Extraordinary Optical Transmission in Nanopatterned Ultrathin Metal Film without Holes

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Supplementary Information

I. PERIOD AND R/*a* VARIATION

Period Variation: We present the simulation results for different periods (*a*) = 650 nm, 700 nm and 750 nm for constant R/*a* = 0.33 in Fig. S1. It can be seen that the surface plasmon resonance peak of gold appears at same wavelength λ_{sp} ~ 504 nm for all the three cases. The EOT peak appears at a wavelength slightly smaller than *a*. Notably, the position of the transmission peak scales with the period of the structure, that is, the peak transmission wavelength increases as *a* increases. The Wood's anomaly where $T = 0$ is also seen at $\lambda_W = \sqrt{3}a/2$ ~ 580 nm, 610 nm and 650 nm for *a* = 650 nm, 700 nm and 750 nm, respectively. Corresponding to *a* = 650 nm, 700 nm and 750 nm, the EOT peak appears at wavelength λ_1 ~ 625-640 nm, 665-695 nm and 707-720 nm, respectively. For our analysis, we choose *a* = 750 nm since it is closest to the experimental structure. The precise shape of the transmission curves does not scale with *a* since the dielectric function of gold is wavelength-dependent.

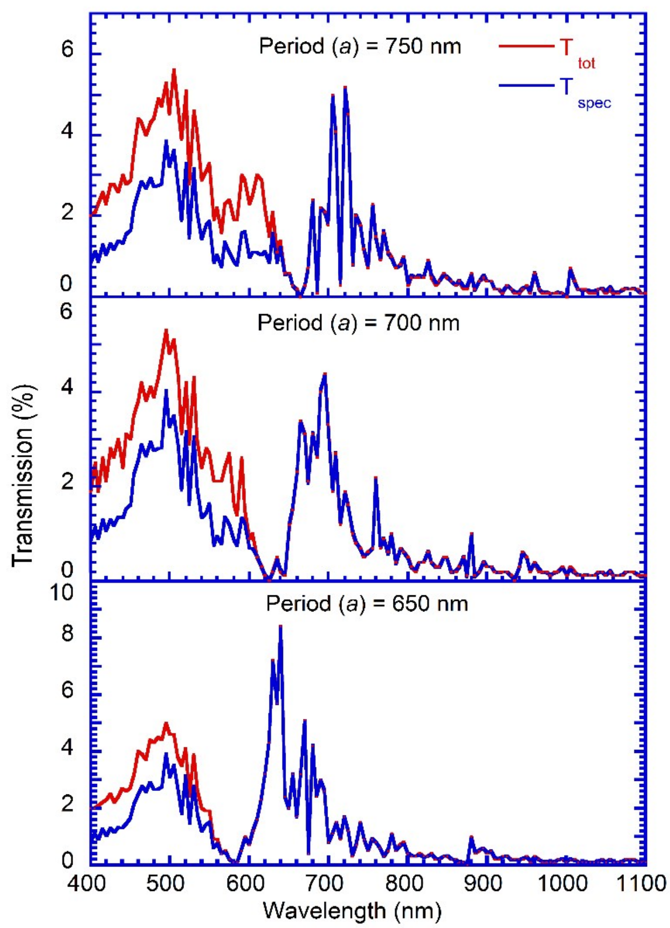

Figure S1. Simulated total transmission and specular transmission spectra for the nanocup structure with different periods (*a*) = 650 nm, 700 nm, and 750 nm. The value of R/*a* = 0.33 for all the cases.

R/*a* Variation: We present the simulation results for different R/*a* = 0.27, 0.30, and 0.33 for constant pitch *a* = 750 nm in Fig. S2. Similar to Fig. S1, the surface plasmon resonance peak of gold appears at same wavelength λ_{sp} ~ 504 nm for all three cases. Since the period is constant for all the cases, the EOT peak (~700 nm) and the Wood's anomaly point (~650 nm) appear at nearly the same wavelength. Notably, when R/*a* is decreased the EOT peak becomes narrower and the transmission intensity also reduces due to the decrease in aperture of the nanocup. We present the results in the manuscript for R/*a* = 0.33, which corresponds to the experimental structure.

