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Heater optimization for polymer in silica optical switch

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ABSTRACT

An optimization process of specialized heater electrode design for a Multimode Interference (MMI) based polymer in silica thermo-optical switch is described. The switch is designed based on the waveguide structure of photodefinable BenzoCyclobutene (BCB 4024-40) polymer core, sandwiched by a 6 μm thickness of silica (SiO_2) upper clad layer and BK7 glass as a substrate. The upper clad thickness has been chosen such that to avoid any attenuation due to lossy behavior of the metal electrode. The light path is controlled by embedded thermal heater on top of the waveguide at specified location. Starting from a straight rectangular heater at pre-designed location, a migration technique and optimization toward a trapezoidal heater structure has been proposed which utterly claimed a significant improvement in terms of tuning power by more than 15%.

1. Introduction

In view of the current trends in optical switch development, greater interest has been placed on the application of Multimode Interference (MMI) effect such as demonstrated by Ibrahim et al. [1], Al-Hetar et al. [2] and Wang [3]. This is mainly due to portrayed advantages which include polarization insensitivity, low loss, large fabrication tolerances and compatible to the weakly-guiding and strongly-guiding waveguide structure, as compared to counterpart approaches (X-junction, Y-branch and directional coupler).

One of the common technologies for optical switch application is a thermo-optic effect which originates from the temperature dependency of material's refractive index. Organic polymers are good candidates for thermo-optic switch as the thermal conductivity is low and refractive index exhibit greater temperature dependence [4]. BenzoCyclobutene (BCB 4024-40) is a polymer material that exhibits low loss characteristic, low thermal conductivity and high thermo-optic coefficient [5]. Our previous work [6], has demonstrated the suitability of BCB 4024-40 as waveguide material which further pave the material for thermo-optic switch application.

The main factor that needs to be considered in thermo-optic switch development is the tuning power which is desirably small in magnitude. Various techniques have been proposed to achieve this requirement which include the application of tapered heater structure [7]. However, brief explanation on the migration and optimization technique from rectangular to tapered structure is not discussed in detailed which is of great concern to potential researchers and scientists. Hence, the motivation of this paper is to propose a migration and heater optimization technique toward a tapered structure for an MMI thermo-optic switch, utilizing a BCB 4024-40 polymer core in silica clad. Significant changes of tuning power between a rectangular and tapered heater structure will definitely lead to better switching performance of polymer in silica thermo-optic switch as described in this paper.

2. Basic switch structure

The proposed optical switch is designed according to the 2 × 2 MMI cross coupler which is based on the paired interference scheme of self imaging effect [8]. In this work, a hybrid polymer silica has been adopted in designing the 2 × 2 MMI based cross coupler. The passive arrangement of this coupler has been successfully developed utilizing the wet-etching technique, as described in our publication [9]. The MMI structure consists of BenzoCyclobutene (BCB 4024-40) polymer as core layer surrounded by silica (SiO_2) upper clad and BK7 glass as a substrate. The refractive indices of BCB 4024-40 polymer, SiO_2 and BK7 glass are 1.5556, 1.45 and 1.50101, respectively [6].

In our basic switch design, 2000 Å-thick aurum was shaped as a straight heater on top of upper cladding layer. Fig. 1 shows the cross section of the thermo-optic MMI switch with a straight heating electrode. Initially, the heater had been optimized to be 6 μm wide and 3508 μm long, corresponding to the length of MMI coupler, L_{MMI} as shown in Fig. 2. In addition, the heater electrode is positioned 20 μm right to the symmetry axis. The heater position and size selection will be thoroughly discussed in the following section.

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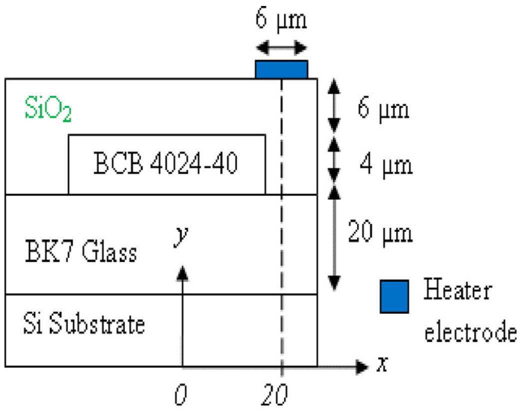

Fig. 1. Cross section of the thermo-optic MMI switch with a straight heating electrode.

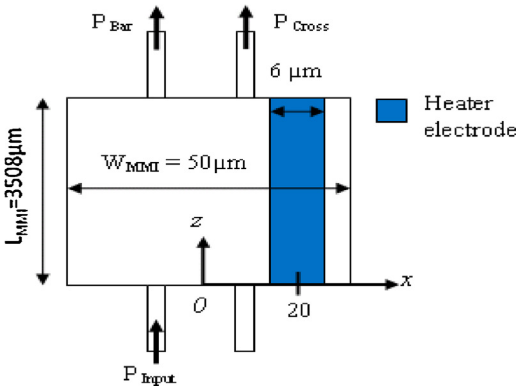

Fig. 2. Layout configuration of the thermo-optic MMI switch with a straight heating electrode.

