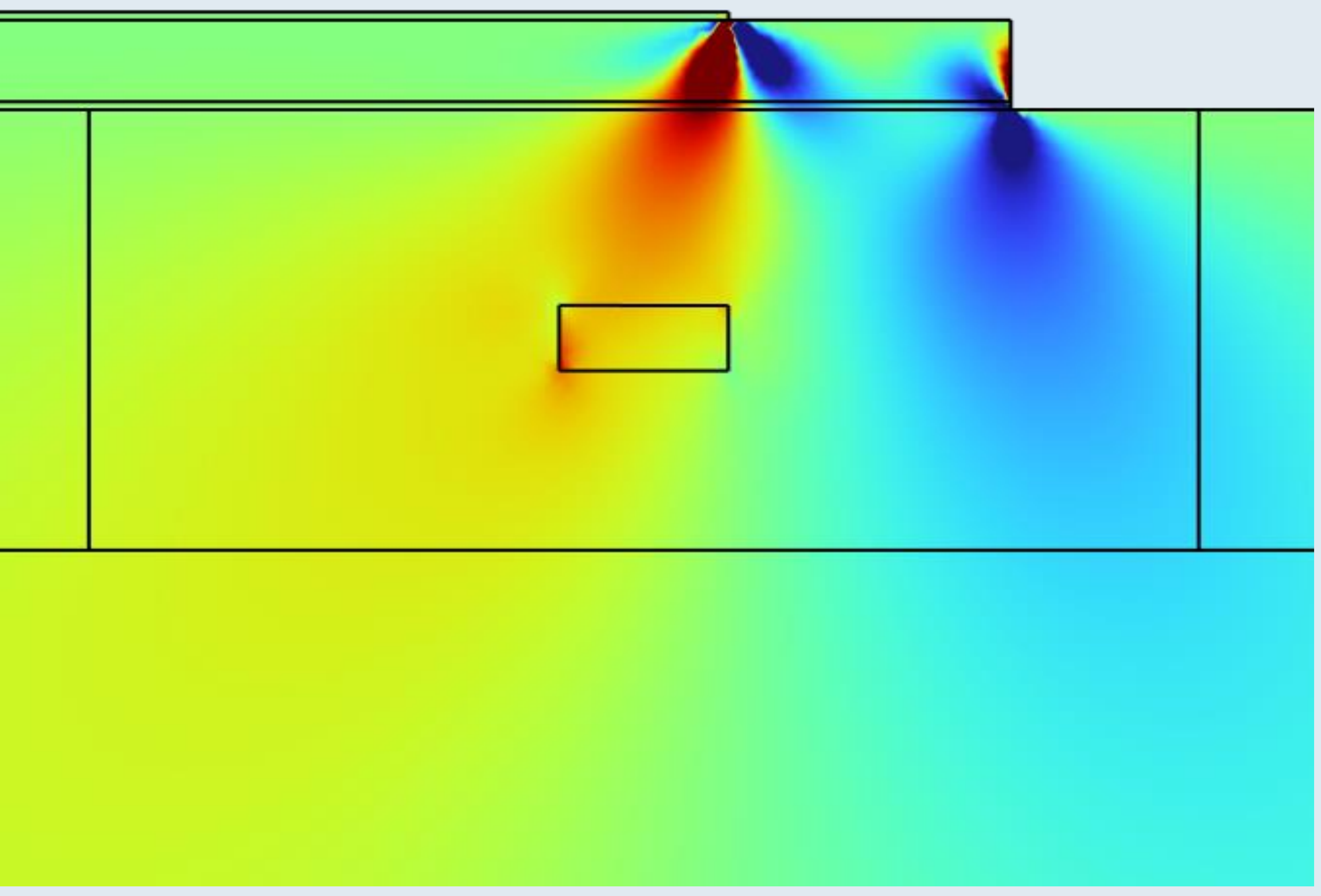

# Simulation of Stress-Optic Microresonator Modulator

This work demonstrates the simulation of stress-optic effect with COMSOL®, using RF, electrostatics and solid mechanics modules to accurately model and analyze the behavior of piezo-actuated heterogeneously integrated microresonator modulators.

