

Surface Plasmon Effects in Near-field Optical Readout Systems

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Abstract: The effects of surface plasmons on enhanced transmission and readout contrast in a near-field optical readout system are studied numerically using a Green's tensor formulation. Techniques for increasing readout contrast using plasmon effects are described.

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1. Introduction

Since the discovery of enhanced transmission through subwavelength-size hole arrays in metal plates [1], there has been much research and interest in the optical transmission properties of both hole arrays and single subwavelength apertures [2]. The origin of this enhancement is generally credited to surface plasmons (although enhancement can also be observed in certain configurations which excite no plasmons [3,4]), which create large field amplitudes at the edges of the aperture and which result in more light throughput. Transmission has been further increased by incorporating surface features such as ridges around the outside of the aperture to couple and reflect more plasmons back into it [5].

Although it has been suggested that the phenomenon of enhanced transmission could be useful in such fields as near-field optics, nano-lithography and superresolving near-field optical readout systems, little work has been done to study such possible applications theoretically. In this paper, we consider the application of enhanced transmission effects in superresolving near-field optical readout systems.

2. Method

We have simulated such a readout system using a Green's tensor formulation in a two-dimensional geometry, with a single slit in a metal plate used as a near-field probe (see Fig. 1). A monochromatic electromagnetic wave is normally incident upon a metal plate of finite conductivity which contains a single subwavelength slit that acts as the readout system probe. The metal plate is situated a short distance away from a semi-infinite data layer which serves the role of an optical disk. In our simulations we consider one or more data structures ('pits' or 'bumps') on the surface of the data layer. Furthermore, to study the effects of enhanced transmission we consider the effect of placing a pair of surface features on the metal plate, either on the light side or the dark side, referred to as 'plasmon pits', which allow the coupling of light to surface plasmons.

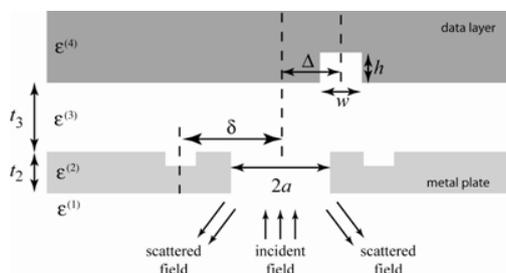


Fig. 1. Illustration of the configuration used in readout system simulations.

The total electric field $\hat{\mathbf{E}}$ may be written as the sum of two parts, namely the incident field $\hat{\mathbf{E}}^{\text{inc}}$ and the scattered field, $\hat{\mathbf{E}}^{\text{scatt}}$. The incident field is here taken to be the field that would occur in the absence of the slit in the plate, which can readily be calculated by use of the electromagnetic boundary conditions. It is then possible to show [3] that the i th component of the total electric field satisfies an integral equation of the form

$$\hat{E}_i(x, z) = \hat{E}_i^{\text{inc}}(x, z) - i\omega \int_D \Delta\epsilon(x', z') \hat{G}_{ij}^E(x, z; x', z') \hat{E}_j(x', z') dx' dz', \quad (1)$$

where the integral is over all rectangular regions (slit, data structure, plasmon pits) in which the system deviates from the ideal layered geometry. Here $\Delta\epsilon(x', z')$ is the difference between the background permittivity of the system at that point and the permittivity of the ‘deviant’ region, and $\hat{G}_{ij}^E(x, z; x', z')$ is the electric Green’s tensor pertaining to the ideal layered geometry. This equation can be solved numerically within the ‘deviant’ regions by the collocation method with piecewise-constant basis functions. The field everywhere else may then be calculated by substituting back into Eq. (1).

3. Readout system analysis

We have used the Green’s tensor method described in the previous section to numerically analyze the effect of surface plasmons and enhanced transmission schemes on the ability to detect and superresolve individual data ‘bits’ on the surface of an optical disc. The detection process was simulated by calculating the total power scattered from the readout system, neglecting the power which would be directly reflected back from a smooth planar surface.

A typical result for a TM-polarized incident field, without plasmon pits, is shown in Fig. 2(a). Surprisingly, it is found that the reflected power oscillates strongly as a function of data structure position, completely obscuring any possible readout of the data. This effect can be attributed to surface plasmons propagating on the surface of the metal plate – because the field of the plasmons extends away from the surface, they can be reflected by the data structure and return to the slit, where they can couple into the backscattered field. This field may constructively or destructively interfere with the backscattered field which is directly reflected from the data layer, resulting in an oscillation of reflected power as a function of data structure position. This plasmon reflection can be seen explicitly by plotting the electric energy density in the neighborhood of the data structure and slit; an example is shown in Fig. 2(b).

