

# Simulation of Confined and Enhanced Optical Near-Fields for an I-shaped Aperture in a Pyramidal Structure on a Thick Metallic Screen

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## 1. Introduction

Recently, several interesting techniques for reducing the spot size without decreasing the field intensity of the emitted light have been proposed in near-field optics (NFO) <sup>1-5</sup>. The present authors recently proposed an I-shaped (dumbbell-shaped) aperture in a metallic screen that provided both high emission intensity and small spot size simultaneously, and showed that this effect is due to the surface plasmon polariton (SPP) excited inside the aperture <sup>6</sup>. The I-shaped aperture proposed previously is constructed in the flat metallic screen <sup>6</sup>. In order to apply the aperture to the practical NFO system, the aperture on the flat surface is not convenient, because it is not easy to place the aperture very close to the object in the NFO technology. The aperture in the conical or pyramidal structure is preferable in the practical NFO systems. In this paper, an I-shaped aperture in a pyramidal structure on a thick metallic screen is proposed, also provides high emission intensity and small spot size simultaneously. The scattering of optical waves by this structure in the thick metallic screen is solved numerically in order to show the high emission and small spot size. The problem is solved using a volume integral equation (VIE) by generalized conjugate residual (GCR) iteration and fast Fourier transformation (FFT). Basic characteristics of the near-field intensities of the I-shaped aperture in the pyramidal structure are also investigated.

## 2. Geometry of the problem

The problem of optical wave scattering by an I-shaped aperture in a thick metallic screen of infinite extent is shown in Fig. 1. A uniform metallic screen (slab) with thickness  $w$  and relative complex-valued permittivity  $\epsilon_1$  is placed on the  $x$ - $y$  plane. A pyramidal structure of the same metal is fabricated on this screen, as shown in Fig. 1, and an I-shaped aperture, where a rectangular narrow gap-region of  $a_x \times a_y$  is sandwiched by two rectangular wide gap-regions of  $b_x \times b_y$  in the cross section of the aperture as shown in Fig. 1, is formed in the screen through the pyramidal structure. The base of the pyramidal structure has dimensions  $B_x \times B_y$ , and the flat tip of the structure has dimensions  $a_x \times \xi$ . In this paper,  $B_y = b_y$  is assumed for simplicity. The height of the pyramidal structure from the screen to the tip is given by  $h$ . A plane electromagnetic wave is assumed to be normally incident to the screen from the negative  $z$ -direction below the metallic screen in the region (I), and the electric field polarization is parallel to the  $x$ -axis.

## 3. Numerical Solutions

The following parameters are fixed in the simulation: wavelength  $\lambda$ , incident electric vector  $E^i(x)$  is fixed parallel to the  $x$ -axis in Fig. 1, and the complex permittivities of the metallic screen and surrounding free space are given by  $\epsilon_1 = -7.38 - j7.18$

and  $\epsilon_0 = 1.0$ , respectively. All lengths used are normalized by the wavenumber  $k_0 = 2\pi/\lambda$  throughout this paper. The techniques for numerically solving the volume integral equation (VIE)

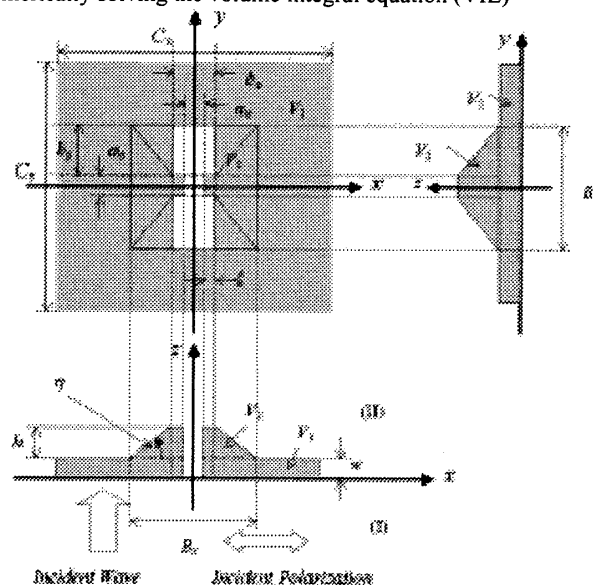
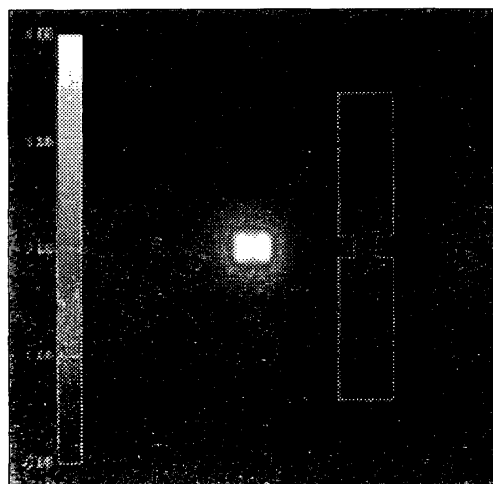


