Master thesis proposal

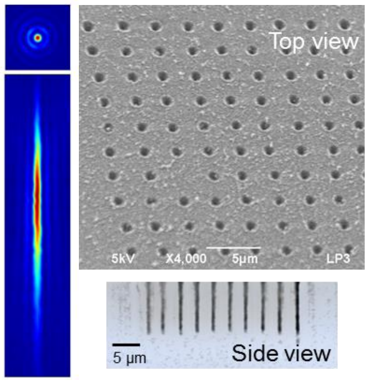
Fabrication of photonic-crystal structures with short-pulse lasers

Context

Femtosecond laser pulses are able to fabricate 3D components in transparent materials. Indeed, such short and intense pulses focused to micrometer-sized spots offer the possibility to locally modify the material properties (from slight refractive index modification up to matter ablation). The resulting application is the unique capability to write with high spatial resolution various functions in dielectric materials (waveguides, gratings, channels) as well as to perform high-quality cutting (dicing of smartphone screens, humain cornea surgery). A major objective of our research is to extend these capabilities to novel applications: the writing of fonctional optical structures, like photonic crystals and metasurfaces. Such direct laser fabrication has not been achieved up to now, and would constitute a new technological approach capable of outperforming existing nanoprocessing techniques (nanolithography, electron or ion beam) by offering versatility and universality of application to various materials: from glasses and crystalline dielectrics (fused silica, quartz, sapphire) to nonlinear crystals (lithium niobate), at the basis of photonic integrated circuits.

Objectives

The aim of this internship is to realize arrays of microchannels by laser ablation, whose dimensions match the required ones for photonics structures: typically few hundreds of nanometers in diameter and few micrometers deep. This topic addresses optics, lasers, matter interaction, nanostructures and photonics devices. Several aspects will be explored:



1/ *Shaping of the laser beam.* We recently developed an experiment using a modified Bessel beam [1,2]. The student will continue to develop the experimental set-up for writing arrays of channels at the surface of silica, with the objective of exploring the minimum achievable spatial periodicity (<< 1 µm) while maintaining significant depths. The related limitations should be identified, such as the influence of the presence of the previous channel on the writing of the next channel, the perturbation of the propagation of the beam by the created plasma, etc.

2/ *Experimental strategies to finely control the excitation of the material*: influence of the laser pulse duration, the number of pulses, the spatial shaping and possibly the temporal shaping (pulse trains of variable intensities). The objective is to characterize and control the fundamental mechanisms of interaction and the plasma created within the material [3,4] and to be able to propose advanced beam shaping solutions (e. g. increasing intensity along the propagation axis) to overcome the limitations previously identified and thus demonstrate the interest and unprecedented versatility of laser ablation for the fabrication of photonic components.

3/ *Characterization of structures written by laser* (optical microscopy, SEM, AFM, TEM after FIB...). The aim is to obtain precise quantitative information on the dimensions, reproducibility, regularity of channel arrays, etc., and also assessing the invasiveness of the ultra-short laser writing technique (possible collateral structural changes in the material).

4/ Depending on the duration and progress of the internship: the design, writing and functional tests of two types of optical components: metasurfaces and/or photonics structures.

Resources available. To carry out this work, the student will use the femtosecond laser system ASUR his environment, as well as the diagnostics of the LP3 laboratory (Luminy Campus, Marseille, www.lp3.univ-mrs.fr). He/she will work in a team of about 7 people (researchers, doctoral students, post-docs) working on laser-matter interaction in an ultra-short regime.

Keywords. Ultra-short laser pulses, laser-matter interaction, optics, plasmas, dielectric materials, micro-nano-structures, photonic components.

Recent references

[1] X. Liu, N. Sanner, M. Sentis, R. Stoian, W. Zhao, G. Cheng, O. Utéza, "Front-surface fabrication of moderate aspect ratio micro-channels in fused silica by single picosecond Gaussian-Bessel laser pulse", Appl. Phys. A 124, 206 (2018).
[2] X. Liu, Q. Li, A. Sikora, M. Sentis, O. Utéza, R. Stoian, W. Zhao, G. Cheng, N. Sanner, "Truncate d Gaussian-Bessel beams for short-pulse processing of small-aspect-ratio microchannels in dielectrics", Opt. Express 27, 6996 (2019).
[3] M. Lebugle, N. Sanner, N. Varkentina, M. Sentis, and O. Utéza, "Dynamics of femtosecond laser absorption of fused silica in the ablation regime", J. Appl. Phys. 116, 063105 (2014).
[4] C. Pasquier, M. Sentis, O. Utéza, N. Sanner, "Predictable surface ablation of dielectrics with few-cycle laser pulse even beyond air ionization" Appl. Phys. Lett. 109, 051102 (2016).

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Additional information

Monthly allowance for the duration of the internship (if duration is >2 months): 568 Euros
An excellent candidate will have the **possibility to apply for a PhD** after the MS thesis.