Impact of Tapered Nano-Slits Grating on The Optical Enhancement of Photo-Sensing Devices

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Abstract: A nano-grating structure with a 5nm slit and 15 nm thickness was simulated. Optical enhancement, which can be harnessed to improve photo-sensing devices such as photodetectors and biosensors, was calculated for various tapered nanoslits.

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A metallic structure geometry with nanoscale features can be considered as one factor that can control surface plasmon resonances (SPRs). Plasmons, which are the harmonic oscillations of free electron sea in a piece of metal, can generate electromagnetic waves that may strongly couple with incident light and produce new electromagnetic modes, called surface plasmon polaritons (SPPs). Such modes can enhance the so-called *local field* (E_{local}). The local electric field strength could become much greater or smaller than the incident electric field (E_o), depending on the nanostructure geometry, incident wavelength, polarization, and optical properties of surrounding medium. The local field appears as "hot spots" near the metallic nanostructures, thereby improving the near fields in the surrounding media. Optical enhancement, that is the squared ratio between the local and incident electric fields, can play an important role in different areas of nanoscience. For example, this phenomenon can be used to enhance various photo-sensing applications such as photodetectors[1–3], photovoltaics[4,5], biosensing[6,7], and surface-enhanced Raman spectroscopy (SERS) [8–10].

It has been proven that optical enhancement of a gold nanostructure with tapered nanoslits and surrounding media, air and air/glass, can be greater than that with straight nanoslits [11]. This work studies the impact of tapered nanoslits on the optical enhancement in the GaAs substrate when the periodicity is less than 410 nm, wire thickness $t = 15$ nm, and the separation nanoslit opening at the bottom is $g = 5$ nm. The taper angle (α) and wire width (w) are swept from 0^o to 60^o and 30 to 405 nm with a step size of 2^o and 15 nm, respectively. An illustration of the modeled nanostructures is shown in Fig. (1). The model consists of two nanowires separated by a nanoslit, where (a) shows a straight nanoslit ($\alpha = 0^o$) and (b) with a tapered nanoslit. Light with a wavelength of 875 nm is simulated as normally incident on the metallic structures, which constitute a plasmonic grating. This is one technique that can excite surface plasmons and enhance the incident electric field in the GaAs due to constructive interference effects. The electric field distributions are illustrated in (c) and (d) for the taper angles shown in (a) and (b). They show that the electric field in case of $\alpha = 60^o$ is much larger than that in the $\alpha = 0^o$ case.

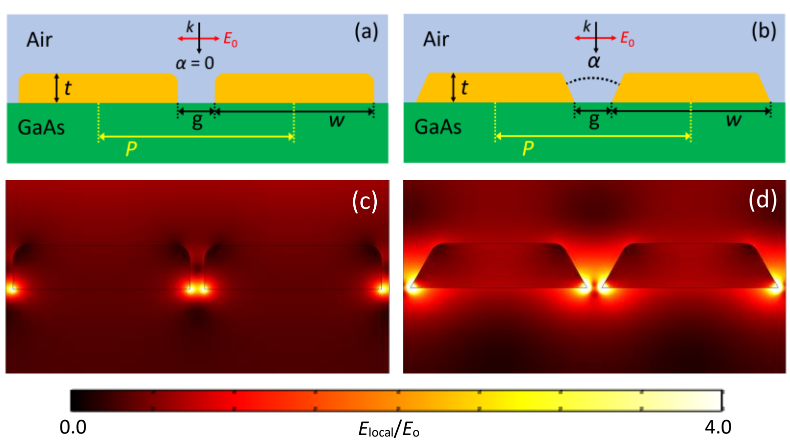

Fig. 1. Schematic illustration of the gold nanostructure grating on a GaAs substrate (a) with straight nanoslit (b) with tapered nanoslit. The electric field distributions are represented in (c) and (d). For both (c) and (d), $w = 60$ nm (bottom wire width) but $\alpha = 0^o$ and $\alpha = 60^o$, respectively.

Such a difference in enhancement can be attributed to the wire bottom edges, which are sharper in case of $\alpha = 60^o$, as this can generate more enhancement due to plasmonic coupling. Plus, a larger opening angle can collect more light, focusing it in the gap space.

Furthermore, absorption, transmission, and reflection are calculated and plotted in Fig. 2. Each plot is a color map of the calculated value as it depends on α and w. Fig. 2(a) shows the absorption that is calculated in the GaAs. In (c), the reflection at $w = 60$ nm over the range $\alpha = 24^o$ to 30^o is very high. The absorption (a) has the highest values at this range and the transmission (b) is extremely low. This implies that the largest amount of the electric field that transmits into the GaAs is absorbed, as little to no absorption occurs in other materials in the model. This ability to tune and increase the absorption can be utilized to enhance metal-semiconductor-metal photodetectors and plasmonic solar cells. In addition, the high reflectivity of this structure could be harnessed to improve the performance of biosensors and other applications such as SERS.

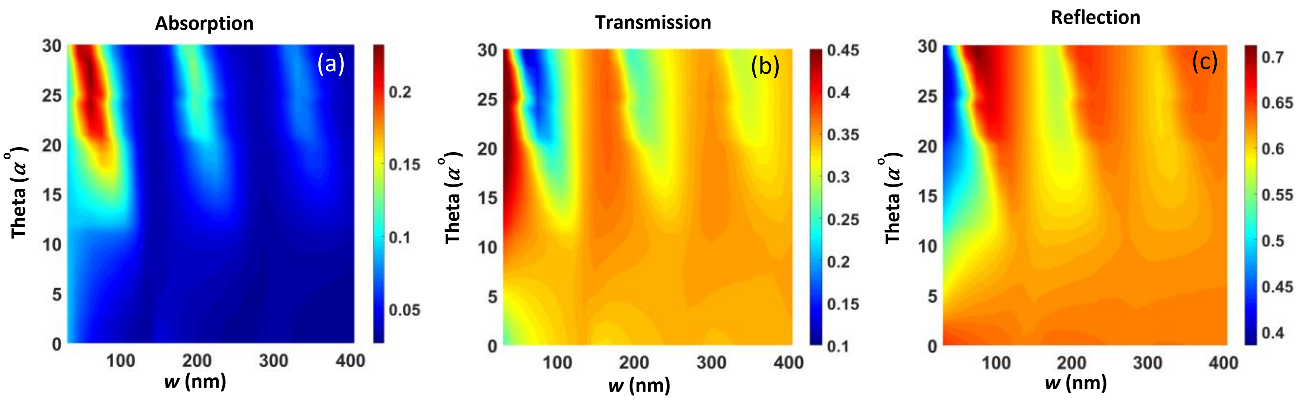

Fig. 2. Color maps of (a) absorption, (b) transmission and (c) reflection as a function of w and α. w is swept from 30 to 405 nm and α is swept from 0^o to 60^o with step sizes of 15 nm and 2^o, respectively.

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