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Nano-Imaging with TiO_2 Superlenses: A Comparative Study of Design Variants

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Abstract: We evaluate and compare the super-resolution imaging performances of different TiO_2 superlens designs (hemisphere, super-hemisphere, and full spheres) in wide-field and confocal modes. Our findings are important for many super-resolution applications.

1. Introduction

Microsphere-based super-resolution imaging has emerged as a simple yet effective method to overcome the diffraction limit that limits the resolution of conventional lenses. Significant progress has been made in the past decade including the development of scanning superlens, bio-superlens and TiO_2 metamaterial solid immersion lens (i.e., TiO_2 superlens). Compared to widely used $BaTiO_3$ (BTG), Polystyrene (PS) and SiO2 microsphere Superlenses, TiO_2 superlens made from densely packed TiO_2 nanoparticles offers higher quality super-resolution images with better imaging contrast and sharpness, and the potential for resolution down to 15 nm scale [1]. However, there lack of systematic research on its imaging performance for different design variants at present, including hemisphere, super-hemisphere, and full sphere designs. This work aims to provide the first experimental evidence on the direct comparison of their super-resolution imaging performance in all three designs under both wide-field and confocal imaging modes. Our work will lay down the foundation for the development of more advanced TiO_2 superlens which is important for super-resolution applications including imaging, sensing, and manufacturing.

2. Methodology

Three designs of TiO_2 were synthesized in this work: hemisphere, super-hemisphere, and full sphere. Figure 1 45illustrates the synthesis process. Two-steps centrifuge of 15-nm anataseTiO_2 nanoparticles aqueous suspension was used to remove uneven particles and obtain closely packed nanoparticle precipitate. And hexane and tetrachloroethylene with a volume ratio of 1:2 was used later as organic mixture. Subsequently, the precipitate was diluted with deionized water with weight ratio of 1:2 to form the suspension. The suspension is ready to be sprayed once the suspension is loaded in the airbrush and a thin layer of organic mixture was dropped on the surface of a chip. To control the fabricated structure, the thickness of the organic mixture layer should be increased to form hemisphere, super-hemisphere and sphere. This is because longer self-assembly time is required to form a higher height/width ratio superlens. The imaging performance of fabricated superlenses was then evaluated by Olympus DSX1000 wide-field microscope with a 40X lens (NA = 0.8) and OLS5100 confocal microscope with a 100X lens (NA = 0.95), respectively.

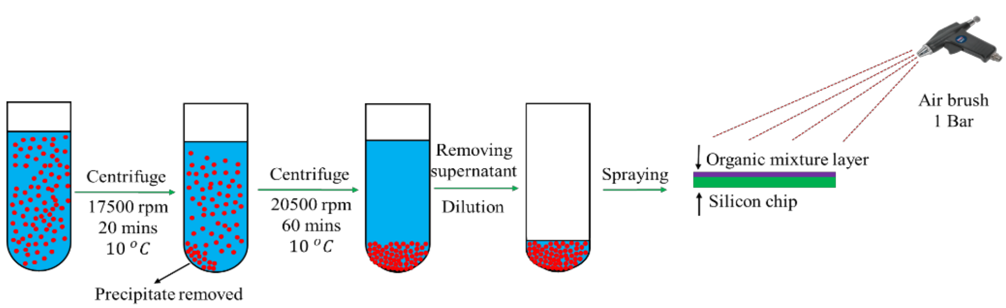

Fig. 1. Schematic illustration of the fabrication processes of TiO_2 superlens. The height/width ratio of the superlens is determined by the thickness of organic mixture layer.

