Simulation of the Frequency Response of a Mach-Zehnder Modulator Actuated by a PZT Chip

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Abstract

Piezoelectrically actuated integrated photonic devices offer a promising route to compact, tunable photonic systems, but their design is challenging because mechanical, electrical, and optical effects interact. We present a multiphysics modeling framework for a tantalum pentoxide (Ta_2O_5) Mach–Zehnder modulator (MZM) actuated by a top-bonded lead zirconate titanate (PZT) chip. The model predicts waveguide stress, actuator frequency response, and electro-optic tuning efficiency. Simulated tuning efficiency and 3-dB bandwidth agree with experimental measurements, supporting design optimization of PZT-actuated photonic devices.

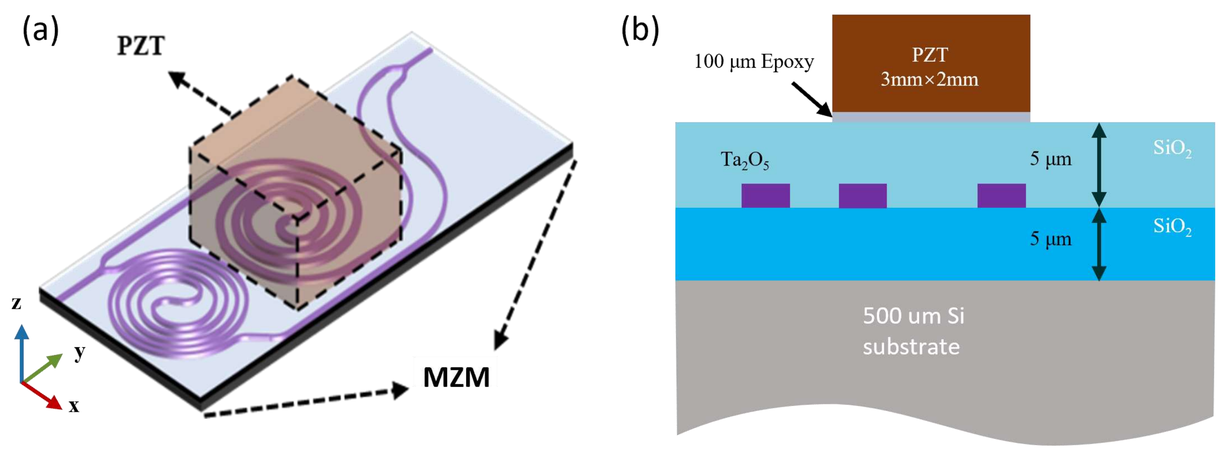


Fig. 1 (a) The 3D artistic illustration of a Ta_2O_5 MZM bonded with a PZT chip on top. (b) The cross-sectional view of the piezoelectric optical modulator.

Geometry

The 3D model consists of a $SiO_2/Ta_2O_5/SiO_2$ photonic platform, an epoxy adhesive layer and a top-bonded PZT actuator. The PZT chip measures 3 mm × 3 mm × 2 mm and is bonded to the platform via a 100 μm-thick epoxy layer. The 2D optical cross section consists of a 500 μm-thick Si substrate, a 5 μm SiO_2 lower cladding, a Ta_2O_5 waveguide with a cross section of 2.8 μm × 90 nm, and a 5 μm SiO_2 upper cladding.

Methodology

The Electrostatics and Solid Mechanics interfaces are coupled to calculate the deformation and stress generated by the PZT actuator. The piezoelectric response is described by the strain–charge equations:

$$S = s_{\mathrm{E}} T + d^{\mathrm{T}} \vec{E}$$
$$\vec{D} = dT + \epsilon_0 \epsilon_{\mathrm{r,T}} \vec{E}$$

The transferred stress changes the refractive indices of the Ta_2O_5 waveguide through the stress-optic effect:

$$n_{\mathrm{x}} = n_0 - C_1 \sigma_{\mathrm{x}} - C_2 (\sigma_{\mathrm{y}} + \sigma_{\mathrm{z}})$$
$$n_{\mathrm{y}} = n_0 - C_1 \sigma_{\mathrm{y}} - C_2 (\sigma_{\mathrm{z}} + \sigma_{\mathrm{x}})$$
$$n_{\mathrm{z}} = n_0 - C_1 \sigma_{\mathrm{z}} - C_2 (\sigma_{\mathrm{x}} + \sigma_{\mathrm{y}})$$

Stress Distribution

Fig. 2 (a) displays the structural deformation under a DC bias of 10 V. The induced in-plane stresses (S_{x} and S_{y}) along a cut-line is shown in Fig. 2 (b). The cut-line is in the *x*-*y* plane along the *x*-axis. It is in the Ta_2O_5 device layer and passes through the PZT block's vertical central line.

