Light Harvesting at the Infrared

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New developments in optoelectronics and chemical sensing are based on a single subwavelength aperture drilled in an opaque metallic film, which surface is sculpted at the scale of the wavelength. In systems, like the slit-groove array (SGA) sketched in Fig. 1, surface corrugation acts like an antenna to couple the incident light into surface modes that squeeze the electromagnetic energy into the aperture [1, 2]. Surface modes are responsible of the light harvesting process. Transmission resonances can be controlled adjusting the geometric parameters of the SGA [3].We study SGA of Fig.1 in order to identify simple design rules for optimal light transmittance. Such rules are developed from the physical mechanism responsible for squeezing light into the aperture. The light harvesting process is also optimized using the conjugate gradient (CG) algorithm which uses as seed optimal values taken from simulations based on the physical intuition. We shall consider uniform and periodic groove arrays as well as nonuniform and non periodic ones. The calculations are done in the framework of the coupled-mode method with surface boundary conditions [2]. We compute the intensity of the light radiated to the far field and normalize it to the light incident on the area of the slit, this quantity, called η, accounts for the efficiency of the light harvesting process. Fig.2 shows η as a function of groove period (a), the distance from the slit to the nearest groove (b) and the groove width (c), for an optimal SGA with N_g= 10, w_s= 0.36μm, h_s = 1.28μm, P = 3.81μm, d_{sg} = 3:64μm and wavelength λ = 4.0μm. We find that Fabry-Perot(FP) and cavity modes should be at the same spectral position for the whole IR regime. For subwavelength apertures at a given λ, the position and intensity of the FP modes are controlled by metal thickness and aperture size, respectively. The spectral position for the cavity modes is mainly determined by groove depth and pitch. We also observe that transmission efficiency of a uniform SGA in the infrared is practically independent of λ. In contrast, the enhancement provided by nonuniform SGA decreases with λ. A chirped groove array enhances the transmittance between 15% and 39% for decreasing λ (not shown but discussed in [4]).

References

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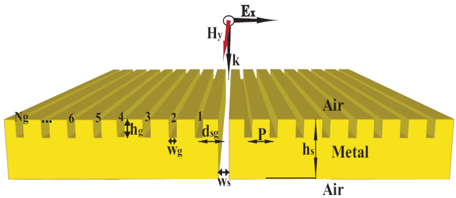

Figure 1: (Color). Schematic representation of the slit-groove array on a free-standing gold film of thickness h_s. The slit of width w_s is surrounded by $2N_g$ grooves (width w_g, depth h_g, and period P). The distance from the slit to the first groove, d_{sg}, is in principle different from P.

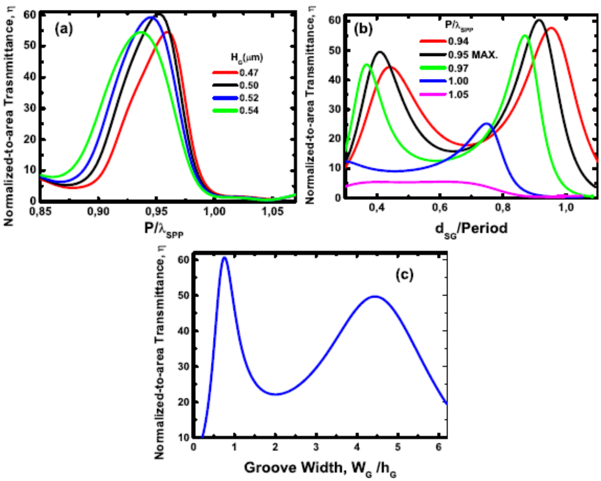

Figure 2: (Color). (a) Normalized-to-area transmittance (η) for a SGA as a function of the groove period P for groove depth increasing from h_g=470 nm to 540 nm at λ = 4:0 µm. P is normalized to λ_{spp} = 3:997 µm. (b) η as a function of the slit-first groove distance d_{sg} for several values of P/λ_{spp} taken from the black curve of (a) (h_g = 0.5µm). (c) η versus the aspect radio ($r = w_g/h_g$) for the optimal geometry of (b): P = 0.95 λ_{spp} and P = 0.91P.