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# Transmission Resonances in Sub-Wavelength Metallic Gratings for Applications to All-Optical Switching.

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**Abstract:** We study the plasmonic transmission resonances of a metallic grating with sub-wavelength period and extremely narrow slits. We point out their possible use for a low-power all-optical switch.

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## Introduction

Scattering of the electromagnetic radiation from metallic gratings [1] has attracted much attention since the beginning of the last century where Wood [2] noted an uneven distribution of the diffraction orders reflected from them under TM polarization of the incident light (i.e. the H-field parallel to the grooves of the grating). In our paper we use to the so-called Fourier Modal Method (FMM) [3] to study the transmission resonances from a silver grating with strongly sub-wavelength slits for a range of the incoming radiation which encompasses the extreme UV, visible and near-IR part of the electromagnetic spectrum, namely from 240nm to 1500nm, and incident angles from  $0^0$  to  $90^0$ . In the FMM technique, for the linear case, the power transmitted at the output of the grating divided the power incident on the grating can be expressed as follows:

$$T(\lambda, \vartheta) = \frac{n_{inc}}{k_0 n_{out}^2 \cos \vartheta} \sum_m |t_m|^2 \operatorname{Re} \left[ \sqrt{n_{out}^2 k_0^2 - \alpha_m^2} \right], \quad (1)$$

where  $k_0 = 2\pi/\lambda$  is the vacuum wave-vector,  $n_{inc}$  and  $n_{out}$  are respectively the refractive index of the input and output medium ( $n_{in} = n_{out} = 1$  in our case),  $\vartheta$  is the incident angle of the incoming wave on the grating,  $t_m$  is the complex transmission coefficient of the  $m$ -th diffracted order,  $\operatorname{Re}$  indicates the real part, and finally  $\alpha_m$  is the generalized transverse wave-vector.

## 2. Results and Discussion

We start our analysis by showing in Figs.1 the four types of transmission resonances that, for exposition purposes, we name respectively Type I, Type II, Type III and Type IV resonances. A careful study of these resonances would reveal that they can be linked to the excitation of short-range (Type I and Type II) and long-range (Type III and Type IV) plasmons. Type II and Type III resonances are grazing angle resonances: in this conference paper we will not concentrate further on these resonances. Indeed we would like to study in particular Type I and Type IV resonances. In Fig.1(a) is shown the Type I resonance which at normal incidence is located exactly at  $\lambda_{res} = 640\text{nm}$ , i.e. double the period of the grating ( $\lambda_{res} = 2\Lambda$ ), with a transmission maximum reaching almost 0.7 (or equivalently 70% of the incoming power). It is interesting to note that this resonance manifests strong wavelength dependence and weak angular dependence, as it can be also appreciated from Fig 1(c). The weak angular dependence was first predicted in Ref.[4] for the waveguide-type transmission resonances found at  $\lambda_{res} \gg \Lambda$ , i.e. for wavelengths much larger than the period of the grating.

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In our case we find the same characteristic, but for a resonance not too far from the grating period ( $\lambda_{\text{res}} \sim 2\Lambda$ ). In Fig.1(c) is shown the Type IV resonance (in front of the Type I) which has a peculiar ridge-like shape similar somehow to a photonic band edge resonance. This resonance is also characterized by an extremely narrow bandwidth ( $\sim 1\text{nm}$ ), which makes it an optimal candidate for a low-power all-optical switching device, for example. It could be very intriguing to study the optical bistability of these Type IV resonances by filling the grating's slits with a Kerr medium. In fact these resonances seem to show all the characteristics necessary to achieve a low-power all-optical switching: they are very narrow, the electric field is highly localized in the slit, and moreover, given their particular ridge-like nature, the switch could take place either for positive and negative values of the  $\chi^{(3)}$  coefficient.

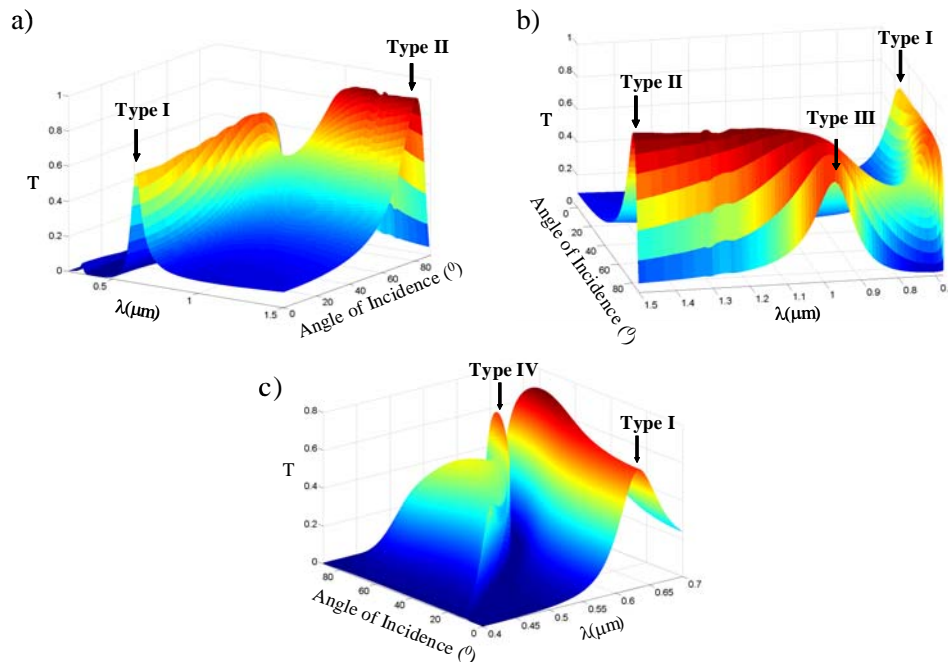


Fig.1. T vs. wavelength ( $\lambda$ ) of the incoming wave and incident angle ( $\theta$ ). The incident wavelength ranges from 240nm to 1500nm and the incident angle from  $0^\circ$  to  $90^\circ$ . The different views shown in the three figures help us to better put into evidence the peculiar characteristics of the resonances. The grating is made of Ag (silver) with period of 320nm, slits aperture of 32nm and thickness 150nm. The complex relative permittivity of Ag ( $\epsilon_{\text{Ag}}$ ) is taken directly from experimentally measured data available in literature [5]

### 3. Conclusions

In conclusion we have discussed some interesting properties of the transmission resonances of sub-wavelength metallic gratings with extremely narrow slits in a quite broad spectral range from UV to near-IR and incident angles from  $0^\circ$  to  $90^\circ$ . We have enucleated four different types of resonances, we have studied their peculiar characteristics and pointed out their possible use for a low-power all-optical switch.

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