Novel voltage-controlled polymeric variable optical attenuator (VOA)

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Abstract
We demonstrate a novel voltage-controlled variable optical attenuator based on polymeric planar lightwave circuit (PLC) and analyzed the attenuation characteristics according to the variation of the angle of electrode. The fabricated VOA shows 30dB attenuation with only 80mW electrical input power at 1.55μm. The polarization dependences at 0 and 10dB attenuations are 0.2 dB and 1dB, respectively.

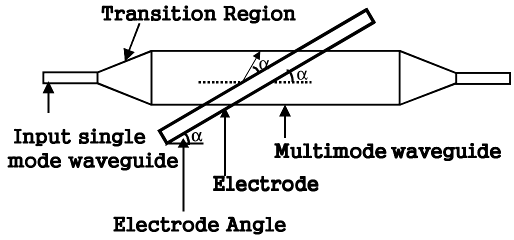

Fig. 1. Schematic diagram of the proposed variable optical attenuator

Introduction

Optical power fluctuation is detrimental to the overall performance of an optical transmission line and can be compensated by use of variable optical attenuators (VOAs). Such compensation is particularly needed at linear repeaters and channel power equalizers in wavelength division multiplexed (WDM) networks [1]. The VOAs have been fabricated by several technologies such as optomechanical systems, micro-electromechanical systems (MEMS) [2], side-polished fiber devices, and Faraday rotators. Meanwhile, new VOAs integrated on PLC were recently reported, in which their structures use Mach-Zehnder interferometer [3] or asymmetric Y-branch waveguide [1]. The VOAs on PLC are usually fabricated using polymer or silica on silicon substrates [4]. The polymeric VOAs have especially been very attractive due to advantages such as low electrical power consumption, low cost and easy fabrication. In this letter, we propose the novel polymeric thermo-optic (TO) VOA structure with superior characteristics than previous structures.

Principle of operation

Fig. 1 shows a schematic diagram of the proposed VOA. It consists of the input and output single mode waveguides, transition regions, multi-mode waveguide and angled electrode with α. Basic operation principles are as follows.

At first, the light is expanded adiabatically from the single mode waveguide into the multimode waveguide that support at least 8 waveguide modes. When the voltage is applied along the electrode, the refractive index under the heater is lowered due to the thermo-optic (TO) effect. Therefore, the propagating light under the heater is partially reflected with the angle of 2 respect to the horizontal axis. If the angle is larger than the fundamental mode of the multimode region, the reflected light is coupled back into the higher order guiding modes after passing the heater. These higher order modes successively filtered out through the output tapering region and the output single mode waveguide. As the applied voltage becomes higher, the amount of the reflected light is larger, which leads to the larger attenuation according to the applied voltage.

The characteristics of attenuations according to the variation of the angle of electrode are shown in Fig 2, which calculated by Beam Propagation Method (BPM). As the angle of electrode is larger, maximum attenuation and the correspondent temperature become larger. The reason is that higher waveguide modes are dominantly excited at the higher angle and filtered out at the transition region. The electrode angle 1.8° is equivalent to the angle of 4^{th} excited mode.

Device design and Experiment

The waveguide is a buried-channel type with

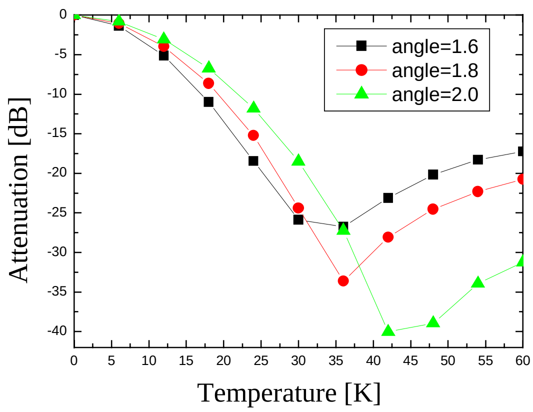

Fig 2. Attenuation characteristics according to the variation of the angle of electrode.

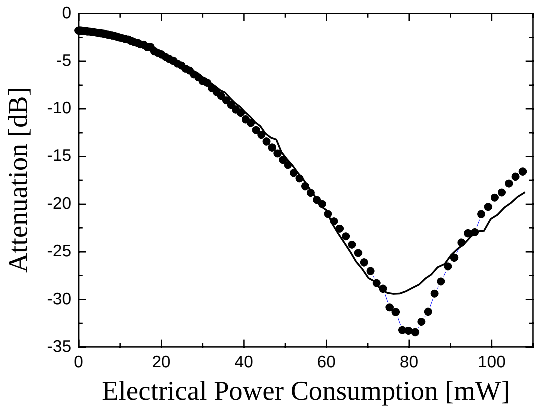

Fig 3. Measured attenuation characteristics according to the applied electrical power. Electrode length; 3800μm, electrode width; 7.2 μm and electrode angle; 1.6°. The solid line is for TE mode and the dotted line is for TM mode

7x7 μm rectangular cross section. The core and clad materials are ZP1010^{TM} and ZP2145^{TM}, respectively, which are polymer materials synthesized at ZenPhotonics Co. The polymer materials are thermally cross-linkable at 250°C. The birefringence between TE and TM modes are about 0.0036 at 1550nm for both of the core and the cladding materials, and the refractive index difference between the core and the cladding is 0.7%.

When the light propagates from the single mode waveguide to multimode waveguide region, a slight higher order mode excitation is not avoidable if the tapering region is not sufficiently long. This higher order mode coupling causes the effect of multimode interference in the multi-mode waveguide region, so that the excess loss varies sinuously with the length of multi-mode waveguide. Therefore the length should be optimized for a given waveguide width and index difference. In this paper, the length of the waveguide is optimized to 3800 μm at the width of multimode waveguide of 40μm.

Fig 3 shows the measured results of the fabricated devices. The result shows that the required electrical power to achieve 30 dB attenuation is only 80mW. This result showing very high attenuation at low electrical power consumption provides good combination that can be well suitable to normal transport networks. The polarization dependence is less than 0.2dB and 1dB at 0 dB and 10dB attenuations, respectively.

However, the polarization dependence is higher than the simulated results(less than 0.05dB). Such deviation may come from a slight difference in the confinement factors of TE and TM modes in real devices. The rising and falling times are measured to be about 5ms. The insertion loss of the device is less than 2dB. The fabricated devices have very compact size of 2×25 mm^2 which can be further reduced to 2×15mm^2. This device shows superior characteristics compared to previous results in the size and the power consumption.

Conclusions

A novel and compact VOA based on the higher order mode excitation and single mode filtering mechanisms has been proposed and fabricated on polymer PLC. The device shows 30dB attenuation with only 80mW input electrical power.

Acknowledgement

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