

Advances in PZT-on-SiN electro-optic modulator platform

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Abstract: We demonstrate an O-band electro-optic modulator on SiN platform based on ferroelectric PZT thin films. A ring modulator with a small signal bandwidth in excess of 33 GHz is reported. © 2018 The Author(s)

1. Introduction

Electro-optic modulators based on the Pockels effect are highly desirable as they produce pure phase modulation to encode advanced modulation formats [1]. SiN is a passive waveguide platform characterized by its broadband transparency, low loss, and good optical confinement. However, active devices such as modulators, and lasers are hardly available. Due to the centro-symmetric crystal structure of the SiN, -electro-optic interactions based on the Pockels effect are absent. In this work, we demonstrate a high-speed electro-optic Pockels modulator based on SiN platform.

To achieve this, highly electro-optic PZT layers are deposited over the SiN waveguide using a novel chemical solution deposition method [2]. We have reported C-band electro-optic modulation on this platform [3]. Here, we demonstrate measurements performed on the O-band ring resonator (MZI) modulators show a small signal bandwidth beyond 33 GHz, and a $V_{\pi}L_{\pi}$ of 3.19 V cm. The effective electro-optic coefficient is extracted to be 200 pm/V, which is comparable to state-of-art ferroelectric- Si modulators [4].

2. Device fabrication

The waveguides, ring resonators etc. are first patterned into a layer of LPCVD SiN (350 nm) on top of a buried oxide layer ($\approx 3 \mu\text{m}$) on a silicon handle wafer in a CMOS pilot line. Subsequently, PECVD SiO₂ layers ($\approx 1 \mu\text{m}$) are deposited over the waveguide and planarized by chemical mechanical polishing (CMP), to facilitate the PZT deposition. Firstly, a thin intermediate La₂O₂CO₃ layer ($\approx 25 \text{ nm}$) is deposited over the planarized waveguide, to serve as seed layer and diffusion barrier for high temperature PZT growth. The PZT layers are deposited in a step of 25 nm followed by pyrolysis, and annealed in an oxygen ambient, to achieve a total layer thickness of 150 nm. The PZT layers are selectively patterned over the grating couplers by a SF₆ based reactive ion etching (RIE) chemistry. The grating couplers are used to interface with chip for optical measurements. Finally, electrical contacts are defined using photolithography, thermal evaporation and lift-off. Figure 1(a) and Figure 1(b) represent the microscope and SEM cross section image of the fabricated device.

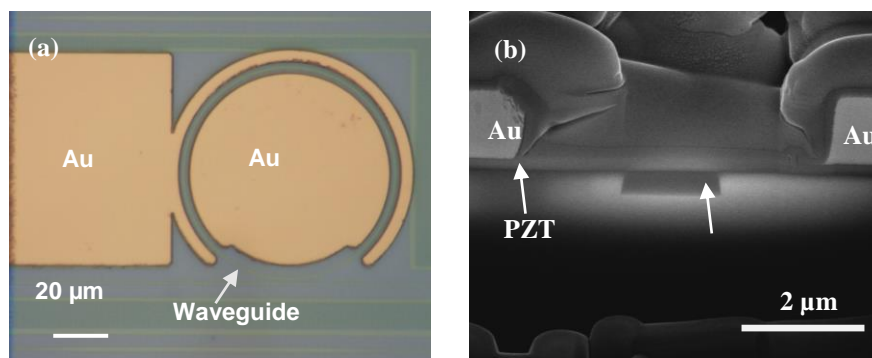


Figure 1: (a) Top view of PZT-on-SiN O-band ring modulator. (b) SEM cross section image of the PZT covered SiN waveguide with patterned gold electrodes.

