

Isotropic Metal-Dielectric Composites for Subwavelength Imaging

Zs. Szabó^{*1} and Y. Kiasat²

¹Department of Broadband Infocommunication and Electromagnetic Theory, BUTE, Hungary

²Electronics and Photonics Department, IHPC, Singapore

*corresponding author: szabo@evt.bme.hu

Abstract- After reviewing the requirements, which has to be satisfied by a metamaterial based subwavelength imaging systems a thin films lens is reported herein. The material of the lens is a composite of spherical Ag nanoparticles embedded in SiO₂ host material. The image of the lens is calculated, by solving the Maxwell equations, with the Transfer Matrix method. The procedure applies Maxwell-Garnet mixing rule and high frequency effective medium theory to calculate the electromagnetic parameters of the composite material. The formula of the composite material, the optimum working frequency and the thicknesses of the layers are determined minimizing the absolute difference between the source and image. The details of the design procedure are presented and optimized configurations obtained under different constrains are discussed. The main advantage of the composite lens is that it can eliminate the ‘hotspots’ present in the images of metallic superlens.

One of the promises of metamaterial research is to produce near field lenses with a negative refractive index for optical subwavelength imaging [1]. However the metamaterial based imaging system will have a cutoff frequency due to unavoidable losses, and the finite size of the unit cell. An estimate based on the frequency domain analysis of the image formation and the Nyquist-Shannon sampling criteria indicate that 100 nm resolution requires unit cell sizes smaller than 20 nm (see Figure 1, where the highest spatial harmonic which is passed has a wavelength of 21.24 nm and the unit cell size of the metamaterial must be smaller than half of this length). At this unit cell size, it remains a challenge to fabricate the required negative magnetic response.

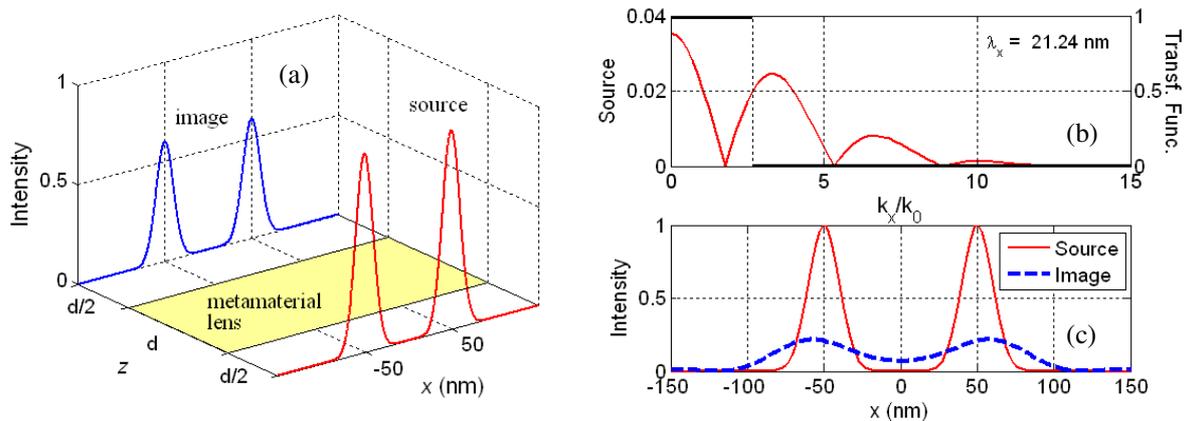


Figure 1 The image formation of the metamaterial based imaging system with a double Gaussian excitation, (a) the geometry of the system, (b) the Fourier transform of the source and the unit step transfer function of the imaging device, (c) the intensity distribution of the source and image.

For the special case of a transverse magnetic (TM) source, a thin film lens with negative electric permittivity is sufficient to produce subwavelength images [2]. However the surface imperfections of metallic thin film lenses can support localized surface plasmons, leading to ‘hotspots’ which can destroy the image. In this paper composite materials of small metallic inclusions in dielectric host are proposed to eliminate this fault.

