FDTD ANALYSIS OF LIGHT TRANSMISSION THROUGH A NANOHOLE IN A METAL FILM

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Bethe's aperture theory states that light transmission through a hole significantly smaller than half the wavelength of light decreases as the fourth power of the ratio of the hole dimension to the incident wavelength [1]. Recently, it was demonstrated that the optical transmission increased when the hole area was reduced [2]. Even more surprisingly, the peak in transmission wavelength increased as the hole was reduced in size. We have presented a model to explain the red-shifting in the peak transmission as coming from the excitation of surface plasmons within the hole [3]. So far, there has been no comprehensive numerical investigation of the enhanced transmission and red-shift results. In this work, we adopt an FDTD method to analyze the transmission of light through a single rectangular nanohole in a metal film. We study the transmission spectra for varying the polarization angles of the incident light and varying hole-widths. Our simulations agree with previous experiments and show the role of surface plasmons in the transmission dynamics.

Figure 1 shows the setup of our FDTD simulation. The sample is a 300 nm thick silver film with a hole of dimensions 270 nm by 105 nm. A normally incident excitation field is used, with a broadband pulse of 2 fs, and an integration time of 30 fs. Perfectly-matched layer boundary conditions were used to prevent reflection of the out-going waves. Typically, grid sizes of 10 nm were used; however, this value was varied to ensure that the main results were not dependent upon the grid size.

Figure 2 shows the transmission spectrum for various incident polarizations. We found that as the angle of polarization of the incident wave was varied from 0^0 to 90^0 there was a switching of the mode from a lower to higher wavelength. This is explained by the excitation of the surface plasmons by the normal components of the electric field [2].

Figure 3 shows the transmission spectrum for different hole widths of 105 nm, 185 nm, and 260 nm. This figure shows the surprisingly result that the transmission peak increases as the hole is made smaller, and the peak is red-shifted to longer wavelengths. These observations are in good quantitative agreement with past experiments [2]. Animations from the FDTD-simulation dynamics show the strong excitation of the edges of the hole, which is a clear indicator of the role of surface plasmons on the observed dynamics.

In conclusions, we have verified the role of surface plasmons in governing the dynamics of transmission through a nanohole in a real metal. This work will be useful for the development of plasmonics, including applications in nanolithography and biosensors [4]. Further work is planned to investigate how different hole shapes may be used to best harness the surface plasmon wave.

References:

[1] H. A. Bethe, "Theory of Diffraction by Small Holes," *Phys. Rev*. vol. 66, no. 7-8, pp. 163-182,1944.
[2] A. Degiron, H. J. Lezec, N. Yamamoto, T. W. Ebbesen, "Optical Transmission Properties of a Single Subwavelength Aperture in a Real Metal," *Optics Communications*, vol. 239, no. 1-3, pp. 61-66, 2004.
[3] R. Gordon and A. G. Brolo, "Increased cut-off wavelength for a subwavelength hole in a real metal," Opt. Express **13,** 1933-1938 (2005),
[4] A. G. Brolo, R. Gordon, B. Leathem and K. L. Kavanagh "Surface Plasmon Sensor based on the Enhancement Light Transmission through Arrays of Nanoholes in Gold Films" *Langmuir* 2004

Acknowledgements:

Lumerical Solutions Inc.

Figures:

Figure 1: Simulation set up

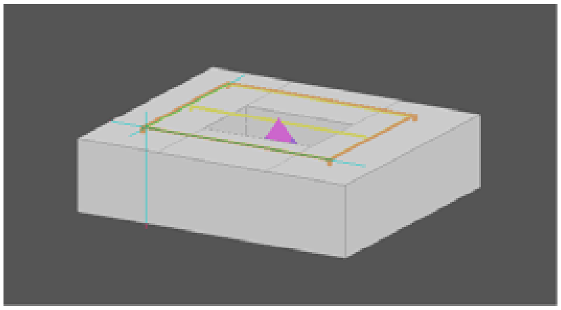

Figure 2: Results for variation in polarization angles

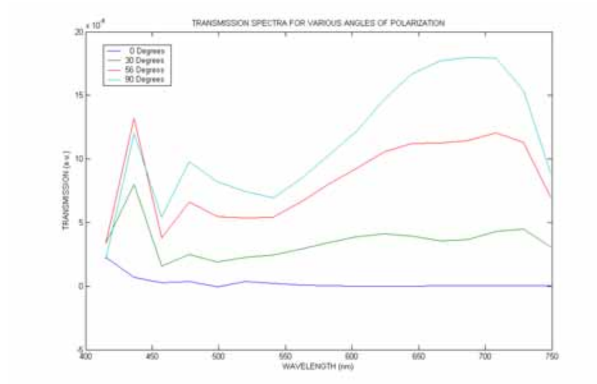

Figure 3: Results for variation in width of aperture