Precision manipulation of surface machining at the nanoscale utilizing the fs-UV interference method

Dominyka Stonyte[1,*], Darius Gailevicius[1], Tadas Latvys[1], and Domas Paipulas[1]

[1] Laser Research Center, Faculty of Physics, Vilnius University, Sauletekio av. 10, LT-10223 Vilnius, Lithuania

[*]Corresponding author email: dominyka.stonyte@ff.vu.lt

Recent industrial-grade systems now allow for ultrashort, high-intensity femtosecond laser pulses in the UV spectral domain, enhancing micro processing with unprecedented precision and efficiency. Shorter pulses minimize heat affected zones (HAZ), ensuring superior ablation quality compared to longer pulses. This UV shift offers advantages over traditional IR or visible spectrum approaches [1]. While current interference research often uses longer nanosecond/picosecond pulses [2], shorter pulses promise improved precision in large-area surface patterning. Traditional lithographic techniques with dry etching offer limited etch rates for materials like sapphire or yttrium aluminum garnet (YAG) [3], while focused ion beam milling is slow for nanoscale features [4]. Multiphoton femtosecond-IR processing suits microscale features but achieving sub-micron precision requires linear absorption. Femtosecond-UV interference patterning emerges as a promising solution, addressing control and throughput challenges for such materials.

Therefore, we present our findings regarding two-beam interference patterning of silicon and selected optical materials. We showcase a straightforward process for creating homogeneous gratings with nanoscale sizes on centimeter-scaled areas. Further etching of these gratings in a 1% KOH solution led to a tenfold increase in structure height. The main challenge lies in managing the pulsed nature of the beams; hence, we discuss pulse delay and spatial overlap, which are sensitive to alignment. Our focus centers on fabricating harmonic gratings with periods ranging from Λ = 600-700 nm using the third (343 nm) and fourth (257.5 nm) harmonics of an amplified Yb:KGW laser system, providing pulse durations of 240 fs at a repetition rate of 100 kHz. The results were obtained with compact classical Talbot approach (Fig. 1).

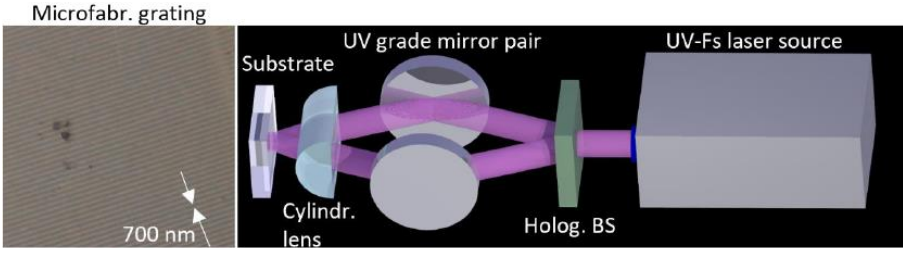

Fig. 1: Example of fabricated surface relief grating and one of the used (Talbot) configurations.

References: [1] D. M. Karnakis, M. R. H. Knowles, K. T. Alty, M. Schlaf, H. V. Snelling, Comparison of glass processing using high-repetition femtosecond (800 nm) and UV (255 nm) nanosecond pulsed lasers, Proc. SPIE 5718, Microfluidics, BioMEMS, and Medical Microsystems III, (22 January 2005); [2] B. Henriques, D. Fabris, B. Voisiat, A. R. Boccaccini, A. F. Lasagni, Direct Laser Interference Patterning of Zirconia Using Infra-Red Picosecond Pulsed Laser: Effect of Laser Processing Parameters on the Surface Topography and Microstructure. Adv. Funct. Mater. 2024, 34, 2307894; [3] D. S. Hobbs, B. D. MacLeod, E. Sabatino III, T. M. Hartnett, and R. L. Gentilman, Laser damage resistant anti-reflection microstructures in Raytheon ceramic YAG, sapphire, ALON, and quartz, in Window and Dome Technologies and Materials XII, R. W. Tustison, ed. (2011), 8016, p. 80160T; [4] Q. Wen, X. Wei, F. Jiang, J. Lu, and X. Xu, "Focused Ion Beam Milling of Single-Crystal Sapphire with A-, C-, and M-Orientations,"
Materials 13(12), 2871 (2020).