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Overdriven Characteristics of Silica Switching Devices

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Abstract

We have built and characterized silica on silicon switching devices fabricated by using the electron beam irradiation. It is based on Mach-Zehnder structure fabricated on silica on silicon layers where the upper cladding used the MgF_2 layers to bury the core. The switching speed of 2.0 μs has been achieved. To further increase the switching speed we have used larger voltage to the Ti heating electrode to increase the thermo optics effects on silica structures. The higher driving voltage have been used that falls to zero exactly as the first extinction is reached, therefore three fold increase in modulation speed is achieved.

Keywords: *silica on silicon waveguides, switching devices, photonics devices, overdriven switching*

1. Introduction

Optical waveguide switches are key component in modern optical communication networks. Many different optical switching technologies are currently available or under development. In practical use switching with stable and low driving power as well as polarisation insesintives are also necessary. These switching characteristics can be built using several effects such as: the electro-optic effect [1] [2], the thermo-optic (TO) effect [3]-[5], or mechanical means [6]. Recently, one of the leading technology for optical waveguide switching devices is Ti-diffusion in $LiNbO_3$, where the electro-optics effects have been used. Today, switched directional couplers based on $LiNbO_3$ devices are commercially available. However, it is polarization sensitives and expensive even though the main benefits of such devices can operate very fast, in the sub-nanosecond regime.

Polarisation insensitive in some applications is more important than high switching speed, such as switching in LAN with ring topologies and video distribution using circuit switching [8][19]. From those available technologies, the optical waveguide switching based on thermo-optics effects would be a good alternatives, because not only it offers polarisation independent effect it also gives switching times of the order of milliseconds.

The TO effects in material is the change of index refraction due to temperature changes. For optical waveguides the phase shifters usually consists of thin film heater deposited on top of the cladding layers of buried channel guides. In conventional TO phase shifters a thin film heater deposited on the cladding of a buried channel guide, usually the Ti heating electrode has been used. Since in a silica-on-silicon optical waveguide, the glass conductivity is larger than air, heat will be conducted to the silicon substrate, which acts as a heat sink. In the steady-state condition, the result is a linear temperature gradient between the heater and the substrate, which will rises the average temperature of the core. However, in this scheme relatively high power consumption is needed and lateral heat diffusion inside the glass may cause a thermal crosstalk between two closely spaced guides [9] [10]. These difficulties may be reduced by using a bridge-suspended waveguide or using etched groove waveguide structures, which can lowers the required drive power and reduces the thermal crosstalk [7]. However, switching time required is lengthened proportionally.

The main purpose of this article is to explain on thermo-optic switching using Mach-Zehnder interferometer (MZI) structures. A thermo optic phase shifter consisting of thin film heater deposited on top of one Mach-Zehnder arms has shown to be very effective to change

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the effective refractive index of MZI so that the switching occurs. Further higher modulation speed can be achieved by increasing the driving voltage.

2. Research Method

The Mach-Zehnder interferometer (MZI) is another widely used device which has been developed to act as a switch (in its balanced form) and as a multiplexer or demultiplexer (in its unbalanced form) and it is a device that can used the TO effects excellently [11]. The MZI consists of two back to back Y-junctions, connected by linking waveguides. Introducing a phase delay to one linking guide via the thermo-optic effect enables the MZI to be used as a switching device as shown in Figure 1 (a). The phase shifter can be put in either or both of the straight arms to allow the relative phase of the recombining components to be altered [12][13]. If it is in the phase the guided output is high and if it is out-of-phase, it is low.

When the phase shifter or heater is on, the waveguide temperature beneath the heater increases, then the effective optical straight arm length increases by $\left(\frac{dn}{dT}\right)L\Delta T$, here $\frac{dn}{dT}$ is the thermo-optic constant of the silica waveguide, *L* is the heater length and ΔT is the temperature rise [17]. The typical value of $\frac{dn}{dT}$ for silica is $10^{-5}\,{}^{o}C^{-1}$. For example, heating a 10 mm long guide by $15.23^{o}C$ will produce a π radians phase shift at 1.523 μm wavelength [14]. The power needed and the response time are heavily depend on the thickness of cladding layer, thermal conductivity of silica waveguides and the lower substrate material used. In the case of silica on silicon structure, where the heat supplied by the Ti heater diffuses into the lower Si substrate through the MgF_2 cladding layers immidiately below the heater and then through SiO_2 layer immediately beneath the MgF_2. This immidiate heat diffusion between the three material layers due to the thermal conductivity of Si is much larger than that of SiO_2, MgF_2 and the surrounding air. Any lateral heat flow into the cladding glass is small, and all the glass reaches thermal equilibrium very quickly [15][17].

