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Supplementary information

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Large-area straight, regular periodic surface structures produced on fused silica by the interference of two femtosecond laser beams through cylindrical lens

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Section 1: Simulation of the distribution of light field on the structured surface of fused silica

Nanostructures on fused silica surface and the numerical simulation of light field

Figure S1 presents the schematic of the nanostructures on fused silica surface and the incident light in the numerical simulation with COMSOL multiphysics software (COMSOL 4.4.0.150)[1–4]. The simulation field is 15 × 5 × 1.3 μm^3 in volume, where three layers of air (1.0 μm), fused silica in the excited state (0.1 μm) and in the ground state (0.2 μm) are enclosed. A plane wave of 800 nm light illuminates vertically on the fused silica surface, as shown as the red square plane (incident plane). There are three parallel nanogrooves with a cross section of 0.1 × 0.1 μm^2 in the surface layer of excited fused silica. The two boundaries perpendicular to the nanogrooves are set as periodic boundary conditions (PBC boundary), and the two parallel to the nanogrooves are set as perfect electric conductor (PEC boundary). The upper and lower boundaries parallel to the fused silica surface are set as the scattering boundaries (SBC boundary)[2–4]. The element size was set as cubic with a size 10 nm in the numerical calculations.

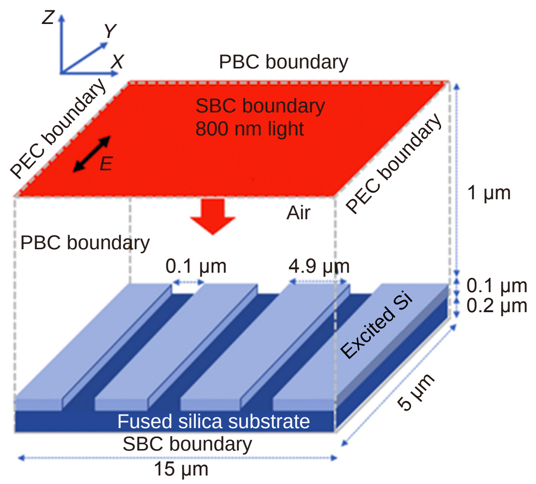

Fig. S1 | Schematic of the nanostructures on fused silica surface and the incident light in the numerical simulation with COMSOL multiphysics software. The arrow ***E*** shows the laser polarization.

Simulated light field distributions on the structured surfaces induced by single beam and TBI

During LIPSSs processing, laser ablation is always accompanied by the generation of a large amount of debris and surface defects, which greatly affects the distribution of light field and the interference between the incident fs laser and the scattering light. Broken and curved LIPSSs formed on the sample surface, especially after the irradiation of the initial several laser pulses, as shown in Fig. S2(a). These effects are clearly illustrated by the simulation results with COMSOL multiphysics software, as shown in Fig. S2(b), where four nanopits with size of 0.1 × 0.1 × 0.1 μm^3 act as the surface defects. The dielectric constant in the excited state was taken as 1.35 + 1.6i, and it is 1.45 + i0 in the ground state for 800 nm light[5,6]. These scattering lights interfere constructively or destructively with each other. The pattern of light field is very irregular, which accords well with the results in Fig. S2(b). Moreover, the intensity ratio of the adjacent peak and the dip is very low, only 1.45 on average.

As is shown in Fig. S2(c), LSFLs are very regular and straight processed by TBI on fused silica after irradiation of 5 laser pulses with a fluence of 2.8 J/cm^2. Figure S2(d) shows the distribution of the light field simulated with COMSOL multiphysics software, where the dielectric constant in the excited state was taken as 1.35 + i1.6, and it is 1.45 + i0 in the ground state for 800 nm light. When the distance of adjacent nanogrooves was set as 5.0 μm, the interference between the incident laser and the scattering light is constructive. The local light intensity at the peak increase significantly to 1.88 and decreases to 0.13 at the dip, and the ratio enhances to 14.5 : 1. Moreover, the interference between the incident laser and the scattering light outside the three nanogrooves is also constructive. The peak intensity increases to 1.82 on average, and the dip intensity reduces to 0.12. The ratio is as large as 15.2 : 1 on an average. The peak and dip intensities inside and outside the nanogrooves are nearly equal, which is beneficial in addressing the problem of inhomogeneity originating from the interference pattern of the light field. The TBI is expected to produce homogeneous LSFLs.

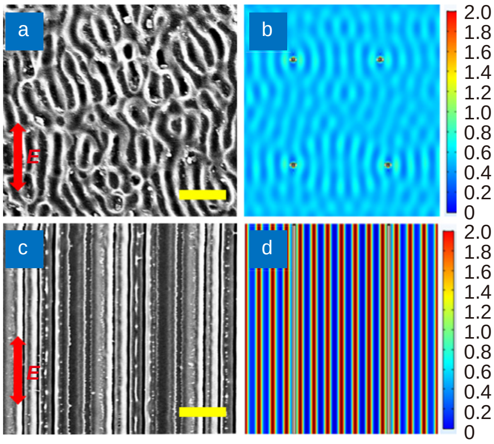

Fig. S2 | (**a**) LIPSSs processed with a cylindrical lens on fused silica after irradiation of 10 laser pulses with a fluence of 2.8 J/cm^2. The arrow E is the laser polarization. (**b**) Light field distribution on the surface of fused silica with 4 nanopits. The scale bar of light intensity is on the right side, where the incident light intensity is set as 1. (**c**) LIPSSs processed by TBI on fused silica after irradiation of 5 laser pulses with a fluence of 2.8 J/cm^2. (**d**) Light field distribution on the surface of fused silica in the excited state with two parallel nanogrooves at a distance of 5.0 μm.

References

1. Xia YJ, Zhao H, Zheng CJ, Zhang SA, Feng DH et al. Selective excitation on tip-enhanced Raman spectroscopy by pulse shaping femtosecond laser. *Plasmonics* **14**, 523–531 (2019).
2. Kluczyk K, David C, Jacak J, Jacak W. On modeling of Plasmon-induced enhancement of the efficiency of solar cells modified by metallic Nano-particles. *Nanomaterials* **9**, 3 (2019).
3. Mu HW, Xu WJ, Xu CH, Lv JW, Liu W et al. Dual-band unidirectional forward scattering of Au–Si sliced nanorod in the visible region. *Appl Phys A* **125**, 388 (2019).
4. Xia YJ, Zhao H, Zhang SA, Feng DH, Sun ZR et al. Selective excitation of one among the three peaks of tip‐enhanced Raman spectroscopy by a shaped ultrafast laser pulse. *J Raman Spectrosc* **51**, 461–475 (2020).
5. Höhm S, Rosenfeld A, Krüger J, Bonse J. Femtosecond laser-induced periodic surface structures on silica. *J Appl Phys* **112**, 014901 (2012).
6. Fang Z, Zhao YA, Shao JD. Femtosecond laser-induced periodic surface structure on fused silica surface. *Optik* **127**, 1171–1175 (2016).