Opto-Electronic
Advances

Supplementary information
January 2024, Vol. 7, No. 1

DOI: 10.29026/oea.2024.230033

Non-volatile dynamically switchable color display via chalcogenide stepwise cavity resonators

Kuan Liu[1]†, Zhenyuan Lin[3], Bing Han[1], Minghui Hong[2]* and Tun Cao[1]†*

[1]School of Optoelectronic Engineering and Instrumentation Science, Dalian University of Technology, Dalian 116024, China; [2]Pen-Tung Sah Institute of Micro-Nano Science and Technology, Xiamen University, Xiamen 361102, China; [3]Department of Electrical and Computer Engineering, National University of Singapore, 4 Engineering Drive 3, Singapore 117576, Singapore.

†These authors contributed equally to this work.

*Correspondence: MH Hong, E-mail: elehmh@xmu.edu.cn; T Cao, E-mail: caotun1806@dlut.edu.cn

Supplementary information for this paper is available at https://doi.org/10.29026/oea.2024.230033

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License.
To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

© The Author(s) 2024. Published by Institute of Optics and Electronics, Chinese Academy of Sciences.

In Fig. S1(a), we schematically present the experimental setup of non-contact microsphere femtosecond laser irradiation. A microsphere is used to focus the high repetition rate fs laser (Mira 900 of Coherent, Inc., 800 nm, 76 MHz) via the objective lens (10×, 0.26 NA). The laser fluence can be tuned by an isolator and half-wave plate. A lens holder can fix the soda-lime glass microsphere with a radius of ~27 μm (SLGMS, Cospheric) and is lined up to a microscope system. The device is placed on a three-dimensional nano-stage with a maximum speed of 5 mm/s, a minimum moving accuracy of 10 nm, and a traveling range of 20 mm (FS-3200P-WE2 series, OptoSigma). An in-house code is programmed to automatically move the nano-stage. The working distance is experimentally observed from top and side views using two charge-coupled devices and a long working distance objective lens. The side view of the experimental setup is presented in the zoom-in picture. The focal length is ~35 μm, which includes a working distance of ~8 μm and a microsphere radius of ~27 μm. This focal length is about 44 times larger than the laser wavelength of $\lambda = 0.8$ μm. Thus, the fs laser irradiation integrated with the microsphere operates in an optical far field, where a significant ablation depth can be obtained[S1–S3] . Note that, near-field fs laser writing mainly demands a smooth target surface because of its short working distance. As the sub-50 nm ablation relied upon near field effect is caused by the generation of evanescent waves and the ablated depth is less than 10 nm[S4,S5]. Thus, the far-field fs laser fabrication has the advantage of a longer working distance over the near-field. By lifting up the microsphere, random surface patterning can be realized using the programming movement of the nano-stage. To explore the possibility of printing with a sub-diffraction resolution, nano-line arrays with different gaps and profiles are patterned on the Sb_2S_3 film surface. At the scanning speed of 100 μm/s and laser fluence of 0.42 mJ/cm^2, the Sb_2S_3 film is ablated obviously and a sub-50 nm nano-line is created. Figure S1(b) shows the SEM images of the sub-50 nm line structures realized on the 30 nm thick Sb_2S_3 film, where we have written a series of irregular nano-lines at the linewidth of sub-50 nm, and the spaces from 100 to 400 nm are achieved. The creation of these nano-lines indicates the microsphere femtosecond laser irradiation is able to realize desirable nanostructures and make high-performance optical devices.