The characteristics of output power of Mach-Zehnder interferometers can easily be described by using the coupled mode theory. In the simplest case, assuming no loss and perfect *y*-branches with a 3-dB splitting ratio, the output power is given by [16][18]:

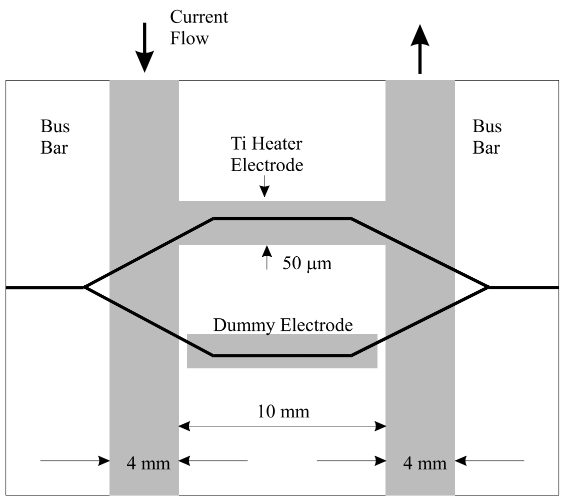
$$P_{out} = P_{in} cos^2(\frac{\varphi}{2}) \quad (1)$$

where P_{out} and P_{in} are the optical output and input powers respectively, and φ is the phase difference between the two paths. A phase difference may be changed by changing the refractive index of one arm with respect to the other. If the change in refractive index is proportional to the temperature change, it must also be proportional to the power dissipated in the heater, so the output intensity is given by:

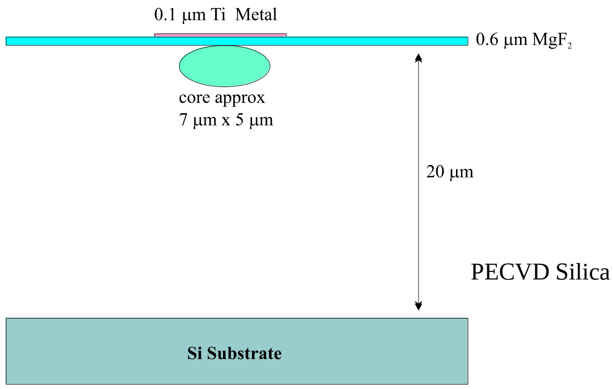
$$P_{out} = P_{in} cos^2(\frac{\pi}{2}\frac{P}{P_\pi}) \quad (2)$$

where $P = \frac{V^2}{R}$ is the electric power dissipated in the heater, *V* is the applied voltage, *R* is the measured heater resistance, and P_π is the power which gives a π radians phase shift.

The structure of the Mach-Zehnder Interferometers 1x1 single mode optical switches used to investigate thermo-optic switching in irradiated waveguides is shown in Figure 1. The device has two straight arms of 10 mm length and an additional thin film of Ti metal, to act as a heater electrode.



(a)



(b)

Figure 1. (a) Layout of thermo-optic Mach-Zehnder interferometric switches,
(b) Cross section of a straight guide of a Mach-Zehnder interferometer with an MgF_2 cladding layer and an additional Ti heater

The waveguides were formed in PECVD silica-on-silicon. Irradiation parameters of 1.06 C/cm^2 charge dose at 30 keV energy were chosen to obtain essentially polarization independent insertion losses of ≈ 1 dB at λ=1.523 μm for 3.4 cm lengths of straight guide with an oil cladding. The guide width was 7 µm, and the index difference between the core and buffer layer was $\Delta n \approx 6x10^{-3}$. Insertion losses for an electrodeless interferometer measured using an oil cladding were 2.0 dB (TE) and 2.5 dB (TM), with the difference being ascribed to slight birefringence. The heater was deposited above one arm of each interferometer by patterning a 0.1 µm thick layer of sputtered Ti metal into 50 µm wide strips fed by 4 mm wide bus bars, and a dummy electrode was placed above the unheated arm to avoid any phase or amplitude imbalance [14].

The current for the heater was supplied by a signal generator. However, due to the very low maximum voltage (10 V) provided by the source, a high power driving circuit was needed. Figure 2 shows the driver used in the experiments. It consists of two transistors (TR1 and TR2), which are used as a power switches. A minimum driving voltage of 0.7 V turns on the transistor TR1 which in turn switches transistor TR2 on and off allowing the supply voltage of +V to be dropped across the heater. With a suitable DC supply, this circuit provides a maximum output of up to 65 V [14].

