Broadband super-resolving lens with high transparency in the visible range

Giuseppe D'Aguanno, Mark J. Bloemer, Nadia Mattiucci, Michael Scalora, Neset Akozbek
Dept. of the Army, Charles M. Bowden Facility, Bldg. 7804 Research, Development, and Engineering Command, Redstone Arsenal, AL 35898
giuseppe.daguanno@us.army.mil

Since the introduction of the metallo-dielectric superlens [1] there have been numerous attempts to design structures with high transmittance for the evanescent waves [2]. However, very little has been said about the transmittance of the propagating waves and the bandwidth of the lens. Here we take a slightly different approach to the problem and start with a metallo-dielectric structure known to have broadband and high transmittance for the propagating waves and ask: "What are the transmission characteristics for the evanescent waves?" The structure we examine is a 1-dimensional metallo-dielectric photonic crystal (1-D MDPC) based on Ag/GaP. Here we compare 3 geometries, a Periodic MDPC [6 periods of Ag/Gap (22 nm/35 nm)], a Symmetric MDPC [5.5 periods of Ag/GaP (22 nm/35 nm)], and a Transparent Metal MDPC [5.5 periods of Ag/Gap (22 nm/35 nm) with 17 nm thick GaP antireflection (AR) coatings on the entrance and exit faces]. Fig.1 is a 3-D plot of the transmittance versus wavelength and k_x/k_0 (k_x is the transverse wavevector and k_0 is the wavevector in vacuo). To save space we plot the 3-D transmittance for the transparent metal MDPC and the periodic MDPC. The symmetric MDPC is only slightly better than the periodic MDPC. The notable feature in Fig. 1 is the broadband, high transmittance of the propagating and evanescent waves for the transparent metal MDPC. The five resonances associated with the five coupled cavities are clearly evident. It is surprising that the AR coatings can have such a drastic effect on the transmittance of the propagating and evanescent waves over a broad range of wavelengths. The super-lensing properties were examined by imaging 2 slits separated by less than $\lambda/2$ in free space. As an example, we look at a wavelength of 532 nm and compare all three MDPC. Fig. 2 shows the image formed by the three lenses and also the case of the transparent metal MDPC, but without evanescent components (diffraction limited). The slits (40 nm wide with a center to center spacing of 140 nm) are placed at the entrance of the lens (but in free space) and the image plane is located 50 nm beyond the end face of each lens. Images similar to those shown in Fig. 2 were calculated throughout the transparency band of the transparent metal lens. It was found that over the wavelength range of 500 nm to 650 nm, the transparent metal lens could resolve two 40 nm wide slits with a contrast >80% and slit separation of $<\lambda/2.5$ where lambda is the free space wavelength for the incident radiation. At most wavelengths, the slit separation was $\sim\lambda/4$. In addition, the transmittance for the normal incidence propagating waves was ~ 50% over the super-lensing band. Finally, the transparent metal approach is based on relatively thick metal films that can be fabricated by traditional deposition techniques.

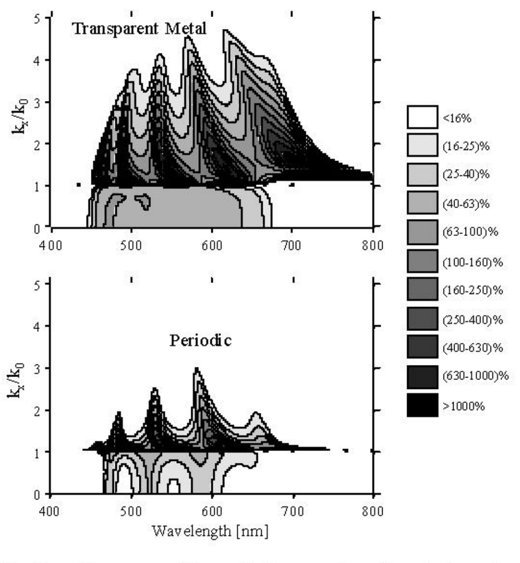

Fig.1: Topographic 3-dimensional plot of the transmittance versus wavelength and k_x/k_0 for the transparent metal MDPC and the Periodic MDPC.

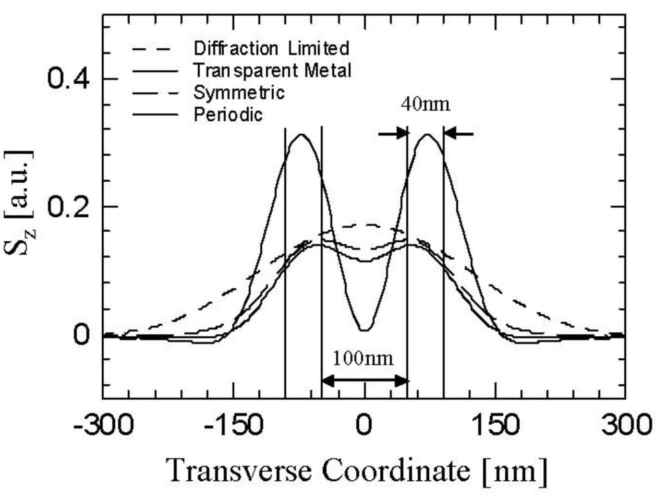

Fig.2: Image formed by the lenses for 2 slit sources at a wavelength of 532 nm. S_z is the component of the Poynting vector along z (propagation direction).

References:
1. S.A. Ramakrishna, J.B. Pendry, M.C.K. Wiltshire, W.J. Stewart, J. Mod. Opt. **50**, 1419 (2003)
2. H. Shin and S. Fan, Appl. Phys. Lett. **89**, 151102 (2006) and references therein