Light enhancement by Metal-Insulator-Metal Plasmonic Focusing Cavity

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Abstract- **A Metal-Insulator-Metal (MIM) Plasmonic Focusing Cavity is simulated. The structure includes a large upper metallic grating to couple incident light into the cavity and a small lower metallic grating to couple the light into the Avalanche Photodiode (APD) below the MIM cavity. Our results provide a possibility to reduce the dark current of an InGaAs/InP APD operated under the Geiger mode through decreasing the Photo-sensitive area, while remaining the high detection efficiency.**

I. INTRODUCTION

Geiger-mode Avalanche Photodiode (APD) is widely used in single photon detection, especially Si APDs in the visible range [1]. For the near infrared range, InGaAs/InP APDs would be the best choice due to the simplicity and stability of fabrication and a moderate working temperature [2-3]. However, owing to materials defects, InGaAs/InP APD suffers from dark current that are orders of magnitude higher than for their Si counterparts [4]. An effective method is to reduce the photo-sensitive area, but the quantum efficiency is sacrificed. So, how to reduce the dark current while keeping the high quantum efficiency is crucial to a Geiger-moded InGaAs/InP APD.

In this paper, a Metal-Insulator-Metal (MIM) Plasmonic Focusing Cavity is integrated with an APD. Through the MIM cavity, light from a large incident area is efficiently coupled to a small output area. The output light is confined and propagates straight to the APD under the cavity with little divergence.

II. SIMULATION RESULTS

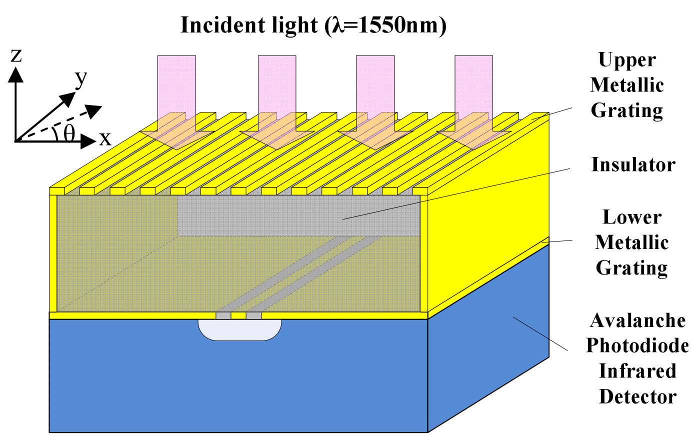

Fig. 1 Schematic diagram of MIM cavity

The structure in our simulation is shown in Fig. 1. The MIM cavity consists of three layers: the SiO_2 insulator layer, two metallic gratings on its upper and lower side. The upper Metallic grating is composed of periodic Au bars, and the lower Metallic grating is composed of a center Au bar and two Au plate on its two sides. The thickness of Au is 0.1μm and the thickness of mid SiO_2 is 0.3μm. Fig. 2 depicts the cross section of the simulated structure. p is the period of the upper metallic grating and d/p is the duty cycle. For the wavelength of 1.55μm, p=1.12μm, d=0.7μm. APD is placed under the MIM cavity, with the active region area a little lager than the lower metallic grating.

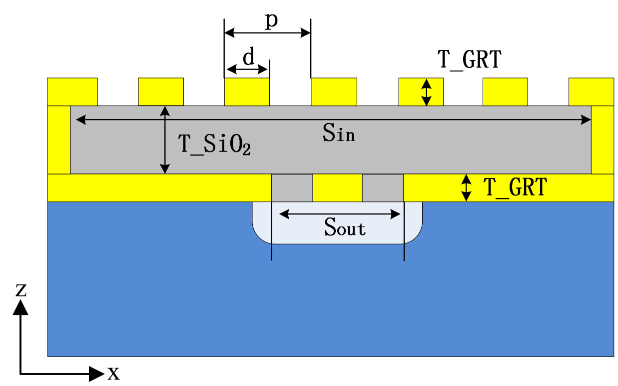

Fig. 2 Cross section of MIM cavity

The transmission spectrum of MIM cavity is shown in Fig. 3. The peak transmission located at 1.55μm reaches 63.7%.

$$\frac{\frac{P_{out}}{S_{out}}}{\frac{P_{in}}{S_{in}}} = \frac{P_{out}}{P_{in}} \cdot \frac{S_{in}}{S_{out}} = T \cdot \frac{S_{in}}{S_{out}} \quad (1)$$

We consider $\frac{P_{out}}{S_{out}} / \frac{P_{in}}{S_{in}}$ as the light enhancement factor, as shown in Eq. (1). T is the transmission of the MIM cavity. Fig. 4 shows the relationship of the light enhancement factor Vs the number of period of the upper metallic grating. We can see that the light enhancement factor increases with the number of period, and comes to saturation at about 30 periods, which is approximately 9.3 at this point. For the 30 periods, the incident width is 33.6μm, which is similar to the diameter of the commercial APD.

