Integration of Novel Ferro-Electric Thin Films in Silicon Photonics for High Speed Modulators

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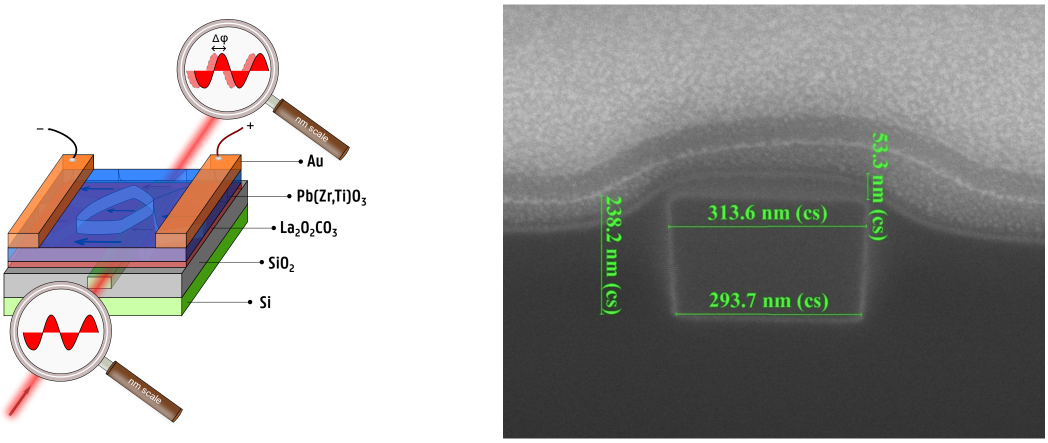
Abstract: Lead zirconate titanate (PZT) exhibits a large Pockels coefficient and remnant polarization, making it a suitable candidate for integration in photonics circuits. In this work, a platform is developed to directly integrate PZT thin films on silicon-on-insulator (SOI) wafers to create electro-optic (EO) modulators.

1. Introduction

Silicon photonics has become one of the most used platforms for photonic integrated circuits for a wide array of applications. Almost all of them require high-speed, low-power modulation. Modulators based solely on silicon rely on the plasma dispersion effect to achieve phase shifting. This effect induces a refractive index change in the silicon waveguide through the movement of the carriers, which comes with the limitation that the operation speed is limited by the charge-carrier lifetime, meaning maximal bandwidth is on the order of tens of gigahertz. This limitation is not present in modulators that make use of the Pockels effect. When deposited as a thin film on a silicon photonic chip, lead zirconate titanate (PZT) has a large Pockels coefficient with large remnant polarization, making it a suitable candidate for high-speed, low-power modulators. In this work, a full-stack integration platform, consisting of electron-beam lithography, reactive ion etching and plasma cleaning, is proposed to directly integrate ferro-electric thin films on silicon-on-insulator (SOI) wafers in order to create fast and efficient electro-optic (EO) modulators.



(a) (b)

Fig. 1: **(a)** Cross-section of an oxide-cladded silicon waveguide with PZT thin film. By applying an electric field across two electrodes, one can induce a phase change to light travelling through the waveguide. **(b)** Cross-section of a planarized SOI waveguide fabricated in-house using electron beam lithography.

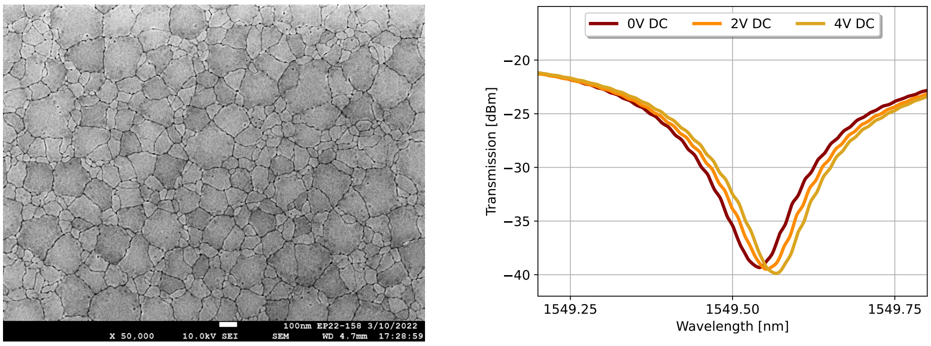
2. Device Fabrication

The resulting structure is represented by Figure 1a. In the first step, positive e-beam resist is spin-coated on top of a blank SOI substrate containing 220 nm of Silicon. The photonic circuit is then patterned onto the substrate through a Raith Voyager electron beam lithography system. After development of the e-beam resist, the desired design can be etched into the silicon via reactive ion etching using a PlasmaPro 100 Cobra ICP RIE Etch system. Before continuing, additional cleaning is necessary to ensure there is no remaining contamination from the e-beam resist or passivation gasses of the etch process. Failing to do so may result in damage and high excess propagation losses to the silicon waveguides during further processing steps [1]. An in-house procedure consisting of three consecutive oxygen plasma cleaning steps was developed for this purpose, providing a safe and easy-to-use method of cleaning, without the need of any dangerous chemicals which can harm both the user and environment. The cleaning itself has three major components. The first two steps consist of a regular oxygen plasma and act as a pre-cleaning step to remove any excess contamination from the etch chamber and substrate itself. In the final step, the substrate is immediately transferred to a UV ozone chamber, to further clean the surface from any remaining contamination [2].

After cleaning, NDG-100 Spin-On Glass is spin-coated on the surface for planarization of the substrate. A cross section of this planarization is shown in Figure 1b. A fiber-textured PZT thin film can now be integrated by using the lanthanum oxycarbonate (LOC) template film (8 nm) as reported by E. Picavet *et al* [3]. This intermediate LOC layer is crucial to ensure the proper growth of the PZT micro-structure. Finally, electrical contacts were defined using photo-lithography, metal sputtering and lift-off.

3. Results

In order to test the operation of the PZT thin films, several ring modulator designs were fabricated onto a photonic chip, using the process outlined in Section 2. Figure 2a shows the micro-structure of the PZT film, clearly showing the different crystallographic domains grown from the LOC seed layer. Proof of modulation is presented in Figure 2b, where the transmission spectra of a ring modulator is shown for different voltages applied across the ring section.



(a)

(b)

Fig. 2: **(a)** Top-down scanning electron microscopy (SEM) image of the micro-structure of PZT. **(b)** Transmission spectra of a ring modulator is shown for different voltages.

4. Conclusion

In this work, a platform for integration ferro-electric thin films in silicon photonics is provided, showcasing a working EO modulator. The technological process outlined above is readily transferred to different ferro-electric thin films.

References

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