Strain-induced electro-optical effect in silicon Mach-Zehnder modulators

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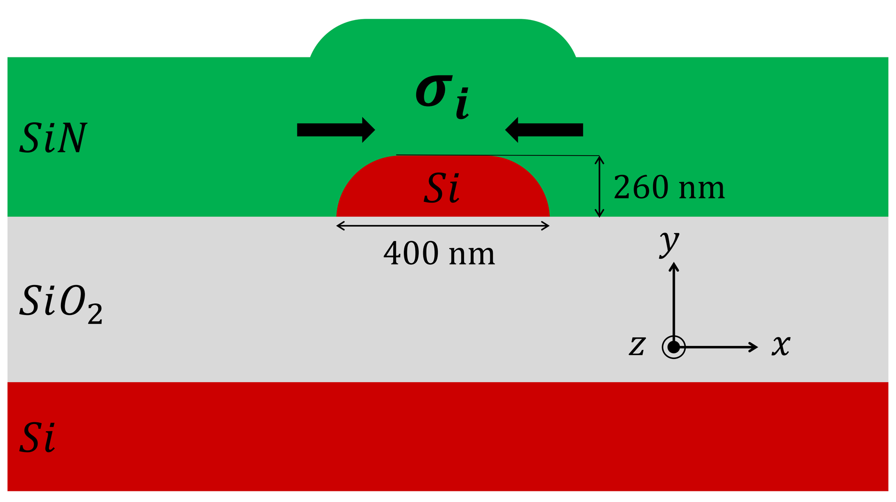
Context

Todays electro-optic modulators do not address the issues of energy consumption and mass production at the same time. Taking advantage of second order nonlinear optical effects, such as Pockels effect, in silicon would answer both challenges. Indeed, Pockels effect is an ultra-fast linear electro-optic effect and silicon is fully compatible with CMOS industrial fabrication lines. However, due to its centrosymmetry, silicon does not naturally provide Pockels. A stressing layer is used to break this symmetry, enabling the existence of second order nonlinearities in silicon.

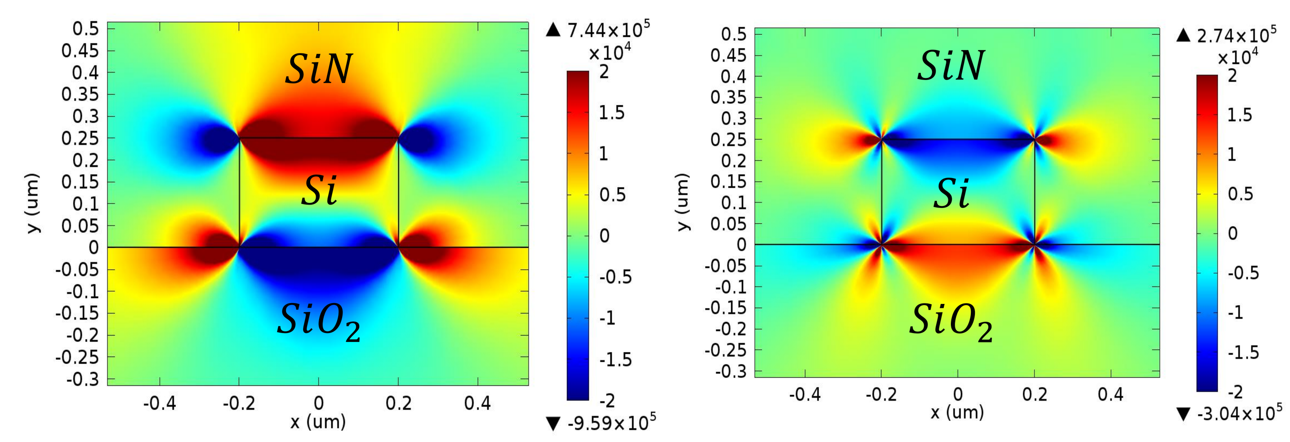
How to strain silicon?