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## Abstract

Thanks to the advances in Micro-Electro-Mechanical Systems (MEMS) [1], there is a thrust in developing piezoelectric actuated optical modulators based on stress-optic effect recently [2], [3], [4]. It involves heterogeneous integration of piezoelectric material and electrodes with optical microresonators. Such a device needs the interplay between photonics, solid mechanics, and material science. However, the complexity of multi-physics hinders the numerical modeling of the devices. In this work, we developed a multiphysics modeling approach to simulate the piezoelectric optical modulator by using COMSOL Multiphysics®. In this example from Ref.[2], the device is a silicon nitride modulator capped with an AlN-based actuator. The device has a modulation efficiency of 0.0257 pm/V as shown in Fig. 3. The simulation results of the model are quite close to the experimental results (~ 0.02 pm/V) [5], which shows the high accuracy of the model.

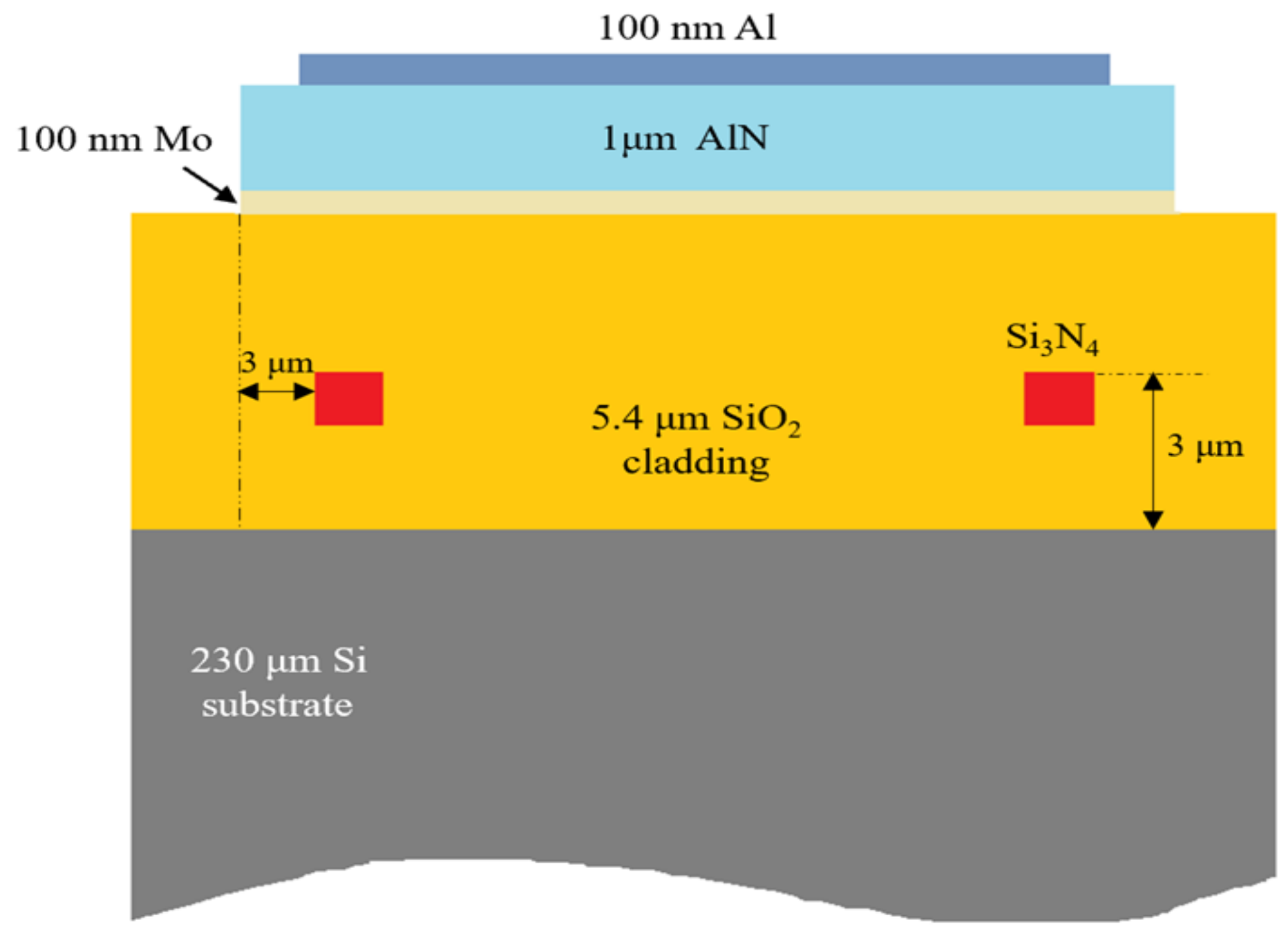

FIGURE 1. The cross-section of piezoelectric optical modulator.

