Optimization of a hybrid $BaTiO_3$/Si Waveguide Structure for Electro-optic Modulation

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Silicon photonics technology is currently one of the most promising platforms for enabling automated and low-cost volume manufacturing of highly integrated and complex photonic circuits, mainly because the fabrication processing steps are developed using standard CMOS (Complementary Metal Oxide Semiconductor) fabrication infrastructure. In this context, the integration of CMOS compatible active materials such as barium titanate ($BaTiO_3$ or BTO) has become a promising way to achieve electro-optic (EO) modulation by means of the Pockels effect [1,2]. In this work, a Mach-Zehnder Modulator in a hybrid BTO/Si optical waveguide is proposed for enabling EO modulation with high performance. A layer of amorphous silicon (a-Si) is deposited on top of the $BaTiO_3$/SOI structure and then etched down to form the optical waveguide. The influence of waveguide parameters on the static EO performance has been previously reported [2]. Besides, a silicon oxide (SiO_2) layer is deposited over the optical waveguide to protect the device and lateral windows are open to place the electrodes on top of the $BaTiO_3$ layer thus enhancing the modulation efficiency. The waveguide structure and parameters are shown in Fig. 1(a). The electrodes have been designed to achieve RF impedance matching and high EO bandwidth. Simulations have been carried out with COMSOL^{TM}.

The high permittivity of $BaTiO_3$ (ε_z~56, ε_x~2200) reduces the RF impedance in comparison with usually lower dielectric constant substrates or thin films with symmetric coplanar waveguides. In such a way, the electrode dimensions have been designed to overcome the high permittivity of $BaTiO_3$. Asymmetric coplanar electrodes, as depicted in Fig. 1(a), have been chosen to achieve the matching impedance around 50Ω, maintaining a narrow gap in the optical waveguide with the aim of keeping the modulation efficiency as high as possible. Figures 1(b) and (c) show the RF impedance and losses and RF, effective and optical group indices as a function of the frequency. It can be seen that the impedance is quite well matched. On the other hand, an EO bandwidth higher than 40 GHz is ensured as a result of the velocity matching between the electrical and optical signals. The modulation efficiency variation with the RF frequency is shown in Fig. 1(d). The $V\pi L$ is below 1V·cm in the 40 GHz frequency range.

To summarize, the RF electrodes in a hybrid BTO/Si waveguide structure have been designed for optimum EO performance. This work was supported by the European Commission under project FP7-ICT-2013-11-619456 SITOGA.

References

[1] C. Xiong et al., Nano Letters, vol. 14(2014), pp. 1419–1425.
[2] P. Castera et al., Opt. Express, vol. 23(2015), pp. 15332-15342.

Figures

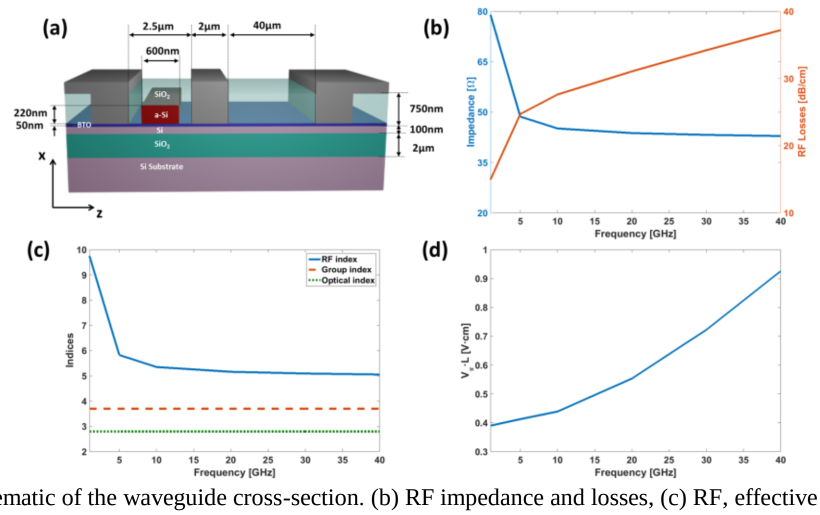

Figure 1. (a) Schematic of the waveguide cross-section. (b) RF impedance and losses, (c) RF, effective and optical group indices and (d) modulation efficiency as a function of the frequency.