3. Rectangular heater design and optimization

In this paper, the simulation work have been carried out using BEAMPROP® optical simulation package. In optical switch design, low crosstalk level and high extinction ratio are desirable since it indicates small signal interference and high signal quality at output ports, respectively [10]. As such, for rectangular heater design and optimization, the aim is to fulfill the said recommendations.

The optimization begins with the size of straight heater electrode. The simulation was done for different strip width of heater electrode, varied from 4 μm to 10 μm. As shown in Fig. 3, at 6 μm wide of strip heater electrode, low driving power of 54.41 mW and highest extinction ratio of 13.23 dB were produced. In term of crosstalk performance, at 6 μm wide of heater electrode, low crosstalk level of −19.14 dB was observed as shown in Fig. 4. Therefore, 6 μm wide was selected as an optimal width of heater electrode to obtain low driving power, high extinction ratio and low crosstalk.

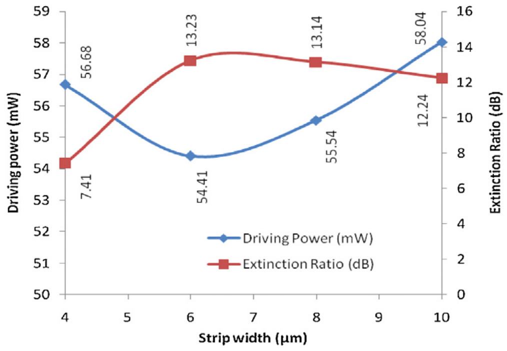

Fig. 3. Driving power and extinction ratio versus several strip width of straight heater electrode.

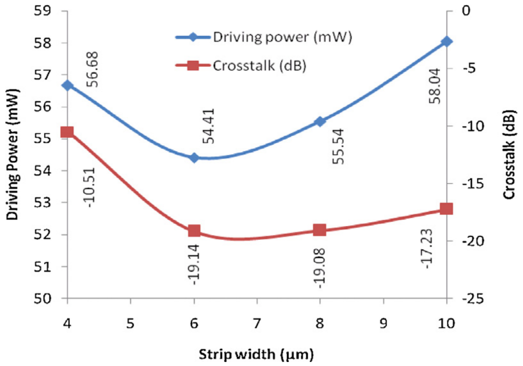

Fig. 4. Driving power and crosstalk versus several strip width of straight heater electrode.

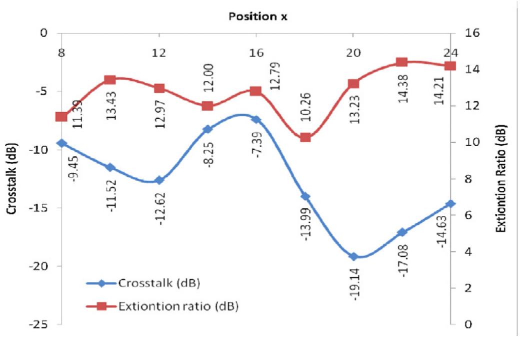

Fig. 5. Crosstalk and extinction ratio versus several positions of straight heater electrode.

The optimal position of straight heater electrode was simulated as well. Fig. 5 shows the crosstalk and extinction ratio versus the position of straight heater electrode. From the graph, it clearly shows that when heater is positioned 20 μm right to the symmetry axis, low crosstalk of −19.14 dB and high extinction ratio of 13.23 dB were achieved. The optimal width of straight heater is 6 μm wide, while the optimal position is 20 μm right to the symmetry axis. The switching characteristic for straight heater electrode is represented in Fig. 6. At a driving power of 54.41 mW, switching operation occurred with crosstalk performance of −19.14 dB and extinction ratio of 13.23 dB.

But prior to this, the optimal upper clad thickness need to be simulated to avoid any loss due to lossy metal behavior [11]. Therefore, the analysis was done to investigate the effect of upper

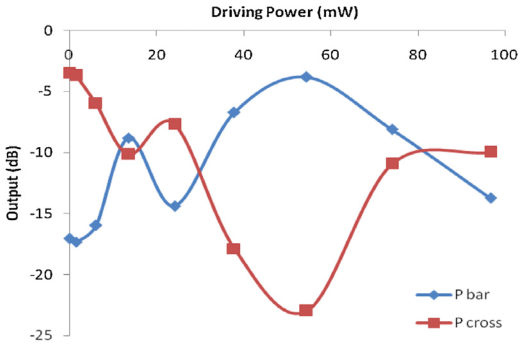

Fig. 6. Switching characteristics with 6 μm width of straight heater electrode.