Design of novel broadband electro-optic modulator

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The electro-optic modulator with the novel structure combining ridge structure and T-type electrode is given. Integrating T-type electrode structure and ridge wave guide structure should realize phase velocity matching, reduce effectively electrode loss and improve the performance and bandwidth of the modulator. The design structure is analyzed and optimized by the finite-element method.

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The electro-optic modulator is one of the important devices in high speed light communications.The light modulators are divided into two types, inner and outside modulators. Outside modulator is the main type in wide bandwidth and high speed communications. Comparing with polymer and electro absorption modulators, the $LiNbO_3$ electro-optic modulators possess the properties of broadband, high stability, low loss and so on. Many researches on $LiNbO_3$ electro-optic modulator have been developed. Some optimizing structures are brought forward[1−3].

On basis of the modulator structures which had been put forward[4,5], the new electro-optic modulator is designed by combining practical T-type electrode structure with ridge wave guide structure in this paper. Using T-type electrode structure realizes phase velocity matching and reduces electrode loss effectively. And using ridge wave guide structure should reduce microwave equivalent refractive index. The design structure is analyzed by finite-element method with the 'Ansys.' software. The bandwidth of the modulator by optimizing the structure and parameter achieves 150 GHz.

The design of the modulator should consider four aspects[6]: matching of microwave and phase velocity of light, lower loss of microwave electrode, lower half-wave voltage, and matching of characteristic impedance of driving supply. The main factors which restrict bandwidth of travelling wave electro-optic modulator are the phase velocity matching and the electrode loss.

The product of bandwidth and length of the modulator is given by

$$\Delta f \bullet L = \frac{2}{\pi} \bullet \frac{c}{N_{\mathrm{m}} - n_{\mathrm{e}}}, \tag{1}$$

where N_{m} is the equivalent refractive index of microwave transmission through modulator and n_{e} is the equivalent refractive index of light transmission through the device ($n_{\mathrm{e}} = 2.14$ as light wavelength is 1.55 μm). On condition of phase velocity matching, the bandwidth of the modulator is governed by

$$\alpha_0 \sqrt{\Delta f_{3-\mathrm{db}}} L = 13.8 \quad (\mathrm{dB}), \tag{2}$$

where α_0 is the loss coefficient of the modulator. In the modulator with the travelling wave guide, the field mode should be considered as transverse electromagnetic mode (TEM) pattern, which distribution approaches static field. Dividing the system field by making use of the finite-element method, the space distribution of the electric potential can be gained by the Laplace equation and the electric capacity should be calculated. Then the equivalent refractive index of microwave transmission N_{m}, the microwave characteristic resistance Z_{c}, the loss coefficient α_0 and the bandwidth of the modulator should be confirmed.

The equivalent refractive index is written by

$$N_{\mathrm{m}} = \sqrt{\varepsilon_{\mathrm{eff}}} = \sqrt{\frac{C_1}{C_0}}; \tag{3}$$

the microwave characteristic resistance Z_{c} is given by

$$Z_{\mathrm{c}} = \frac{N_{\mathrm{m}}}{C_1 \bullet c} = \frac{1}{c\sqrt{C_1 \bullet C_0}}, \tag{4}$$

where C_1 is distributing capacitance per unit length electrode of the modulator, C_0 is distributing capacitance per unit length electrode when the air fills; c is the light velocity in vacuum. Another important parameter of the modulator is the half-wave voltage

$$V_\pi = \frac{G \bullet \lambda}{2n^3 \gamma_{33} \bullet \Gamma \bullet L}, \tag{5}$$

where G is the width of the electrode interval, λ is the light wavelength in free space, n is the equivalent refractive index of the $LiNbO_3$ waveguide, γ_{33} is the electro-optic coefficient of the $LiNbO_3$ crystal and $\gamma_{33} = 30.8 \times 10^{-12}$ m/V, Γ is the electro-optic overlapping integral which shows the lap degree between the light and field, L is the electrode length.

As shown above, it is obvious that the main parameters of the modulator are dependent on solving the distributing capacitances C_1 and C_0.

