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High Performance Polymeric Optical Waveguide Devices

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Abstract: Variable optical attenuators (VOA) made of low-loss fluorinated polymers are demonstrated which shows a low operating power less than 30 mW due to the superior thermo-optic effect of polymer material and a low insertion loss less than 1.0 dB by incorporating highly fluorinated polymers to reduce the absorption loss at 1550 nm. An attenuator-integrated low-crosstalk polymeric digital optical switch (DOS) is also demonstrated. The switch and attenuator shares a single connected electrode which is controlled by a single current source. Due to the simple structure of the integrated attenuator, the device length is reduced to 1 cm so as to provide low insertion loss of 0.8 and 1.1 dB for 1300 and 1550 nm, respectively. The attenuator radiates remained optical signal on the switch-off branch in order to decrease the switching crosstalk to be less than -70 dB with an applied electrical power of 200 mW.

Silica waveguide fabricated on a silicon substrate is the most widely adopted PLC structure for passive optical devices such as power splitter, wavelength multiplexer, etc. Especially, when the waveguide length is long, the silica waveguide has the advantage over the polymer because of the extremely low propagation loss. Compared to the silica, though the absorption loss is higher, polymer waveguide has strong competitiveness when one needs to control the optical signal with an electrical signal. Due to the high thermo-optic coefficient and the slow heat transfer of the polymer, the efficiency of index modulation is more than 10 times higher than that of the silica [1]. However, there was widely spread concern regarding the long-term stability of the polymeric waveguide device. Though there are some reports demonstrating how stable the polymer material is [2], it should be resolved from each polymer material used in the device before the device could be adopted for commercial transmission system.

A schematic diagram of the proposed VOA structure is shown in Fig. 1. It consists of single mode waveguide sections at the input and output for single mode fiber attachment, a tapered waveguide section for adiabatic mode transition, a wide waveguide section supporting multimodes, and a heating electrode tilted by an angle of with respect to the propagation direction. The operation principle of the VOA could be explained by the mode coupling and filtering process. When there is no index perturbation, the fundamental mode of light passes under the electrode without any coupling to the higher mode. Then it couples back into the output single mode waveguide. On the contrary, when a voltage is applied across the heating electrode, the refractive index of the multimode supporting waveguide underneath the heater is lowered due to the thermo-optic (TO) effect of the polymer film. By the induced index perturbation, the light will experience a coupling to a higher order mode and it results in a partial reflection by an angle of 2 degree. These excited higher order modes are filtered out as it propagates through the output tapered waveguide and the output single mode waveguide. The higher voltage introduces the higher perturbation to the guided mode and provides the higher attenuation.

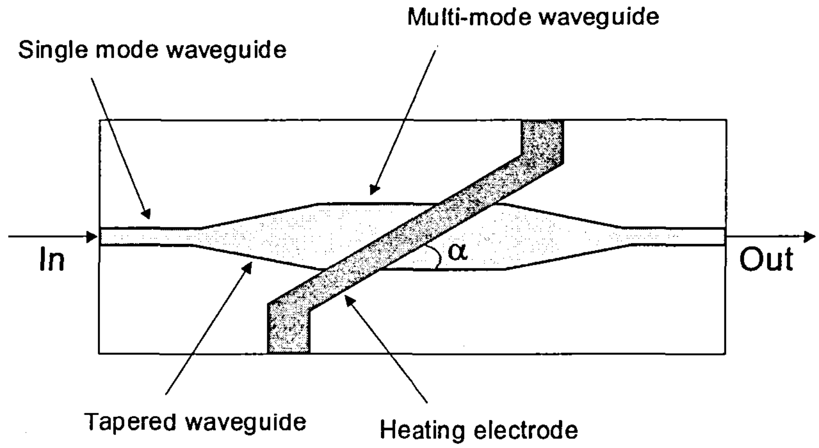

Fig. 1. Schematic diagram of the proposed VOA

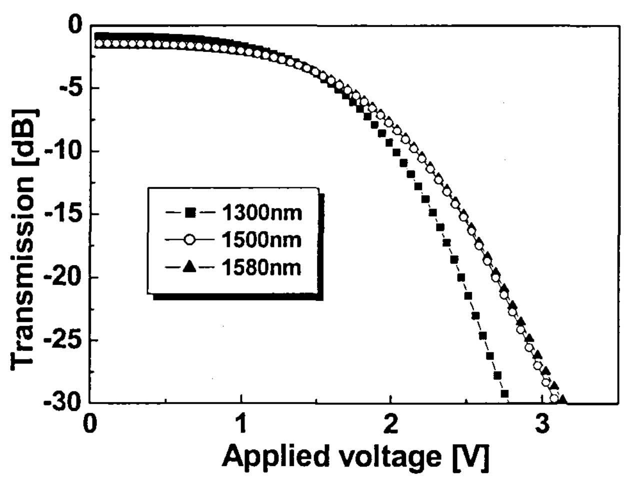

Fig. 2. Typical attenuation characteristics of the fabricated VOA for 1300 and 1550 nm

The polymeric digital optical switch consists of a conventional Y-branch waveguide structure and heating electrodes covering the waveguide pattern as shown in Fig. 3. It can be divided into two sections, the switch section and the attenuator section. Configuration of switching section is designed to have optimum adiabatic mode evolution for the low-loss and low-crosstalk. When electrical power is applied to one of the heating electrodes, the refractive index of one branch under the heater is decreased by the thermo-optic effect of the polymer. As a result, the guided mode evolves into the un-heated branch where the refractive index is higher than the heated branch.