## Geometry

A microresonator modulator is constructed in a 2D axial symmetry model to reduce the computational efforts while capturing the full 3D behavior of the device. The $Si_3N_4$ resonator has a waveguide cross-section of 0.8 μm × 1.8 μm and a radius of 118 μm. The top $SiO_2$ cladding is 2.4 μm-thick. On top of the waveguide cladding layer sits a piezo-electric actuator which is composted of 100 nm Mo/1 μm AlN/100 nm Al from bottom to top.

## Methodology

The optical mode is simulated by the RF module, where an azimuthal mode number is obtain to track the desired resonant frequency. By applying external voltage, the effective mode index of the guided mode changes, leading to a resonant frequency detuning. Stress-optic effect is applied to the materials' refractive indices [5]:

$$n_r = n_0 - C_1\sigma_r - C_2(\sigma_\varphi + \sigma_z)$$
$$n_\varphi = n_0 - C_1\sigma_\varphi - C_2(\sigma_z + \sigma_r)$$
$$n_z = n_0 - C_1\sigma_z - C_2(\sigma_r + \sigma_\varphi)$$

Piezoelectric effect is included in the simulation model to generate the stress from applied voltage [6]:

$$T = \mathrm{c}_E S - \mathrm{e}^T E$$
$$D = \mathrm{e}S + \epsilon_0\epsilon_{rs}E$$

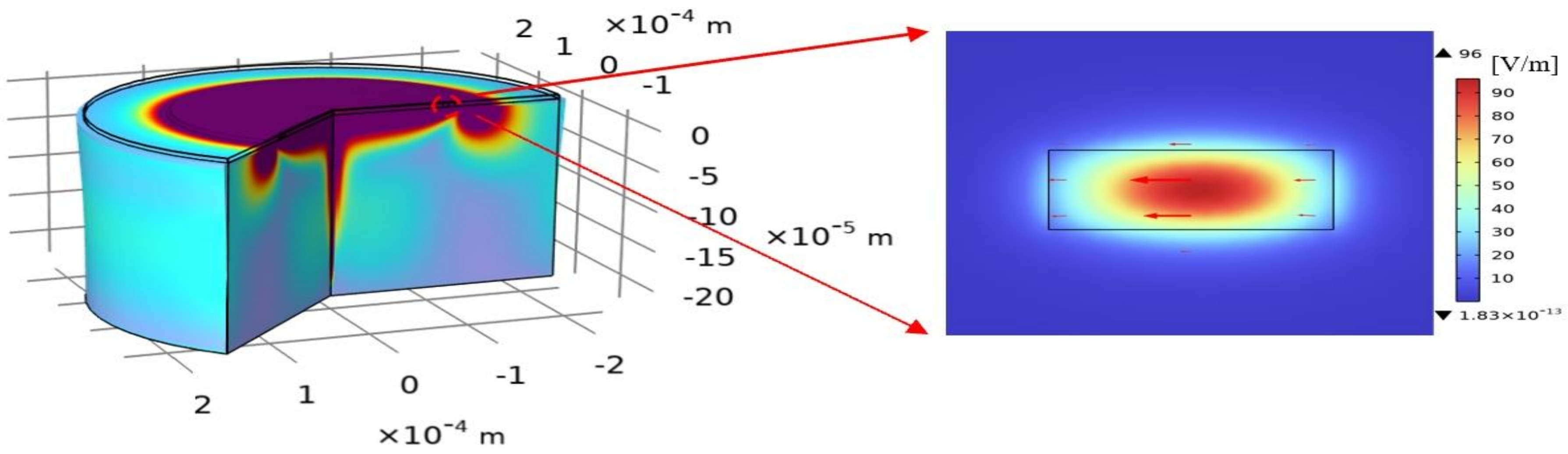

FIGURE 2. Left: von Mises stress on the device. Right: the normalized electric field in the waveguide

## Results

The device has a modulation efficiency of 0.0257 pm/V as shown in Fig. 3. The simulation results of the model are quite close to the experimental results (about 0.02 pm/V) [5], which shows the high accuracy of the model.

