Optimizing the superlens geometry

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Abstract: We study the effect of superlens geometry on its performance. We introduce the *optimal configuration* that minimizes local field at *front* interface of superlens, maximizes resolution, and brings focal point to point of maximum intensity.

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The imaging device, based on a planar slab of a material with negative refractive index [1], ideally matched to surrounding space, also know as a superlens [2], has recently attracted unprecedented attention[2-5]. It has been theoretically predicted and experimentally verified that such a system can outperform the "conventional" near-field imaging techniques and may in principle be used to achieve the better-than-diffraction limit resolution [2-6]. It has been also demonstrated, that a planar slab of a material with negative permittivity, and trivial permeability can be used *in near-field, single polarization imaging* [2-4]. However, despite the extensive research on the properties of the superlens, most analytical studies of planar-lens imaging focus on the single superlens geometry when the planar slab of a material is centered between the object and image ($b=2a$ in Fig.1) [2,3,5]. In this work we study the effect of the planar lens configuration on its imaging properties.

To develop the analytical description of the optical properties of the planar imaging system, we follow the Fourier-transform based approach, described in detail in Refs.[5,6]. In this approach, the field distribution at an arbitrary point inside the system is related to the field distribution of the source and the *transfer function* describing the propagation of an individual plane wave through the system. Thus, the magnetic field of a TM wave, can be found as:

$$H_y(x,z;t)=\int a(k_x)\tau(x,z;\omega,k_x)e^{-i\omega t}dk_x\,, \tag{1}$$

where $a(k_x)$ is the spectrum of the source and τ is the transfer function.

We use the Eq.(1) to find the resolution limit of a planar lens. Following the approach of Refs.[5,6], we use the properties of Fourier transform to relate the spatial resolution to the system's ability to restore the evanescent $|k_x|>>\omega$ part of the spectrum at its focal point, given by $\tau(x,2b;\omega,k_x)$. An ideal superlens with $\varepsilon=\mu=-1$ would have $\tau(x,2b;\omega,k_x)=e^{i k_x x}$. However, any deviation of permittivity or permeability from these idealized parameters (due to, e.g. losses in the system or a minor mismatch in the permittivity of superlens material and its surroundings) lead to exponential suppression of evanescent waves [6]. This behavior, in turn, introduces a finite value of the spatial resolution Δ, which can be deduced from the following transcendental equation:

$$\frac{2\pi b}{\lambda}=-\frac{\ln\frac{1}{2}\left[\varepsilon''+\frac{\varepsilon''+\mu''}{2\chi^2}\right]}{\chi}, \tag{2}$$

with $\chi=\sqrt{\xi^2\lambda^2/\Delta^2-1}$, $\xi\approx 0.6$, and ε'', μ'' being the imaginary parts of superlens permittivity and permeability responsible for the losses in the system [6]. It can be shown that under realistic conditions the super-imaging is possible only in near-field proximity of the source ($a,b<<\lambda$) [5-7].

One of the main results of this work is the fact that the resolution of the superlens is defined not by the distance from the source to the lens a, but rather by the total distance from the source to the image $2b$. The majority of near-field applications require maximization of the separation between the source of radiation and the imaging system. Thus, the configuration $a=b$, that *maximizes this separation* is optimal for these applications. This particular configuration has a number of important practical benefits, which we present below.

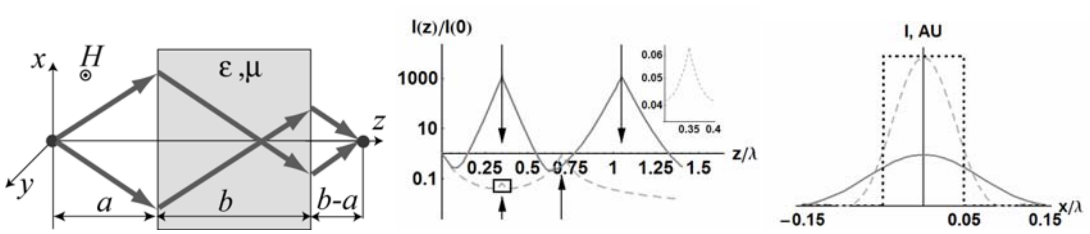

Fig. 1. (left) Generalized superlens geometry. (center) Intensity distribution along the *z* axis in the symmetric (solid lines) and optimal (dashed lines) superlens configurations; $\varepsilon''=10^{-5}$; lens positions are shown with arrows; note the field enhancement at both lens interfaces. (right) Imaging in the systems shown in (center); source is shown with dotted line.

In contrast to commonly used superlens picture, the field in the symmetric configuration has its maxima at *both* interfaces of the planar system [3,6]. The field maximum at the front interface of the lens ($z=a$) can be estimated as

$$H_y^{(\max)}(0,a) \approx (\varepsilon''/2)^{a/b-1}/2 \,. \quad (3)$$

Such a field maximum leads to a strong absorption inside the superlens, and consequently reduces its resolution. The optimal configuration ($a=b$) minimizes such an energy loss.

Another common problem of planar superlens is the fact that the field maximum in the sub-diffraction imaging regime is located at the superlens interface ($z=a+b$), away from the focal point ($z=2b$). The optimal superlens configuration solves this problem.

Finally, we note that the resolution of any planar imaging system falls below the resolution of its "conventional" near-field counterpart when the material loss (or mismatch in optical parameters) becomes larger than critical value $\varepsilon''_{cr} \approx 0.3$ [6].

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