Shape resonances in extraordinary transmission

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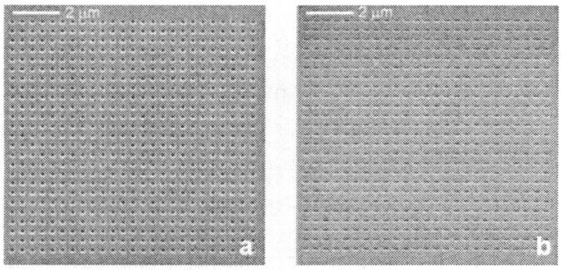
Plasmonics is an emerging field in (nano-)optics in which the excitation of surface plasmons is used to manipulate light on length scales smaller than the wavelength. The phenomenon of extraordinary transmission is one of the most beautiful examples of plasmonics: in a periodic arrangement of sub-wavelength holes in a metal film the transmitted fraction of the incident light exceeds the open air fraction of the film for certain colours (Ebbesen and co-workers, nature 1998)! This enhanced transmission has been attributed to a resonant excitation of surface plasmons set up by the periodicity of the array.

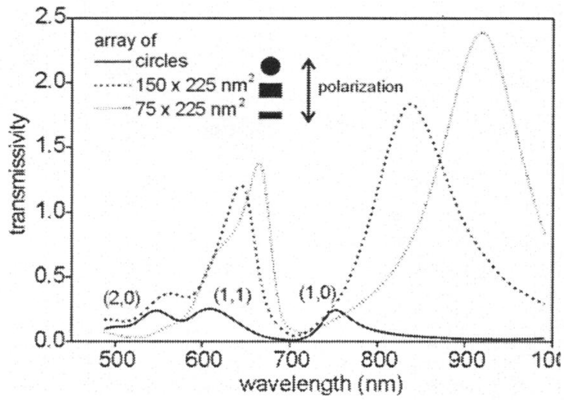
Here, we will show that this explanation cannot be the whole story.

By merely changing the shape of the sub-wavelength holes from circular to rectangular we can greatly affect the extraordinary transmission. On the one hand, we can enhance the normalized transmission by an order of magnitude. On the other hand, and maybe more importantly, the shape change induces a large *red-shift* of the transmission peaks [1]. We show that smaller shifts can even be created by simply changing the size of the holes [2]. Because in all experiments the periodicity of the arrays and the thickness of the metal film were kept constant, no spectral shifts would be expected based on a surface plasmon only explanation. By investigating the transmission of isolated holes and by determining the dispersion of the transmission peaks of the periodic structures, we prove that *localized shape resonances* in the individual holes play a crucial role (submitted). Nevertheless, we also show that the observed effects do depend on the type of metal, with metals with a low surface plasmon damping exhibiting the largest transmission (submitted). This suggests that the current understanding of the extraordinary transmission phenomenon as being *solely* due to surface plasmons is incomplete. The huge increase of the transmission implies huge optical field enhancements. Together with the fact that shape can also be used to control the spectral positions of the peaks, this finding opens new research avenues in plasmonics, like enhanced non-linear optics, sensing & lighting applications and more.

Here, our latest results on shape & size effects in extraordinary transmission will be presented.



Focused ion beam images of two periodic sub-wavelength hole arrays fabricated in a 200 nm thick Au film. Both arrays have a period of 425 nm. **a.** Array consisting of circular holes with a diameter of 190 nm. **b.** Array consisting of rectangular holes of 75 × 225 nm^2.



Measured transmissivity (transmission divided by open air fraction) spectra for 3 different hole arrays

The spectra are measured for array s consisting of circular holes (solid), large rectangle (dashed) and small rectangles (dotted). A huge enhancement of the transmissivity is observed. The (1,0) peak exhibits a large red shift.

[1] K.J. Klein Koerkamp, S. Enoch, F.B. Segerink, N.F. van Hulst and L. Kuipers, Strong influence of shape resonances on extraordinary transmission , *Phys. Rev. Lett.* **92**, 183901 (2004).
[2] K.L. van der Molen, F.B. Segerink, N.F. van Hulst and L. Kuipers, Influence of hole size on the extraordinary transmission through subwavelength hole arrays , *Appl. Phys. Lett.* **85**, 4316 (2004).