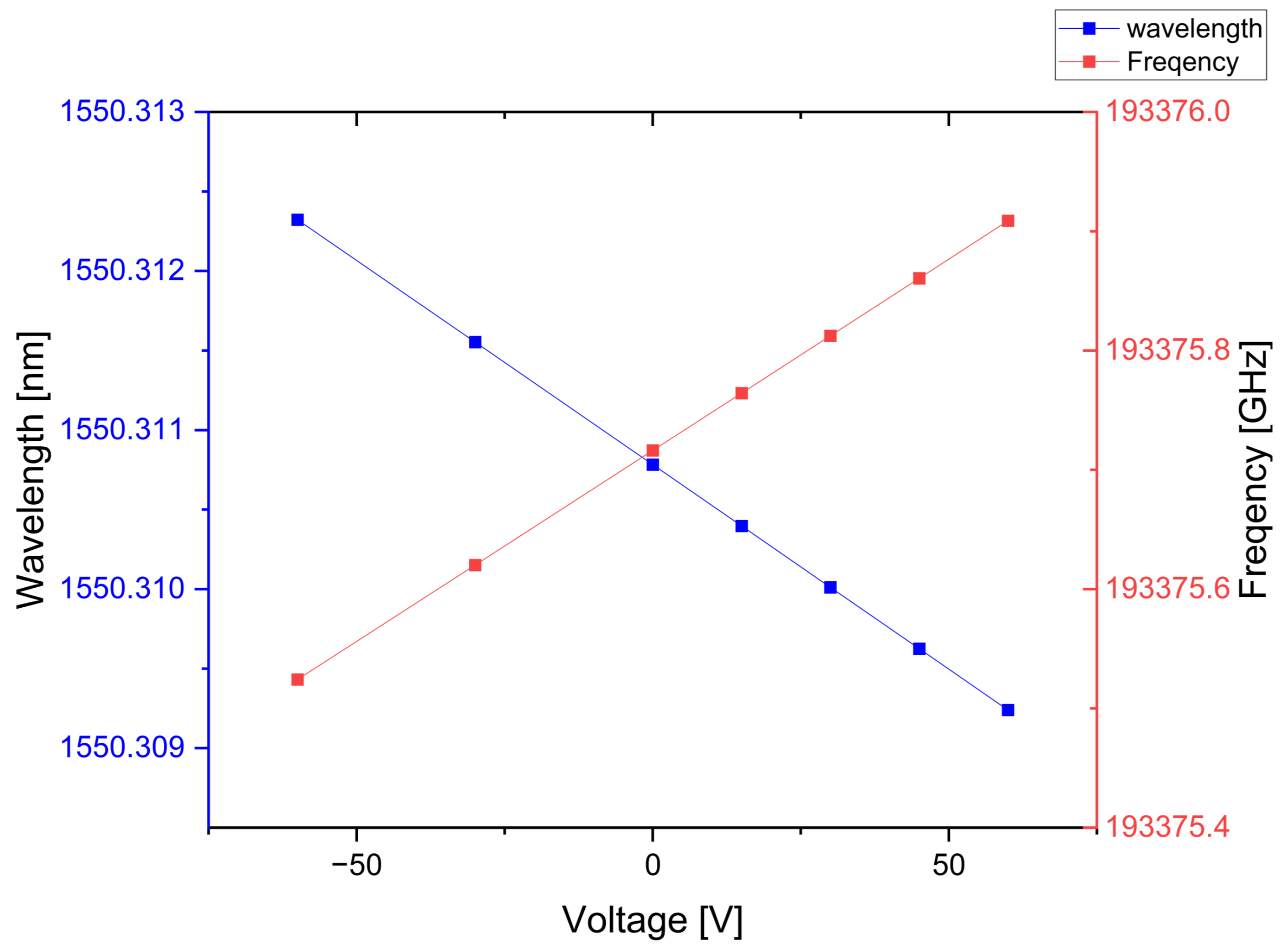

FIGURE 3. The resonant wavelength (left axis) and the resonant frequency (right axis) as functions of the bias voltages.

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