Scattering Lens Resolves Nanostructure

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Abstract

We demonstrate high-resolution focusing of visible light by a combination of scattering and active control of the incident wavefront. The resolution of the resulting lens is better than 100 nm.

1. Introduction

Scattering of light is usually seen as a nuisance in microscopy. Scattering limits the penetration depth and strongly deteriorates the achievable resolution. However, by gaining active spatial control over the optical wave front it is possible to manipulate the propagation of scattered light even far in the multiple scattering regime.[1-3] It was recently shown that in this way scattered light can even be exploited for perfect optical focussing.[4] These wave front shaping techniques pave the way for new high-resolution microscopy methods based on strong light scattering[5-9].

2. Focusing light by scattering

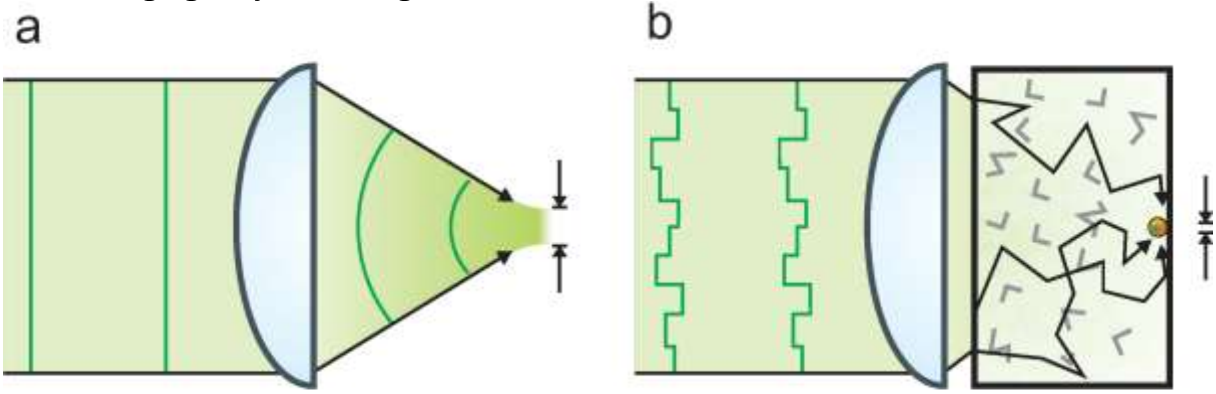

Fig. 1: (a) A normal lens has a restricted numerical aperture (NA), which limits the resolution with which it can focus light. (b) Scattered light can reach the target point from any angle, effectively covering full NA. The incident wave can be structured to force constructive interference at the target [1,2,4,10].

At first sight, opaque disordered materials such as paper, paint, and biological tissue are completely different from lenses and other clear optical elements. In disordered materials all information in the wave front seems to be lost due to multiple scattering. The propagation of light in such materials is described very successfully by a diffusion approach in which one discards phase information and considers only the intensity. However, as can be seen from the phenomenon of laser speckle, coherence is conserved as long as the scatterers are stationary, and in fact all scattering does is perform a linear transformation on the incident light modes [1,3]. By inverting this linear transformation, one can focus light or even project images through an opaque material [1,3,7] and even inside it [2], as illustrated in

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Fig. 1. Since the scatterers can subtend a much higher angle as seen from the focus, scattering can be exploited to form a focus that is smaller than the diffraction limit of the optics [4].

3. High resolution focusing

An extremely high resolution focus can be obtained using scatterers embedded in a high-index medium, where the diffraction limit for focusing is reduced by a factor *n*. We have constructed a scattering lens made of the high-index material Gallium Phosphide (GaP) which is transparent over most of the visible spectrum and has the highest index of all nonabsorbing materials in the visible range. A schematic of the scattering lens is shown in Fig. 2.

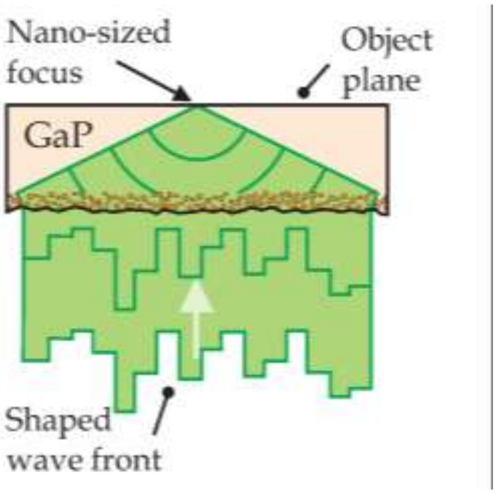

Fig. 2: Layout of a GaP scattering lens. The incident wavefront is shaped to that constructive interference is forced in a nano-sized focus in the flat object plane. The numerical aperture of the lens can in principle be increased up to the refractive index of the material.

The nano-sized focus is scanned in the object plane of the lens using memory-effect scanning [5,6,11,12]. A scan result is shown in Fig. 3, indicating an imaging resolution of better than 100 nm.

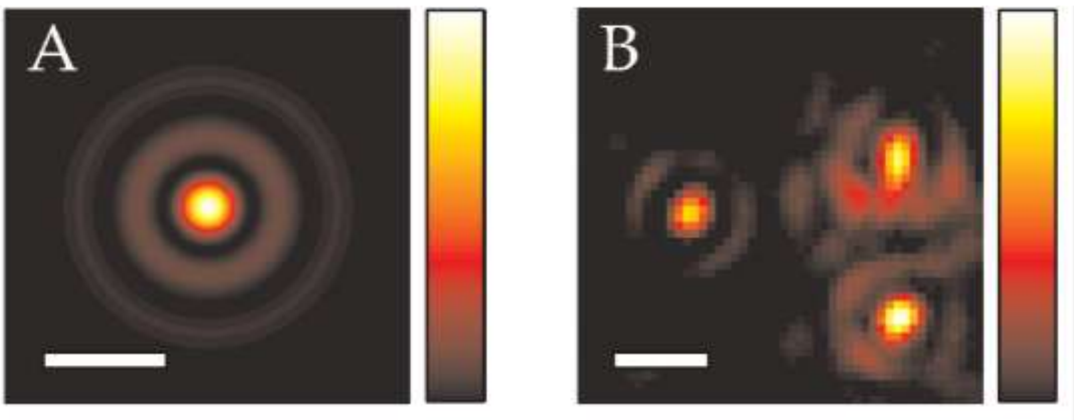

Fig. 3:(A) (A) The calculated intensity profile of the focus. Concentric rings appear due to structured non-Gaussian illumination of the scattering layer. (B) A collection of gold nanoparticles imaged with the GaP scattering lens. The image contains the scattering intensity as a function of the focus position. Due to the profile of the focus, sidelobes are visible around the nanoparticles. The scale bars represent 300 nm.

4. Conclusion

We demonstrate concentration of scattered light into a focus much smaller than the wavelength. Exploiting such a small focus, we demonstrate imaging of gold nanostructures through an opaque scattering layer. We obtained a very high resolution proving that scattering can significantly improve the image quality in microscopy.

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