Analysis of the extreme transmission effect via discrete sources method

Y. Eremin*[,1], E. Eremina[2], N. Grishina[1], and T. Wriedt[3]

[1]*Moscow Lomonosov State University, Vorobyov's Hills, 119991 Moscow, Russia.*
[2]*University of Bremen, Badgasteiner str.3, 28359 Bremen, Germany.*
[3]*Institute of Materials' science, Badgasteiner str.3, 28359 Bremen, Germany.*

The Discrete Sources Method (DSM) has been adjusted to model polarized light transmission through metal film deposited on a glass prism with nano-sized inhomogeneity. A correlation between Extreme Transmission Effect (ETE) and Surface Plasmon Resonance (SPR) has been investigated. The distribution of the scattered intensity in the peak of ETE has been analyzed.

INTRODUCTION

The discovery of enhanced optical transmission through sub-wavelength holes in noble metal film has attracted considerable interest to this optical phenomenon [1]. Different groups of researchers worldwide have recently examined the transmission properties of sub-wavelength apertures. But the most of them considered normal incidence of an exciting plane wave on the film surface. At the same time, there are multiple practical applications involving an evanescent wave scattering in nano-optics and biophotonics [2-3]. Using evanescent waves allows in particular avoiding the problem of filtering of the scattered light from the refracted one behind the film.

Extreme Transmission Effect (ETE) through a nano-sized hole in noble metal film deposited on a glass prism has been reported in [4]. Later it was found that the ETE also occurs with other types of the film inhomogeneities [5]. The ETE arises in the region of evanescent waves behind the angle of total internal reflection. It demonstrates a sharp (by an order of magnitude) increase in the total scattering cross section compared to the normal incidence of the wave on the film. In this case, the diameter of an inhomogeneity is much smaller than the diffraction limit. A specific feature of this effect is that it is independent of the inhomogeneity shape, diameter and material, the film thickness, and the filling of the external half-space; it can only be determined by the film material.

In this paper, we consider a correlation between ETE and Surface Plasmon Resonance (SPR) [6]. The Discrete Sources Method [3] has been adjusted to model polarized light transmission through metal film deposited on a glass prism with nano-sized inhomogeneity. The distribution of the scattered intensity in the peak of ETE has been analyzed.

* Corresponding author: Yuri Eremin (eremin@cs.msu.ru)

The Discrete Sources Method

The model presented here is based on the Discrete Sources Method (DSM), which seems to be one of the most flexible techniques for scattering problems treatment. The advantage of the DSM is that it is a semi-analytical meshless method and it does not require any integration procedures. By use of this technique, the scattered field everywhere outside an axial-symmetric inhomogeneity is constructed as a finite linear combination of the fields resulting from multipoles distributed over the axis of symmetry inside the inhomogeneity. The DSM solution satisfies the Maxwell equations, required conditions at infinity, and transmission conditions enforced at the layered interfaces. The Green Tensor of a layered plane interface is employed to account for the complete interaction of the inhomogeneity with a stratified interface analytically. While most of the conditions of the boundary-valued scattering problem are satisfied analytically, the unknown discrete sources amplitudes are determined from transmission conditions enforced at the inhomogeneity's surface only [3]. One of the most attractive features of the DSM implementation consists in a flexible choice of the discrete sources system that is used for the approximation of the solution. Besides, the DSM enables to employ different numbers of basic functions for scattered and internal field representation that gives an opportunity to examine the obstacle with high refractive indices.

DSM numerical scheme is based on the axial symmetry of the scattering problem geometry (inhomogeneity plus interface). While the multipoles generating the fields are distributed over the axis of symmetry inside the inhomogeneity, the DSM solution including Weyl-Sommerfeld integrals accepts the form of finite Fourier series with respect to the azimuth angle. Exciting evanescent wave impinging the inhomogeneity from prism surface is resolved in Fourier series with respect to the azimuth angle. This leads to the reducing surface approximation to a set of one-dimensional approximating problems enforced at the inhomogeneity's meridian. To fit the transmission conditions we use generalized point-matching technique distributing the matching points over the meridian. It provides reduction of the sizes of linear systems to be solved and thus leads to a reduction of the computation time and memory storage. Multipoles' amplitudes are determined as pseudo-solutions over-determined systems of the linear equations. To ensure the full rank a rectangular matrix of the over-determined systems regularization procedure is applied. We use complex shift of spectrum of the extended rectangular matrix, which enables to get normal pseudo-solution.

The DSM numerical scheme allows considering of all incident angles and both polarization P and S at once. The DSM computer model controls convergence and stability of the results by a posterior evaluation of the surface residual at the inhomogeneity surface in least square norm. Besides, the corresponding far field pattern is represented as a finite linear combination of elementary functions allowing fast computer analysis of the intensity distribution and objective response [4].

NUMERICAL RESULTS

Let us consider the scattering of a P/S polarized plane wave propagating from glass (LASF46A) prism with a refractive index n_p=1.904, on Si (n=4.37-0.08j) sphere, D=49 nm, immersed in Au (n_f=0.18-3.26j) film of thickness d=50 nm. We analyze the scattered intensity in the incident plane versus scattering angle and Scattered Cross Sections (SCSs) in upper and lower hemispheres versus incident angle with respect to the normal to the plane interfaces.

Figure 1 demonstrates the SCS in μm² units for P/S polarized incidences versus incident angle. In this particular case the critical angle behind which the evanescent wave appears is θ_c=31.68°. One can see the close correlation between the SPR (minimum value of the reflection coefficient from prism-film-air media) and ETE. Minimum value of scattering appears at the incident angle of 32.5° and the maximum at 33.7°.

Figure 2 shows the distribution of the scattered intensity in the incident plane. Data for normal incidence - 180° demonstrate symmetry with respect to 0-180° plane. For the oblique incidences maximal values are achieved in the incident and specular directions.

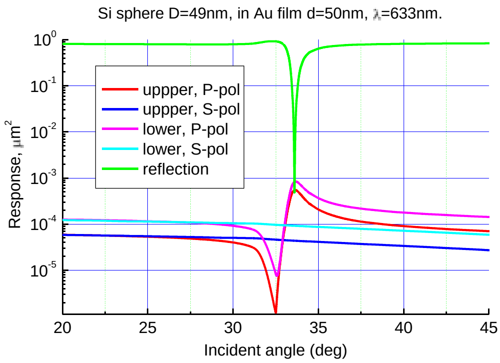

Figure 1.

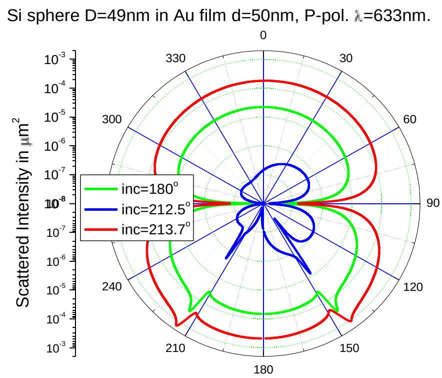

Figure 2.

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