Controlling the absorption resonances of sub-wavelength cylinder arrays

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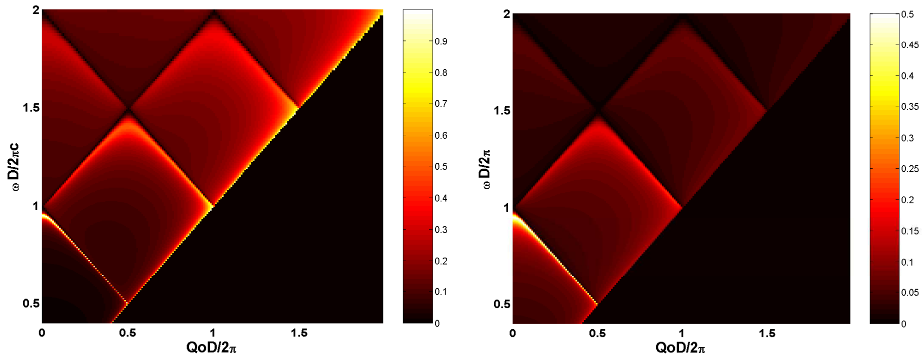
The study of light scattering from periodic structures has been a topic of interest since Wood [1] reported remarkable effects (known as Wood's anomalies) in the reflectance of one-dimensional (1D) metallic gratings. Two different types of anomalies were definitely identified by Fano [2]. One is associated to the discontinuous change of intensity along the spectrum at sharply defined frequencies and was already discussed by Rayleigh [3]. The other is related to a resonance effect. It occurs when the incoming wave couples with quasi-stationary waves confined in the grating. The nature of the confined waves depend on the details of the periodic structure [4] and is usually associated to surface plasmon polaritons in shallow metallic gratings, standing waves in deep grating grooves [4] or guided modes in dielectric coated metallic gratings [5]. Recently, the observation of enhanced transmission through a metallic film perforated by a 2D array of sub-wavelength holes [6], has led to a renewed interest in analyzing and understanding the underlying physics of both reflection and transmission "anomalies"[7–9].

The problem of absorption by gratings [10, 11] and photonic crystals [12] has also drawn much attention since the control of thermal emission (by Kirchhoff's law, equivalent to the absorption) has become a key issue in lots of application (thermophotovoltaics, infrared sources...). The role of Rayleigh anomalies, surface plasmon polaritons, standing waves in deep grooves in the resonant absorption phenomenon still need further understanding.

In this paper, we focuss on the properties of reflection and absorption of an array sub-wavelength cylinders. In absence of resonant surface modes (or surface plasmons for metallic particles) the scattering cross section of subwavelength-sized particles is very small. However, in a periodic array of small particles, the coupling of the scattered dipolar field with diffraction modes may induce a *geometric* resonance [13] close to the onset of new propagating modes (i.e. close to the Rayleigh frequencies). Following a multiple scattering approach [14], we analytically derive the resonance conditions as a function of the geometry and the polarizabilities of each individual scatterer. As we will show, in absence of absorption, it is possible to have a perfect reflected wave even for vanishingly small scatterers [13]. In the presence of losses, we predict the existence of a resonant absorption phenomenon. At resonance conditions, and for an appropriate set of parameters, we show that the cylinders can absorb up to half of the total incident power.



(a)Reflection

(b)Absorption

FIG. 1: s-polarization : Calculated reflectance R (a) and absorption A (b) in a frequency ω versus in-plane wave number $Q_0 = (\omega/c)\sin(\theta)$. The parameters of the array of cylinders are a period $D = 2\,\mu m$, a radius of $a = 0.2\,\mu m$, a real dielectric constant $\varepsilon = 5$ for (a) and a complex dielectric constant $\varepsilon = 5 + i0.85$ for (b).

Fig. 1a presents the calculated reflectance in a ω *vs.* Q_0 map (frequency versus in-plane wave number $Q_0 = k^2 \sin\theta$). For simplicity, we have considered a real dielectric constant ($\varepsilon = 5$) independent of the frequency, $a = 0.2\,\mu$m and $D = 2\,\mu$m. . The reflectance presents sharp maxima $R = R_{\max}$ at frequencies $\omega = \omega_{0m} \lessapprox \omega_m$. Just at the onset of a new diffraction channel, i.e. at the Rayleigh frequencies $\omega = \omega_m$, the reflectance goes to zero. For $\omega = \omega_{01}$, i.e. at the lowest resonance frequency,

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there is a perfect reflection ($R = 1$) even for vanishingly small cylinders (although, in these extreme cases, the resonance width $\Gamma \approx \gamma(\omega_m^2 - \omega_{0m}^2)/\omega_m$ goes to zero). Notice that for metallic cylinders or strips (with $\alpha_s < 0$) there will be no sharp resonances.

In the presence of losses, the reflection resonances become absorption resonances for very close frequencies. At resonance conditions, and for an appropriate set of parameters, we show that the cylinders can absorb up to half of the total incident power ($A_{\mathrm{max}} = 1/2$).

Fig. 1b. presents the calculated absorption in a ω *vs.* Q_0 map. For simplicity, we have considered a dielectric constant ($\varepsilon = 5 + 0.85i$) independent of the frequency, $a = 0.2\,\mu$m and $D = 2.0\,\mu$m. . In analogy with the reflectance curves, the absorption presents clear maxima at frequencies $\omega = \omega_{Am} \lessapprox \omega_m$. Just at the onset of a new diffraction channel, i.e. at the Rayleigh frequencies $\omega = \omega_m$, the absorption goes to zero. For $\omega = \omega_{A1} \simeq \omega_{01}$, i.e. at the lowest resonance frequency, the absorption reaches its maximum value ($A = 1/2$). Notice that for metallic cylinders or strips (with $\alpha_s < 0$) there is no resonant absorption.

We will also discuss the case of resonant absorption in p-polarization and study finite-size effects.

To summarize, in this work we have discussed the optical properties of an array of sub-wavelength Rayleigh cylinders. We have shown that, for non-absorbing scatterers, it is possible to have a perfect reflected wave even for vanishingly small cylindrical radii. In the presence of losses, we predict the existence of a resonant absorption phenomenon. At resonance conditions, and for an appropriate set of parameters, we show that the cylinders can absorb up to half of the total incident power. We believe that our study of reflectance resonances provide a new physical insight into the general mechanisms of light interactions with periodic structures of sub-wavelength objects.

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