Our design model is shown in Fig. 1, which combines practical T-type electrode with ridge wave guide structure. The electrode material is metal Au, buffer layer is SiO_2, ridge wave guide layer is polytetrafluoroethylene (PTFE), underlay is $LiNbO_3$. W_{G} is horizontal breadth

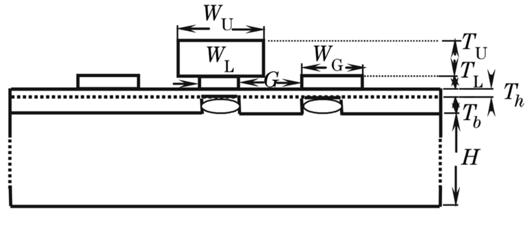

Fig. 1. The cross-sectional configuration of the electrode model.

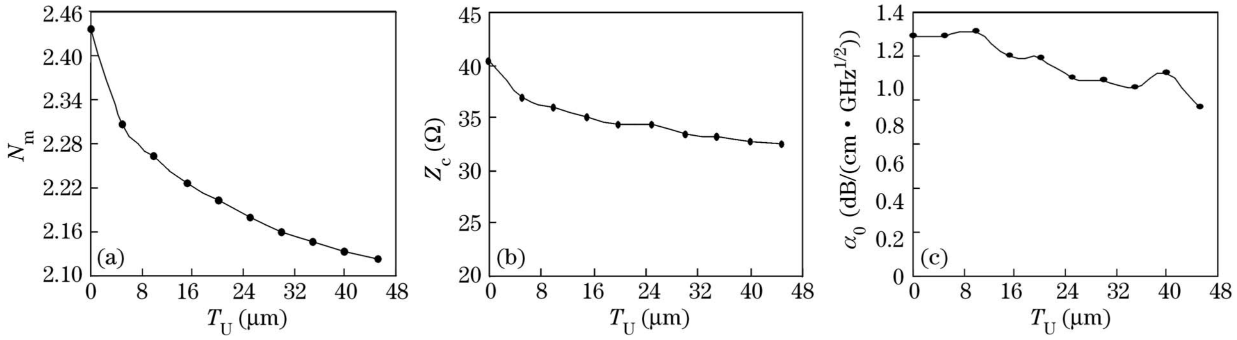

Fig. 2. N_m ,Z_c and α_0 versus T_U when $T_h = 5$ μm, $T_b = 0$ μm,$W_U = 23$ μm.

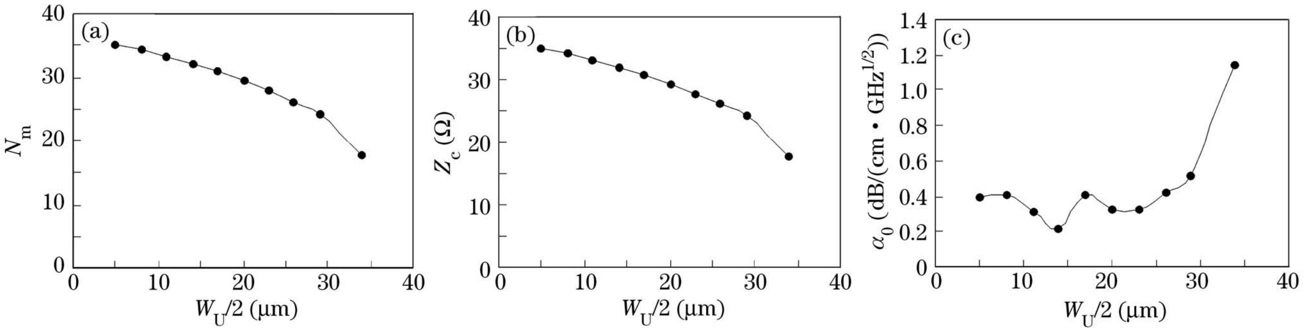

Fig. 3. N_m, Z_c and α_0 versus W_U, when $T_h = 5$ μm, $T_b = 0$ μm, $T_U = 35$ μm.

of the ground pole, G is interval of the poles, W_U is the horizontal breadth of the upper pole, W_L is the breadth of the lower pole, T_U and T_L are the vertical sizes of the poles, T_h is the thickness of the buffer layer, T_b is the thickness of the ridge waveguide, H is the thickness of the $LiNbO_3$ cushion.