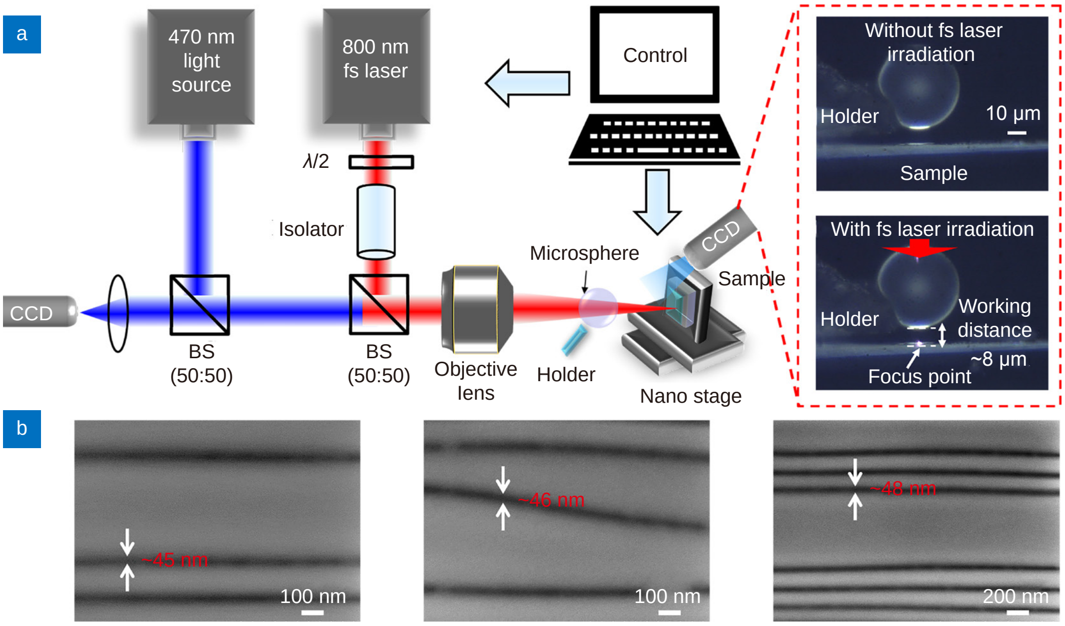


Fig. S1 | (**a**) Scheme of non-contact microsphere fs-laser setup. Inset: side view of microsphere focusing of fs-laser beam. (**b**) Various types of super-resolution nano-lines are formed by microsphere fs laser irradiation on 30 nm-thick Sb_2S_3 layers residing on the Si substrate.

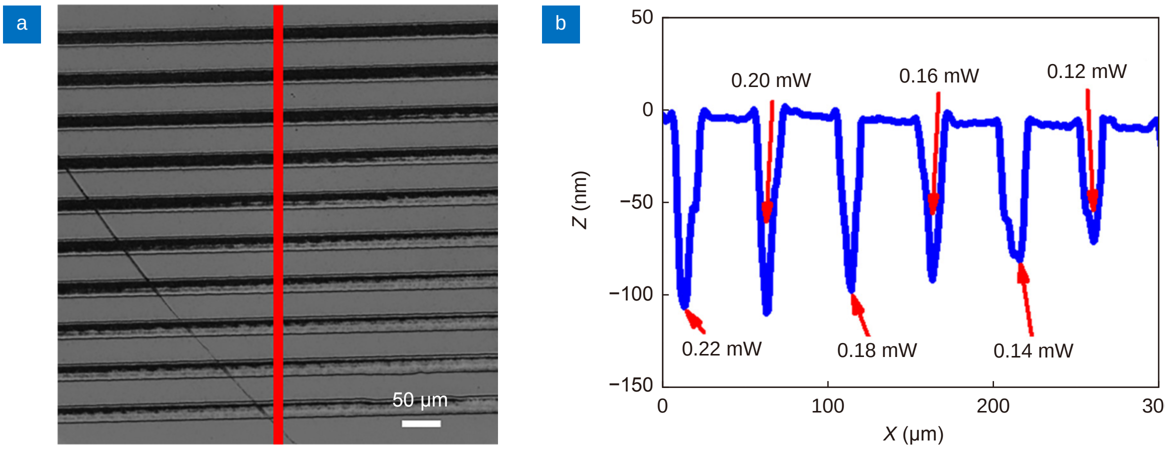
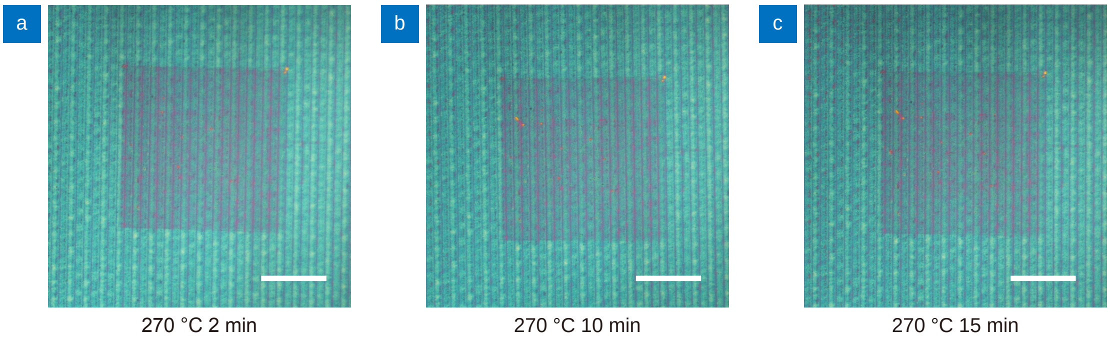


