Femtosecond laser interference patterning for highly accurate material structuring

Irene Solana[1,*], Fernando Chacon-Sanchez[1], Mario Garcia-Lechuga [1], and Jan Siegel[1,*]
[1] Laser Processing Group, Instituto de Óptica Daza de Valdés (IO), CSIC, Serrano 121, 28006 Madrid, Spain
*Corresponding author email: isolana@io.cfmac.csic.es

The use of fast and ultrafast laser pulses is nowadays a well-established technique for micro- and nano-structuring of materials. Direct laser interference patterning (DLIP) with ps and ns pulses has evolved into a promising technique for material micro-structuring thanks to the precise and controlled energy deposition achieved through the interference of two or more coherent laser beams, which allows to fabricate a wide variety of structures in a broad range of materials [1].

When using ultrashort laser pulses, one of the major issues of this technique is the need of a nearly perfect temporal and spatial overlap between the interfering beams. To achieve this, we made use of an imaging set-up by combining commercial or ad-hoc laser-fabricated diffractive optical elements (DOE) with a demagnifying optical system. High-contrast, well-defined excitation profiles with a Gaussian envelope and periods between 5 µm and 650 nm (Fig. 1a) can be achieved employing a commercial Ti:Sa amplified laser (800 nm, 120 fs, 1 mJ) by slightly changing the irradiation configuration. We employed this setup to obtain amorphous or ablative nanostructures in crystalline silicon (Fig 1b-c). The topography of the amorphized regions of the sample shows a strong dependence on the imprinted fringe width (Fig 1d-e). Moreover, we demonstrate the versatility and scalability of this technique by imprinting micro-dots of 1 µm-600 nm diameter (Fig. 1f) and large area (5 mm x 5 mm) nanogratings (Fig 1g).

The results obtained allow a detailed investigation of the mechanisms responsible for the surface deformation, including melting, Marangoni convection, capillary waves, and resolidification [2]. Furthermore, the technique's exceptional upscaling capacity renders it highly appropriate for industrial applications.

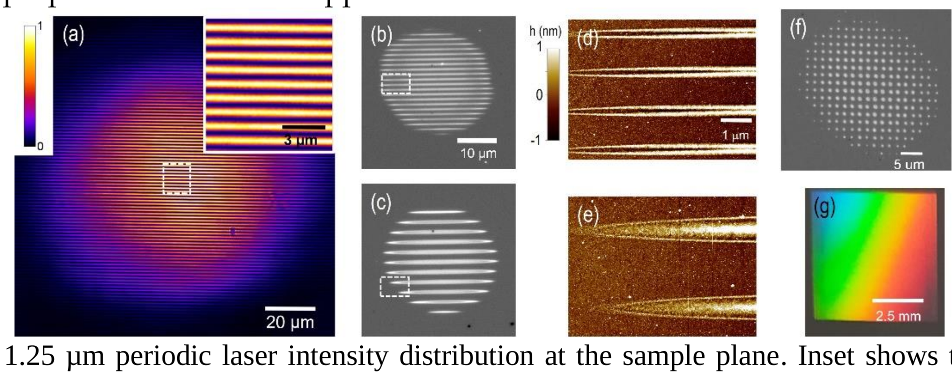

Fig 1. (a) 1.25 µm periodic laser intensity distribution at the sample plane. Inset shows the zoomed image of the selected area. (b-c) Optical microscopy images of single shot imprinted patterns in c-Si with 1.25 µm (b) and 2.52 µm periodicity. (d-e) AFM map of the outlined areas in (b-c). (f) Optical microscopy image of a dot-like pattern. (g) Macroscopic image of a large-area grating with 1.25 µm period, illuminated by white light.

Acknowledgements: This work has been partly funded by the national research grant ULS_PSB (PID2020-112770RB-C21) from the Spanish Research Agency (AEI, Ministry of Research and Innovation) and the European Regional Development Fund (ERDF) as well as by research grants HyperSolar (TED2021-130894B-C22) and ASSESS (TED2021-129666B-C22) funded by NextGenerationEU.

References: [1] L. Mulko, M. Soldera, A.F. Lasagni, Nanophotonics. 11 (2022); [2] M. Alvarez-Alegria, C. Ruiz de Galarreta, and J. Siegel, Laser & Photonics Rev. 17, 2300145 (2023)