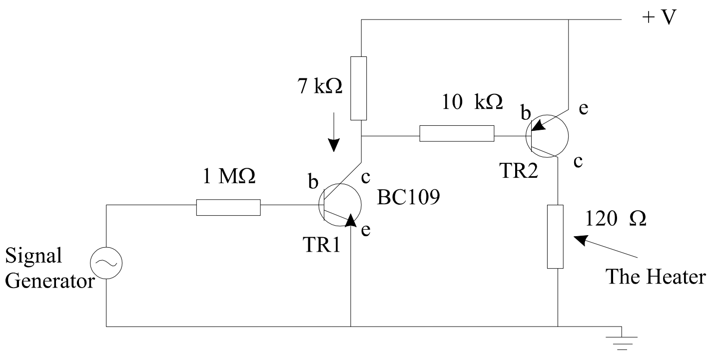


Figure 2. Driver circuit used to control the Ti heater

3. Results and Analysis

The measurement of switching characteristics was performed using a laser at a wavelength of 1.523 μm. The incident light was butt-coupled into the input end facet of the device using a single mode fibre. The circuit of Figure 2 was used to supply current to the heater and hence obtain a phase shift. The output light was detected using a photodetector, and the time variation of the detected signal was displayed on an oscilloscope.

Three types of experiment were carried out. In the first experiment, the variation of transmission with heater power was measured by applying a low frequency square-wave voltage of varying amplitude to the heater. In the second, faster-varying signals were used and the frequency response of the switch was measured. In the third, overdriven switching characteristics were measured. Figure 3.shows the variation of normalised transmission with heater power, which follows the conventional sinusoidal form. Points are experimental data; the solid line represents the calculated transmission as given by a best fit to Equation (2). Switching performance was essentially similar to devices demonstrated by other technologies [3] [15]. The lack of phase bias in the curve suggests that there is no phase shift between the two-interferometer arms, although the relatively poor extinction ratio (10 dB) suggests unequal splitting in the Y-junctions. The first extinction was obtained at a power of ≈ 0.5 W while the second was obtained at a power of ≈ 1.6 W.

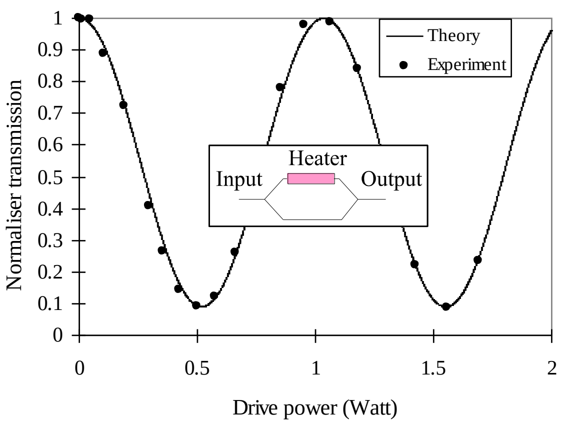
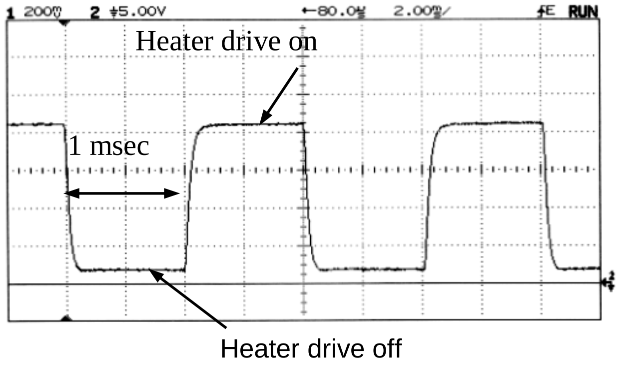
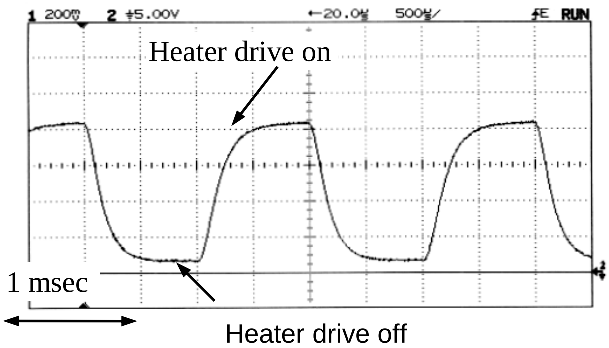


Figure 3. Variation of normalized transmission with heater power for a thermo-optic Mach-Zehnder interferometer modulator formed by irradiationl

Figures 4 (a), (b), (c) show switch characteristics obtained using a square wave heater drive at frequencies of 125 Hz, 500 Hz and 1 kHz, respectively. Complete switching is clearly achieved at the lowest frequency. However, as the drive frequency is raised, the relatively slow response of the switch quickly limit its ability to reach the ON and OFF states fully. Minimum switching times of ≈ 0.5 ms are slightly shorter than results obtained with topographic guides with a much thicker silica cladding, formed by flame hydrolysis deposition [17].