3. Experimental results

The fabricated O-band ring resonator modulator uses waveguide of width 1600 nm, the electrode separation of 5 μm , and the length of the phase shifter section is 195 μm . The ring has a Q-factor and the free spectral range of 1820 and 3.27, respectively. Since the deposited PZT films show preferential out-of-plane crystal growth without any specific in-plane orientation, therefore it is essential to pole the films to obtain strong electro-optic response. In this case, a DC voltage (≈ 50 V) above the coercive field is applied to the electrode for 30 minutes. To characterize the static performance of the modulators a set of DC voltages [0 to 6V] are applied to the gold electrodes (Figure 2(a)). The obtained resonance shift as function of applied DC voltage is shown in Figure 2 (b). The modulation efficiency of the current O-band modulator is 3.16 V cm, this could be further improved by increasing the PZT thickness. We extracted an effective pockels coefficient of 200 pm/V, which is comparable to the BaTiO₃ modulators demonstrated on the Silicon-on-insulator platform [4]. Propagation losses of the PZT-on-SiN waveguides can be as low as 1-2 dB/cm, when measured with a cut back method.

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 Figure 2 (b)). The resulting response shows bandwidth in excess of 33 GHz for the O-band modulators, which is currently limited by the experimental set-up.

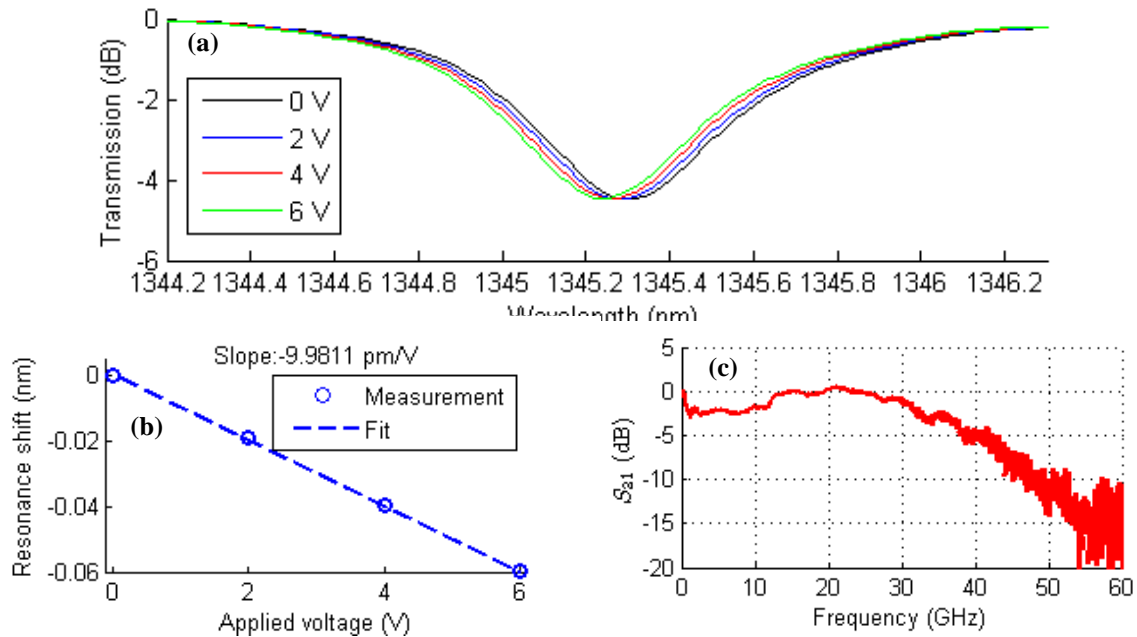


Figure 2: (a) Transmission spectrum of the ring for different DC voltages. (b) Resonance shift as a function of Voltage. (c) Small signal modulation response ring modulator.

4. Conclusion and future outlook

In this work, we have demonstrated an O-band high speed ring resonator modulator on the SiN platform, based on integrated electro-optic PZT thin films. The ring modulators demonstrate a small signal bandwidth beyond 33 GHz, with a modulation efficiency of 3.16 V cm. Further measurements on the devices are ongoing, and it will be presented at the conference.

4. References

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