Investigation on Subwavelength Focusing Properties of Metal-Dielectric Multilayer

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Abstract

We present a planar multilayered structure composed of metal-dielectric layers which is capable to enhance the near-field at optical frequencies by adding contributions to the evanescent spectrum of the transmitted field, thus generating an electrically narrow field spot after the last interface. Numerical simulations have shown the possibility of achieving subwavelength resolution when using the proposed multilayer as a near field lens.

1. Introduction

In the last decade, a huge effort has been made in studying the properties and the feasibility of lenses which would break the classical lens resolution diffraction limit. In fact, it has been proposed in the literature that by using the so-called left-handed materials [1], [2] it is possible to improve the resolving power of the lens. Based on the above considerations, different types of structures have been proposed where the negative ϵ and μ have been achieved by periodic metallic structures, as in [3]. At the same time, studies about super-lenses by considering only negative dielectric permittivity have been performed. Due to their peculiar dispersion and anisotropy, metallic layers have been considered as suitable structures for enhanced near field lensing. Silver has been considered as a good candidate for plasmonic constituent because of its moderate losses at optical frequencies [2], [4]. Thin silver lenses have already been built and measured, thus proving sub-wavelength resolutions capabilities [5].

The resolution improvement provided by properly sized silver layers at optical frequencies is given by an effect of near-field enhancement which is mainly composed by the evanescent part of the spectrum of the field radiated by the source. The enhanced near-field on the opposite side of the lens thus adds a strong spectral contribution which is able to partially reconstruct the original spectrum of the source, hence the improved lens resolution. Recently, researchers have proposed different multilayers for sub-wavelength resolution where the metal is substituted by some metal-dielectric composite [6] which may suffer from high losses in the visible region of the spectrum, as mentioned in [7].

In this paper, we analyze a silver-silica multilayer for the near-field enhancement where the overall thickness is about half-wavelength, which exhibits good resolving power when used as a lens.

2. Near-Field Enhancement and Lens Resolution

The multilayer is composed of two layers of silica (SiO_2), whose relative dielectric permittivity was set to $2.15 - j2 \cdot 10^{-4}$, and two layers of silver, for a total thickness of $t = 130$ nm, as shown in Fig.

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1. For the silver relative dielectric constant a Drude dispersion model with $\epsilon_\infty = 5$, plasma angular frequency $\omega_p = 1.37 \cdot 10^{16}$ rad/s and collision frequency $\gamma = 27.3 \cdot 10^{12}$ s^-1 has been adopted [8]. The following simulations have been carried out by computation of the Green's function of multilayered

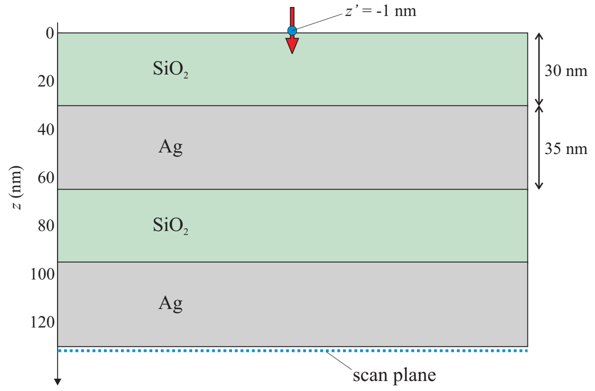


Fig. 1: Multilayer composed of 2 layers of silica (SiO_2) and 2 layers of silver (Ag). The blue spot is referred to the z-polarized point source location.

media which have infinite extension in the transverse direction. First, the near-field has been computed at an observation point located at $\mathbf{r}= (0, 0, t + 1\text{nm})$, for varying frequency. The source is an electric short dipole oriented along z with a unit dipole momentum, and located at $\mathbf{r}'= (0, 0, 1\text{nm})$. From Fig. 2a, we notice that the field enhancement, defined as the ratio between the field intensity with and without the multilayer, has three main peaks corresponding to the frequencies where most likely the multilayer may exhibit improved resolution properties. The next step has been the evaluation of the near field spot size, defined by the x coordinates where the field magnitude is reduced by one half. The simulations have been performed at 813 THz, corresponding to the first field peak, since at this frequency we noticed a remarkably narrow width of 46 nm $= 0.125\lambda$ in addition to the absence of side lobes, which is crucial for sharp imaging (Fig. 2b). In order to check the resolving power of the multilayer for lensing applications,