On basis of the researches that have been made already, we analyze mainly the influence of the ridge waveguide and T-type electrode on the modulating performance in this paper. In analytical process, some related parameters are fixed as: $G = 30$ μm, $W_L = 10$ μm, $T_L = 5$ μm, $W_G = 15$ μm, H=200 μm. The electrode parameters W_U, T_U, T_h and T_b are calculated and optimized as below.

Figure 2 shows the influence of electrode size T_U on the characteristic parameters of the modulator. It is obvious that increasing T_U could bring on reduction in N_m and the microwave loss which should improve the bandwidth as phase speed match, but the microwave characteristic resistance Z_c gradually departs from the speciality resistance 50 Ω.

Figure 3 shows the influence of electrode size W_U on the characteristic parameters of the modulator. It is clear that with W_U increasing, N_m and Z_c decrease, but the loss coefficient α_0 increases, which could be considering emphases in designing pole breadth.

Figure 4 gives the influence of ridge wave-guide layer on the modulator performance. The equivalent refractive index of microwave reduces effectively when increasing thickness of the ridge wave guide. Therefore the bandwidth of the modulator could be improved if the ridge wave guide structures are adopted in T-type electrode.

Figure 5 shows the influence of the ridge wave guide layer and buffer layer with different medium filled on the modulator performance, which the buffer layer is filled with SiO_2 and the ridge wave guide layer is filled with PTFE. It is seen that this structure with different medium filled is more suitable practical facture and gains preferable results.

This paper puts forward a new pattern modulator which combines practical T-type electrode with ridge wave guide structure. On basis of mass of computing

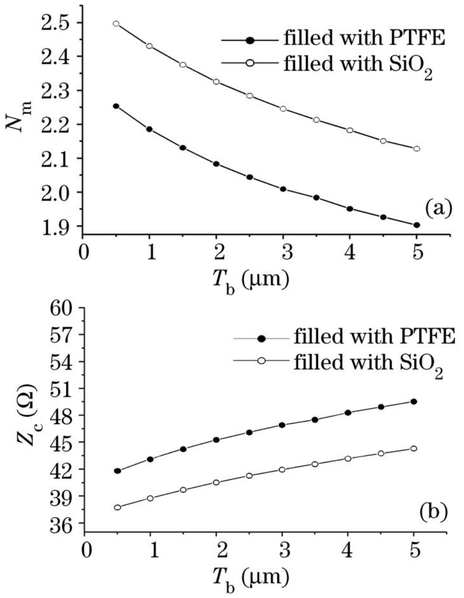

Fig. 4. N_m and Z_c versus T_b, for $T_h = 1$ μm, $W_U = 27$ μm, $T_U = 23$ μm, one medium filled.

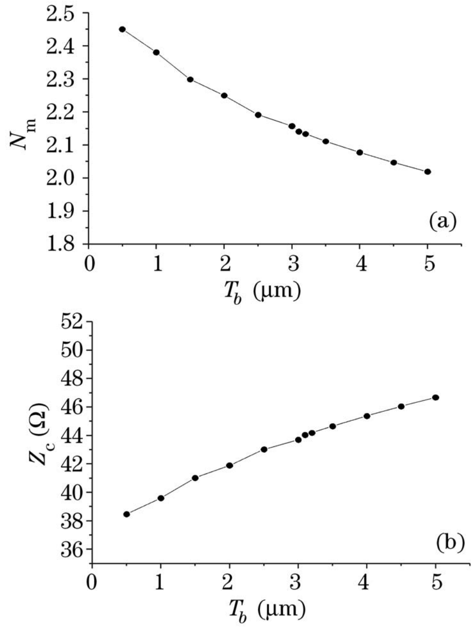

Fig. 5. N_m and Z_c versus T_b for $T_h = 1$ μm, $W_U = 27$ μm, $T_U = 23$ μm.

and analyzing, it is proved that the design can improve greatly the bandwidth of the modulator. Making use of optimizing, the design example of the modulator is given which the half-wave voltage is 8.55 V, the characteristic resistance is 44 Ω, and the bandwidth is 150 GHz.

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