Optical modulators are devices that can be used to manipulate the properties of optical beams, e.g., a laser beam, in integrated optical chips. A wide range of optical modulators are used in very different application areas, such as in optical fiber communication, displays, for active Q switching or mode locking of lasers, and in optical metrology. Phase modulators are optical modulators that can be used to control the phase of an optical beam. For decades, it has been a challenge to increase the efficiency and the modulating speed. We tackle the problem by applying the stress-optic effect induced by depositing a piezoelectric layer on top of an integrated optical device.

By applying a static electric field to the PZT layer, a relative phase difference \( \Delta \phi \) is induced between two arms. When \( \Delta \phi \) between the two arms equals \( (2n+1)\pi \) where \( n \) is an integer number, destructive interference occurs, corresponding to a 0 output for the modulator. In this work, we search for the optimized optical waveguide structure including a thin layer of PZT on top to find the lowest interaction length inducing optical phase shift \( \Delta \phi \) of \( \pi \).

The figures above show the normal stress distributions, \( \sigma_x \) and \( \sigma_y \), in the structure. The initial stress is induced by electro-deformation of the PZT layer in structure.

Tuned refractive index in waveguide structure after applying constant electric field to the PZT layer. The resulting stresses throughout the structure induce a corresponding change in refractive index.

### Stress Distribution in Optical waveguide structure

#### Mach-Zehnder Interferometer System

- **Left figure shows the z-component of the Poynting vector distribution of TM00 (G W/m²).**
- **Right figure is the log-scale of the mode in dB unit.**

### Stress-Optical Phase Modulator

#### Values for materials parameters used

<table>
<thead>
<tr>
<th>Material</th>
<th>Si-Substrate</th>
<th>Thermal SiO2</th>
<th>LPCVD SiO2</th>
<th>PEOVD SiO2</th>
<th>PZT</th>
<th>Pt</th>
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<tr>
<td>Young's Modulus</td>
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<td>Refractive Index</td>
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<td>1.45</td>
<td>1.45</td>
<td>1.45</td>
<td>1.98</td>
<td>-</td>
</tr>
</tbody>
</table>

Optimization of the top Pt electrode to get the maximum waveguide effective index change (\( \Delta n_e \)) for the TM00 mode. The colored lines show the dependence of \( \Delta n_e \) on different top cladding heights with 2 \( \mu \)m PZT layer thickness (a) and different PZT layer thickness with 8 \( \mu \)m top cladding height(b). The electric field across the PZT layer is 20 V/\( \mu \)m.

### Conclusions

The geometrical parameters such as top electrode width, SiO2 layer thickness and PZT thickness are varied to find the optimal structure with maximum tunability. The results show a structure with 8 \( \mu \)m top cladding thickness, 2 \( \mu \)m PZT layer thickness and around 30 \( \mu \)m top electrode width offers the most optimum structure for propagating light with TM polarization. According to the simulation results, this structure can provide a \( \pi \)-phase shift in the propagating light if the interaction length will be in order of 5 mm. To observe the stress effect experimentally, the Mach-Zehnder interferometer structures with various top electrode widths ranging between 10 and 100 \( \mu \)m, have been fabricated in LioniX BV.

As future works, the characterization of the fabricated structures will be performed.