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Analysis of response characteristics for polymer directional coupler electro-optic switches

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ABSTRACT

By using the coupled mode theory, electro-optic modulation theory, conformal transforming method, image method and the proposed transfer matrix technique, novel expressions for the both cases of the low switching frequency and the ultra-high switching frequency are presented for analyzing the transmission powers, rise time, fall time, switching time and switching frequency of the polymer directional coupler electro-optic switches. Simulation results of an application based on the technique show that, the switching voltage and coupling length are about 1.457 V and 4.374 mm, respectively, and the switching time and cutoff switching frequency are about 32.8 ps and 114.7 GHz, respectively, for the designed switch.

1. Introduction

As the fast development of optical communication systems and technologies, optical switches and arrays have been playing an important role in information transferring, information exchange, optical cross-connect (OXC), optical add-drop multiplexer (OADM), and optical line protection (OLP), due to their great applications in optical signal processing, optical computer, optical instrument, equipment, and sensors [1–4]. Nowadays, in order to increase the bandwidth, capacity, and speed of the local and trunk optical networks, optical switches should be designed and fabricated with short switching time and high switching frequency, which should be up to the orders of ps and GHz, respectively [5–6].

Switching time and switching frequency depend on many factors, which involve the response time of the electro-optic polymer materials, the light-wave propagation velocity along the waveguide, the microwave propagation velocity along the traveling-wave electrodes, the waveguide length, and the electrode structure of the switch. First, since the response time of almost all polymers, e.g. the polymer core AJ309 [7] used in this paper, can be as fast as subpicosecond or femtosecond, which is so fast compared with the period of the electric signal that it can be neglected, so we can reasonably think that, there exists no delay between the change of the electric signal and that of the refractive index of the electro-optic polymer. Moreover, the microwave propagation velocity depends on its effective refractive index, which can be calculated by using the characteristic parameters of the traveling-wave electrode. These parameters are obtained by solving the traveling-wave line equation through equaling the traveling-wave electrode to distributed parameter circuit [8].

In order to analyze the response characteristics including the switching time and switching frequency, a simulation technique is proposed in this paper. First in Section 2, the structural schematic of the switch and its traveling-wave electrode are presented. The push–pull electrodes are analyzed by utilizing the conformal transforming method and image method. The power transfer matrixes due to the change of the operation voltage applied on the traveling-wave electrodes are obtained by using the electro-optic modulation theory and coupled mode theory. Novel expressions are presented for analyzing the transmission powers, rise time, fall time, switching time, and switching frequency for the both cases of the low switching frequency and the ultra-high switching frequency. Then in Section 3, the simulation for the response characteristics is performed, which include the characteristic impedance, microwave effective refractive index, output powers, switching time, and cutoff switching frequency. Furthermore in Section 4, in order to check the accuracy of this technique, comparisons are carried out between the results calculated from this technique and those from the experimental method and extended point-matching method reported in Refs. [9,10]. Finally, a conclusion is reached in Section 5 based on the analysis and discussion.

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2. Model and theory

2.1. Model and structure

Fig. 1 shows the structural diagram of the polymer directional coupler electro-optic switch, which consists of two identical parallel rib waveguides and a push–pull electrode structure. The coupling region is shown in Fig. 1a, where d is the coupling gap between the waveguides and L is the length of the coupling region. The cross-section of the coupling region is shown in Fig. 1b, where the structure of the rib waveguide is given as: air/upper electrode/upper buffer layer/core/under buffer layer/under electrode/substrate, and only the core is electro-optic poled polymer material. The push–pull electrode structure consists of a pair of upper electrodes and a pair of under electrodes. During the poling, the applied poling voltage U_{pol} is shown in Fig. 1b; during the operation, the applied operation voltage U is shown in Fig. 1c. Denote W as the electrode width, and G as the electrode gap. Let a be the core width, b_1 be the core thickness, h be the rib height, n_1 be the core refractive index, and α_1 be its bulk amplitude attenuation coefficient. Let b_2 be the thickness of the upper/under buffer layers, n_2 be the refractive index of the upper/under buffer layers and the cladding beside the rib, and α_2 be their bulk amplitude attenuation coefficient. Let b_3 be the thickness of the upper/under electrodes, n_3 be its refractive index, and κ_3 be its bulk extinction coefficient. Let n_4 be the refractive index of the cladding above the upper electrode, and α_4 be its bulk amplitude attenuation coefficient. Denote U_s as the switching voltage.

