cycle of the current pulse.

14. A circuit comprising: a current mirror coupled to a supply voltage node; a programmable current source coupled to a first path of the current mirror; a decoupling capacitor coupled to a second path of the current mirror; an output node coupled between the decoupling capacitor and the current mirror on the second path; a laser diode coupled to the output node, wherein the circuit is configurable to provide a fixed current pulse through the laser diode to emit light by setting the programmable current source and is further configurable to provide a reverse bias to the laser diode; and a fly capacitor comprising a first end coupled to an anode of the laser diode, wherein the decoupling capacitor and the fly capacitor are charged in a parallel arrangement and discharged in a serial arrangement to provide the fixed current pulse.

15. The circuit of claim 14, wherein a second end of the fly capacitor is coupled with a first reference terminal in the serial arrangement and wherein the second end of the fly capacitor is coupled with the output node in the parallel arrangement.

16. The circuit of claim 14, wherein the first end of the fly capacitor is coupled to the output node in the parallel arrangement and wherein a second end of the fly capacitor is coupled to the output node in the serial arrangement.

17. The circuit of claim 14, wherein the fly capacitor and decoupling capacitor may be toggled between the parallel arrangement and the serial arrangement by one or more switches.

18. The circuit of claim 14, wherein a cathode of the laser diode is coupled to the output node in the parallel arrangement and the cathode of the laser diode is coupled to a first reference terminal in the serial arrangement.

19. The circuit of claim 14, wherein the output node and the decoupling capacitor are decoupled from the current mirror in the serial arrangement.

20. The circuit of claim 14, wherein, in the parallel arrangement, a cathode of the laser diode is coupled to a voltage supply node at a potential substantially equal to a potential at the output node to provide the reverse bias to the laser diode until the fly capacitor is charged.
