Phase Singularities and Enhanced Transmission at a Subwavelength Slit

H.F. Schouten, T.D. Visser, G. Gbur, D. Lenstra and H. Blok

Recent research has demonstrated a connection between two seemingly disparate and blossoming fields of optical science, namely, singular optics and the anomalously high transmission of light through subwavelength size apertures.

Anomalous light transmission, first demonstrated experimentally by Ebbesen et al.,[1] is the surprising property that subwavelength size apertures in metal plates can transmit much more light than predicted by the standard theory of aperture diffraction. It has been suggested that this enhanced transmission is due to the coupling of light to surface plasmons. A good understanding of the origins of enhanced transmission could lead to novel near-field optical measurement devices, among other things.

It has also been known for some time that the phase of a wave field can exhibit unusual yet physically relevant behavior in the neighborhood of points at which the field amplitude is zero. The systematic study of such singular points has developed into the vibrant field now referred to as singular optics.[2] The phase of the field in the neighborhood of a singular point can exhibit a rich variety of behaviors, such as a vortex structure, and such points possess certain conserved quantities such as topological charge.

We have undertaken two-dimensional numerical calculations of the electromagnetic field in the neighborhood of a subwavelength size slit in a thin metal plate. In particular, the behavior of the time-averaged Poynting vector was analyzed by use of a rigorous integral equation method.[3,4] We found that the field of power flow typically possesses numerous phase singularities; an example of such a field is shown in Fig. 1. More importantly it was found that, by increasing the slit width, the annihilation of phase singularities and the resulting smoother power flow coincide with the onset of anomalous light transmission through the slit. This analysis was done in a configuration that does not support surface plasmons, indicating that anomalous transmission can occur even in their absence.

Our results give new insight into the study of transmission through subwavelength size apertures and show that a good understanding of the phenomenon requires that the behavior of the phase singularities of the field be taken into account.

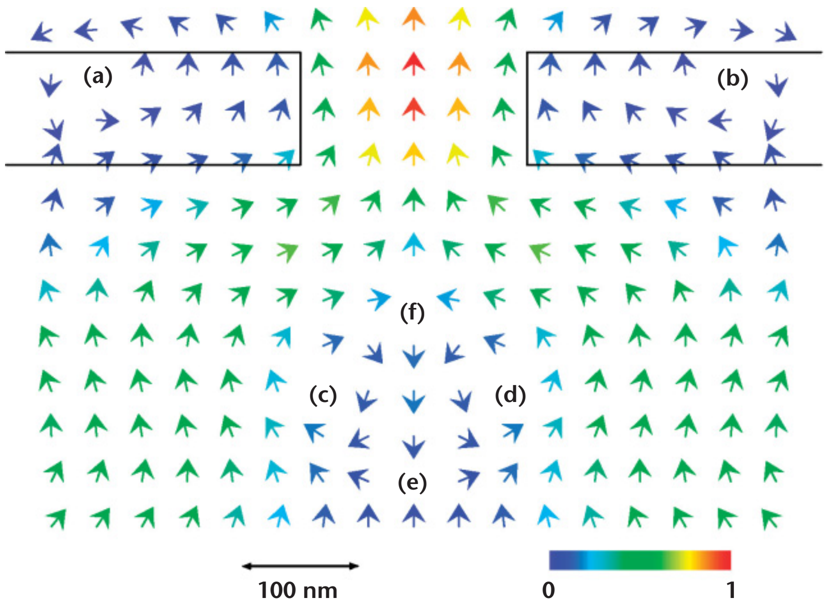

Figure 1. Illustration of the power flow in the neighborhood of a 200-nm-wide slit in a 100-nm-thick plate of evaporated silver (with refractive index n = 0.05 + i 2.87). The incident field (coming from below) has a wavelength of λ=500 nm. Features (a) and (d) are left-hand vortices, (b) and (c) are right-hand vortices and (e) and (f) are saddles. For this example the transmission coefficient T = 1.11. The color coding indicates the modulus of the (normalized) Poynting vector.

References

1. T. W. Ebbesen, H. J. Lezec, H. F. Ghaemi, T. Thio and P. A. Wolff, Nature **391**, 667-9 (1998).
2. M. S. Soskin and M. V. Vasnetsov, "Singular optics," in Progress in Optics, E. Wolf, ed. (Elsevier, Amsterdam, 2001), Vol. **42**, pp. 219-76.
3. H. F. Schouten, T. D. Visser, D. Lenstra and H. Blok, Phys. Rev. E **67**, 036608 (2003).
4. H. F. Schouten, T. D. Visser, G. Gbur, D. Lenstra and H. Blok, Opt. Express **11**, 371-80 (2003), www.opticsexpress.org.

H.F. Schouten, T.D. Visser (tvisser@nat.vu.nl), G. Gbur and D. Lenstra are with the Department of Physics and Astronomy, Free University, Amsterdam, The Netherlands. H. Blok is with the Department of Electrical Engineering, Delft University of Technology, Delft, The Netherlands.