

All-dielectric metamaterial superlenses: A new route to near-perfect lenses

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Our research centres on the development of dielectric superlenses and their super-resolution imaging applications. In recent years, we pioneered ‘microsphere superlens (2011)’[1], ‘spider silk superlens (2016)’[2] and ‘ TiO_2 nanoparticle-made metamaterial superlens (2016)’[3]. These techniques were widely publicized and able to deliver resolution between 45 and 100 nm under white light, well surpassing the classical half wavelength diffraction limit which is about 200-300 nm for white light. Of these developments we envisage the last one, the metamaterial superlens made from high-index TiO_2 nanoparticles ($n=2.55$) has the great potential to be further developed to realize a near-perfect optical superlens in visible band. This is because of its unique working principles. Based on full-wave EM simulation, we discovered that such high-index nanoparticle assembled metamaterial superlens can effectively convert evanescent waves into propagating waves travelling into the far-field (Fig. 1a). Using 15 nm TiO_2 as building block, hotspots are formed at gaps of nanoparticles, the field spot on substrate surface can realize a FWHM of about 8 nm (a near-perfect resolution), half the nanoparticle size. In such situation, the resolution is determined by particle size instead of wavelength, a case similar to the NSOM[4,5].

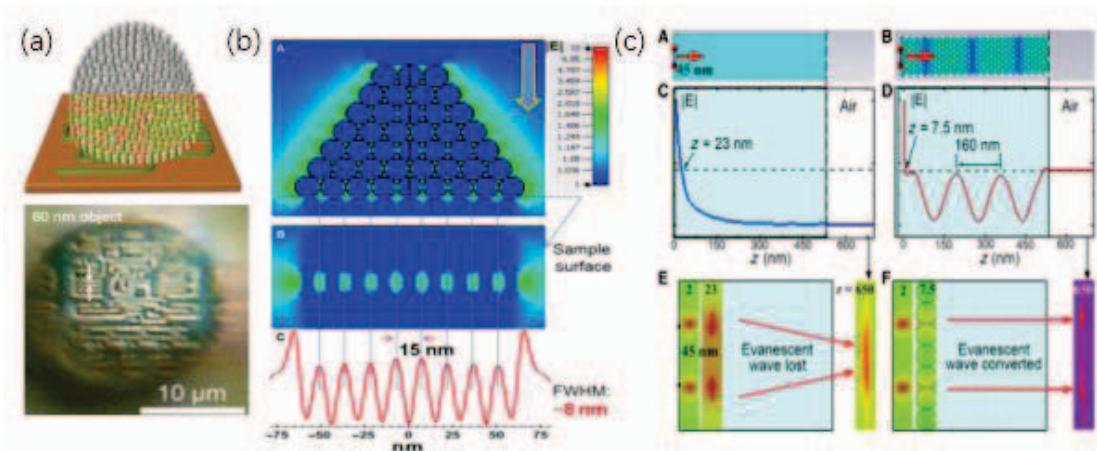


Fig. 1 (a) Concept of high-index nanoparticle made metamaterial superlens, and experimental evidence of super-resolution imaging of 60 nm objects. (b) Full wave simulation of light passing through densely packed particle stacks, noting spot on surface is controlled by particle size. (c) Inverse calculation, for two incoherent dipole source separated 45 nm. Conventional medium doesn't support evanescent wave collection (left panel) while nanoparticle medium causes conversion of evanescent wave into propagating waves. Such ability is unique and allows engineering of a near-perfect lens based on high-index material.

It is desirable to have a gap between nanoparticles and imaging substrate so that a scanning operation can be implemented [6]. But because evanescent waves decay rapidly for source we need consider to amplify them to accommodate the gap, one possible way is to adding plasmonic metal layer at bottom of dielectric superlens. Another proposal, as will show in our presentation, is to use a 4Pi-illumination, i.e. illumination by using two opposite-travelling coherent beams, to enhance the evanescent fields. The combination of 4Pi-illumination and nanoparticle metamaterial superlens could help create a near-perfect superlens with resolution on the order of 10-20 nm in visible band.

References

- [1] Z.B.Wang, W.Guo, L.Li, B.S.Luk'yanchuk, A.Khan, Z.Liu, Z.Chen and M.H.Hong, "Optical virtual imaging at 50 nm lateral resolution with a with-light nanoscope", *Nat. Commun.* **2**, 218 (2011).
- [2] J.N.Monks, B.Yan, N.Hawkins, F.Vollrath and Z.B.Wang, "Spider silk: Mother Nature's Bio-superlens", *Nano Lett.* **16**, 5842 (2016)
- [3] W.Fan, B.Yan, Z.B.Wang, L.Wu, "Three-dimensional all-dielectric metamaterial solid immersion lens for subwavelength imaging at visible frequencies", *Sci. Adv.* **2**, e1600901 (2016).
- [4] Z.B.Wang, "Microsphere super-resolution imaging", *Nanoscience*, **3**, 193 (2016).
- [5] L.Yue, B.Yan and Z.B.Wang, "Photonic nanojet of cylindrical metalens assembled by hexagonally arranged nanofibers for breaking the diffraction limit", *Opt. Lett.* **41**, 1336 (2016).
- [6] B.Yan, Z.B.Wang, A.Parker, Y.K.Lai, J.Thomas, L.Yue, J.N.Monks, "Superlensing microscope objective lens", arXiv: 1611.00077 (2016)