

# Fractional Talbot effect in a dielectric micro-spheres array

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**Abstract:** A hexagonal array of dielectric micro-spheres can work as diffraction-limited or super-resolution lens array. The fractional Talbot effect is obvious for those diffraction-limited foci, but is not well-defined for the super-resolution foci.

The Talbot effect [1] is one of the basic diffractive phenomena in Gaussian systems, which appears for periodic dielectric or plasmonic [2] structures with 1D or 2D periodicity when illuminated with a coherent wave source. The foci of a conventional half-ball-shaped microlens array (MLA) are in periodic arrangement and the foci are self-imaged in the Talbot planes and the number of the foci is multiplied in fractional Talbot planes [3]. Due to the better cavity resonance condition, spherical particles can generally produce higher level of intensity at foci with smaller spot size down to sub-wavelength scale (i.e., a super-resolution spot, coined as ‘photonic jets’ by Chen et al. in 2004 [4]), which is due to the presence of evanescent wave components in optical near-fields [5]. It is so far, however, not clear whether the classical Talbot effect is still valid for these small micro-spheres array system. To understand it, we have performed a full-wave numerical modelling based on Finite Difference in Time Domain (FDTD) method, with periodical boundaries applied to a hexagonal unit cell.

Figure 1 shows the calculated intensity field distribution with yz-plane around a hexagonal array of microspheres with different particle diameter  $d$  and refractive index  $n$ : (a)  $d=1.0\ \mu\text{m}$ ,  $n=1.46$ , (b)  $d=1.0\ \mu\text{m}$ ,  $n=2.40$ , (c)  $d=5.0\ \mu\text{m}$ ,  $n=1.46$ . The incident laser wavelength is  $\lambda=532\ \text{nm}$  and is linearly polarized along the x-direction [see Fig. 1. (d) for coordinates]. The foci spots in Fig. 1(a) and (b) are diffraction limited with a full width at half maximum (FWHM) of 480 and 400 nm respectively, which are larger than the half wavelength diffraction limit of  $\lambda/2=266\ \text{nm}$ . Super-Resolution foci were seen in Fig. 1(c) for 5.0  $\mu\text{m}$  diameter particle, where the foci FWHM is 200 nm. In this case, the intensity field at foci is greatly enhancement with a normalized enhancement factor of 150. These sub-wavelength foci array can be utilized for various application such as high-density data storage, high-resolution surface nano-patterning and nanoparticles detection and trapping.

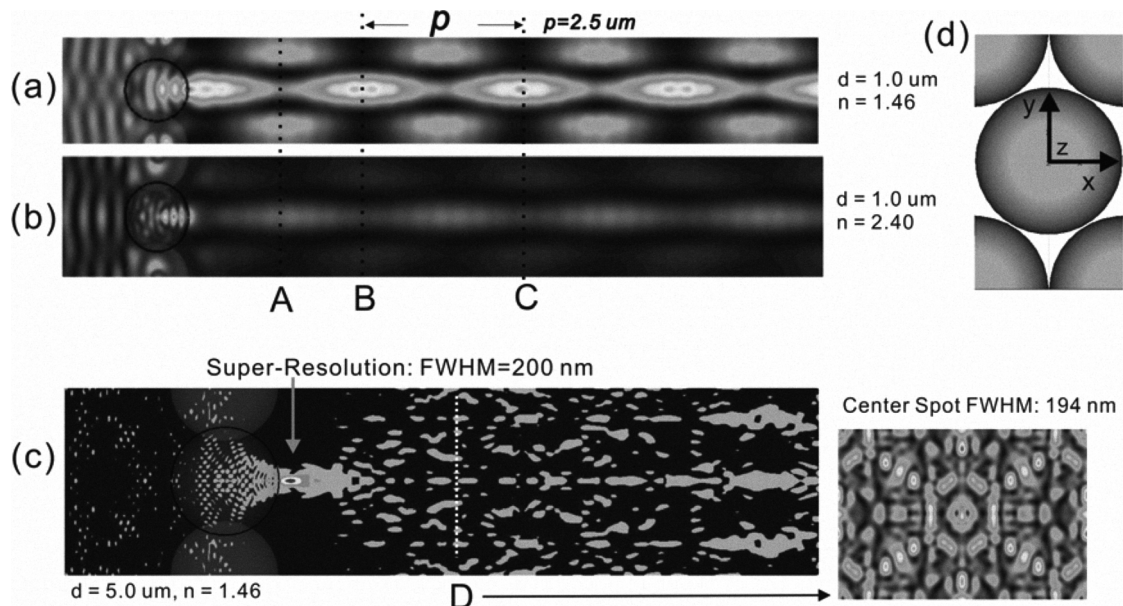


FIG.1 The intensity field distribution around a hexagonal array of microspheres with different diameter  $d$  and refractive index  $n$ , (a)  $d=1.0\ \mu\text{m}$ ,  $n=1.46$ , (b)  $d=1.0\ \mu\text{m}$ ,  $n=2.40$ , (c)  $d=5.0\ \mu\text{m}$ ,  $n=1.46$ . Fractional Talbot effect is clearly seen in (a) and (b). In (c) the effect is hardly to be seen. (d) is the top view drawing of the hexagonal unit cell for modelling. Periodic boundaries were applied.

Figure 1 also clearly shows that the foci of the diffraction-limited spots in Fig. 1 (a) and (b) are self-imaged and repeated at a distance of 2.5  $\mu\text{m}$ . This value is around 2/3 of the classical Talbot distance of  $Z_T = 2.d^2 / \lambda = 3.76\ \mu\text{m}$  for 1.0  $\mu\text{m}$  particle array under 532 nm laser illumination. It could be due to the fact that classical Talbot effect was formulated based on parabolic approximation. The fractional Talbot effect happens for half period distance at positions as marked with line A in Fig. (a). The number of foci is doubled which is in agreement the findings for conventional MLA as in Ref. [3]. Interestingly, when the particle refractive index changes from 1.46 (Fig. 1a) to 2.40 (Fig. 1b), there is a half period shift in the Talbot imaging by comparing Fig. 1(b) with Fig. 1(a). This phenomenon is new and has never been reported in MLA self-imaging studies. Unlike the cases in Fig. 1(a) & (b), the super-resolution foci for 5.0  $\mu\text{m}$  in Fig. 1(c) was not reproduced at a well-defined period and thus no clear Talbot effect can be observed. A caustic line was formed along the z-axis. Nevertheless, we still observed super-resolution spots in far-field with FWHM of around 194 nm within the cross sectional plane at a distance 10  $\mu\text{m}$  away from the super-resolution foci as in Fig. 1 (c). These far-field super-resolution spots could be related to optical super-oscillations [5]. Further theoretical and experimental investigations are in progress.

## References:

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