Tunable Plasmonic Light Trapping Metal Structures

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There is a significant scientific and technological interest in zero-reflectivity substrates for enhanced light harvesting in applications ranging from photovoltaics[1] to enhanced photocatalysis to photocathodes for the next generation light sources[2]. A scheme for the complete absorption of light using a subwavelength nano-grooves (NGs) on a metallic surface has been proposed by Le Perchec *et. al*.[3]. The dimensions of these grooves are very small compared to the wavelength of light. For example, for a gold structure designed to trap 720 nm light, the NGs would be 14 nm wide by 45 nm tall. We have confirmed the light trapping effect of such structures in a recent experimental demonstration[4,5].

For many applications it is desirable to operate at wavelengths deeper into the NIR compatible with high power lasers such as Ti:sapphire (800 nm) and Ytterbium-based fiber lasers (1064 nm). A structure resonant at such wavelengths would have NGs less than 8 nm wide, which is a major fabrication challenge. In this work we present a new method for tuning the resonance of a subwavelength metallic grating in post-fabrication by coating the structure with a known dielectric. This method is well suited for tuning the absorption resonance from the visible to the near IR spectrum. Fine control over the resonance position can be readily achieved via atomic layer deposition (ALD) that allows sub nanometer control of the dielectric layer thickness.

Yet another challenge in designing an efficient metal absorber is the angle-of-incidence dependence. While for a grating-coupled system the angular bandwidth is only a few degrees, the NGs–as described above–open up a new area of possible applications due to their extreme angular bandwidth exceeding 150 degrees. In this work, we present an experimental demonstration of the ultimate tuning for the plasmonic subwavelength gratings ranging from the narrow spectral and angular bandwidth to the > 99% absorbing extreme spectral (> 350 nm) and angular (> 80^o) bandwidths metallic absorber.

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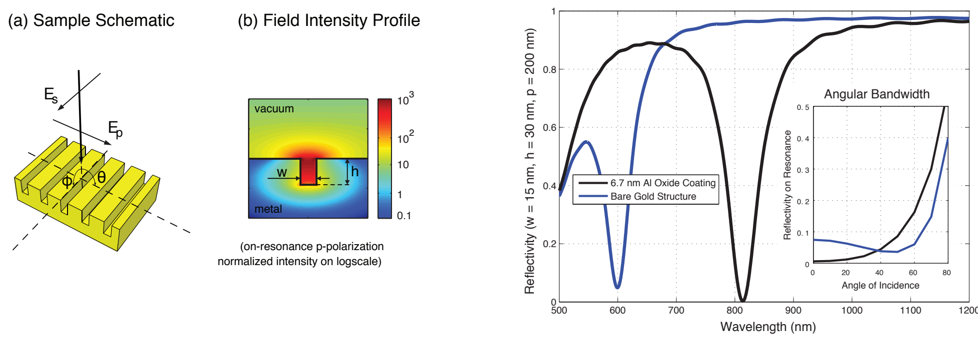

Figure 1: The schematic for the subwavelength grating is shown in (a), where the light is injected perpendicularly to the grating surface, and if polarized perpendicular to the geometry of the grooves the surface plasmon polariton (SPP) mode is excited in the groove as illustrated in (b). The groove geometry is optimized to produce a resonance at a target wavelength, which can be adjusted in post-fabrication by coating the structure with a dielectric layer. An example is illustrated showing the resonance shift in the reflectivity spectrum when a gold grating is coated with 6.7 nm of aluminum oxide. The inset figure shows that the angular bandwidth is preserved, thus allowing completely flexibility in design of a complete light trapping structure from the ultraviolet to the near infrared.

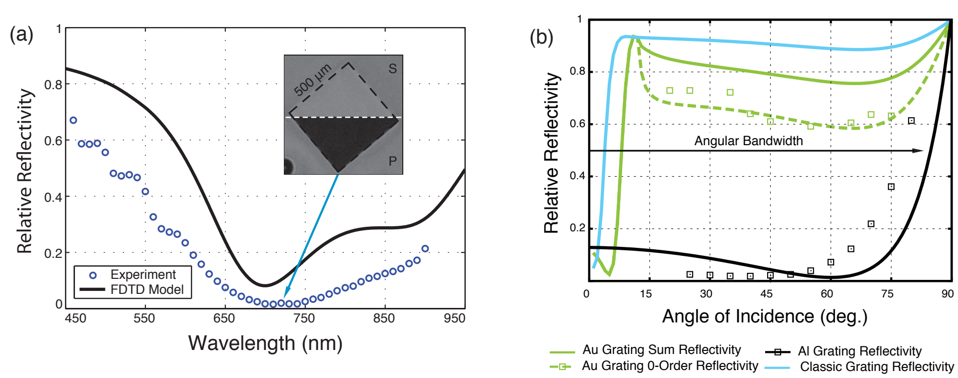

Figure 2: By choosing the period of the grating to be much smaller than the resonant wavelength the grating can be designed for an ultra-wide spectral bandwidth as shown in (a). The circles show the experimental data and the solid black line shows the FDTD model. Another advantage of choosing a small period is the increase in the angular bandwidth. In (b) the solid blue line shows the angular bandwidth of a classical grating, where the SPPs are coupled via the grating momentum. In contrast, the NG-coupled SPP modes have larger angular bandwidth. The gold grating studied in this work has the angular bandwidth as shown by the green squares (experiment) and the green solid line (FDTD model). The optical response of the aluminum grating designed for large angular bandwidth absorption is shown in black.