Periodic polarisation of MgO-doped lithium niobate

Arthur Chorley

Master Ondes, Atomes, Matière, Université Côte d'Azur

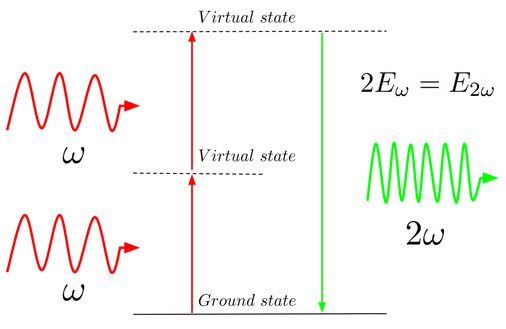
Supervisor : Florent Doutre

Institut de Physique de Nice, CNRS

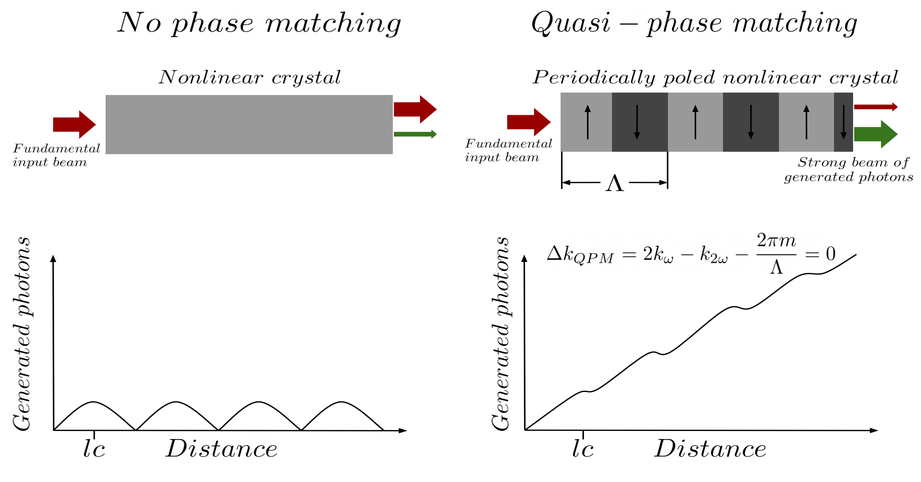
Abstract

Emerging quantum communication applications drive the rapid development of upconversion single-photon detectors and entangled photon-pair sources, both of which rely on frequency conversion in periodically poled lithium niobate (PPLN) waveguides as their core components. MgO-doped congruent lithium niobate (MgLN) is recognized as the most promising material for fabricating PPLN due to its attractive properties. However, leakage current complicates the high-quality periodic poling of MgLN, especially when using the technique with liquid electrodes. In this study, we investigate the poling properties of MgLN and describe the modifications made to an existing experimental setup and protocol for PPLN production to meet the requirements of PPMgLN manufacturing.

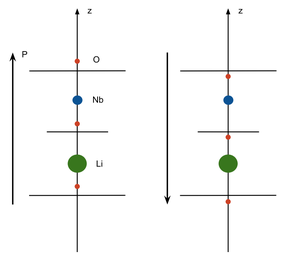
1. Quasi-phase matching (QPM) and second harmonic generation (SHG)



Developing a reliable method for consistently achieving high-quality periodic poling of MgLN is a crucial advancement for nonlinear optics.



2. Advantages and disadvantages of MgO-doped Lithium niobate



Advantages

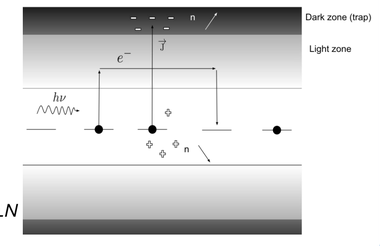
- ***Lower coercive field*** *than CLN (Δ=17kV/mm)[1]*
- *Higher **resistance** to **optical damage**[2]*
- *Room temperature **high power operations***

Disadvantages

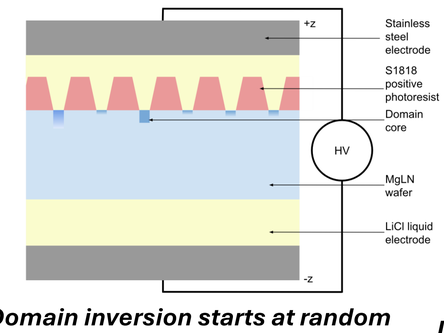
- *Emergence of **leakage current** due to lower resistance[1] (Δ=10⁶ Ω.cm)*
- ***Longer poling times** required[1,3]*

Note: the issues associated with using MgLN are solely related to the poling process.

