Bend effect of the electrode for travelling wave integrated electro-optic modulators

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In this paper, we have studied electrode bend effects on electrical characteristics of the modulator in the three aspects, which are arc length, characteristic impedance, and loss, applying the model in Ref. [1] and the finite element method (FEM). The results have shown that the effect only caused by the characteristic impedance is necessarily considered while its deviation is large, but others are negligible as we design a practical device. Finally, some transmission characteristics of coplanar line with different arc length of the bend have been tested, and the measured results are in good agreement with the theoretical analyses.

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Travelling-wave integrated electro-optic modulators, particularly, the $LiNbO_3$ Mach-Zehnder modulators with thick electrodes, have received a lot of attentions due to their applications in broadband long-haul optical communication systems. The microwave parameters of the packaged optical modulators are important factors[2], in the condition of velocity matching, which are mainly restricted by losses intrinsic to the device electrode, by losses due to coupling to substrate modes[3], and also by impedance mismatch between the device and a 50-Ω driver[4]. Because of packaging requirements, the electrical transmission line integrated on the modulator is composed of the following sections, which are input and output section, tapers, bends and active section, shown in Fig. 1. The bends can easily result in reflection and scatter losses of microwave transmitting. Therefore, it is very interesting for the research on the bend effects of a coplanar waveguide electrode.

In this paper, we have studied bend effects on electrical characteristic of the modulator in the three aspects, which are arc length, characteristic impedance, and loss, using the model in Ref. [1] and the FEM. The transmission responses of the three groups of coplanar waveguides are measured. Conclusions are presented finally.

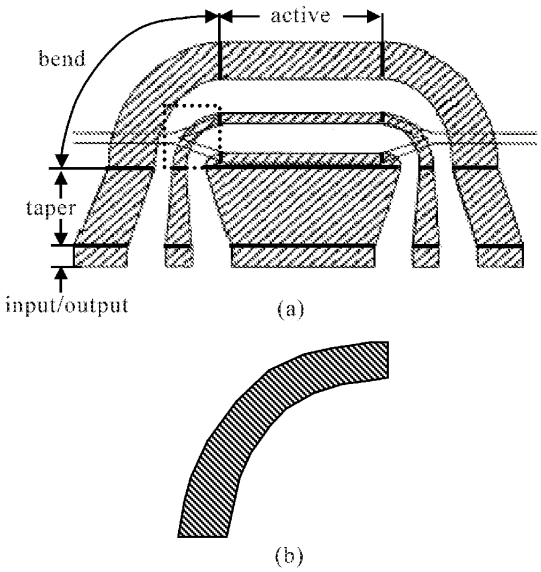

Fig. 1. (a) Layout of modulator electrodes; (b) enlarged view of electrode bend in dashed line part.

Using the method above, we have calculated bend effects on electrical characteristics of the modulator in the three aspects, which are arc length l, characteristic impedance Z, and loss α, respectively. Here, it is pointed out that when each parameter of the electrode bend changes, the others do not change and are still referred to Table 1, and the relations among parameters of the bend are also not taken into account. In order to show the calculation results clearly, we have applied some large parameters of the bend during the computation.

From Fig. 2, we find that the effect on the electrical characteristic is obviously strong as the frequency is over 10 GHz and we increase the arc length. But it should be mentioned that the increase of arc length can lead to the increase of the electrode dimension. Fortunately, the long arc length is not applicable to the modulator, because both width of an optical waveguide and distance between two optical waveguides of a Mach-Zehnder interferometer are very small, and this is not favorable of integration for optical devices. Therefore, we can not consider its effect on the practical modulators. Figure 3 shows the relation between the electrical characteristic of modulator and the characteristic impedance of electrode bend. It is evident that the effect caused by the characteristic impedance is large and can not be negligible, since the difference of the characteristic impedance easily occurs as we design a device. In addition, when we consider all the possible losses of the electrode bend, we find the effect on the electrical characteristic is necessarily considered as shown in Fig. 4. However, it is certain

Table 1. The Parameters Used to Calculate the Fit Curves

Section	l_i (mm)	$Z_i(\Omega)$	α_i (dB(cm$\sqrt{\text{GHz}}$)$^{-1}$)
Transition	0.4	40	0.010
Taper	2.4	48	0.010
Bend	0.2	42	0.042
Active	25.0	42	0.040