Fig. S2 | (**a**) Optical microscope image and (**b**) corresponding cross-sectional profile of the nano-structures created on Sb_2S_3 thin film at a laser power of 0.12~0.22 mW.

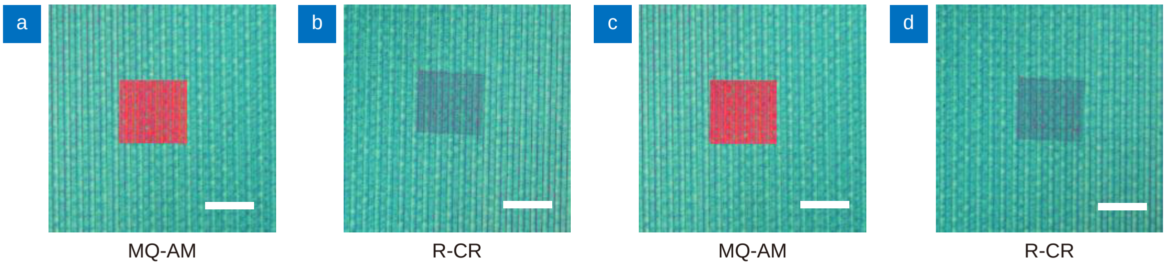


270 °C 2 min

270 °C 10 min

270 °C 15 min

Fig. S3 | The photo images of the R-CR strip (ii) in Fig. 1(c) at 270 °C for the various durations of (**a**) 2 min, (**b**) 10 min, and (**c**) 15 min. Scale bar is 100 μm.



MQ-AM

R-CR

MQ-AM

R-CR

Fig. S4 | The reversible color variation of the strip (ii) in Fig. 1(c) beween red (MQ-AM) and cyan (R-CR). Scale bar is 100 μm.

References

S1. Yan B, Yue LY, Monks JN et al. Superlensing plano-convex-microsphere (PCM) lens for direct laser nano-marking and beyond. *Opt Lett* **45**, 1168–1171 (2020).

S2. Chen LW, Zhou Y, Li Y et al. Microsphere enhanced optical imaging and patterning: from physics to applications. *Appl Phys Rev* **6**, 021304 (2019).

S3. Chen L W, Zhou Y, Wu M X et al. Remote-mode microsphere nano-imaging: new boundaries for optical microscopes. *Opto-Electron Adv* **1**, 170001 (2018).

S4. Lin Y, Hong MH, Wang WJ et al. Sub-30 nm lithography with near-field scanning optical microscope combined with femtosecond laser. *Appl Phys A* **80**, 461–465 (2005).

S5. Chimmalgi A, Choi T, Grigoropoulos CP et al. Femtosecond laser aperturless near-field nanomachining of metals assisted by scanning probe microscopy. *Appl Phys Lett* **82**, 1146–1148 (2003).