2.2. Electric field and refractive index change

The electric field along the y-direction in the rib core is the sum of three parts as follows:

$$E_y^{(1)}(x,y) = E_{1y}(x,y) + E_{2y}(x,y) + E_{3y}(x,y), \tag{1}$$

where $E_{1y}(x,y)$ is the uniform electric field caused by a pair of upper/under electrodes, which is determined by

$$E_{1y}(x,y) = \frac{n_2^2 U}{2n_1^2 b_2 + n_2^2 b_1}. \tag{2}$$

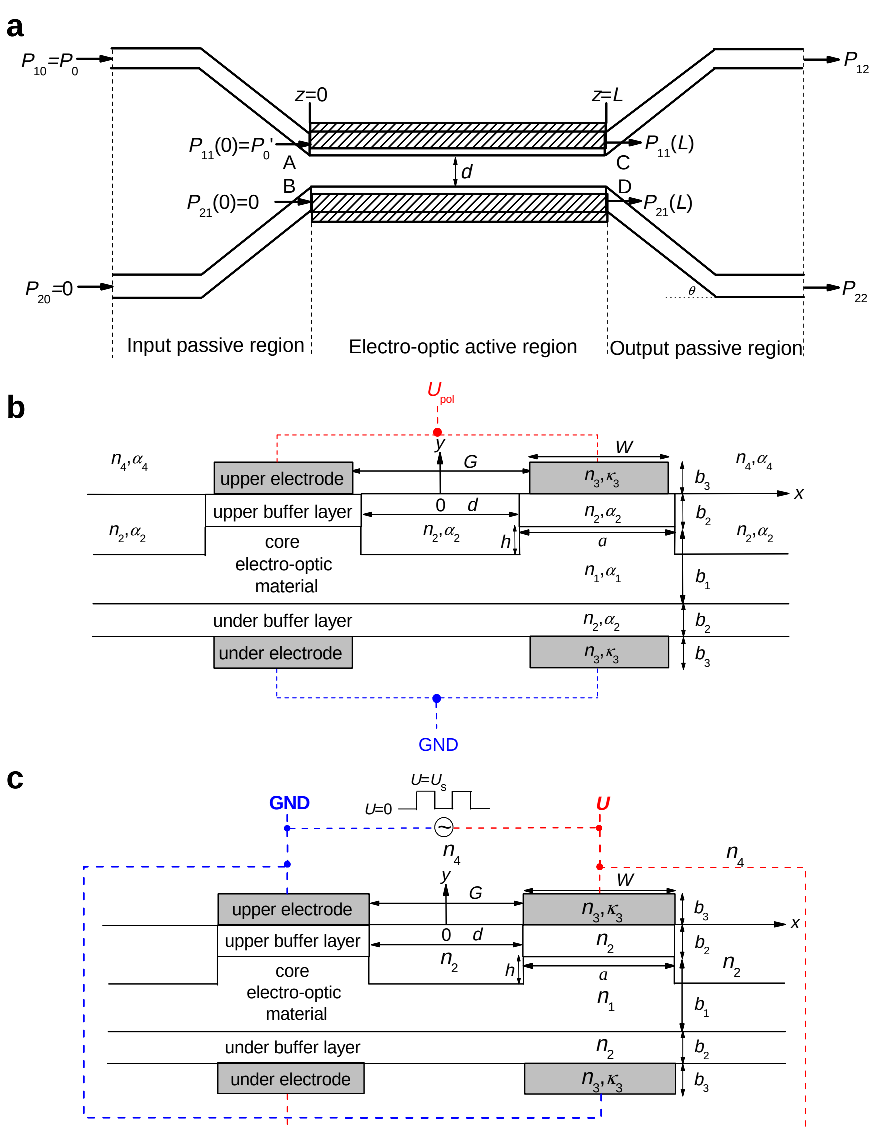

Fig. 1. (a) Structural diagram, (b) cross-section with poling voltage, and (c) cross-section with operation voltage in the electro-optic active region of polymer directional coupler electro-optic switches with push-pull traveling-wave electrodes.