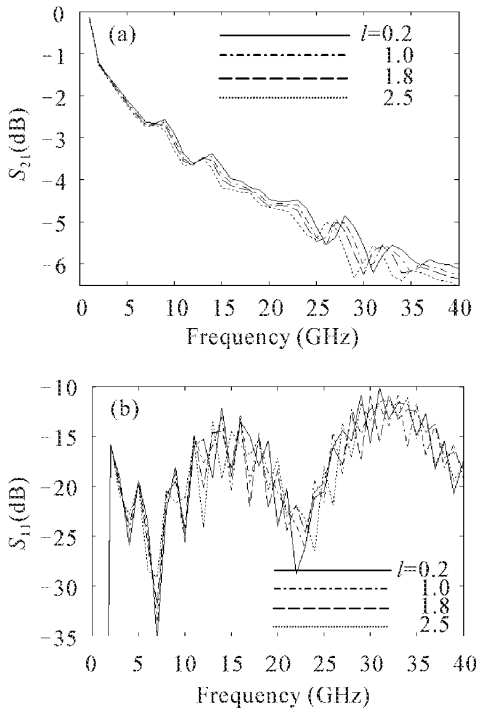

Fig. 2. Bend effects on electrical characteristics of the modulator calculated by arc length l.

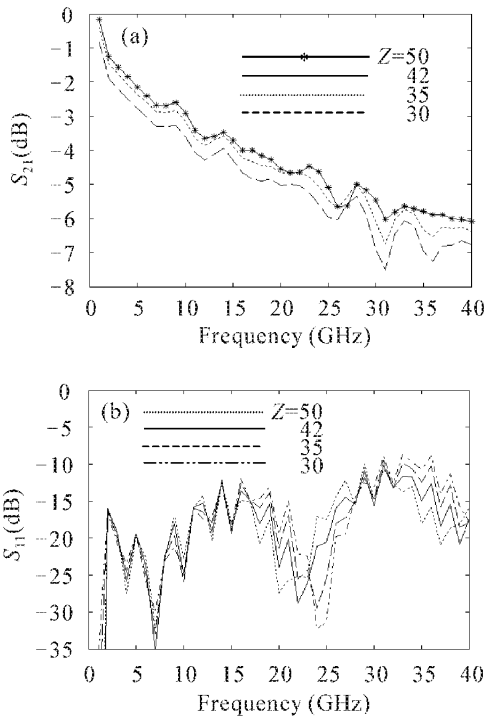

Fig. 3. Bend effects on electrical characteristics of the modulator calculated by characteristic impedance Z.

that the devices with a very large loss are not valuable. In fact, we cannot consider the losses of electrode bend have an effect on the electrical characteristic of devices.

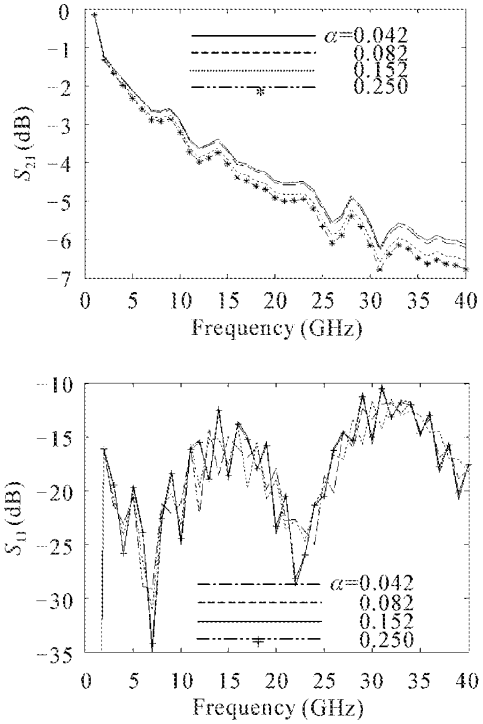

Fig. 4. Bend effects on electrical characteristics of the modulator calculated by loss α.