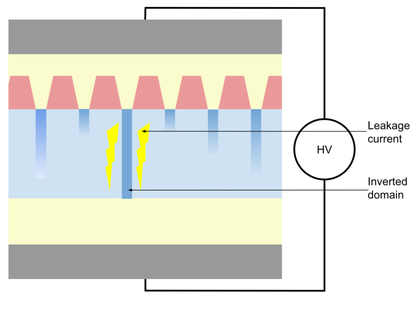
Photorefractive effect



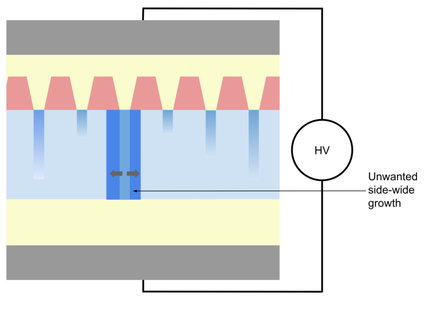
3. MgLN's behaviour while undergoing polarisation



Domain inversion starts at random *under the surface in contact with the electrode[1]*, it starts at the edges of the electrodes, then progresses inward and outward from the edge.[4]

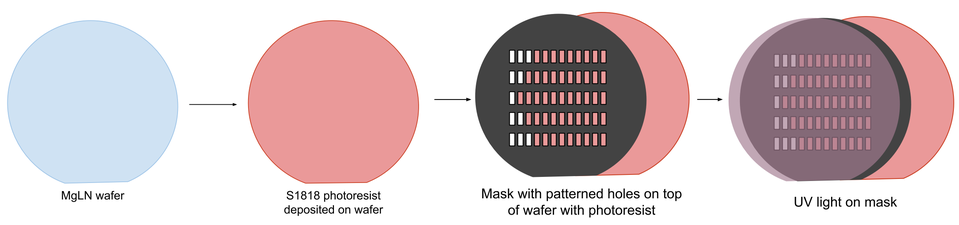


Leakage current emerges *when a domain is fully inverted. This leakage current hampers the inversion of neighbouring domains[1]*



*The leakage current heats up the local area around the inverted domain and favors **side-wide growth**[1]*

4. Manufacturing process of periodically polarised MgO-doped lithium niobate (PPMgLN)

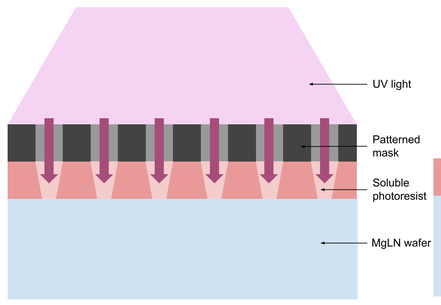


*Virgin 5 mol.% MgO doped lithium niobate **wafer***

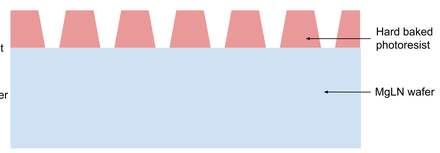
***Photoresist** is deposited with a spin coater*

***Mask** with ~16 µm period pattern layed on top of wafer*

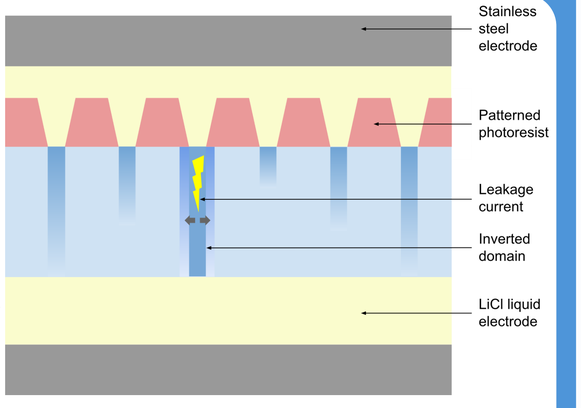
*Mask is illuminated with **UV light** (~2,5 mJ.cm^{-2})*