Silicon waveguide strained by a silicon nitride layer (SiN)

A highly stressed SiN layer is deposited on the silicon waveguide (PECVD)

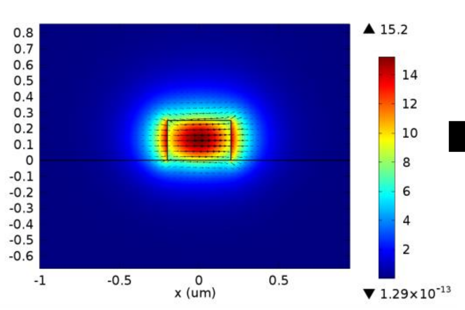
$$\chi^{(2)}_{ijk}(\vec{r}) = \sum_{mnl} \Gamma^{ijk}_{mnl}\, \eta_{mnl}(\vec{r}) \neq 0$$



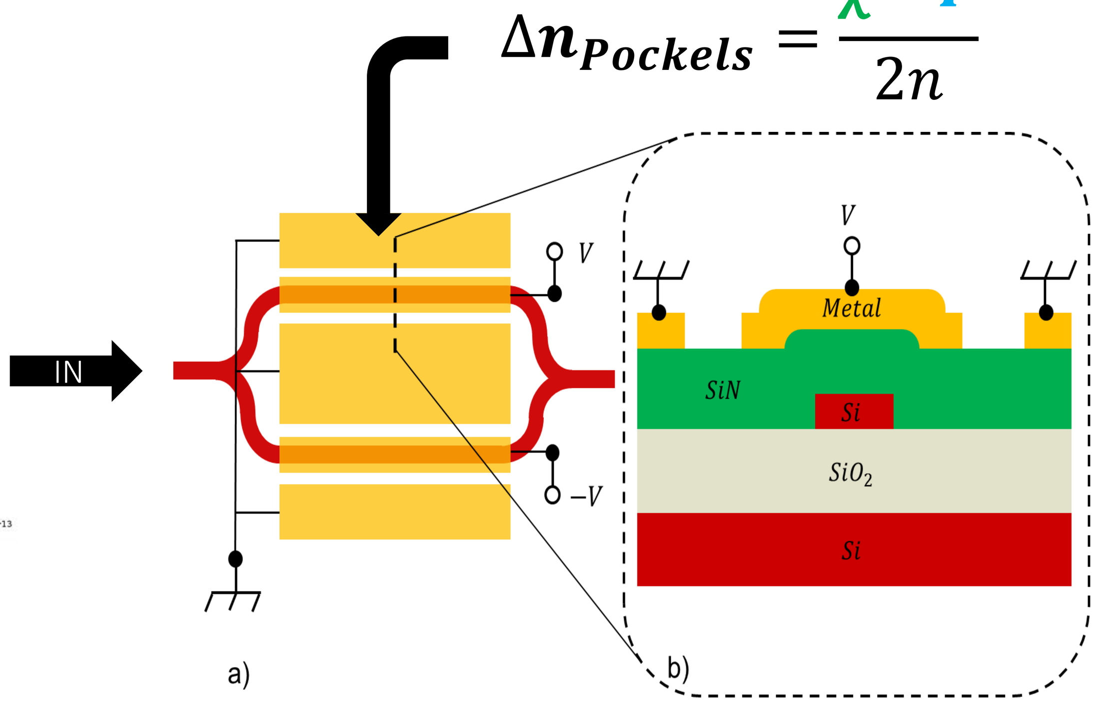
Distribution profiles of strain gradients η_{xxy} and η_{yyy} in the waveguide

Experimental characterization: electro-optic modulation[1]