3. Results

The comparison is depicted in Figure 2. The side view of the synthesised hemisphere, super-hemisphere and full sphere were illustrated in (a, d, g), along with the wide-field images (b, e, h) and confocal images (c, f, i) of the observed pattern through three superlenses. None of the optical microscopy images is capable of discerning the pattern with a gap down to 50 nm, and the super-hemisphere lens provides the highest contrast and the image observed. For confocal microscopy images, hemisphere, super-hemisphere and sphere TiO_2 superlenses provide magnification factors of 2.0, 4.7, and 3.0, respectively, the super-hemisphere and sphere lenses attain a resolution of 50 nm with the help of confocal microscope, however, although the confocal microscope is introduced, the pattern is still unable to be identified through hemisphere, as shown in Figure 2 (c).

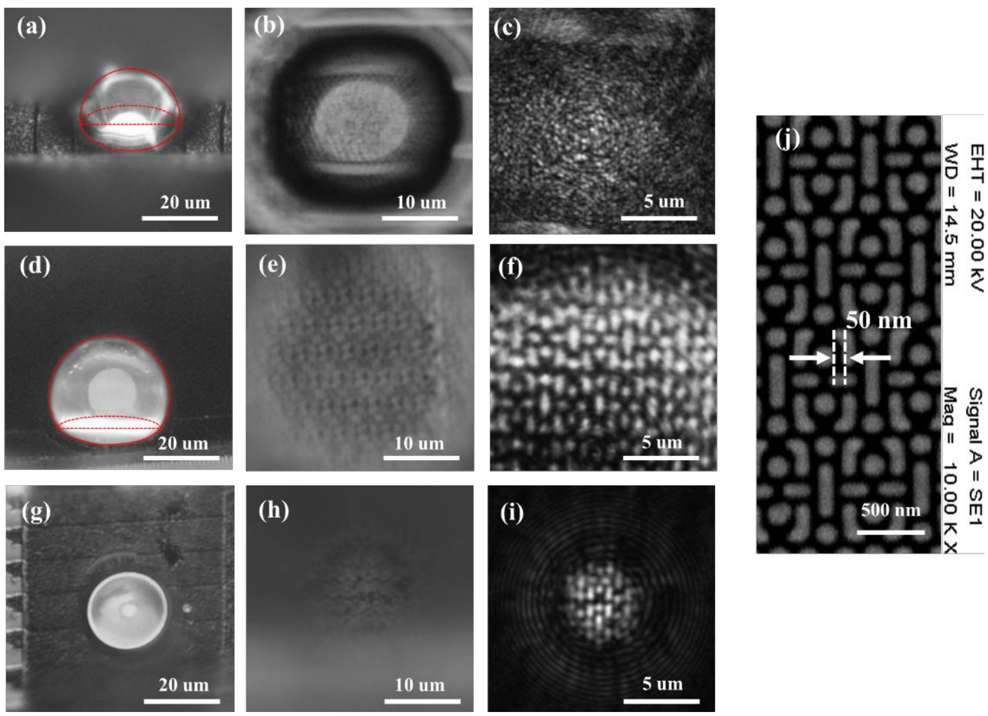

Fig. 2. The oblique view (at 60°) of the hemisphere, super-hemisphere and full sphere TiO_2 superlenses (a, d and g), the optical wide-field microscopy images of a pattern (SEM image shown in j) on chip observed through above 3 superlenses (b, e and h). (c), (f) and (i) are the corresponding confocal microscopy images with decreasing magnification factors of 2.0, 4.7 and 3.0. The outlines of the hemisphere and super-hemisphere are highlighted by red solid and dashed lines.

In conclusion, the super-hemisphere TiO_2 superlens shows the highest magnification factors (4.7) and best imaging contrast with a super-resolution of at least 50 nm and it is promising to achieve a higher resolution in conjunction with the confocal microscope. The application of hemisphere and sphere lenses is potentially limited due to their low magnification factor, resolution, and contrast, respectively.

4. Reference

[1] Z. Wang and B. S. Luk'yanchuk, "Super-resolution imaging and microscopy by dielectric particle-lenses,"in Label-Free Super-Resolution Microscopy, edited by V. Astratov (Springer Nature, 2019), Chap. 15, pp. 371–406.