The composite lens is made of spherical Ag nanoparticles immersed in SiO₂ host material. The average radius of the Ag spheres is 2 nm, therefore in the visible and near ultraviolet the dipole term of the Mie expansion is the dominant mode. The image of the composite lens is calculated with the transfer matrix method. The procedure can calculate the electromagnetic material parameters of the composite with the Maxwell-Garnet mixing rule or Mie theory based high frequency effective medium theory [3]. The design procedure invokes the differential evolution algorithm to minimize the error surface, which is the averaged absolute difference between the intensity distribution in the source and image plane. The procedure is employed to design single and multilayer composite thin film based imaging systems. In Figure 2 the transfer function and the image of a 30 nm thick composite lens immersed in SiO₂ with filling factor 0.5 and working frequency 0.79 PHz are presented. The source and image planes are at a distance of 15 nm in front and behind the lens. In Figure 2.a the transfer function of the lens (red) and the transfer function without the lens (black) are shown. Figure 2.b presents the source, the image calculated with the Maxwell-Garnett and Mie scattering based effective medium theory. For reference the image produced without the lens is presented as well.

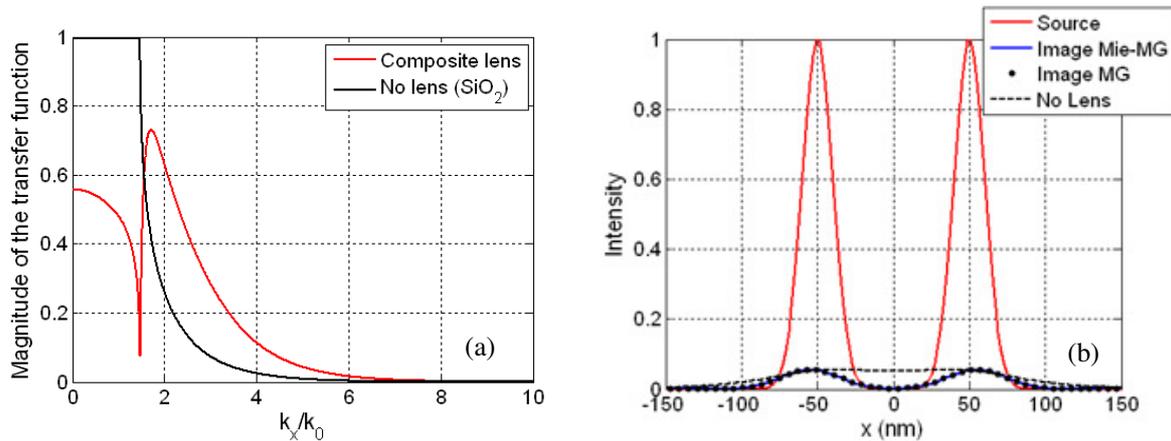


Figure 2 The transfer function of the imaging device (30 nm thick composite lens with filling factor 0.5 surrounded with 15 nm thick SiO₂, the working frequency is 0.79 PHz) and the transfer function without the lens are shown in (a). In (b) the source, the image calculated with the Maxwell-Garnett mixing rule, the image calculated with high frequency effective medium theory and the image without the lens are presented.

Acknowledgements This work has been supported by the New Hungary Development Plan TECH_08-D5/2-2008-0051 and by the New Széchenyi Plan TÁMOP-4.2.1/B-09/1/KMR-2010-0002.

REFERENCES

1. Cai, W. and V. Shalaev, *Optical Metamaterials: Fundamentals and Applications*, Springer, 2010.
2. Pendry, J. B. “Negative Refraction makes a perfect lens”, *Physical Review Letters*, Vol. 85, No. 18, 3966–3969, 2001.
3. Sihvola, A. *Electromagnetic Mixing Formulae and Applications*, The Institution of Engineering and Technology, 2000.