Soutenance de thèse

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Optical phase modulation by Pockels effect in silicon platform

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Abstract :

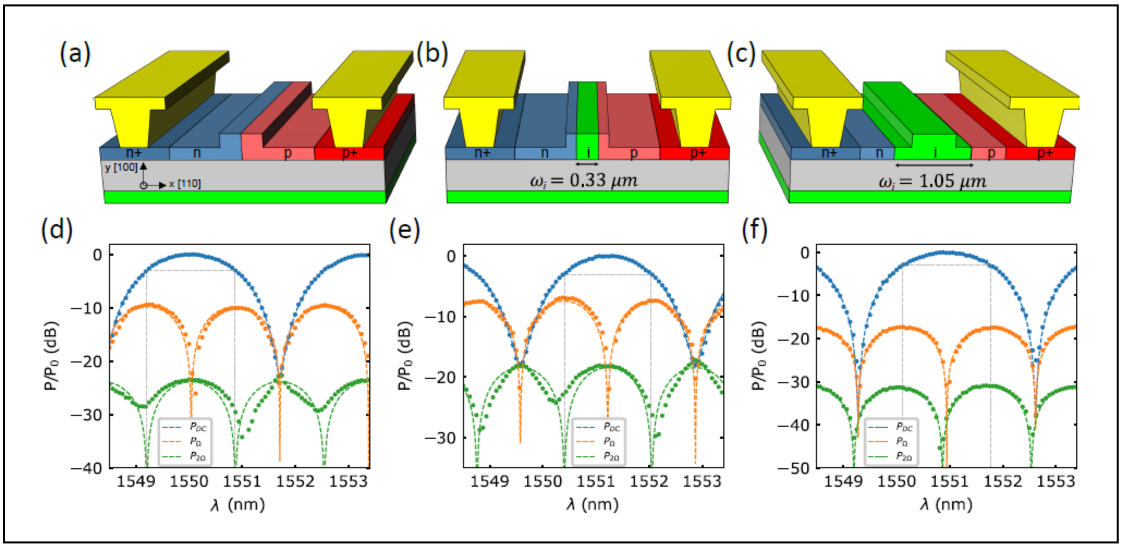
The performance evolution of classical and quantum optical communication networks, computing systems, sensing circuits (including gyroscopes and lidars), as well as integrated circuits, requires the development of pure phase optical modulators compatible with silicon photonics platforms. Addressing this need will directly tackle key challenges in various applications (detection, quantum photonics, optical communications) where silicon photonics could play a transformative role. Silicon's potential for photonics has been recognized to overcome the limitations of interconnect efficiency, while also offering a versatile platform to solve emerging issues in fields such as Lidar and quantum photonics.

Despite progress in high-performance silicon electro-optical modulators, germanium photodetectors, and III-V lasers on silicon, several challenges remain, including the integration of these elements on a single chip, improving the energy efficiency of optical modulators, and achieving pure phase optical modulation. However, because silicon is a centrosymmetric material, it lacks second-order optical nonlinearities, meaning that there is no inherent Pockels effect or wavelength conversion. To overcome this significant limitation, mechanical stress can be applied to silicon to break its centrosymmetry, thereby inducing second-order nonlinearities. Recent proofs of concept have demonstrated modulation speeds of up to 20 GHz using silicon nitride stress layers deposited by PECVD on silicon.

This thesis focuses on optimizing both the strain-induced Pockels effect and the associated electrode designs. The first part delves into the potential of strained silicon as a platform for achieving the Pockels effect through mechanical stress. Various optical waveguide structure, such as slab and slot waveguides, were explored, but the initial waveguide design from previous work was ultimately the most effective in maximizing the Pockels tensor.

In addition, slow-wave electrodes were proposed as a method to increase electro-optic modulator bandwidth by reducing the velocity mismatch between RF and optical modes. Preliminary results suggest that this method could improve bandwidth, though the fabricated devices—employing silicon nitride stressors—revealed that plasma dispersion effects and carrier absorption mechanisms dominated over the desired Pockels effect. No Pockels effect was detected, primarily due to the strong carrier influence on the modulation process.

Recognizing these limitations, the thesis shifts its focus toward alternative approaches. While silicon nitride stressors have been widely studied, they have proven unsuitable for reliable Pockels modulators due to issues such as surface charges and interface traps. Consequently, the second half of the work explores the study and experimental validation of DC Kerr modulators, which offer a promising solution for pure phase modulation and high-speed applications. The Kerr modulations were quantified through a new experimental protocol designed to separate the contributions of the Kerr effect from plasma dispersion in high-speed modulations. Experimental results showed that the modulation in the studied devices was exclusively due to the DC Kerr effect, enabling the demonstration of an open eye-diagram at 100 Gbps. This advancement sets the stage for future silicon modulators leveraging the DC Kerr effect in high-speed applications.



Légende : (a,b,c) Three differents PIN diodes used to study the Kerr effect in Mach-Zehnder modulators. Experimental results shows that the third diode can be used to have a DC Kerr modulation as the main effect for the high-speed modulation.