Large area mask writing with fs-laser pulses

Saulius Juodkazis[1,*], Tomas Katkus[1], Soon Hock Ng[1], Haoran Mu[1], Nguyen Hoai An[1], Dominyka Stonytė[2], Yoshiaki Nishijima[3], Justas Baltrukonis[4], Orestas Ulčinas[4], Mindaugas Mikutis[4], Vytautas Sabonis[4]

[1]Optical Sciences Centre, ARC Training Centre in Surface Engineering for Advanced Materials (SEAM), Swinburne University of Technology, Hawthorn, Victoria 3122, Australia
[2]Laser Research Center, Vilnius University, Saulėtekio Ave. 10, 10223 Vilnius, Lithuania
[3]Department of Electrical and Computer Engineering, Graduate School of Engineering, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama, 240-8501, Japan
[4]Altechna R&D, Mokslininku str. 6A, 08412 Vilnius, Lithuania

*Corresponding author email: sjuodkazis@swin.edu.au

Large surface area applications such as high-efficiency > 26% solar cells require surface patterning with 1-3 µm periodic patterns at high fidelity fabrication over 1-10 cm^2 areas. Next target is scaling up such laser patterning to the solar panel size ~2 m^2. The ultimate goal to approach the one-junction one-Sun Shockley–Queisser limit requires to exceed the Lambertian (ray optics) limit of light trapping [1]. The current quality of Si, its passivation and maturity of technology to make electrodes with minimal losses allow to approach ~29% efficiency in theory, which could be surpassed if a more efficient light trapping and charge collection can be realized. We developed electron beam lithography (EBL) based patterning for the photonic crystal (PhC) light trapping [1], which surpasses the Lambertian limit. However, for a more practical large-area patterning we introduced stepper-based lithography and laser writing using Gaussian laser beam for the definition of etch masks [2]. The PhC light trapping using mask ablation on actual solar cells with contactless front surface [3] showed an enhancement of light trapping by 2% at the efficiency of 23.1% [4]. Here we show a pathway to high-resolution sub-1 µm etch mask patterning by ablation using the direct femtosecond (fs-)laser writing performed at room conditions without the need for a vacuum-based lithography approach. The Bessel beam was used to alleviate the required high tolerance of surface tracking for ablation of 0.3-0.8 µm diameter holes in ~40 nm alumina Al_2O_3-mask at a high writing speed 7.5 cm/s. The patterning rate was 1 cm^2 per 20 min. Plasma etching protocol was optimised for a zero-mesa formation of PhC trapping structures and smooth surfaces at nanoscale level. Scaling up in area and throughput of the demonstrated approach is outlined.

Acknowledgements: We acknowledge the support via ARC DP190103284 "Photonic crystals: the key to breaking the silicon-solar cell efficiency barrier".

References:

[1] M.-L. Hsieh, A. Kaiser, S. Bhattacharya, S. John, and S.- Y. Lin, Experimental demonstration of broadband solar absorption beyond the Lambertian limit in certain thin Silicon photonic crystals, Scientific Reports 10, 11857 (2020).
[2] J. Maksimovic et al., Beyond Lambertian light trapping for large-area Silicon solar cells: fabrication methods, Opto-Electron Adv 5, 210086 (2022).
[3] F. Haase et al., Laser contact openings for local poly-si-metal contacts enabling 26.1%-efficient POLO-IBC solar cells, Solar Energy Materials and Solar Cells 186, 184 (2018).
[4] M. Rienäcker et al. , Integration of photonic crystals in highly efficient POLO^2-IBC cells - interplay between structural, optical, and electrical properties, 13th Int. Conf. on Crystalline Silicon Photovoltaics (Delft, Netherlands, 2023) SiliconPV April 11-14 2023.