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(54) **Title:** INTEGRATED OPTIC DEVICE

(57) **Abstract:** An integrated optical device including an electrically controllable switching element and an electrically controllable attenuating element cascaded together, wherein the switching element may be switched from a maximum attenuation state at zero electrical power input to a minimum attenuation state by the input of electrical power, and wherein the attenuating element may be switched from a minimum attenuating state at zero electrical power input to a state of greater attenuation by the input of electrical power, the attenuating element capable of exhibiting greater maximum attenuation than the switching element.

INTEGRATED OPTIC DEVICE

The present invention relates to an integrated optical device.

An integrated optical device may comprise, for example, a pin diode attenuating element. Pin diode attenuating elements of the kind described in co-pending UK application nos GB0019971.5 or GB0104384.3, whose contents are incorporated herein by reference, exhibit low insertion loss and low polarisation dependency whilst being capable of achieving relatively high levels of attenuation. These attenuating elements may be used to control the average power of an optical signal propagating through a waveguide or to switch the associated waveguide between an "on" state which allows propagations and an "off" state in which the propagation is extinguished. When no voltage is applied across the p-doped and n-doped regions, the attenuating element exhibits minimum attenuation. Consequently, if there is an inadvertent loss of power supply to the pin diode attenuating element, the attenuating element will revert to the state of minimum attenuation, and the resulting uncontrolled propagation of the optical signal may have adverse effects on the optical component to which the signal is subsequently directed.

It is an aim of the present invention to provide an integrated optical device which at least partially overcomes this problem.

According to a first aspect of the present invention, there is provided an integrated optical device including an electrically controllable switching element and an electrically controllable attenuating element cascaded together, wherein the switching element may be switched from a maximum attenuation state at zero electrical power input to a minimum attenuation state by the input of electrical power, and wherein the attenuating element may be switched from a minimum attenuating state at zero electrical power input to a state of greater attenuation by the input of electrical power, the attenuating element capable of exhibiting greater maximum attenuation than the switching element.

As mentioned above, the first and second attenuating elements are cascaded together such that they act in series on an input optical signal. In the embodiment described later, the two attenuating elements are placed adjacent to each other, but the advantages of the present invention may also be achieved with other optical components interposed between the two elements. Furthermore, either the switching element or the attenuating element may be positioned for first receiving an input signal and outputting it to the other of the two.

According to a second aspect of the present invention, there is provided a method of operating such an integrated device, including the steps of supplying an optical signal to the integrated optical device for propagation through the switching element and attenuating element, supplying electrical power to the switching element to maintain it in a minimum attenuation state, and controlling the input of power to the attenuating element to adjust the power of the optical signal to a desired level.

Embodiments of the present invention shall now be described hereunder, by way of example only, with reference to the accompanying Figure 1, which shows a schematic view of an integrated device according to an embodiment of the present invention.

An optic system including an integrated device according to a first embodiment of the present invention is shown schematically in Figure 1. The system includes the integrated device 20 and a processor 14 for controlling the integrated device 20. The integrated device includes a Mach-Zehnder Interferometer (MZI) –type attenuating element 4 and an in-line attenuating element, such as, for example, a pin diode attenuating element, monolithically integrated in a silicon-on-insulator (SOI) chip 2 and cascaded together along an integrated waveguide 8, which may, for example, be connected to optic fibres at the input and output ends of the chip.

The MZI-type switching element 4 includes an additional waveguide 10 defined in the SOI chip 2. It is designed such that a portion of the power of an optical signal propagated along waveguide 8 is split into the additional waveguide 10 at the input end and the portions of the signal in each waveguide are recoupled at the output end, with most of the power of the recoupled signal propagated further along waveguide 8. An electrically controllable element 12 is provided for adjusting the refractive index of a portion of the additional waveguide (by the reversible injection of charge carriers into the waveguide) and consequently adjusting the effective path length of the additional waveguide 10. The physical length of the additional waveguide is selected to give a phase difference at the point where the signals in each waveguide are recoupled at the output end which results in maximum destructive interference and hence maximum attenuation without any input of electrical power to the element 12. The switching element can be switched "on" .i.e. to a state at which the attenuation of the signal is reduced to a minimum level by inputting electrical power to the element 12 to the extent required to adjust the effective path length to an extent sufficient to give a phase difference at the point where the signals in each waveguide are recoupled at the output end which results in maximum constructive interference and hence minimum attenuation.