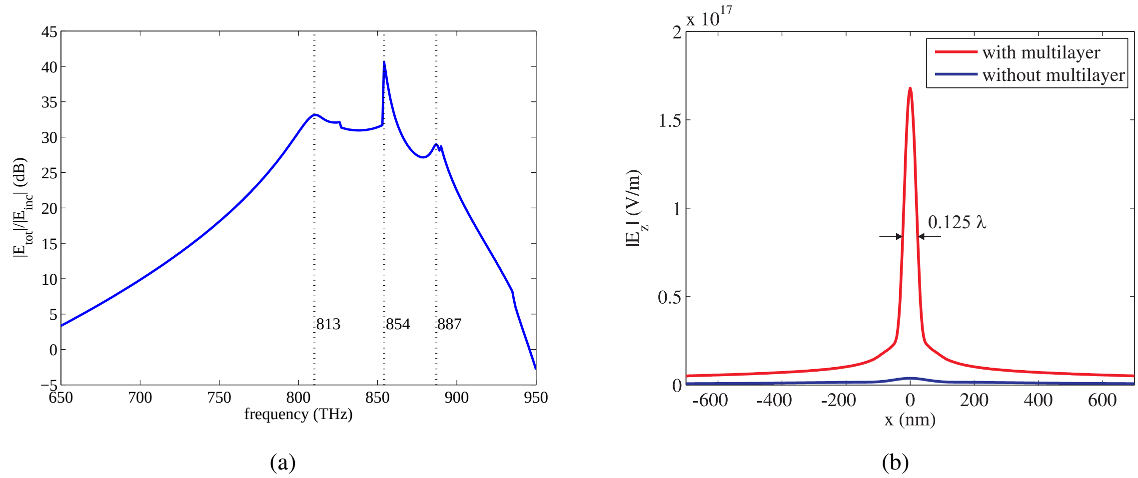
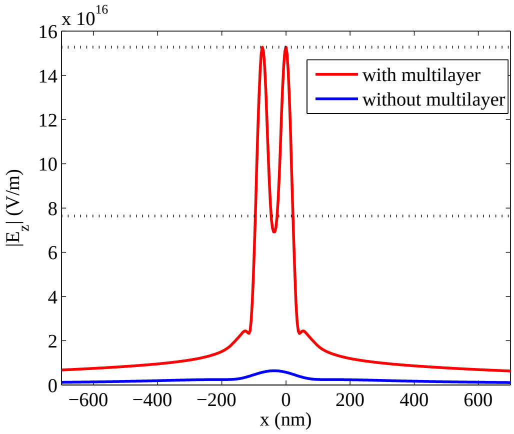
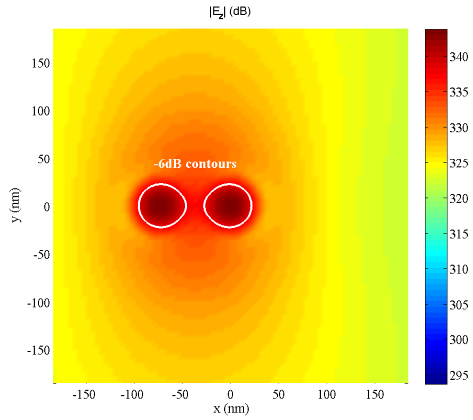


Fig. 2: Near-field enhancement at different frequencies (a) and field focusing at 813 THz (b). The observation plane is located 1 nm away from the last silver interface.

we locate two distinct vertical dipoles at a distance of 74 nm $= 0.2\lambda$ along the x axis. Fig. 3 shows the field distribution at the image plane resulting from the two sources, where a -6dB (half field magnitude)



(a)



(b)

Fig. 3: Resolution for two point sources at a distance of 0.20λ from each other: (a) scan along the x axis and (b) on the x-y plane where the white contours represent the -6dB isolines.

detection threshold had been chosen. We notice that the two contributions are still separate, unlike for the free-space case where they are definitely not distinguishable one from the other.

3. Conclusion

In this paper we have described the focusing effect of a multilayer comprising alternating silica and silver layers. Simulations have shown that the multilayer is capable of enhancing the near-field at the last interface and producing a spot of subwavelength size in the transverse image plane. It has been possible to resolve two distinct sources at subwavelength distance.

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