The Grayscale Nanoassemble Fabrication and ultra-realistic imaging of Height Gradient Nanostructures

Ruhao Pan and Junjie Li
Beijing National Laboratory for Condensed Matter physics, Institute of Physics, Chinese Academy of Sciences, Beijing, 100190, China
E-mail: jjli@iphy.ac.cn

Nanostructures with multi degrees of freedom show great applications prospects in many fields like optical components and electric devices and have attracted wide interests. The height gradient as a controllable degree that is indispensable besides the degree of freedom along the x- and y-axis, is conducive to the functional innovation of nanodevices[1,2]. However, the z-direction can hardly be changed simultaneously limited by the state of art. Although there are 3D print methods have been proved to have the capacity of buildup nanostructures with controllable height, the processing speed, material universality of the structures can hardly be simultaneously achieved [3,4]. A high-efficiency and precise method based on the plane fabrication arts for height gradient structures is very desired.

Here, a grayscale assembled nanofabrication (GANF) method is developed, which is suitable for the large area fabrication of high aspect ratio nano-configurations with height gradient. The e-beam lithography and atomic layer deposition (ALD) are the most critical steps in the GANF method, where the e-beam grayscale lithography can be used to fabricate height gradient template, whereas the ALD can ensure that the template can be fully filled by its great sidewall coating ability. As shown in Figure 1a and 1b, the height and the shapes of the nano-configurations can be precisely controlled by the EBL. Figure 1c further demonstrates a series of height gradient nanostructures, including nanopillars, nanotubes, and nanocones, with simultaneously changed height, width and the length, showing that the GANF method will add a new controllable degree of freedom to the nanostructures to improve its properties. A grayscale image was fabricated by an array of nanopillars with different heights, in which one single nanopillar indicates to a pixel and the height orders defines the 256 gray levels, and the resolution of the grayscale image reaches 6.4×10^{10} dpi (Figure 2a). Besides, thanks to the multidimensional controllable degrees of nanostructures fabricated by the GANF method, a structural color metasurface have been designed and experimentally demonstrated. The metasurface can tune the color HSB independently, and Figure 2b shows the optical microscope image and the enlarged SEM image of a water lily.

The GANF method achieves arbitrary structure control in Z direction and X-Y direction simultaneously, which will provide more possibilities for complex configurations and arrangements of 3D nanostructures and its arrays. Tunable height gives a fresh regulated approach for high-quality nanoscale imaging. The newly developed grayscale nanofabrication method opens a new horizon to design and achieve diversified optical metasurface and optoelectronic components with higher performance and smaller footprint.

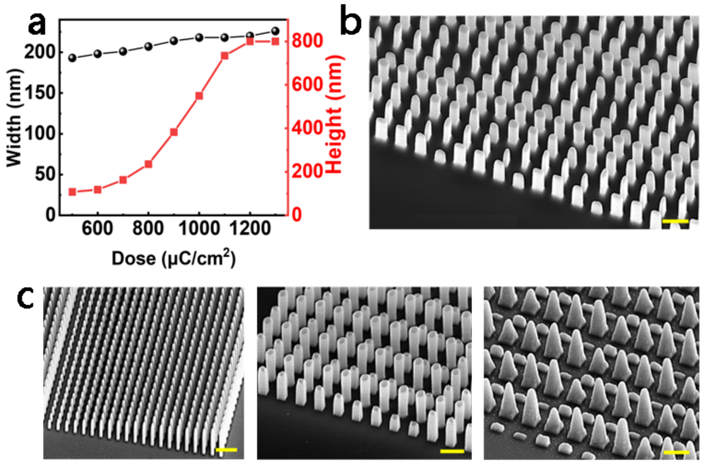

Figure 1 (a) Height and width of 200 nm nanopillar as a function of the exposure dose; (b) Typical SEM images of TiO_2 nanopillars with periodically changing height with different shapes and arrangements; (c) SEM images of height gradient nanorods, nanotubes, and nanocones. Scale bar: (b) 100nm; (c) 1μm

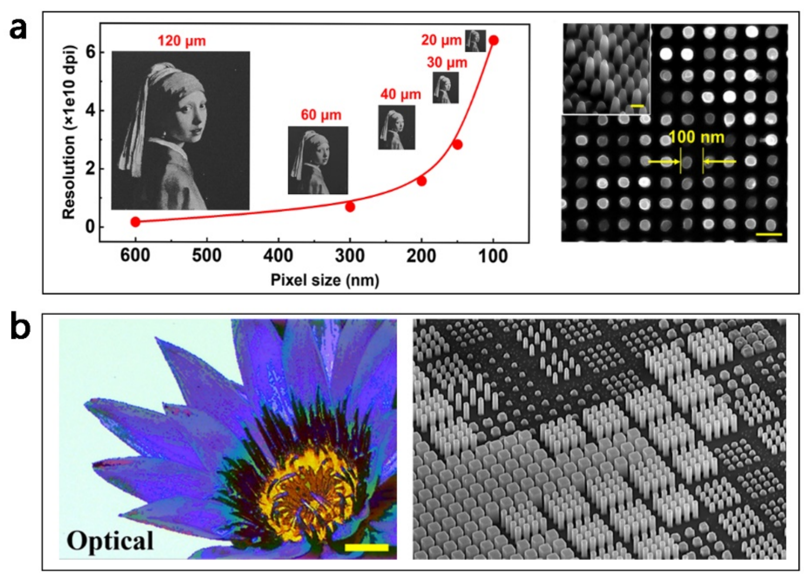

Figure 2 (a) Grayscale and (b) structural color image based on height gradient structures.

References

[1] Z. Wang, L. Jing, K. Yao, Y. Yang, B. Zheng, C. M. Soukoulis, H. Chen, and Y. Liu, Adv. Mater. **29**, 1700412 (2017).

[2] N. Liu, H. Guo, L. Fu, S. Kaiser, H. Schweizer, and H. Giessen, Nat Mater **7**, 31 (2008).

[3] J. Hengsteler, B. Mandal, C. van Nisselroy, G. P. S. Lau, T. Schlotter, T. Zambelli, and D. Momotenko, Nano Lett. **21**, 9093 (2021).

[4] M. Esposito, V. Tasco, M. Cuscunà, F. Todisco, A. Benedetti, I. Tarantini, M. D. Giorgi, D. Sanvitto, and A. Passaseo, ACS Photonics **2**, 105 (2014).