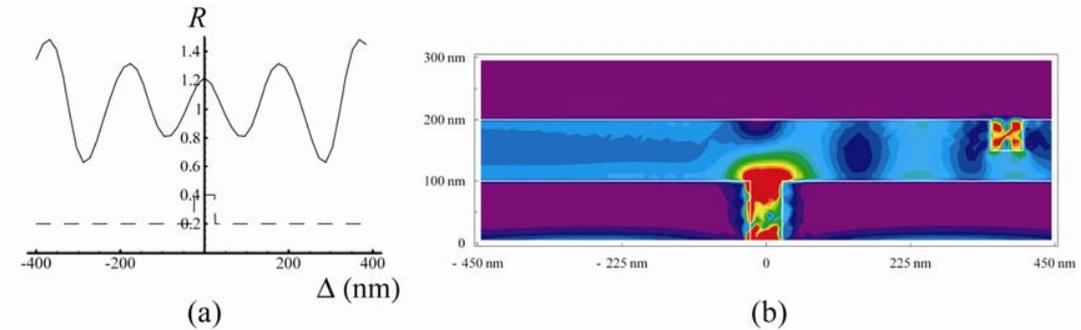


Fig. 2. (a) Reflected power as a function of data structure position Δ . The effective profile of the data structure is shown as a dashed line. Here $\lambda = 500$ nm, $t_2 = 100$ nm, $t_3 = 100$ nm, $a = 25$ nm, $w = h = 50$ nm. The data surface and the metal plate are both taken to be evaporated silver. (b) Plot of the electric energy density in the neighborhood of the slit and data structure. The density has been plotted on a logarithmic scale to enhance visibility of the plasmon standing wave. Redder regions correspond to higher energy density. Here $\Delta = 375$ nm. To the right of the slit, alternating bright and dark regions indicate the presence of a plasmon standing wave.

These plasmon oscillations can be suppressed significantly by a judicious choice of the data surface material as well as of metal plate surface features which are typically used to enhance transmission. The purpose of the ‘plasmon pits’ is twofold: 1. to increase the amount of energy coupled into light on the dark side of the plate, and 2. to restrict the region around the slit within which plasmons propagate.

An example illustrating the influence of a pair of symmetrically-placed plasmon pits on the reflected power is shown in Fig. 3. In figure 3(a), the reflected power as a function of readout position is shown for a configuration without plasmon pits. Although the choice of silicon as a data structure has suppressed much of the oscillation, it is still not possible to distinguish an individual data structure. In figure 3(b), the reflected power is shown for a system which possesses plasmon pits on the dark side of the metal plate. Remarkably, the plasmon oscillations have been nearly completely suppressed, leaving a well-defined dip in the reflected power that corresponds to the data structure. The measured profile of the object is greater than the object itself, but is still significantly smaller than the wavelength; it can be further decreased by decreasing the plate/data surface spacing. Furthermore, the contrast between the pit and background levels is nearly 33%.

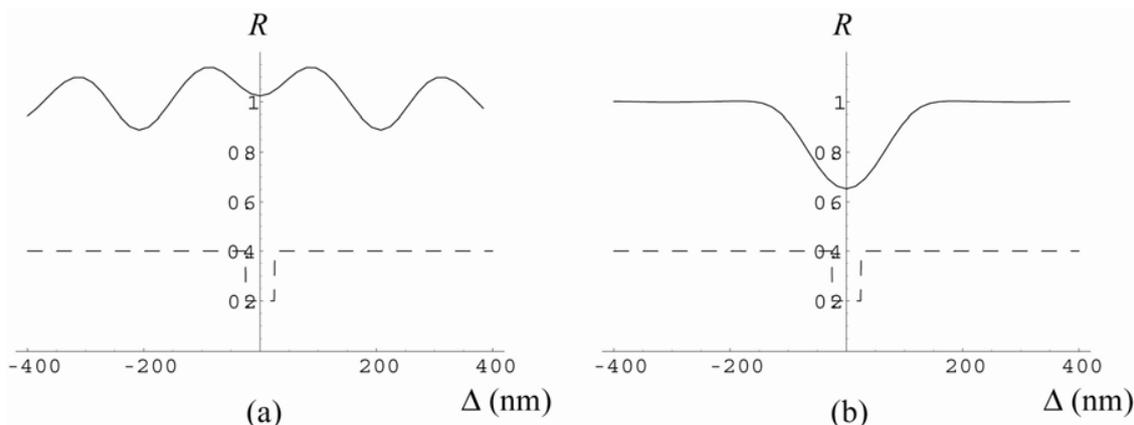


Fig. 3. (a) Reflected power as a function of data structure position Δ , for a configuration without plasmon pits. Significant oscillations in the signal mask the observation of the data structure. (b) Reflected power as a function of data structure position Δ , for a configuration with plasmon pits encircling the slit at distance $\delta = \pm 125$ nm. The oscillations are significantly reduced, and the pit/background contrast is nearly 33%. In both figures, $\lambda = 500$ nm, $t_2 = 100$ nm, $t_3 = 100$ nm, $a = 25$ nm, $w = h = 50$ nm. The plate is evaporated silver, and the data layer is silicon.

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