Fig. 1

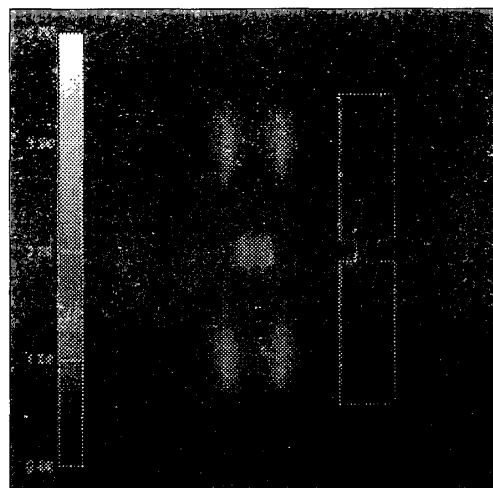
are well established in the field of computational electromagnetic theory. In this paper, the method of moment (MoM) is employed, using the pulse-function as a basis function and the delta-function as a testing function in the discretization of volume integral equation. <sup>7-14</sup>

## 4. Numerical Examples of an I-shaped Aperture with and without the Pyramidal Structure

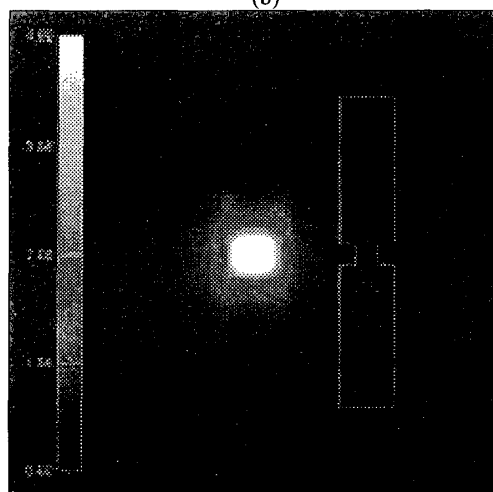
Two-dimensional distribution of total near-field intensities  $|E(k_0x, k_0y, 2.1)|^2$ , i.e., on the plane parallel to the  $x$ - $y$  plane at  $k_0z = 2.1$ , with pyramid structure is shown in Fig. 2(a). The distance  $l$  between the plane and the pyramid tip  $l$  is given by  $k_0l = 0.1$ . Parameters of the I-shaped aperture are given by  $k_0a_x \times k_0a_y = 0.4 \times 0.4$  and  $k_0b_x \times k_0b_y = 1.0 \times 1.6$  and screen thickness is given by  $k_0w = 0.8$  with a pyramidal structure of  $k_0h = 1.2$ . The angle  $\eta$  between the side surface of pyramidal structure and the screen surface shown in Fig. 1 is about 23 degrees. Same distributions  $|E(k_0x, k_0y, k_0w+0.1)|^2$  in a flat screen without pyramid structure ( $k_0h = 0.0$ ) of screen thickness  $k_0w = 0.8$  and  $k_0w = 2.0$  are shown in Figs. 2(b) and (c), respectively. The distance  $l$  between the plane and the flat screen surface is same as that in Figs. 3(a)-(c) i.e.,  $k_0l = 0.1$ . We must notice that intensity scales normalized incident intensity are 0.0-4.0 in Figs. 2(a)-(c). When the distance from the lower screen surface to the upper screen surface is same, i.e.,  $k_0w + k_0h = 2.0$ , the maximum total near-field intensity of I-shaped aperture in a pyramidal structure



(a)



(b)



(c)

is about a half of that without pyramidal structure. However, we can find that near-field intensity of the I-shaped aperture with pyramidal structure is larger than that in the flat screen of thickness of  $k_0 w = 0.8$  without pyramidal structure. Furthermore,

the approximate values of full width at half maximum (FWHM's) of the near-field intensity of aperture with pyramidal structure can be obtained as  $k_0 \times \text{FWHM} = 0.68$  and  $0.61$  in the  $x$  and  $y$ -direction, respectively, from Figs. 2(a) and (b). They are same as those without pyramidal structure given by  $k_0 \times \text{FWHM} = 0.68$  and  $0.61$ , respectively. We can easily see that the near-field intensity of I-shaped aperture is much larger than that of a simple square aperture. So, we can use I-shaped aperture with a pyramid structure as an aperture that gives large near-field intensity and small near-field spot size simultaneously instead of square aperture in the various NFO systems

## 7. Conclusions

The aperture in the conical or pyramidal structure is convenient in the application of the aperture to the practical near-field systems, because it is easy to bring the aperture close to the object. The I-shaped aperture, which has been proposed previously, in a pyramidal structure on a thick metallic screen is investigated in this paper. It is found that this aperture also provides both high emission intensity and small spot size simultaneously through excitation of the surface plasmon polariton on the sidewalls of the I-shaped aperture in the pyramidal structure. Unfortunately, under the condition that the distance from the entrance to the exit of the aperture is same between the aperture in the pyramidal structure and in the flat screen, the near-field intensity of the aperture in the pyramidal structure is smaller than that of the aperture in the flat screen. However, the I-shaped aperture in the pyramidal structure gives much higher near-field intensity and much smaller spot size than those of conventional simple square aperture. A lot of parameters exists in the I-shaped aperture in a pyramidal structure shown in Fig. 1 and it will be important to optimize these parameters in the practical application of the idea in this paper to the practical near-field optical systems.

## References

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