Surface effects in integrated photonic waveguide structures

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Photonic Integrated Circuits (PICs) are becoming a pervasive technology, enabling fields such as telecom and datacom, from automotive to biosensing, from optical computing to neuromorphic, from LIDAR to imaging. Optical waveguides, able to guide light in planar chips are the key building blocks, which characteristics determine the performance of the devices, as well as their integration scale. A waveguide is a high refractive index dielectric medium (core) surrounded by a lower index material (cladding). The surface surrounding the core has a key importance and it is responsible of a number of linear and nonlinear effects that attracted the attention of designers, technologist and researchers for years. At the interface surface, the refractive index discontinuity induces a discontinuity of the electrical field or the electric displacement, having a major impact on the propagation characteristic of the waveguide. The interface is typically affected by imperfections such as roughness, mechanical stresses, dangling bonds, carrier accumulation, voids, etc. and hence these effects are characterized by a statistical behavior.

In this talk three main effects are discussed: i) roughness induced effects; ii) carrier accumulation effects and iii) mechanical stresses effects.

Roughness induced by the technological process of waveguide fabrication is responsible of coupling between guided and radiative modes of the waveguides, that is the induced attenuation, scattering, backreflection, higher order mode excitation and crosstalk between adjacent waveguides. If the waveguide material is based on semiconductors such as silicon, germanium, indium phosphide and their composites, free carriers and carriers generated by single and two photon absorption accumulate on the waveguide surfaces, being responsible of a number of side effects that can be detrimental (losses, nonlinearities, electrooptic behavior) or can be exploited for sensing purposes [2, 5] because of the electrical impedance variations of the waveguide itself.
Further, the mechanical strains between the core and the cladding due to lattice, thermal coefficients, and mechanical mismatches, can induce a deformation of the atomic lattice in the neighborhood of the surface and a peculiar electrooptic and a nonlinear behavior.
The contribution will highlight these effects from the point of view of technology, impact on optical performances and exploitation of side effects that can be not always detrimental.

References

[1] D. Melati, A. Melloni, and F. Morichetti, “Real photonic waveguides: guiding light through imperfections,” Adv. Opt. Photon. 6, 156-224 (2014)
[2] S. Grillanda, F. Morichetti, “Light-induced metal-like surface of silicon photonic waveguides”, Nature Communications 6, (2015)
[3] P. Damas, M. Berciano, G. Marcaud, C., Alonso Ramos, D. Marris-Morini, E. Cassan, and L. Vivien, “Comprehensive descriptionof the electro-optic effects in strained silicon waveguides,” Journal of Applied Physics 122, (2017)
[4] D. Melati, F. Morichetti, G.G. Gentili, and A. Melloni, “Optical radiative crosstalk in integrated photonic waveguides”, Optics Letters Vol. 39, Iss. 13, pp. 3982–3985 (2014)
[5] S. Grillanda, M. Carminati, F. Morichetti, P. Ciccarella, A. Annoni, G. Ferrari, M. Strain, M. Sorel, M. Sampietro, and A. Melloni, “Non-invasive monitoring and control in silicon photonics using CMOS integrated electronics,” Optica 1, 129-136 (2014)
[6] D. Melati, F. Morichetti, and A. Melloni, “A unified approach for radiative losses and backscattering in optical waveguides”, J. Opt. 16 055502 (2014)