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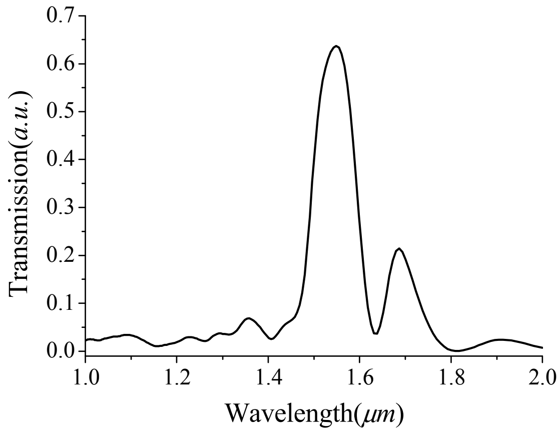

Fig. 3 Transmission spectrum of MIM cavity

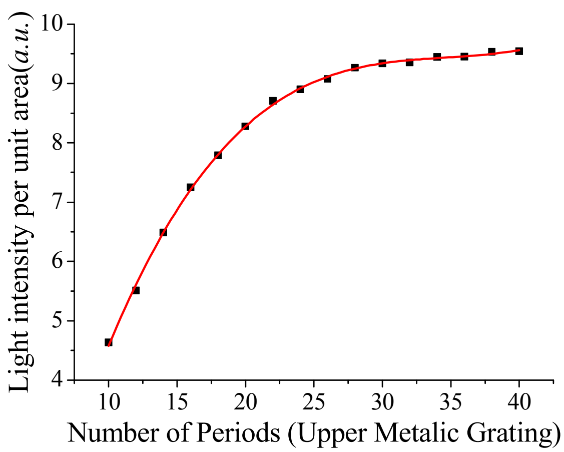

Fig. 4 Light intensity per unit area varying with the number of periods in the upper metallic grating

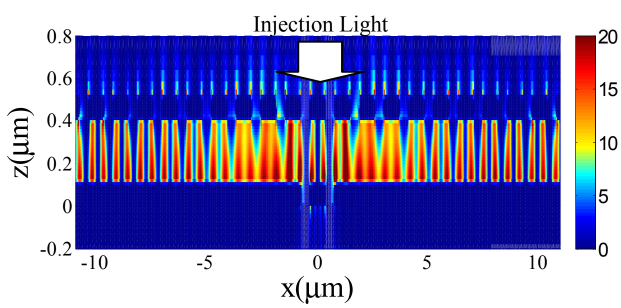

Fig. 5 $|Ez|^2$ distribution at 1.55μm

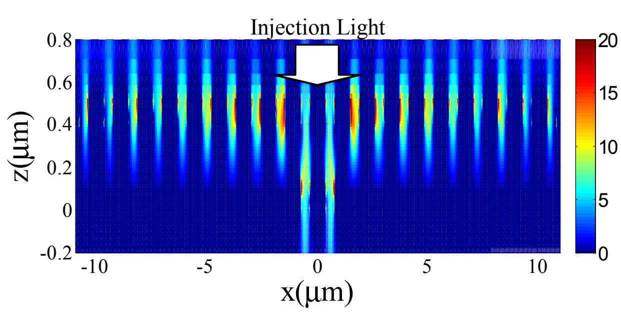

Fig. 6 $|Ex|^2$ distribution at 1.55μm

Fig. 5 and Fig. 6 show the electric field distribution through the MIM cavity. TE light is vertically incident to the MIM cavity. The cavity is located between 0 and 0.5μm in the z direction. As shown in Fig. 5, after passing through the upper metallic grating，light resonate strongly inside the cavity as TM mode, and propagate out from the lower metallic grating as TE mode again, as shown in Fig. 6. From Fig. 6, we can see that the output light from the lower metallic grating goes straight along the z direction in a confined angle and propagate 2μm with only a divergence angle of $\pm 0.3°$. This ensures that the enhanced light can reach the absorption layer of the APD.

Fig. 7 shows the transmission spectrum of MIM cavity with varying the polarization of incident light. The incident light direction is normal to the metal layer with polarization angle θ, as shown in Fig.1. The peak transmission at 1.55um drops off as the polarization angle increases, with a ratio of 52 between polarization angle of 0° and 90°. The high polarization selection is very useful for quantum cryptography, which takes polarizations as code modes.

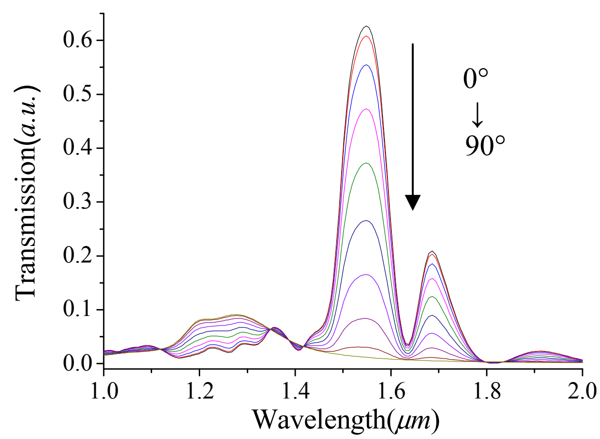

Fig. 7 Transmission of MIM cavity with varying the polarization of incident light

III. Conclusions

The MIM cavity could effectively couple the light from a large incident area to two subwavelength holes. The high light enhancement factor and the convergence of the output light make it possible to reduce the APD's width to a few micrometers while remaining the high quantum efficiency.

Acknowledgment

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