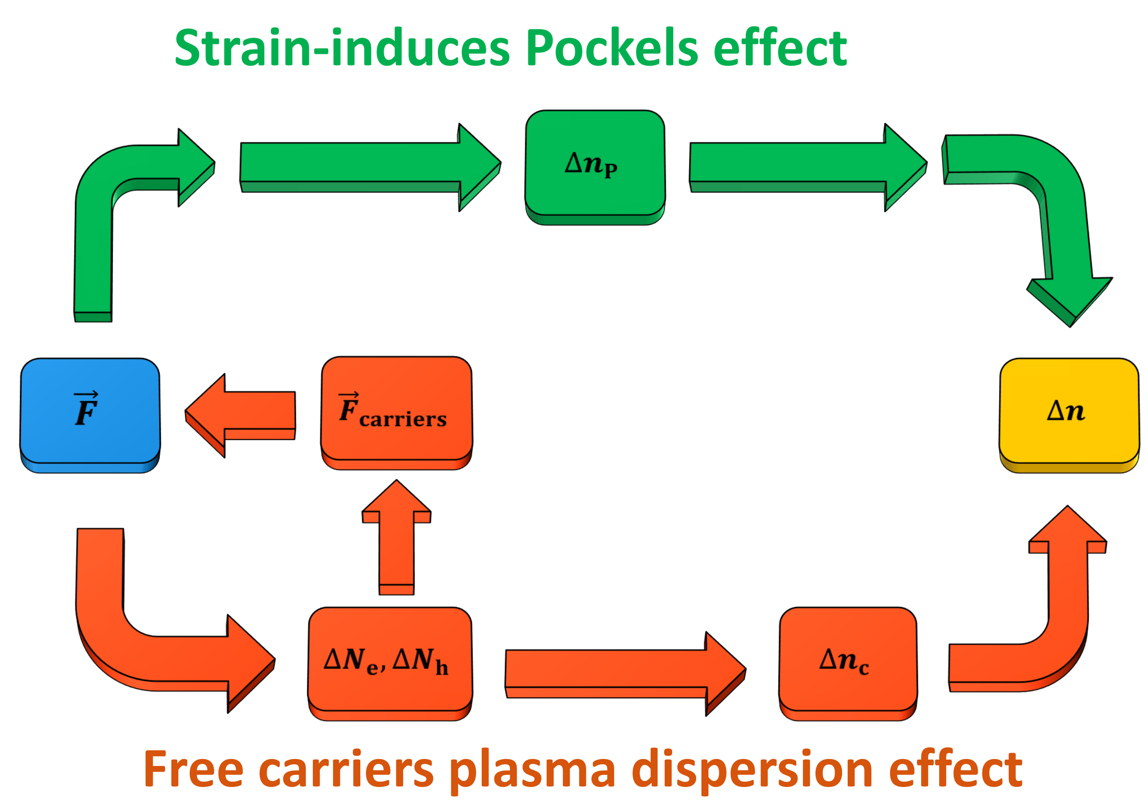
$$\Delta n_{Pockels} = \frac{\chi^{(2)} F}{2n}$$



Single mode waveguide (TE)

