ScuDo

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XXXIV Cycle

Multiphysics simulation of electro-optic modulators based on plasmonic waveguides

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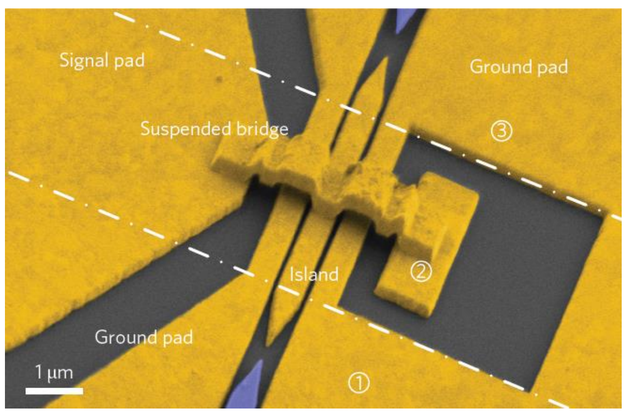
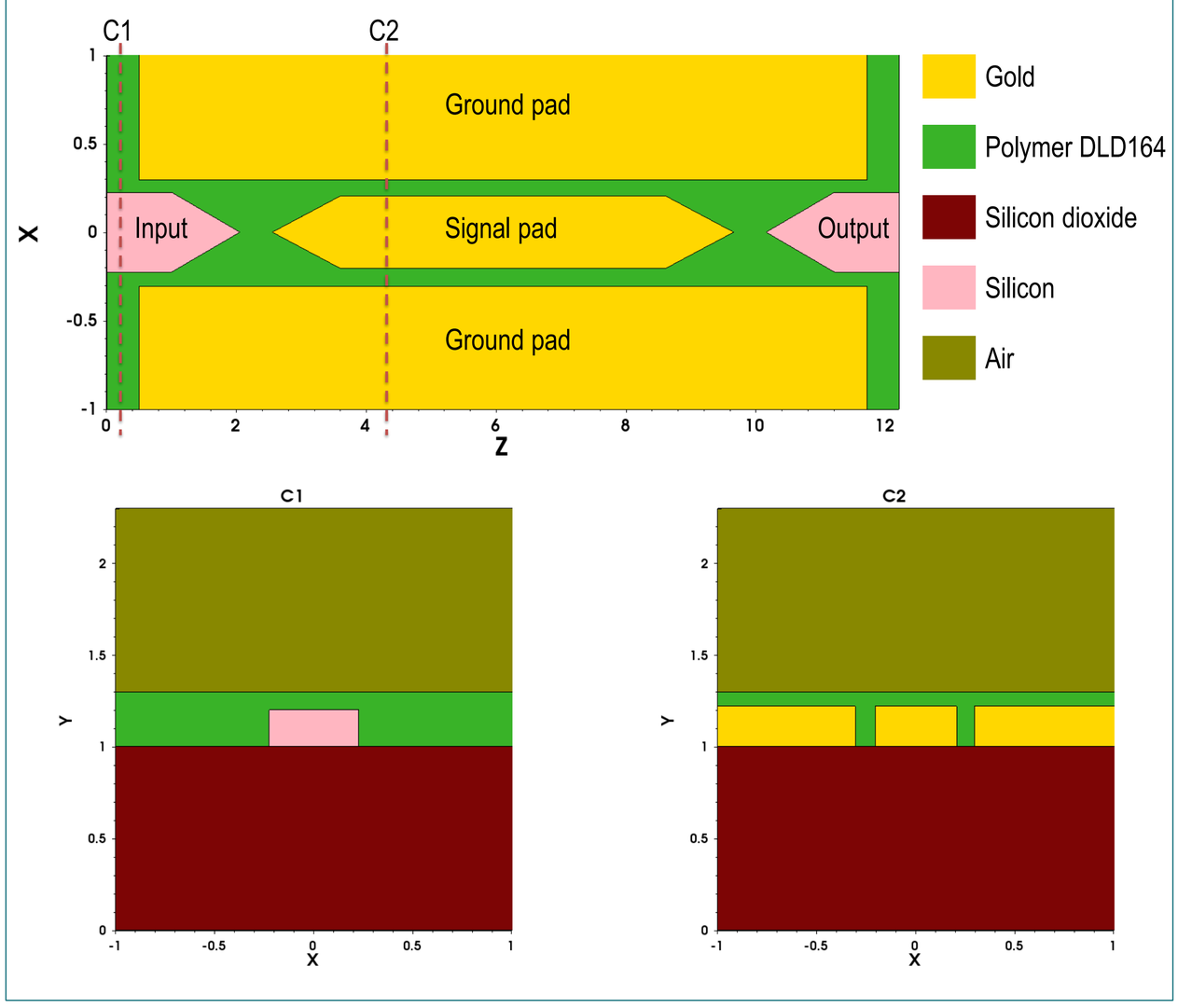
Research context and motivation