Table 2. Designed Bends of the Electrodes

Group No.	1	2	4
l (mm)	0	0.2	0.8

We have fabricated the electrodes with different arc length of bends on the surface of optical $LiNbO_3$ wafers. The arc length of each group of bend is shown in Table 2. No details of the transmission line are required, since the main purpose here is to experimentally study the transmission characteristics of coplanar line with different arc length of bends. The overall transmission response was measured using the swept frequency technique, in which HP network analyzer was used to obtain the very important parameters of S_{21} and S_{11}. From the results of measurement, we have found that both S_{21} and S_{11} have almost no difference among the three groups of electrodes as shown in Fig. 5. Therefore, the effect induced by the different arc length on the transmission response of the electrode is not necessarily considered.

The bend effects on electrical characteristic of the modulator in the three aspects, which are arc length, characteristic impedance, and loss, have been discussed by using the model in Ref. [1] and the FEM. The results show that the effect only caused by the characteristic impedance is necessarily considered while its difference is large, but others are negligible as we design a practical device. Finally, two electrical parameters of coplanar line with different arc length of the electrode bend have been tested, the measured results are in good agreement with the theoretical analyses.

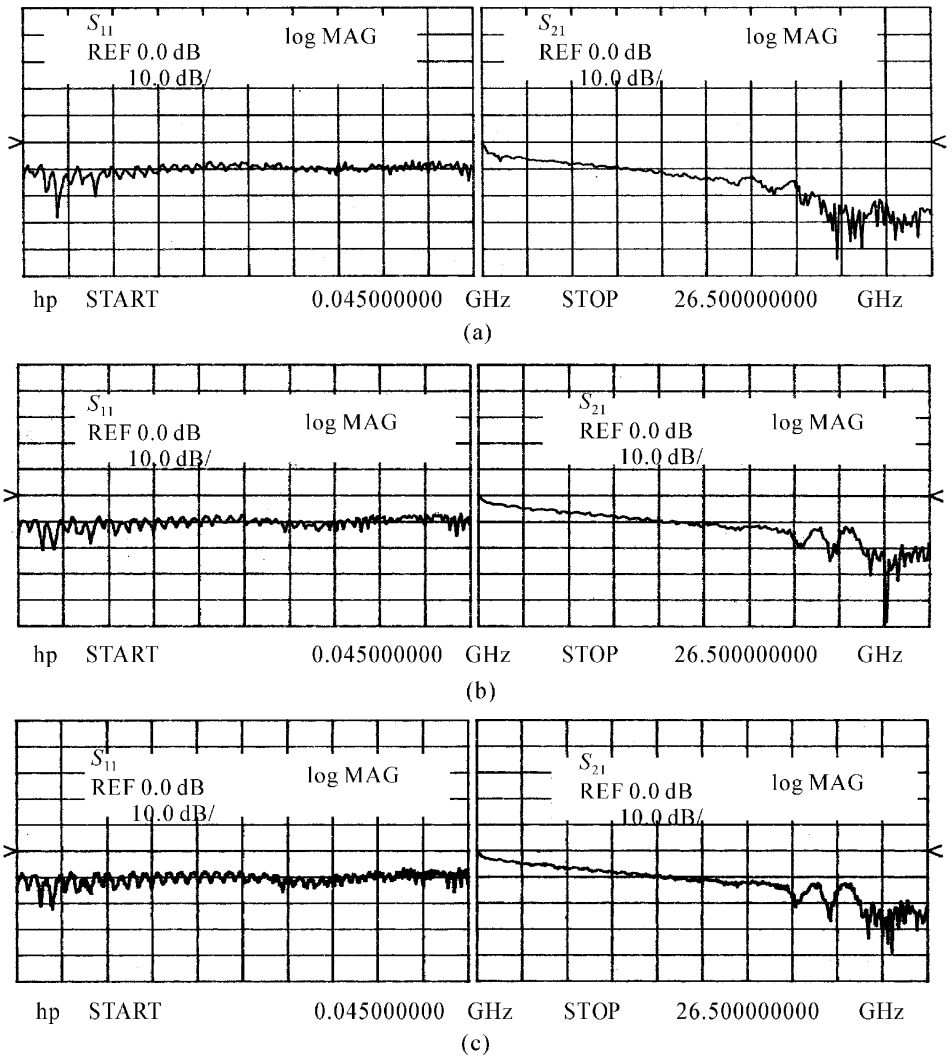

Fig. 5. Measured S_{21} and S_{11} of the CPW with different arc length.

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