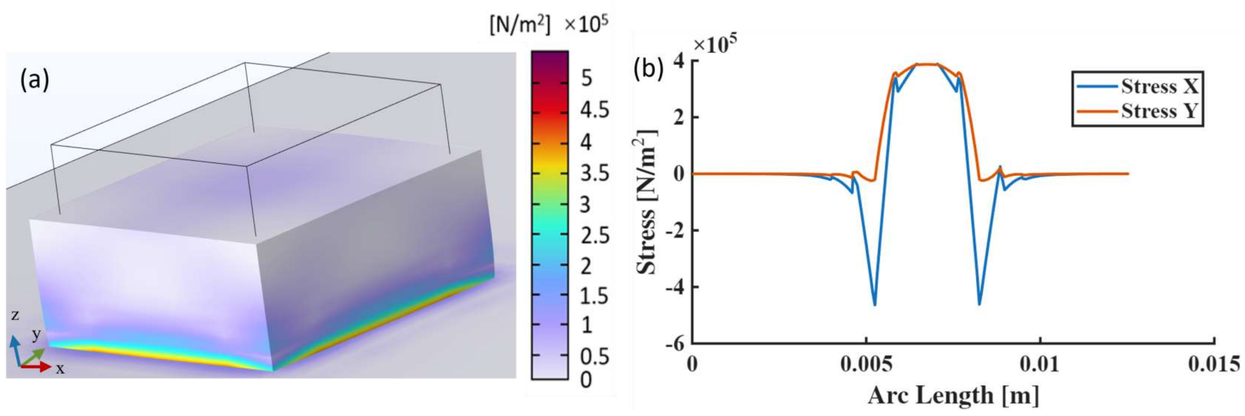


Fig. 2 The 3D deformation and stress distribution of the PZT block bonded to a photonic chip.

Results

Fig. 3 (a) compares the analytical MZM output spectra at 0 V and 10 V. With a 10 V increase in voltage, the resonance minimum is blue-shifted by 302 pm, indicating a tuning efficiency of 30.2 pm/V. By evaluating σ_{y} at the waveguide layer beneath the PZT center point, the frequency response is obtained in Fig. 3 (b), revealing the 3 dB bandwidth is 2985 Hz.

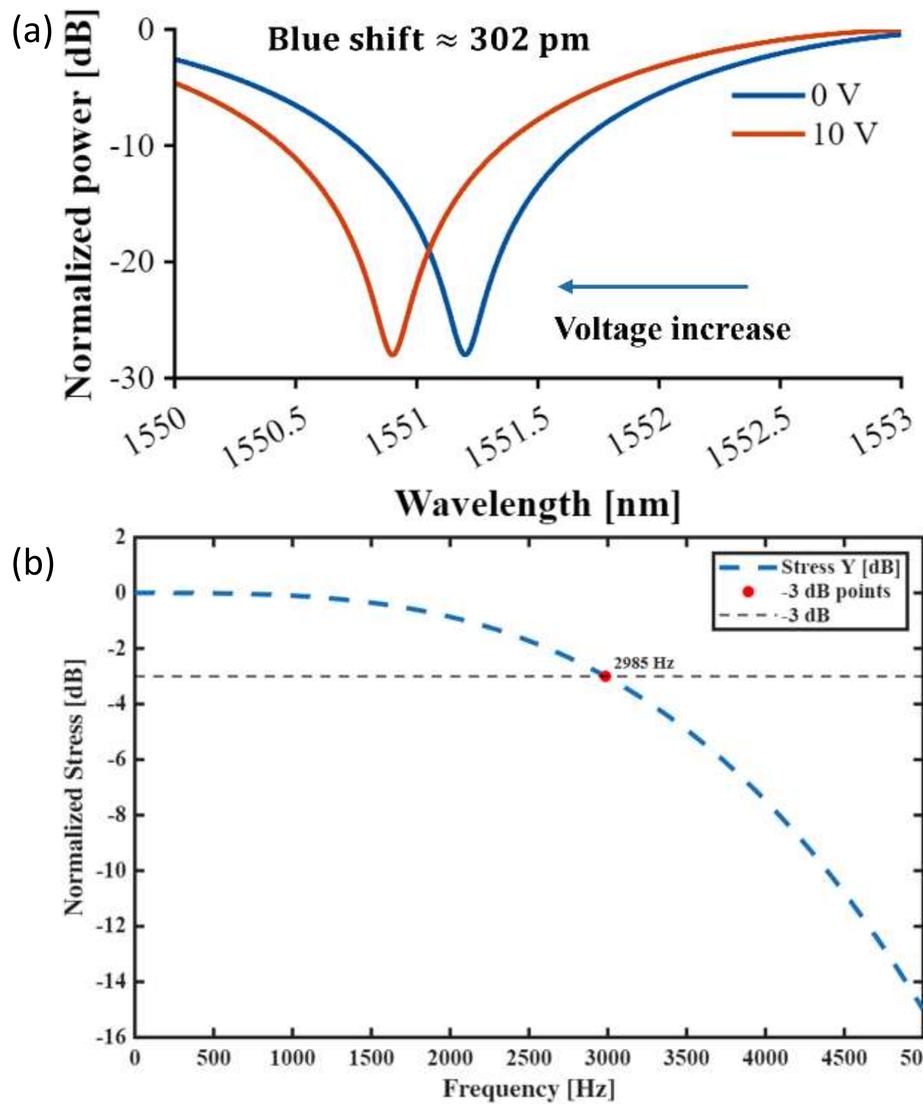


Fig. 3 (a) The analytical MZM output spectra at 0 and 10 V, revealing a resonance blueshift of 302 pm. (b) Frequency Response of y-stress with -3 dB Point