- One of the fundamental components in telecommunication infrastructure is electro-optic modulators. Due to the increasing the worldwide telecommunication, modeling and simulation of modulators is become hot topic in past few years.
- Among all modulator categories, Mach-Zehnder modulators(MZMs) are chose which are very popular in communication system.
- Plasmonic modulators work in higher speed and higher bandwidth in comparison with conventional modulators. They also very compact and can be integrated with electronic circuit in same chip. Although these advantages came by a price and increases the insertion loss
- Usually MZMs have been based on the lithium-niobate material which requires footprints on the order of cm^2. However, MZMs based on plasmonic waveguides can be create blew the diffraction limit of optics and require only a few $\mu\mathrm{m}^2$ of footprint. The right picture is SEM image of the fabricated MZMs with plasmonic waveguides. (Ref.:C. Haffner et al., Nature Photonics, pp. 525-528, Aug. 2015)

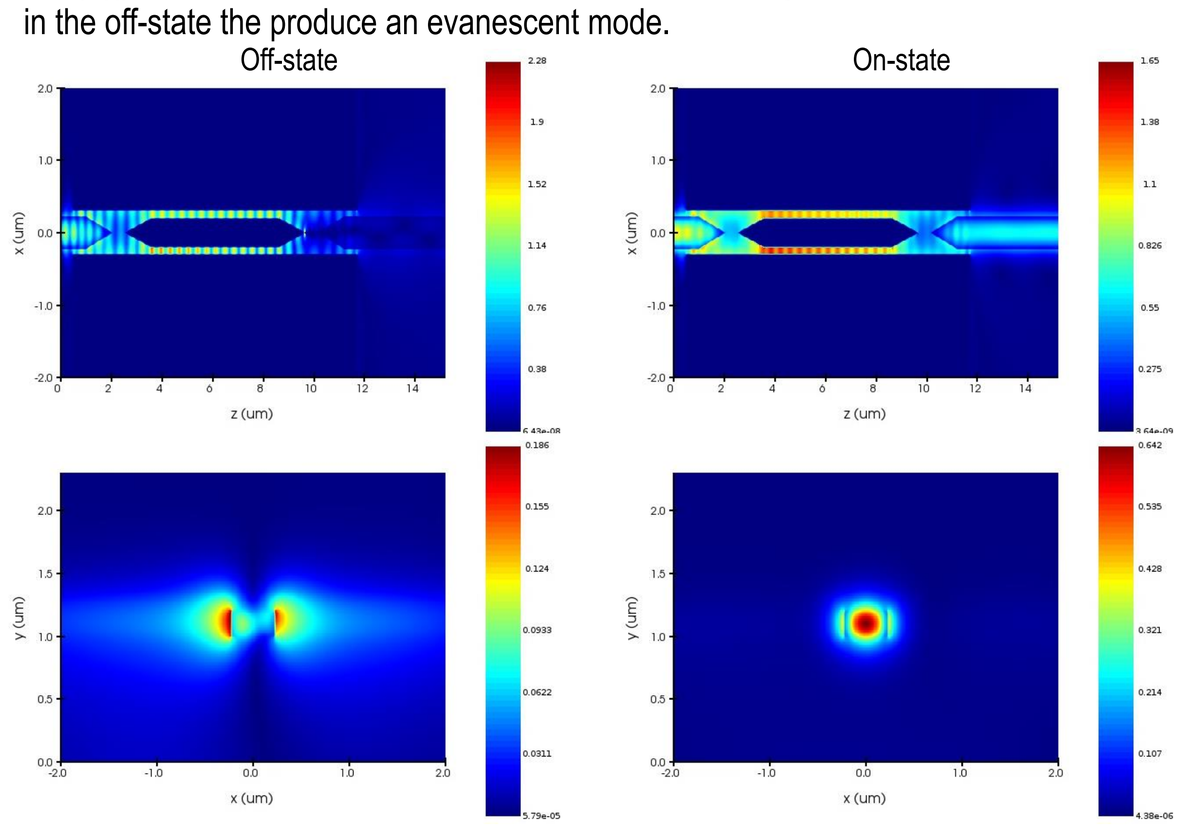


- Geometry of simulated device:



Novel contributions

- The modulator is simulated by 3D FDTD solver of Lumerical software.
- Abs(E_X): In the on-state the surface plasmon produce a guided mode output. Conversely, in the off-state the produce an evanescent mode.

