بیستمین کنفرانس اپتیک و فوتونیک ایران
و ششمین کنفرانس مهندسی و فناوری فوتونیک ایران
۸ تا ۱۰ بهمن ماه۱۳۹۲ - دانشگاه صنعتی شیراز

افزایش عبور نوری از یک نانو-شکاف با بهره گیری از یک کاواک نانو-آنتن

حمید رضا زنگنه و مرضیه اسدنیا فرد جهرمی

دانشگاه کاشان, گروه لیزر و فوتونیک

چکیده – در این مقاله نشان داده می‌شود که عبور غیر عادی نوری از یک نانو شکاف عمودی, با جایگزین کردن شکاف با آرایه‌ای از شکاف‌ها افزایش می‌یابد. یک کاواک نانو آنتن, شامل یک شکاف نانو متری در یک ورقه فلزی است که در بالای شکاف یک نوار فلزی کوچک قرار دارد. در این مقاله مشخصه‌های عبور نور از ساختار پیشنهادی با روش تفاضل محدود در دامنه زمان *(FDTD)* مورد تحلیل و بررسی قرار می‌گیرد. محاسبات عددی نشان می‌دهد که در یک طراحی مناسب, نانو آنتن می‌تواند میزان عبور نور از نانوشکاف را ۳/۵ برابر افزایش دهد. چنین ساختاری کاربردهای فراوانی برای طراحی دستگاه‌های نوری در ابعاد نانو متری دارد.

کلید واژه- امواج پلاسمونیک, موجبر, اپتیک یکپارچه

Optical transmission enhancement through a nanoslit with a single nanoantenna cavity

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Abstract- We have numerically showed that the extraordinary optical transmission of light through a vertical nanoslit in a metal film can be enhanced by replacing the slit with an array of slits. A nanoantenna cavity is formed by a nearby metallic nano-strip over the nano-slits. Using finite difference time domain (FDTD) method, we have studied the transmission properties of the proposed structure. It is shown that in a well chosen geometric condition the optimized cavity antenna can enhance greatly the transmission of light through a lateral nano-slit (about 5.3 times). The transmission spectrum of the structure can be tuned by adjusting the size or the distance between the lateral nano-slits as well. Such structure has promising applications in designing optical nano-scale devices.

Keywords: plasmonic waves; integrated optics; waveguide.

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1 Introduction

Discovery of extraordinary optical transmission (EOT) of light through sub wavelength hole arrays, there has been considerable interest in the manipulation of light in nanoscales. The extraordinary optical properties including beam[1], local field enhancement[2] and beam focusing have been extensively studied. It has been confirmed that surface Plasmon polaritons (SPPs) play an extraordinary role in this phenomenon.

Recently, many studies have focused on enhancement of light in small volumes, such as a hole or a slit in an opaque screen [3, 4]. For example, enhancement of light in the sub wavelength aperture surrounded by the layered films consisting of metal and dielectrics has been studied [5]. Some techniques are proposed to enhance EOT through a nano-slit. It has been shown that the EOT through nano-apertures can be effectively enhanced by utilizing optical-antennas [6]. Gold nano spheres on the surface of Si solar cell are applied to increase the spectral response of the thin-film cell [7]. A gold nano rod can work as an optical antenna with the tunable resonant frequency over a very broad spectrum.

Most recently a resonant cavity antenna has been introduced to enhance the transmission efficiency to η =17.5 (124% larger than η =7.8 for a resonant bare nano-slit) [8], which is not high. It is worth to note that the nano-strip and metal film form a resonant nano-cavity antenna. Field in the resonant nano-cavity antenna is influenced by the reflected field in the straight nano-slit. Thus, the dimensions of the structure must be designed carefully to become a non-resonant cavity at the operated wavelength.

In another work the array of nano-metallic strips are applied as an array of antennas to enhance the transmission efficiency, through a nano-slit in a metal film. It has been shown that the relatively high amount of transmission efficiency of η=128.3 can be achieved which is 16.4 times of that for the bare resonant nano-slit [9]. However this structure is bulky and difficult to use in small size devices. Due to this property, the application of metal slits in designing optical nano-devices is limited. The aim of this paper is to further enhance EOT through an array of slits using one nano-cavity antenna in small size devices. Since we use a single strip in our structure, it is easier to fabricate and it is designed to be more efficient than previous jobs. A two-dimensional finite difference time domain (FDTD) method is performed to investigate the EOT through the metallic nano-slits [10]. We use a computational window size of 2.7μm by 2.2μm with a minimal grid spacing of 0.01nm. The perfectly matched layer (PML) has been applied to boundaries of the simulated area.