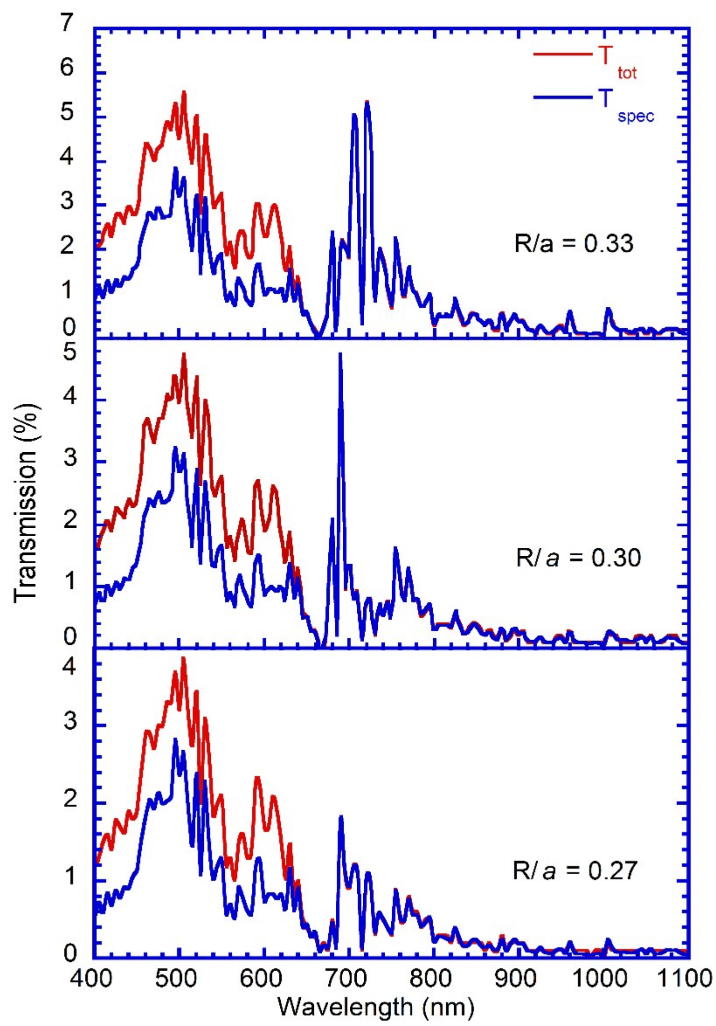

Figure S2. Simulated total and specular transmission spectra for the nanocup structure with different R/*a* = 0.27, 0.30, and 0.33. The value of period (*a*) = 750 nm for all the cases.

II. TRANSVERSE ELECTRIC FIELD PROFILE

The electric field intensity $|\mathbf{E}|^2$ at the EOT wavelength $\lambda_1 \sim 700$ nm in the x-y plane (Fig. S3) just below the surface of the nanocup shows an intensity distribution complementary to that in the *xz*-plane (Fig. 6a). The results are shown for incident field with *x* polarization. The $|\mathbf{E}|^2$ has peaks in small regions at the edges of the circular aperture where $|\mathbf{E}|^2$ is enhanced by ~50-60 in both the *xy* and *xz* cross-sections. Dipolar charge distributions are formed at the edges of the nanocup. This is typical of surface plasmon propagation along the *x*-axis (ref. 26). There are a pair of additional sub-peaks on either side of the center of the nanocup surface (Fig. S3 and Fig. 6a), where the $|\mathbf{E}|^2$ is enhanced by ~50. There is a node of the electric field at the center of the nanocup surface as seen in both Fig. S3 and Fig. 6a. Since the nanocup geometry can be envisaged as a combination of many holes of decreasing radii, we used five layers of holes with decreasing radii (R, $0.8R$, …,$0.2R$) to model the nanocup field intensity. We can see that the electric field plot in Fig. S3 is actually the superposition of well-known field intensity from a single hole (ref. 26) with field maxima lying along *x*-axis for incident field with *x* polarization.

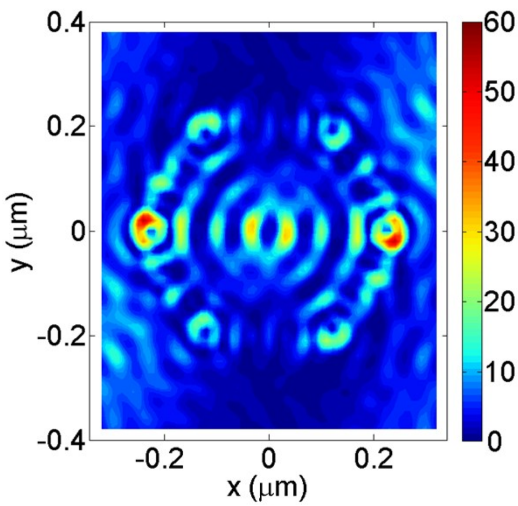

Figure S3. Electric field intensity at $\lambda_1 \sim 700$ nm showing the enhanced field in the *xy* plane just below the surface of nanocup.

III. CONVERGENCE WITH NUMBER OF BLOCH WAVES

We have investigated the convergence of the transmission with increased number of Bloch waves (N_G) per polarization as summarized in Fig. S4, using a 5 nm thick gold layer at the bottom of the nanocup corresponding to the geometry used for simulation in Fig. 4a. The scattering matrix has dimension of 2 N_G x 2 N_G. The N_G values correspond to closed shells of reciprocal lattice ***G*** vectors. The convergence of short wavelengths ($\lambda < 660$ nm = Woods anomaly wavelength, λ_W) or at longer wavelengths $\lambda > 800$ nm is very good for all the chosen N_G values. In the EOT region 650-850 nm (Fig. S4), the transmission is more sensitive to the number of Bloch waves, and we find N_G = 535, 769 are converged. Both N_G = 535 and N_G = 769 show two EOT peaks with a narrower feature around 700 nm and a broader feature (consisting of multiple peaks at 720-780 nm). These two features combine to produce the broader experimental peak centered around 704 nm.

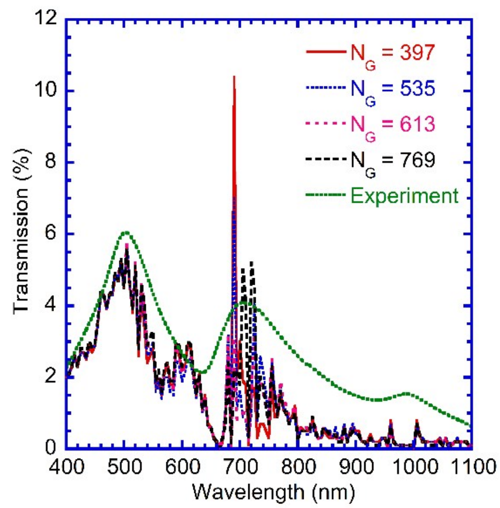

Figure S4. Simulated transmission spectra with N_G = 397, 535, 613, 769 compared to the experimental transmission.