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A Strong Pockels PZT/Si Modulator for Efficient Electro-Optic Tuning

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Abstract: We demonstrate a hybrid PZT/Si Pockels modulator. The PZT is grown on the waveguides and the resulting device shows low-loss and a $V_\pi L \approx 2$Vcm with an effective Pockels coefficient of 225pm/V.

1. Introduction

Silicon photonics integrated circuits (SPIC) are seen as the catalyzers for the next generation technology for communication, sensing, medicine, quantum information processing etc. However, an electro-optic modulator that induces a pure phase shift is missing on the silicon (Si) platform. Si modulators based on plasma dispersion effects suffer from spurious amplitude modulation and high insertion losses. To overcome this limitation, the heterogeneous integration of thin-film electro-optic materials with Pockels effect namely $LiNbO_3$ [1], organic materials [2], and BTO [3]. has been explored as an alternative for phase modulators on Si. While organic materials suffer from instability, $LiNbO_3$ and BTO integration requires expensive bonding. Thin films of Lead Zirconate Titanate (PZT) can be grown on the Si platform by chemical solution deposition [4], and have enabled high speed Pockels modulation on SiN [5]. We demonstrate here the potential of the technology by characterizing a hybrid PZT/Si unbalanced Mach-Zehnder modulators (MZM).

2. Modulator

The unbalanced Mach-Zehnder modulator (MZM) is obtained through a multi-project wafer run. The MZM is designed for quasi-TE optical mode operation. The waveguides are 220 nm thick and 480 nm wide. The samples are planarized through CMP with 10 nm oxide as top cladding. Grating couplers are used to couple light in and out of the chips. We grow 200 nm thick PZT films on the samples by chemical solution deposition (CSD), using a lanthanide-based intermediate layer [4]. Ti/Au electrical contacts are then patterned in the vicinity of the waveguides. The electrodes are 4 µm apart and the phase shifters are 600 µm long. Figure 1a shows the schematic top view of the MZM

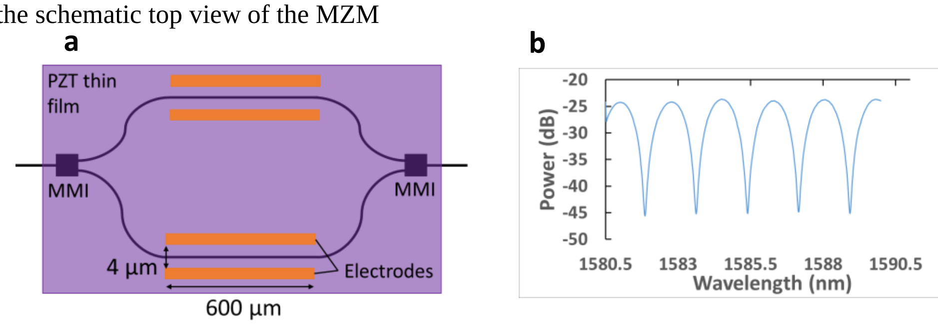

Fig. 1 a Top view of a hybrid PZT/Si Mach-Zehnder modulator. **b** Transmission spectrum of a MZM with free spectral range ΔλFSR ~ 1,7 nm

3. DC characterization

After deposition, the PZT crystallites are preferentially oriented out-of-plane and randomly oriented in plane. To get a significant electro-optic response for a quasi-TE optical mode, the samples are poled by applying 40V for 2h at room temperature. Negligible leakage current is measured during this step. Figure 1b shows the transmission spectrum of the MZM with a free spectral range $\Delta\lambda_{FSR}$ ~ 1,7 nm.

We applied different DC voltages across the PZT layer and measured the peak resonance shift caused by the voltage-induced index change. The tuning efficiency is $\Delta\lambda/\Delta V$ = -24,1 pm/V. From this we extract the $V_\pi L$ of the MZM to be 2,12 Vcm. Combined with the low propagation loss associated to PZT [5], we get $V_{\pi}L\alpha$ = ~2,12VdB which is an order of magnitude better than Si modulators. To access the impact of poling time on the electro-optic response, we measured the resonance shift after different poling times. The electro-optic response goes to a maximum after 2h. Through simulation of the optical mode and DC electric field, the effective electro-optic coefficient r_{eff} of the PZT layer is estimated to be 225 pm/V. The difference with previous reported values [5, 6] is a result of poling and difference in PZT film quality due to processing.

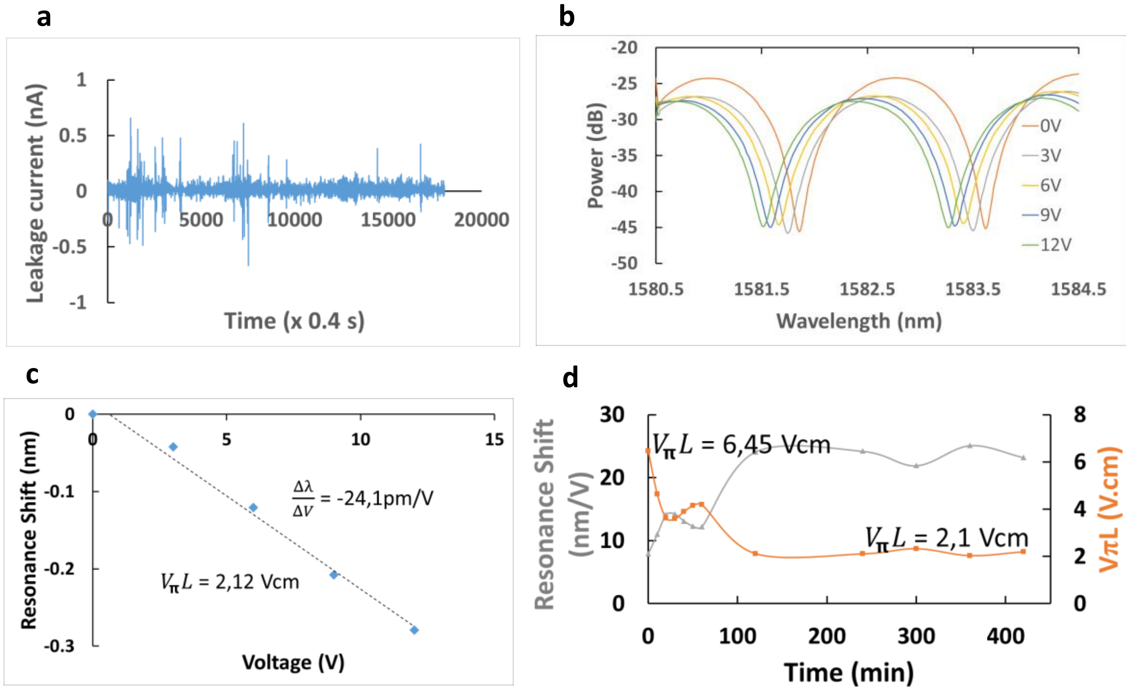

Fig. 2 a Low leakage current measured with 40V applied across the PZT layer (low tuning power). **b** Transmission spectra for different DC voltages. **c** Resonance wavelength shift versus voltage applied across the PZT; dotted lines (fit). **d** Resonance shift measured after poling the samples for different time duration.

4. Conclusion

We have demonstrated a Pockels modulator based on a hybrid PZT/Si platform. The PZT is grown on the waveguides using a cost-effective method and the fabricated Mach-Zehnder shows good performance. A $V\pi L$ ~ 2Vcm is measured and we could extract a strong in plane effective Pockels coefficient of ~ 225pm/V. Moreover, measurements on other devices indicate a record-low spurious amplitude modulation.

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