A Coplanar Waveguide Electrode with Floating Shield Strips for Silicon Optical Modulators

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Abstract—This paper presents a coplanar waveguide (CPW) electrode with floating shield strips (FSS) for silicon optical modulators. The CPW-FSS effectively reduces the substrate-induced microwave loss in silicon optical modulators. Besides, thanks to the slow-wave phenomenon, it can freely control the microwave index of the microwave signal to match with the optical signal. Both features of CPW-FSS help to improve the electro-optic bandwidth of the silicon optical modulators. Compared with existing solutions in the literature, this design does not require customized process steps and can be a cost-effective option for the traveling wave electrode design in silicon optical modulators.

Keywords—Slow-wave coplanar waveguide, floating shield strips, traveling wave electrodes, silicon optical modulators.

I. INTRODUCTION

Silicon optical modulator has received great attention in recent years in the short-reach optical interconnect for its compact size, high bandwidth, and good compatibility with the mature CMOS technology [1]. Many silicon optical modulators are driven by the traveling wave electrodes. To maximize the electro-optic modulation bandwidth of the modulators, the traveling wave electrode should meet three criteria: impedance matching, velocity matching, and low microwave loss [2].

For impedance matching, the characteristic impedance of the traveling wave electrode is usually kept at 50 Ω. For velocity matching, a “T-shape” slow-wave electrode was proposed in [3]. For conductance-induced microwave loss reduction, the single-drive push-pull structure was adopted in [4]. While all these techniques are proven to be effective, little effort has been made to reduce the substrate-induced microwave loss. In [5], a substrate-removed technique was proposed to address this problem. However, it requires customized processing steps, which increases the manufacturing cost and complexity. This paper presents a coplanar waveguide (CPW) with floating shield strips (FSS) that can realize velocity matching and microwave loss reduction simultaneously in a standard CMOS process. The remainder of this paper is organized as follows. Section II presents and analyzes the structure. Section III shows the simulation results. Finally, section IV draws the conclusion.

II. CPW ELECTRODE WITH FLOATING SHIELD STRIPS

Fig. 1 shows the structure of a silicon optical modulator with a CPW-FSS electrode. The signal path and the ground planes are realized with the high-level metal. The floating strips are realized with the low-level metal. The optical waveguide is formed by n- and p-doped silicon. The electrode is periodically connected with the optical waveguide in the gaps of different floating shield strips. The optical waveguide is reversely biased, and the phase of the optical signal is modulated based on the plasma dispersion effect.

Fig. 2 compares the electrical field distribution of the conventional CPW electrode and the CPW-FSS electrode in silicon optical modulators. Most designs apply the conventional CPW electrode structure due to its simplicity and symmetry. As shown in Fig. 2(a), some electric field would leak into the substrate, especially when the resistivity of the substrate is relatively low, which would result in substrate-induced microwave loss. To alleviate this problem, the substrate below the signal path can be partially removed [5]. However, it requires customized process steps, which significantly increase the manufacturing cost and complexity. CPW-FSS was firstly proposed in [6] and has been widely applied in conventional MMICs. As shown in Fig. 2(b), the FSS effectively shields the signal path from the lossy substrate, consequently, the substrate-induced microwave loss in silicon optical modulators can be significantly reduced.

The periodical floating strips also give rise to the slow-wave phenomenon. In silicon optical modulators, the group velocity of the microwave is faster than the optical signal. This phenomenon can slow down the microwave for velocity matching with the optical signal, as a result, it benefits the electro-optic bandwidth of the silicon optical modulators.

Fig. 3 shows the equivalent circuit of the CPW-FSS in silicon optical modulators. $L$, $R$, and $C$ are the unit length inductance, resistance, and capacitance of the CPW respectively. The con-
ductance part in the original RLG$C$ model is ignored thanks to the shielding effect of the FSS. $C_{as}$ and $G_{as}$ represent the capacitance and conductance of the FSS, and $C_{pm}$ and $G_{pm}$ represent the influence of the optical waveguide, which can be regarded as a reverse-biased diode. The conductance loss of the FSS is much smaller than the conventional CPW structure. Consequently, the FSS can effectively reduce the substrate-induced microwave loss. As for the loaded optical waveguide, it also contributes to the substrate-induced microwave loss, and the capacitance of the PN junction would decrease the characteristic impedance of the electrode.

III. SIMULATION RESULTS

To verify the effectiveness of the CPW-FSS electrode in silicon optical modulators, we simulate this structure with different metal material, and substrates in both 10 $\Omega$ cm and silicon photonic SOI process, respectively. All CPW electrodes are designed to have a similar characteristic impedance around 50 $\Omega$ for a fair comparison. Fig. 4 and Fig. 6 shows the microwave loss of different CPW structures in different substrates. Compared with the conventional CPW structure, all CPW-FSS effectively reduce the microwave loss. Fig. 5 and Fig. 7 shows the microwave index of different CPW structures in different substrates. The microwave index can be tuned with different SL/SS. Fig. 8 shows the microwave index and microwave loss of a CPW-FSS electrode at 30 GHz with different strips-BOX gaps. The microwave index can be tuned by the gaps while the microwave loss grows with the gaps increasing.

IV. CONCLUSION

In this paper, we apply the CPW-FSS as the traveling wave electrode in silicon optical modulators. The FSS effectively reduces the substrate-induced microwave loss and controls the microwave index for velocity matching. This technique can be extended to other electrode structures in silicon optical modulators, such as coplanar strips and coplanar strips/waveguide with “T-shapes”, for design optimizations.

REFERENCES