Squeezing light through subwavelength slits with the help of surface plasmons

H.F. Schouten[1], T.D. Visser[1], G, Gbur[1], D. Lenstra[1] and H. Blok[2]

[1]Dept. of Physics and Astronomy, Vrije Universiteit,
De Boelelaan 1081, 1081 HV Amsterdam
[2]Dept. of Electrical Engineering, Technische Universiteit Delft,
Mekelweg 4, 2628 CD, Delft

The anomalously-high transmission through subwavelength apertures is a phenomenon which has been observed in numerous experiments, but whose theoretical explanation is incomplete. We study the light transmission through two subwavelength slits in a thin metal plate by a rigorous scattering model, which takes into account the finite thickness and finite permittivity of the metal plate. The light transmission is found to be enhanced or frustrated, depending on the distance between the slits and the polarization of the incident field. This effect is explained by considering the surface plasmons posssible on the metal-air interface.

Recently there has been a surge of interest in light transmission through sub-wavelength apertures. This is due to its obvious relevance for near-field optics, and because of the extraordinary transmission properties of two-dimensional hole arrays in a metal plate reported by Ebbesen *et al.* [1]. 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. In this paper we study the light transmission for a different configuration, namely one or two sub-wavelength slits in a metal plate with a finite conductivity and a finite thickness.

The electromagnetic field is obtained by converting Maxwell's equations into an integral equation for the electric field inside the slits,

$$\hat{\mathbf{E}}(x,z) = \hat{\mathbf{E}}^{(\mathrm{inc})}(x,z) - \mathrm{i}\omega\Delta\varepsilon \int_{\mathcal{D}} \hat{\mathsf{G}}(x,z,x',z') \cdot \hat{\mathbf{E}}(x',z')\, \mathrm{d}x'\mathrm{d}z', \tag{1}$$

where $\hat{\mathbf{E}}^{(\mathrm{inc})}$ is the field in the plate without the slits being present, $\Delta\varepsilon$ is the difference between the permittivity of the slits and that of the metal plate, $\hat{\mathsf{G}}$ is the electric Green's tensor with respect to the plate without the slits and $\mathcal{D}$ denotes the area of the slits. Eq. (1) is solved numerically by the collocation method.

For a single slit we show that the transmission can be enhanced, and that this can be explained by considering the waveguide modes that are possible in the slit, and the optical vortices near the slit [2, 3]. An example is given in Fig. 1. The anomalous behaviour of the light transmission is found to be strongly dependent on the the polarization of the incident light, which is explained by the difference between the waveguide modes for these polarizations.

It is also found that plates with different material properties, such as conductivity and thickness, show a fundamentally different behaviour of the field near the slit [4]. Depending on the material properties, the light transmission can either be enhanced or frustrated. A correspondence between the handedness of optical vortices and the transmission behaviour is demonstrated.

In the case of a two-slit configuration, the light transmission is shown to be strongly dependent on the distance between the slits. This effect is explained by the occurrence of

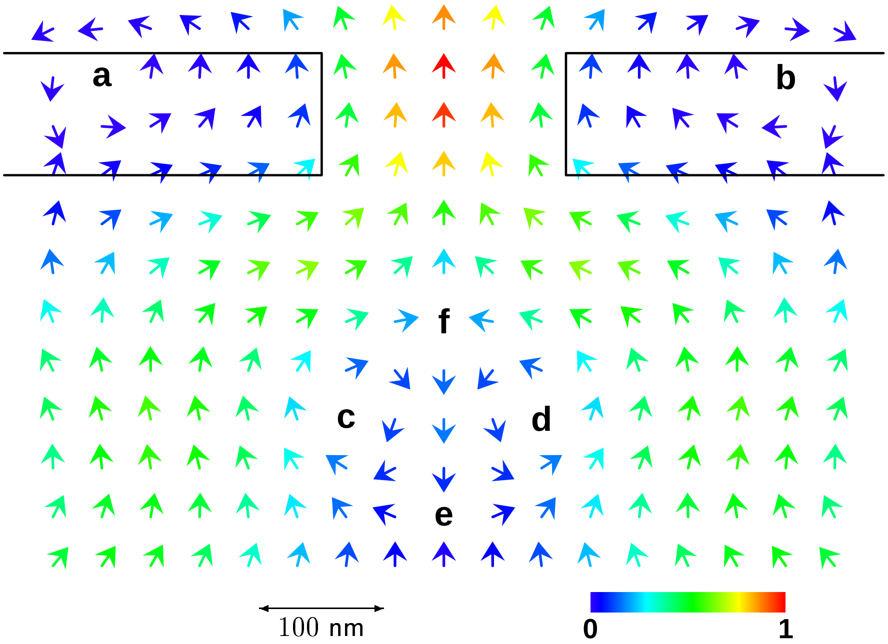

Figure 1: The time-averaged Poynting vector near a slit in a metal plate (after [2]). a and d are left-handed optical vortices, b and c are right-handed optical vortices, and e and f are saddle points.

surface plasmons along the metal-air interface. It is found that these plasmons can either increase or frustrate the transmision. Surface plasmons can only occur if the incident electric field is polarized perpendicular to the slits. This explains why the strong distance dependance of the transmission only occurs for this polarization.

References

[1] T.W. Ebbesen, H.J. Lezec, H.F. Ghaemi, T. Thio, and P.A. Wolff, "Extraordinary optical transmission through sub-wavelength hole arrays", *Nature*, vol. 391, pp. 667–669, 1998.

[2] H.F. Schouten, T.D. Visser, D. Lenstra, and H. Blok, "Light transmission through a sub-wavelength slit: waveguiding and optical vortices", *Phys. Rev. E*, vol. 67, 036608, 2003.

[3] H.F. Schouten, T.D. Visser, G. Gbur, D. Lenstra, and H. Blok, "Creation and annihilation of phase singularities near a sub-wavelength slit", *Opt. Express*, vol. 11, pp. 371–380, 2003.

[4] H.F. Schouten, T.D. Visser, G. Gbur, D. Lenstra, and H. Blok, "The diffraction of light by narrow slits in plates of different materials", *J. Opt. A: Pure Appl. Opt.*, submitted.