Light Transmission through a Subwavelength Slit and Optical Vortices

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Using a rigorous scattering model, we study the electromagnetic field around a subwavelength slit in a metal plate with finite conductivity and finite thickness. It is found that the transmission can be strongly enhanced when the phase singularities ("optical vortices") of the Poynting vector have a certain position. We examine the creation and annihilation of different kinds of phase singularities as a function of the incident wavelength and slit width.

The study of the transmission properties of a narrow slit in a metal plate dates back to Lord Rayleigh [1]. He considered a slit in a perfectly conducting, infinitly thin plate with a width much smaller than the wavelength of the incident field. In the first half of the previous century explicit results for the light transmission as a function of the width of a slit in such a plate were obtained [2]. Around the same time the transmission properties of a cylindrical hole in a perfectly conducting, infinitly thin plate were also studied [3]. An extensive review of this subject was given by Bouwkamp [4]. In the second half of the twentieth century the light transmission through sub-wavelength slits and holes in a thick (i.e, not infinitly thin) perfectly conducting metal plate was also studied [5, 6, 7].

Recently there has been a new surge of interest in light transmission through sub-wavelength structures in a metal plate. This is due to the obvious relevance of the subject for near-field optics, and becauce of the extraordinary transmission properties of two-dimensional hole arrays in a metal plate reported by Ebbesen *et al.* [8, 9, 10]. They observed that the light transmission can be strongly *enhanced*, i.e., more light is being transmitted through the holes than is directly impinging on them. To understand this anomalous behavior we have made a theoretical study of the somewhat more simple structure, namely that of a slit in a metal plate.

We consider a slit in metal plate with both finite thickness and finite conductivity. It is illuminated by a laser, which produces a linearly polarized, monochromatic plane wave with angular frequency ω, propagating perpendicular to the metal plate. To obtain the total field for this configuration, we transform the steady-state Maxwell equations into the *domain integral equation* [11] for the electric field $\mathbf{E}$

$$\mathbf{E}(\mathbf{x}) = \mathbf{E}^{\mathrm{inc}}(\mathbf{x}) + j\omega(\varepsilon_m - \varepsilon_0)\int_{\mathsf{slit}} \mathbf{G}(\mathbf{x},\mathbf{x}')\mathbf{E}(\mathbf{x}')\,\mathrm{d}x', \tag{1}$$

where $\mathbf{E}^{\mathrm{inc}}$ is the electric field of the background configuration (the metal plate without the slit), $\mathbf{G}(\mathbf{x},\mathbf{x}')$ is the Green tensor for the electric field with respect to the background configuration, ε_m and ε_0 are the permittivity of the metal and air, respectivily and $j^2 = -1$. We solve Eq. (1) numerically and can therefore compute the transmission of the slit and the Poynting vector around the slit. In Fig. 1 a typical numerical result is shown.

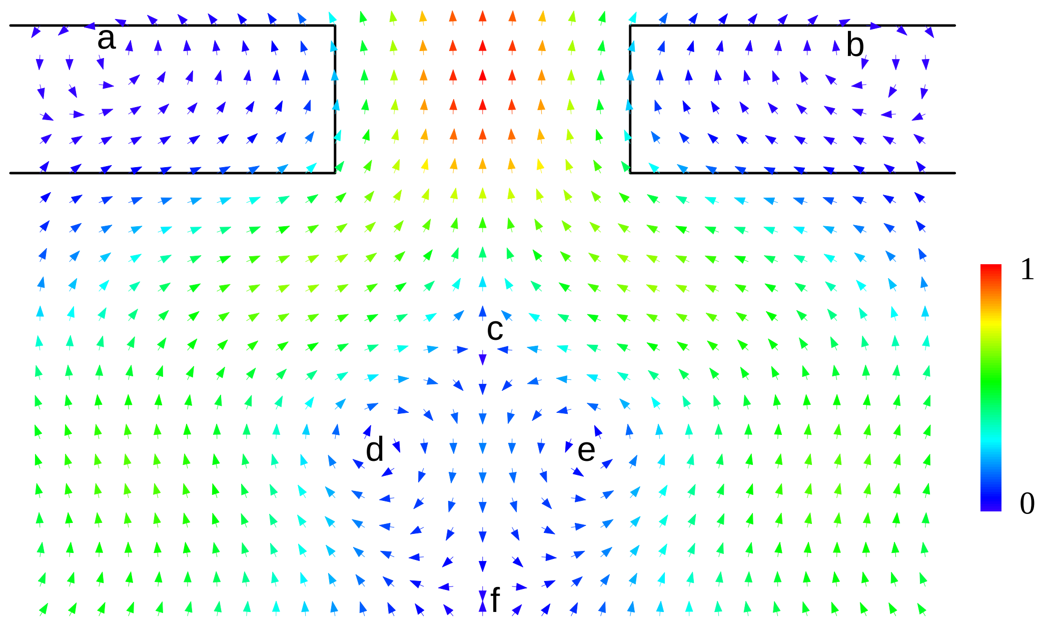

Figure 1: Behavior of the Poynting vector near a narrow slit in a 100 nm thick silver plate for a slit width of 200 nm. The incident light (coming from below) has a wavelength $\lambda = 500$ nm. The left- and righthanded optical vortices (a,b,d and e) each have a topological charge of $+1$, whereas the topological charge of the saddle points (c and f) is -1. The transmission coefficient $T = 1.11$. The color coding indicates the modulus of the (normalized) Poynting vector (see legend).

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