The attenuator is integrated with the switch by extending the switch electrode to cover the curved waveguide after the Y-branch. Similar attenuator structures using guided mode radiation at straight waveguide have been reported [5, 6]. In conventional DOS, after the light signal switched into the unheated branch, there are still some amount of light remained on the heated branch which causes the crosstalk. However, in our proposed structure, the integrated attenuator connected at the

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end of switching section radiates the remained crosstalk light. Due to the index decrease on the waveguide by the integrated heater covering the output section, the remained light cannot be guided through the output waveguide so that the crosstalk is greatly enhanced.

The attenuator section has a curved waveguide with a radius of curvature of 25 mm, which is close to a straight waveguide so that the effect of curve in the radiation is not considerable. The heater covers directly on the waveguide. The heater length for attenuator used for the device is 2500 um, which is part of waveguide reserved for the output waveguide separation of 250 um. The total length of the device becomes less than 10 mm, which is much shorter than the previous device so that the lower insertion loss is expected.

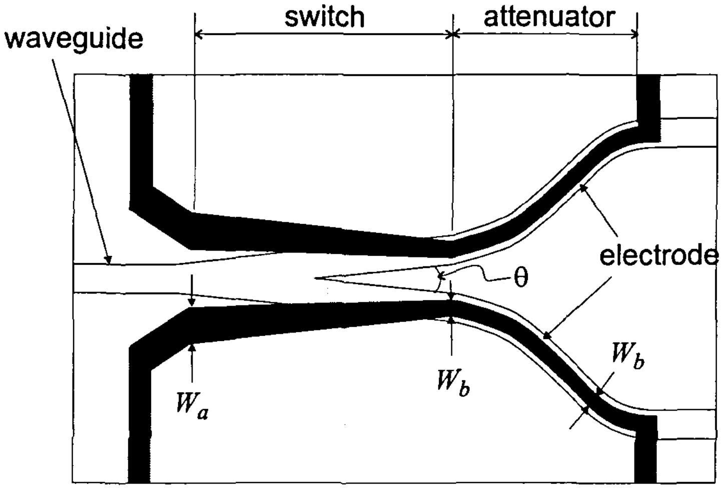

Fig. 3. Schematic diagram of the proposed low crosstalk digital optical switch consisting of 1x2 switch section with Y-branch waveguide, attenuator section, and single connected electrode.

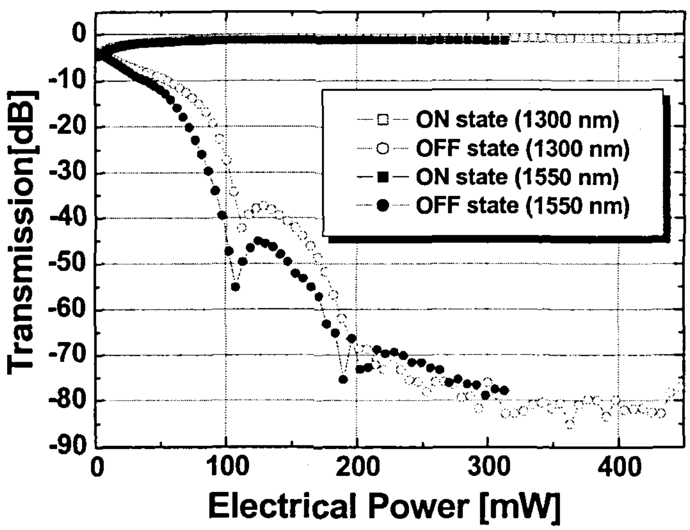

Fig. 4. Switching characteristics measured as a function of the applied electrical power, where -70 dB attenuation is achieved for both 1300 nm and 1550 nm wavelengths when 200 mW is applied.

As a function of the applied electrical power, the transmissions of the two output ports were measured as shown in Fig. 4. It is clearly shown that the response is the multiplication of the DOS switch and the waveguide attenuator responses. The periodic fluctuation observed from the off-state branch was the inherent characteristic of the DOS switch due to the incomplete adiabatic transition. An extremely low crosstalk less than -70 dB was achieved for both 1300 nm and 1550 nm wavelength windows, and the device showed good digital switching responses with no additional loss. The optical power meter (Anritsu MU931421A) had the minimum detectable power range of -80 dBm. The switching power to obtain the minimum crosstalk for the both wavelengths was about 200 mW. For electrical power below 200 mW, the crosstalk for 1550 nm was decreasing faster than that for 1300 nm, which was due to the difference of mode confinement.

References:

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