*Photoresist exposed to UV light **becomes soluble***

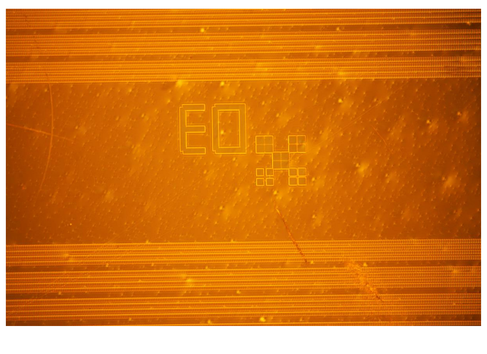


*Photoresist is **hard baked** to **enhance dielectric strength**[5]*

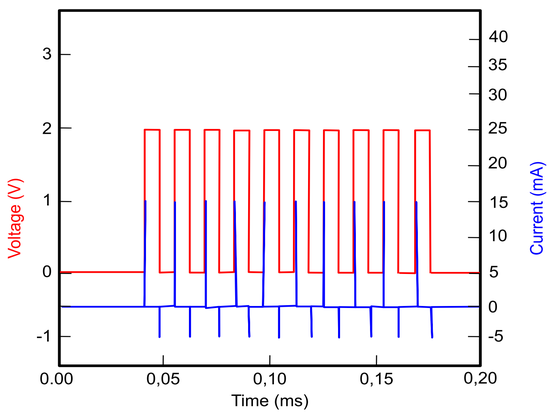


*MgLN is periodically poled using **liquid electrodes** and **multipulse poling technique**[1,5] to avoid leakage current*

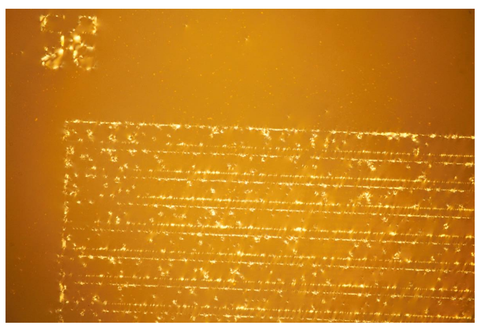
5. Observation of periodically polarised MgLN



Photoresist patterned with a 16,2 µm period observed through a microscope using a 5x lens.



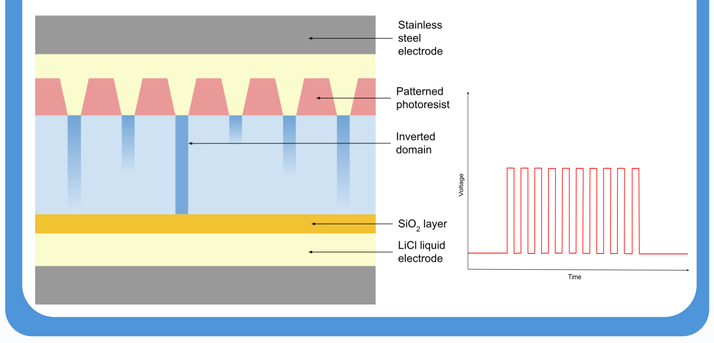
Poling voltage: 11kV/mm
Number of pulses sent: 50
Total poling time: 100 ms



Poling has started to appear throughout the sample. Poling starts at the edges of the electrodes[4] as observed. Sample is observed via transmission imaging between crossed polariser

6. Supressing leakage current

- *Deposition of a **layer of SiO_2** on –z face of the wafer*
- ***Hard bake** recipe after photolithography to enhance dielectric strength of photoresist*
- ***Multipulse** poling technique*
- ***Longer poling time**, spanning over several seconds*



Conclusion and Perspectives

In conclusion, we have had the opportunity to investigate the poling characteristics of MgLN and have explored the new steps involved in the fabrication of PPMgLN, such as the multipulse electric-field poling method and the hard bake recipe. Furthermore, we successfully manufactured a patterned photoresist with satisfying quality with a well-established protocol. We have analysed the various factors responsible for our unsatisfactory results. The time scale dependence of the poling process in MgLN has been identified and highlights one of the parameters that need to be adjusted for PPMgLN manufacturing. The objectives for the near future is to address the limitations we have had regarding the number of pulses we were able to send and thus the poling time. Additionally, we are currently contacting neighbouring labs in order to deposit a 700 nm thick layer of silica on the MgLN wafer.

References

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2. Ashkin, A., G. D. Boyd, J. M. Dziedzic, R. G. Smith, A. A. Ballman, J. J. Levinstein, and K. Nassau, 1966, Applied physics letter.
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