The pin diode attenuating element 6 includes n-doped and p-doped regions on either side of the waveguide 8, such that charge carriers can be injected into the waveguide upon application of an appropriate voltage across the n-doped and p-doped regions. The injection of charge carriers into the waveguide increases the absorption of the waveguide with respect to the optical signal and thus increases the attenuation of the optical signal. The degree of attenuation depends on the amount of charge carriers injected into the waveguide, which in turn depends on the voltage applied across the n-doped and p-doped regions. The pin diode attenuating element 6 may have a structure as described in co-pending UK patent applications no. GB0019971.5 or GB0104384.3, whose contents are incorporated herein by reference. Alternatively, other types of in-line attenuating elements that operate on absorption effects may be used.

The pin diode attenuating element can be used as a switch by controlling it to be in one of two states, an “off” state in which an optical signal is substantially extinguished, and an “on” state, in which an optical signal is subjected to minimum attenuation. Alternatively, the pin diode attenuating element can be used as a variable attenuating element to control the level of attenuation applied to the optical signal such that the optical signal has the desired output power level.

In either case, the MZI-type switching element acts as a safeguard in the event of an inadvertent loss of electrical power supply to the integrated device, since in the absence of any input power it reverts to a default state of maximum attenuation, thereby preventing the optical signal from being further propagated in a completely uncontrolled manner.

The device shown in Figure 1 includes a single pair of switching and attenuating elements without any further optical components. However, the present invention also has application, for example, to integrated devices including components having a plurality of input or output paths (waveguides). A combination of switching and attenuating elements can be provided for each of the input or output paths to independently control the propagation of light through each path.

In the device shown in Figure 1, the MZI-type switching element is provided ahead of the pin diode attenuating element in terms of the direction of propagation of light. Alternatively, the relative positions of these two elements may be reversed.

Furthermore, the present invention is applicable to other classes of integrated devices such as those based on polymers and other semiconductor materials such as III-V materials.

CLAIMS

1. An integrated optical device including an electrically controllable switching element and an electrically controllable attenuating element cascaded together, wherein the switching element may be switched from a maximum attenuation state at zero electrical power input to a minimum attenuation state by the input of electrical power, and wherein the attenuating element may be switched from a minimum attenuating state at zero electrical power input to a state of greater attenuation by the input of electrical power, the attenuating element capable of exhibiting greater maximum attenuation than the switching element.

2. An integrated device according to claim 1, wherein the switching element is positioned for receiving an input signal and outputting it to the attenuating element.

3. An integrated device according to claim 1, wherein the attenuating element is positioned for receiving an input signal and outputting it to the first switching element.

4. An integrated device according to any preceding claim, wherein the attenuating element is a variable attenuating element that is controlled to exhibit a range of levels of optical attenuation.

5. An integrated device according to any preceding claim, wherein the attenuating element is an in-line attenuating element.

6. An integrated device according to claim 5 wherein the attenuating element is a pin diode attenuating element.

7. An integrated device according to any preceding claim, wherein the switching element operates by interference effects.

8. An integrated device according to any preceding claim, wherein the integrated device is a silicon-on-insulator device with the switching and attenuating elements defined in a layer of silicon.

9. A method of operating an integrated device according to any preceding claim, including the steps of supplying an optical signal to the integrated optical device for propagation through the switching element and attenuating element, supplying electrical power to the switching element to maintain it in a minimum attenuation state, and controlling the input of electrical power to the attenuating element to adjust the power of the optical signal to a desired level.

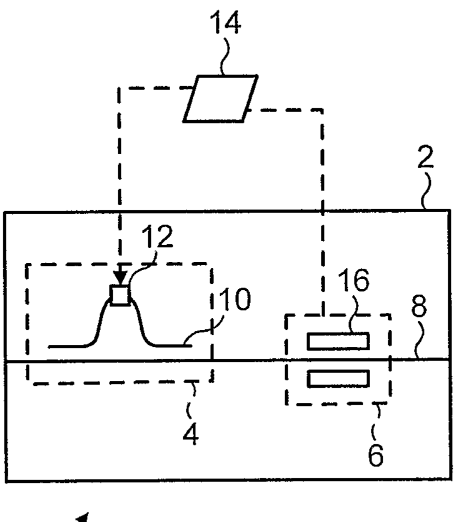

FIG. 1