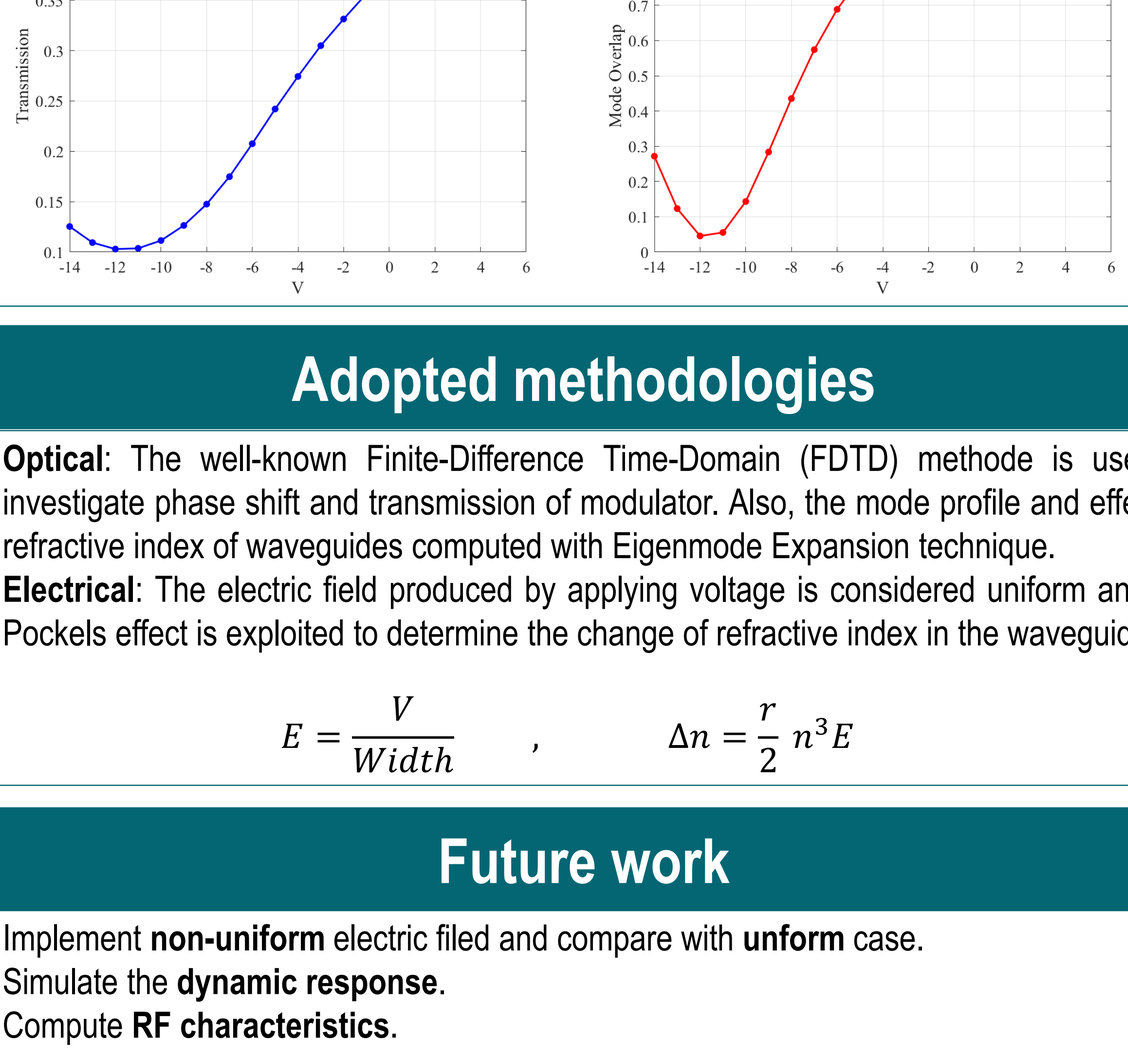


- Transmission and mode overlap versus voltages.

$$\text{Transmission} = \frac{\text{Output optical power}}{\text{Input optical power}}$$

$$\text{Overlap} = \left| \mathrm{Re}\left[\frac{\left(\int \vec{E}_1 \times \vec{H}_2^* . d\vec{S}\right)\left(\int \vec{E}_2 \times \vec{H}_1^* . d\vec{S}\right)}{\left(\int \vec{E}_1 \times \vec{H}_1^* . d\vec{S}\right)} \right] \frac{1}{\mathrm{Re}\left(\int \vec{E}_2 \times \vec{H}_2^* . d\vec{S}\right)} \right|$$

Extinction Ratio = 6.26 dB



Adopted methodologies

- **Optical**: The well-known Finite-Difference Time-Domain (FDTD) methode is used to investigate phase shift and transmission of modulator. Also, the mode profile and effective refractive index of waveguides computed with Eigenmode Expansion technique.
- **Electrical**: The electric field produced by applying voltage is considered uniform and the Pockels effect is exploited to determine the change of refractive index in the waveguides.

$$E = \frac{V}{Width} \quad , \quad \Delta n = \frac{r}{2} n^3 E$$

Addressed research questions/problems

- Review of modeling method for electro-optic modulators.
- Understanding state-of-the-art for plasmonic modulators.
