Broadband Electro-optic Modulation using Low-loss PZT-on-Silicon Nitride Integrated Waveguides

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Abstract: Electro-optic modulation using a low-loss PZT-on-SiN waveguide platform is demonstrated. Using a ring resonator a $V_\pi L_\pi$ of ≈ 1 Vcm is demonstrated. Small-signal measurements have demonstrated a bandwidth surpassing 25 GHz.

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1. Introduction

State-of-the art silicon nitride (SiN) waveguides are characterized by low loss, high optical confinement and a broad transparency window. However, active devices such as light sources, modulators, etc. are not readily available on this platform. Here we demonstrate electro-optic modulation on SiN. For this we deposit a layer of lead zirconate titanate (PZT) on the chip using a standard post-process chemical solution deposition (CSD) step. Measurements on a ring resonator demonstrate a $V_\pi L_\pi$ for the PZT-on-SiN waveguide, comparable to that of state-of-the art Si modulators [1]. We also demonstrate modulation speeds which are much higher than experiments exploiting the piezoelectric effect [2], confirming the Pockels-nature of the modulation. Moreover on straight PZT-on-SiN waveguides a loss <1dB/cm was measured resulting in a figure of merit $V_\pi L_\pi \alpha$ < 1 dBV (where α represents the waveguide loss), surpassing state-of-the-art silicon modulators with an order of magnitude [1].

2. Device fabrication

For the device fabrication, the waveguides, rings, etc. were first patterned into a layer of LPCVD SiN (330 nm) on top of a buried oxide layer (≈ 3 µm) on a silicon handle wafer in a CMOS pilot line. Subsequently, the sample was covered with oxide which was then removed using chemical mechanical polishing, reactive ion etching and wet etching. This way a sufficiently flat surface was obtained near the top level of the waveguides. Afterwards, the PZT layer (≈ 150 nm) was deposited by CSD. To grow the high quality PZT layers, an intermediate LaO_2CO_3 layer of 15 nm is deposited prior to the PZT coating. The details of the deposition procedures can be found in Ref. [3]. A reactive ion etching (RIE) procedure based on SF_6 chemistry is used to pattern the PZT layer. Finally, electrical contacts were defined using photolithography and lift-off. Fig. 1a shows a microscope image of the finalized device, consisting of a ring resonator with electrical contacts for modulation. Grating couplers were used to interface with the chip.

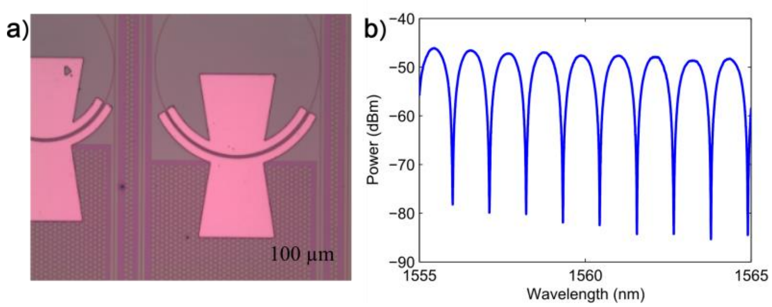

Figure 1: a) Microscope picture of the of the PZT-on-SiN ring resonator with gold contacts. b) Transmission spectrum of a the PZT-on-SiN ring resonator (waveguide width = 1 µm, radius = 150 µm).