2 Results and discussion

First, we consider the case of transmission enhancement with a single nano-antenna. Fig 1 (a) shows the two dimensional schematic diagram for a metallic rectangular nano-strip over a metallic vertical nano-slit. A TM polarized plan wave (with the magnetic field perpendicular to the x-z plane) with wavelength λ_0= 1.5μm is chosen to inside normally from the top of the structure. The metallic nano-strip over the nano-strip seems to block the incident light. However, during the formation of a resonant nano-cavity antenna, the nano-strip can couple more incident light in to the nano-slit and thus enhance the transmission. The physical mechanism has been explained in detail in Ref [9].

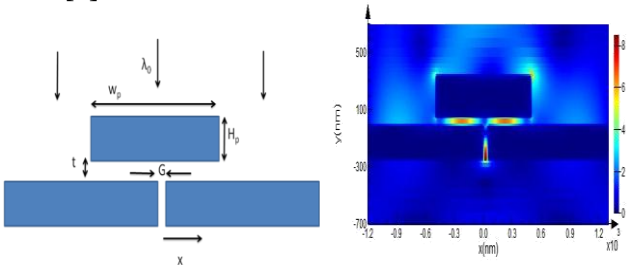


Fig. 1. (a) Schematic of the simulated structure and geometric parameters. Both the film and the nano-strip are made of silver (εAg= -48.8+3.16i [19]). (b) Distribution of the magnetic field Hy with W_p=1 μm and thickness of Hp=300nm, G=40nm and t=44nm. The X arrow in fig (a) shows the beginning of the X axis in fig (b).

The T-shaped cavity consists of the horizontal metal-insulator-metal(MIM) waveguide cavity (nano-cavity antenna) and the vertical MIM slit

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cavity. The fabery-Perot resonance in the slit region dominates the profile of transmission efficiency. There is maximal transmission when the accumulated phase is even integer of $\pi/2$, minimal transmission for odd integer of $\pi/2$ which is due to destructive interference of gap SPPs wave [8]. Fig. 1 (b) shows the distribution of the magnetic field Hy when a silver nano-strip (with W_p=1 μm and thickness of Hp=300nm) is over the silver film (t=44nm). It can be seen that the metallic nano-strip collects the incident light effectively in the nano-slit.

The transmission efficiency η is defined as the ratio of the z-component of the pointing vector in the output opening to the integration of the pointing vector over the input opening of the bare slit. To show the effect of metallic strip on transmission efficiency, we have plotted fig. 2.

To achieve an efficient transmission, the width of the metallic nano-strip should be carefully designed and its height should also be small enough to form a resonant cavity. When we chose W_p=1μm and Hp=300nm the transmission for the resonant nano-slit can be greatly enhanced to η=8.5 (184% larger than η=4.61 for a resonant bare nano-slit). The same configuration is also used in Ref. 8.

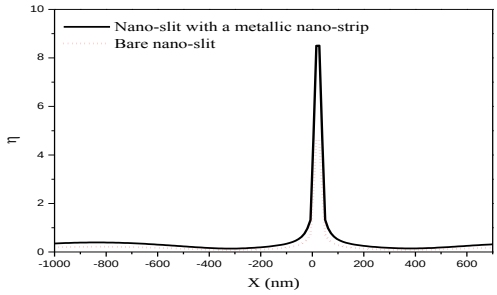


Fig. 2. Transmission efficiency η of nano-slit on x direction, without the nano-strip (dashed line) and with the metallic nano-strip (solid line).

The light transmission enhanced by a single nano-antenna is still not high enough. This can be improved by replacing the slit with an array of slits. Fig. 4 shows the 2D schematic diagram and the $|H_y|$ distribution of an array of nano-slits, consist of the vertical nano-slit of G=40 nm and a lateral nano-slit (on the left of the vertical nano-slit) with the distance d.