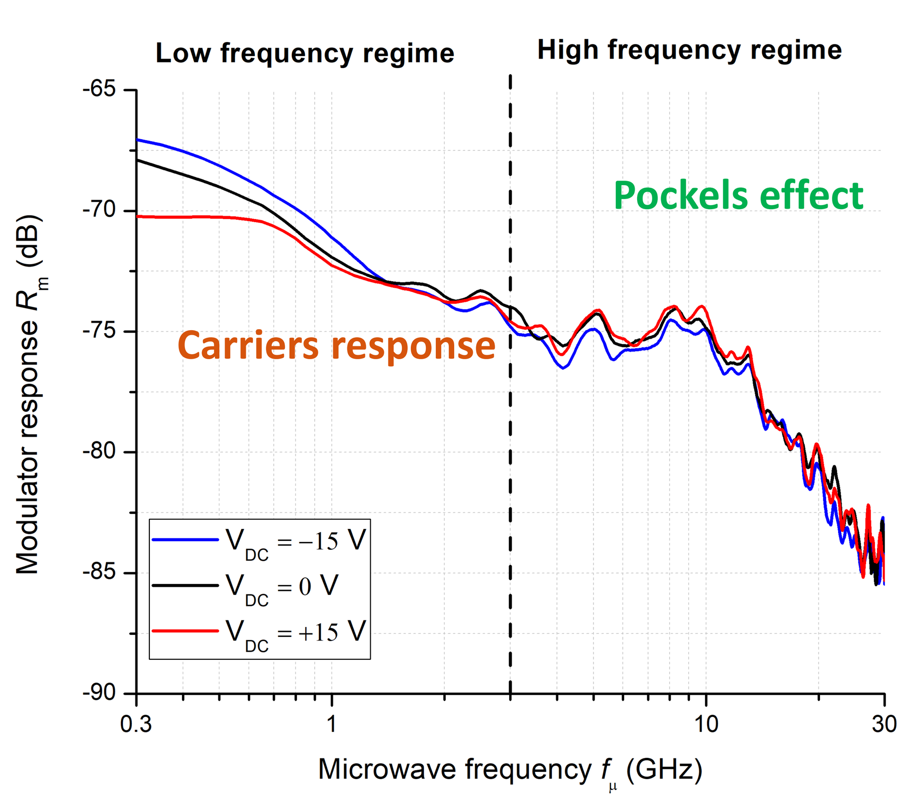


Schematic vue of the modulator



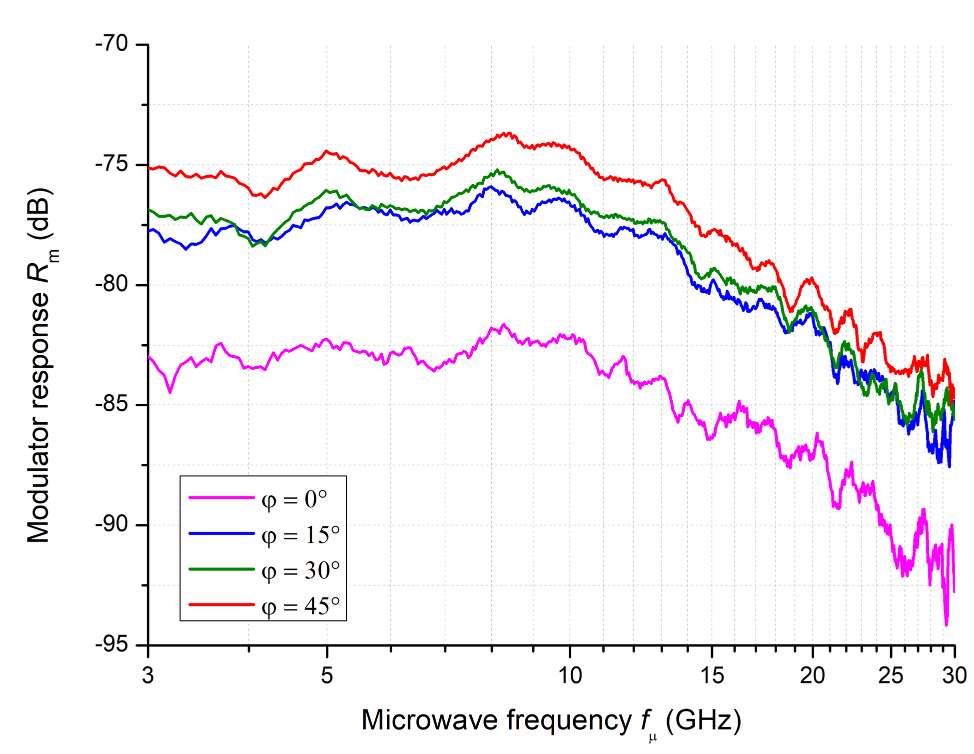
Problem: interplay between Pockels effect and free carriers effect. How to separate them?

Speed

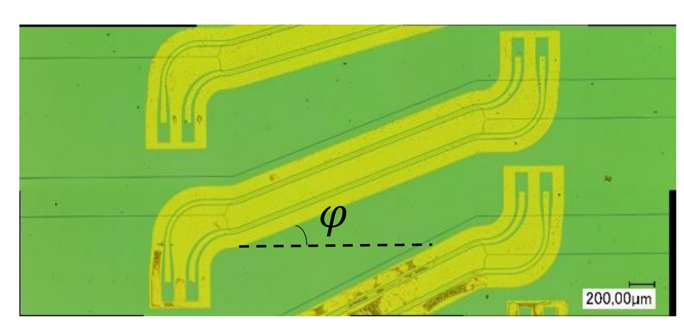


At high frequencies, free carriers are not fast enough to play on the modulation response

Angular dependence



Pockels effect depends on the crystal orientation, while carriers are not.



Conclusion

We demonstrate the possibility to unlock second order nonlinear effects in silicon, a centrosymmetric material, by depositing a stressing layer on top of the device. Experimental results highlight Pockels effect signatures by playing on the modulation frequency and the crystal orientation. A theoretical model developed in our team permits to study the effect of strain on the electro-optic response of the modulator. These studies are promising for the future of the strained silicon platform. Further investigations are currently under study to improve the strain-induced Pockels effect.

[1] M. Berciano *et al.* , « Fast linear electro-optic effect in a centrosymmetric semiconductor », Communication physics, 2018