Reflectionless Evanescent Wave Amplification by Two Dielectric Slabs

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Abstract: It is shown that evanescent waves can be amplified without any reflection simply by two dielectric slabs. This enables non-scanning near-field imaging without direct contact with the object, suitable for biological imaging applications.

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A groundbreaking proposal by Pendry suggests that evanescent waves can be amplified without any reflection in a negative-refractive-index slab [1], generating significant interest as well as controversy in the mechanism of evanescent wave amplification (EWA). In practice, current methods of fabricating a negative-refractive-index material for optical frequencies inevitably introduce significant loss detrimental to the EWA process. A simpler EWA scheme that utilizes less lossy materials is hence much desirable.

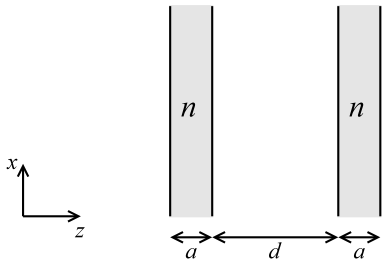

Fig. 1. Reflectionless evanescent wave amplification by two dielectric slabs.

Consider two dielectric slabs in Fig. 1. Let an evanescent wave with a transverse wave vector k_x and an imaginary longitudinal wave vector $k_z = i\sqrt{k_x^2-(2\pi/\lambda)^2}$ impinges on the first slab. The transmitted wave inside the slab has a longitudinal wave vector $k_z' = \sqrt{(2\pi n/\lambda)^2-k_x^2}$, assumed to be real. The transmission and reflection coefficients across the air-dielectric interface are then $t = 2k_z/(k_z+k_z')$ and $r = (k_z-k_z')/(k_z+k_z')$, respectively, and the coefficients across the dielectric-air interface are $t' = 2k_z'/(k_z'+k_z)$ and $r' = (k_z'-k_z)/(k_z'+k_z)$, respectively. The transmission and reflection coefficients across the first slab are therefore $\tau = tt'\exp(ik_z'a)/[1-r'^2\exp(2ik_z'a)]$ and $\Gamma = r + tt'r'\exp(2ik_z'a)/[1-r'^2\exp(2ik_z'a)]$. Evanescent coupling to the waveguide modes of one slab occurs when τ and Γ become infinity, or $1-r'^2\exp(2ik_z'a)\to 0$. When two dielectric slabs are present, however, the total transmission and reflection coefficients become

$$\lim_{1-r'^2\exp(2ik_z'a)\to 0} T = \lim_{1-r'^2\exp(2ik_z'a)\to 0} \frac{\tau^2\exp(ik_zd)}{1-\Gamma^2\exp(2ik_zd)} = -\exp(-ik_zd), \tag{1}$$

$$\lim_{1-r'^2\exp(2ik_z'a)\to 0} R = \lim_{1-r'^2\exp(2ik_z'a)\to 0} \Gamma + \frac{\tau^2\Gamma\exp(2ik_zd)}{1-\Gamma^2\exp(2ik_zd)} = 0. \tag{2}$$

Hence, reflectionless EWA occurs across *two* slabs, when evanescent coupling to the waveguide modes of *one* slab is achieved. This means that reflectionless EWA occurs only for discrete modes with specific k_x's, and the k_x's cannot be bigger than the resolution limit inside the dielectric, $2\pi n/\lambda$. However, very low-loss high-refractive-index dielectrics are available, such as diamond, which is transparent down to $\lambda = 230$ nm and has an index of $n = 2.7$. The proposed configuration therefore elucidates the essential physics of reflectionless EWA, allows a simpler experimental demonstration, and enables non-scanning near-field imaging without direct contact with the object, suitable for biological imaging applications. This work was supported by the DARPA Center for Optofluidic Integration.

1. References

[1] J. B. Pendry, "Negative refraction makes a perfect lens," Phys. Rev. Lett. **85**, 3966 (2000).