Solid-Immersion Microsphere Superlens

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Abstract- In 2011, we demonstrated the first 50 nm resolution white-light nanoscope based on a microsphere superlens (*Nat. Commun. 2, 218, 2011*). In this paper, we present a new generation design of microsphere superlens: the Solid-Immersion Microsphere Superlens (SIMS), which features higher resolution and flexible maneuverability over the previous design. The SIMS enables high resolution (sub-50 nm scale) applications in imaging, sensing, detection, trapping and nanofabrication.

Conventional lenses have a limited resolution of approximately 200 nm in the visible band. A well-known solution to go beyond such a limit is to use a superlens, first proposed by Pendry[1]. A superlens uses a slab of negative index medium (NIM) to achieve "perfect imaging". However, the ideal NIM slab has never been produced and several downgraded versions of superlens were demonstrated using metal-based metamaterials. The best reported resolution is approximately 120 nm after a decade's effort, mainly limited by the intrinsic loss characteristics of metals[2].

The microsphere superlens is another potential solution to beat the conventional diffraction limit. These superlenses are purely dielectric, so naturally loss-free. The main factors affecting lens resolution are wavelength, micropshere geometry, and the refractive indexes of the sphere and the surrounding medium. Super-resolution is obtained via evanescent wave excitation in the near-field produced in the spheres. The super-resolution focusing will take place only in certain parameter windows, and it has to be carefully chosen (see Ref. [3] for suitable parameter window selection). An example is to use silica microspheres with diameters below 10 μm when working with visible light illumination. In 2011, we first demonstrated a 50 nm resolution nanoscope using a microsphere superlens[2]. The basic setup is very simple and is illustrated in Fig 1(a). The silica microbeads (diameter between 2 μm and 9 μm) were self-assembled on the sample surface and imaging was undertaken through the spheres. The silica superlenses magnify underlying objects and project the magnified virtual image into conventional lenses. Different samples have been directly imaged in high resolution without labeling, including adenoviruses, nano-gratings/lines and complex nanostructures. However, practical applications in microscopy require control over the positioning of the microspheres. One concept was suggested in Ref. [4], where movement of microsphere was carried out with a fine glass micropipette. In this paper, we suggest another concept to use high-index microspheres (TiO_2 or $BaTiO_3$) mounted into the solid immersed lens made from polymers or glass (Fig. 1b). The top curved surface in the design is used to reduce the effect

of total internal reflection from a flat surface. The advantages of this design include: (1) Spheres are reusable and the whole lens can be easily positioned and manipulated according to the user needs. (2) By attaching to a nano-stage, scanning operations are now possible. (3) Higher resolution can be achieved; this is because in this design the solid immersion mechanism contributes to the resolution enhancement, as the working wavelength in the near-field region is scaled down by a factor of *n*. As shown in Fig. 1d, lines with size 40 nm can be clearly imaged with the superlens and its contrast is superior to the previous superlens. Theoretical analysis also confirms the new design (Fig. 1b) has better resolution of *n* times that of the previous schemes suggested in Ref. 3 and 4 (Fig. 1a). The results presented here have been recently patented[5].

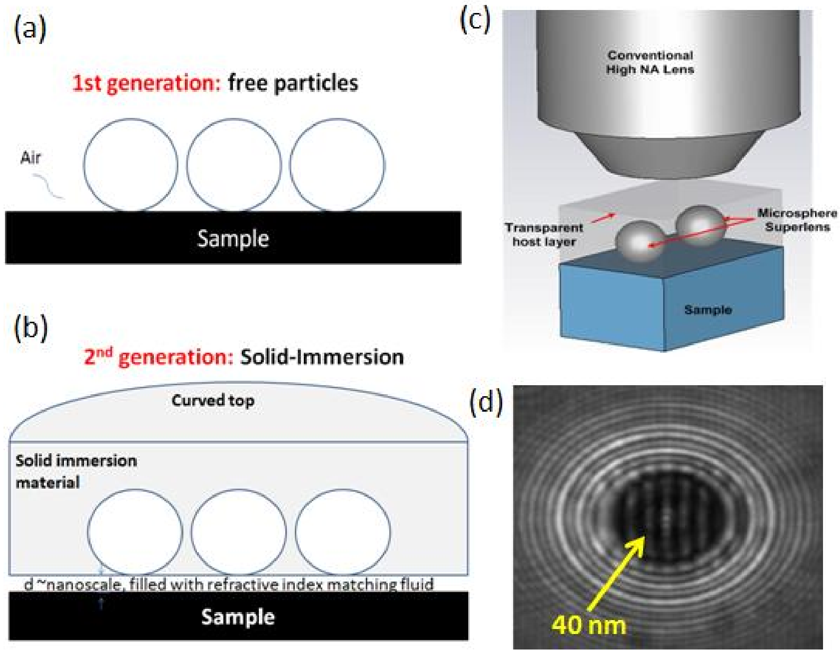

Fig.1 (a) 1st generation microsphere superlens, (b) new 2nd generation solid immersion microsphere superlens (SIMS), (c) configuration for nano-imaging and (d) 40-nm nanoline imaging.

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