3. Experimental results

Fig. 1b shows the transmission spectrum of the ring resonator with a waveguide width of 1 µm and a radius of 150 µm. The spacing between the electrodes is 5 µm and the electrode length is L=315 µm. The measured loaded Q-factor of the ring was 3000, limited by bend losses, and the free spectral range is $\Delta\lambda_{FSR}$= 1.11 nm. As a first experimental verification of electro-optic modulation, the static response of the ring was measured as a function of the applied voltage between the electrodes. To obtain an electro-optic response, the PZT needs to be poled, for this, a static voltage of 40 V was applied during several minutes. Subsequently the transmission spectrum of the ring was measured for a set of smaller voltages. The resulting spectra are shown in Fig. 2a. On Fig. 2b, the resonance wavelength shift is plotted as a function of the applied voltage. The voltages were applied in decreasing order (+9 V to -9 V). At the -9 V, the response becomes less pronounced since the PZT partly gets poled in the reverse direction. The dashed line in Fig 2b shows a linear fit (excluding the point at -9 V). The tuning efficiency equals $\Delta\lambda/\Delta V \approx 17.2$ pm/V. This results in a $V_\pi L_\pi = L\ \Delta\lambda_{FSR}\,\Delta V/(2\Delta\lambda) \approx 1.02$ V cm for the PZT-on-SiN waveguide.

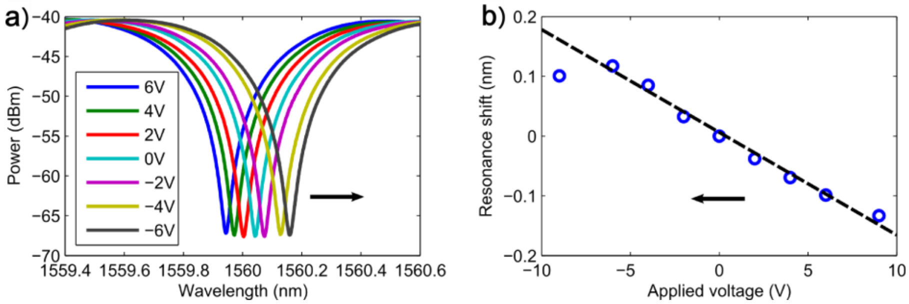

Figure 2: a) Ring transmission as a function of applied DC voltage, the arrow shows in which order the spectra are measured. b) Resonance shift as a function of voltage. Dashed line: slope –17.2 pm/V.

To demonstrate the high-speed properties of the device, we used a vector network analyzer (VNA) to study its small signal response at high modulation speeds (see Fig. 3a). The resulting response function is shown in Fig. 3b. The measured bandwidth is higher than 25 GHz.

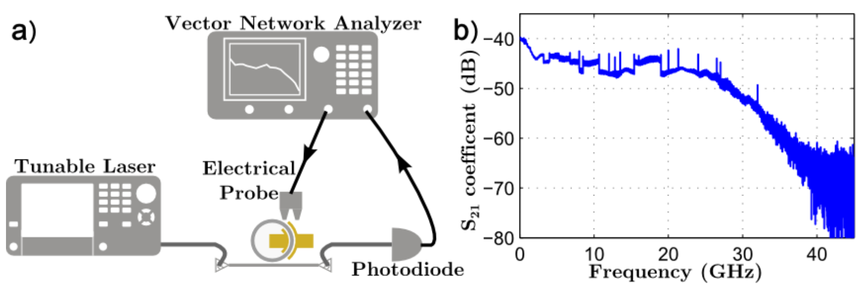

Figure 3: a) Sketch of the setup used to measure the small-signal response b) Electro-optic high-speed response of the ring resonator.

Moreover, we measured a loss below 1 dB/cm on a set of straight PZT-on-SiN waveguides using a cut-back method. Phase modulation was also directly measured on straight waveguides, the measured $V_\pi L_\pi$ and modulation bandwidth were similar to the ones measured on the ring.

4. Conclusion and future outlook

We have demonstrated efficient electro-optic modulation using a PZT-on-SiN platform. A $V_\pi L_\pi$ of 1 Vcm was demonstrated. Silicon modulators can reach $V_\pi L_\pi < 1$ Vcm but have been shown to be limited in terms of the more relevant figure of merit (FOM) $V_\pi L_\pi \alpha$ to values above 10 VdB [1]. Our modulator exhibits a FOM of more than an order of magnitude better. A modulation bandwidth more than 25 GHz is demonstrated. More measurements are ongoing and will be presented at the conference. At the moment, different devices (Mach-Zehnders) are being characterized. Moreover, different wavelength ranges (1310 nm, visible) are being investigated. Further results will be discussed at the conference.

4. References

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