(a)



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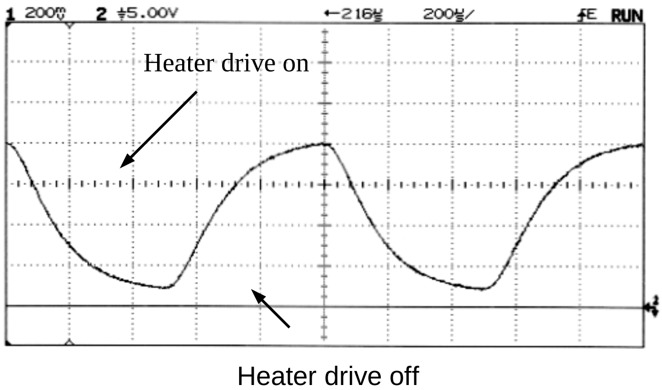
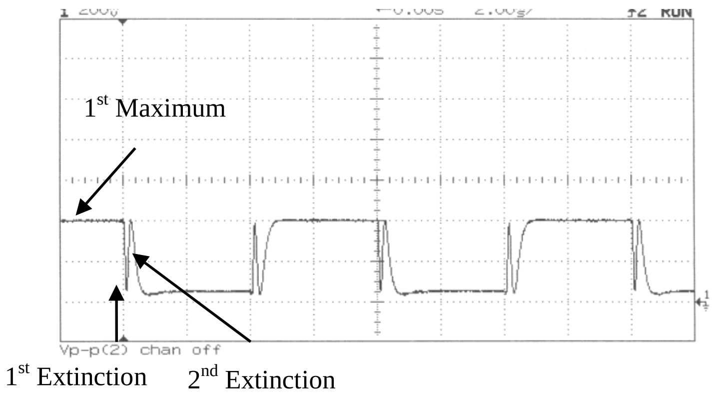


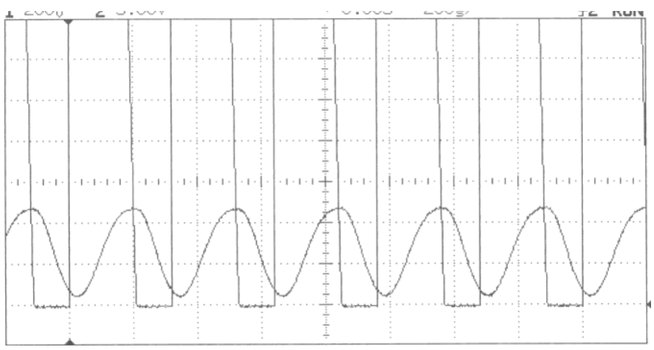
(c)

Figure 4 (a). Mach-Zehnder Interferometer switching characteristics obtained using a square wave heater drive at (a) 125 Hz, (b) 500 Hz, (c) 1 kHz.

In the previous set of experiments, the switch was driven using a voltage exactly sufficient to reach the first extinction. Faster switching speeds can in fact be achieved by using larger driving voltages. For example, Figure 5 (a) shows the switch characteristic obtained using a square wave of voltage 64 V at a frequency of 125 Hz. Here, the heater power is sufficient to drive the switch past the first extinction, through the following maximum, and then to the second extinction. Due to the increased drive power, the first extinction is reached extremely rapidly. Figure 5 (b) shows the corresponding trace obtained at 3 kHz.



(a)



(b)

Figure 5. Overdriven switch characteristic obtained using a square wave heater drive with a voltage of 64 V and a frequency of (a) 125 Hz, (b) 3 kHz.

In this case, the drive signal falls to zero exactly as the first extinction is reached, allowing an approximately three-fold increase in modulation speed over the corresponding result shown in Figure 3 (c). A periodic switching at similar speed may be obtained using shaped drive pulse, where an initially large switching voltage is followed by a smaller holding voltage.

4. Conclusions

We have characterized the switching devices based on Mach Zehnder interferometer where thin layers of evaporated MgF_2 can be used as a cladding for waveguides formed by electron beam irradiation of PECVD silica-on-silicon. Switching can be realized by using a thin film heater to induce refractive index changes in waveguide structures. An unequal splitting in the Y-junctions results in poor extinction, however, a major disadvantage. Switches based on directional couplers would be a good alternative, but heating one waveguide without affecting the other in such a closely-spaced geometry is extremely difficult.

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