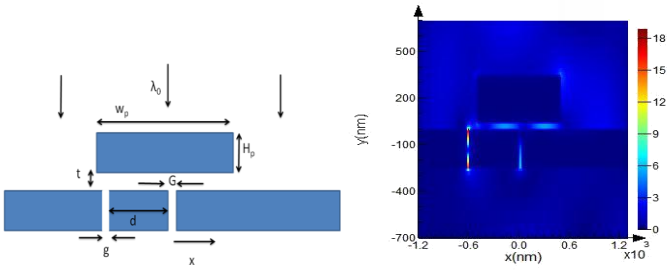


Fig. 3. (a) Schematic of the simulated structure consists of two nano-slits with distance d. (b) distribution of the magnetic field Hy with W_p=1 μm and thickness of Hp=300nm, G=40nm and t=44nm and g=10 nm.

Our numerical simulation results indicate that both the position and size of the lateral nano-slit g influence significantly the transmission of light through the nano-slits. Fig 4 shows the transmission efficiency for different values of d.

Fig. 4 indicates that the maximum enhanced transmission through the nano-slits is quite high η=19.66 at d=300nm which is 4.2 times of that for the bare resonant nano-slit (η=4.61) and 2.31 times larger than that for a single nano-slit with a nano-cavity antennas (η=8.5). The width of the lateral slit can be effective on the transmission spectrum. Fig. 5 indicates that the maximum enhancement of EOT is achieved when the lateral slit width is considered as 10 nm.

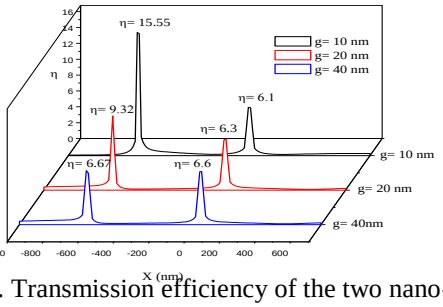


Fig. 4. Transmission efficiency of the two nano-slit structure for different size of the lateral nano-slit (g).

Further efficiency can be achieved with the use of two nano-slits around the central nano-slit, one in the left and the other in the right. Fig. 5 (a) shows the schematic of the proposed structure. Calculations show that in this case, the transmission efficiency can be enhanced to η=24.47 in the left nano-slit (for D=200 nm in fig. 5 (a)) which is 5.3 times of a resonant bare nano-slit (it means 403% larger than η=4.61 of bare nano-slit) and 187% larger than η=8.5 for a nano-cavity antenna with one nano-slit. This result is 40% larger than the highest transmission reported using a nano-cavity antenna η=17.5[8]. Fig. 5 (b)

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shows the results of the calculations for the dependence of the transmission efficiency on the position of the two lateral nano-slits when the position of central nano-slit is fixed.

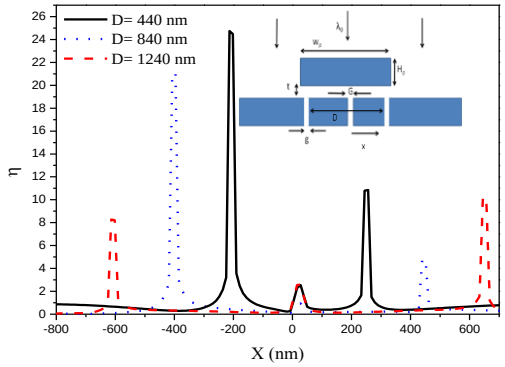


Fig. 5. (a) Schematic of the simulated structure consists of two lateral nano-slits with distance D around the central nano-slit. (b) Dependence of the transmission efficiency on the distance between the two lateral nano-slits and distribution of the magnetic field Hy.

Conclusion

We have introduced a novel model of nano-cavity antenna to achieve more transmission efficiency enhancement of the nano-slits using a single nano-strip. It has been demonstrated that using two lateral nano-slits around the central nano-slit the transmission efficiency can be enhanced up to 187% of when only one central nano-slit is used. This result is 40% larger than the highest transmission reported using a nano-cavity antenna. To achieve an efficient receiving antenna for light conversion from incident light the dimension of the metallic nano-strip, size and position of the lateral nano-slits should be carefully designed. The transmission spectrum of the structure can also be tuned by adjusting the size or the distance between the lateral nano-slits and has promising applications in designing optical nano-scale devices.

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