- Evaluate the commercial software for simulation of plasmonic device: At the beginning, It took a lot of time to get the commercial software working properly for plasmonic device.
- Distinguish between plasmonic mode and other modes: Beside commercial software, an analytical model is needed to determine the plasmonic mode is exited or not.

Future work

- Implement **non-uniform** electric filed and compare with **unform** case.
- Simulate the **dynamic response**.
- Compute **RF characteristics**.
- Evaluate other metals (**Silver**, **Aluminuam**, **Copper**, **Tungsten**) instead of **Gold**.
- Examination of possibility to simulate the **chirp**.

List of attended classes

- 01NVOPE – CAD of semiconductor devices and processes (19/2/2019, 30 hours)
- 01NOPOQ – Photonic device (4/7/2019, 30 hours)
- 01SFURV – Programmazione scientifica avanzata in matlab (27/6/2019, 28 hours)
- 01SWPRV – Time management (10/12/2018, 2 hours)
- 01QFDRV – Photonics: a key enabling technology for engineering applications (26/7/2019, 25 hours)

Submitted and published works

- Ghione, G. , Tibaldi, A., Ghomashi, M., Goano, M., "*Electro-optic modulators: a second youth?*", Huawei Workshop on Novel Photonics Technologies, 2019, Dublin, Ireland

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