Supporting Information for

Metasurfaces with electric quadrupole and magnetic dipole resonant coupling

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Supporting-Information Figure S1

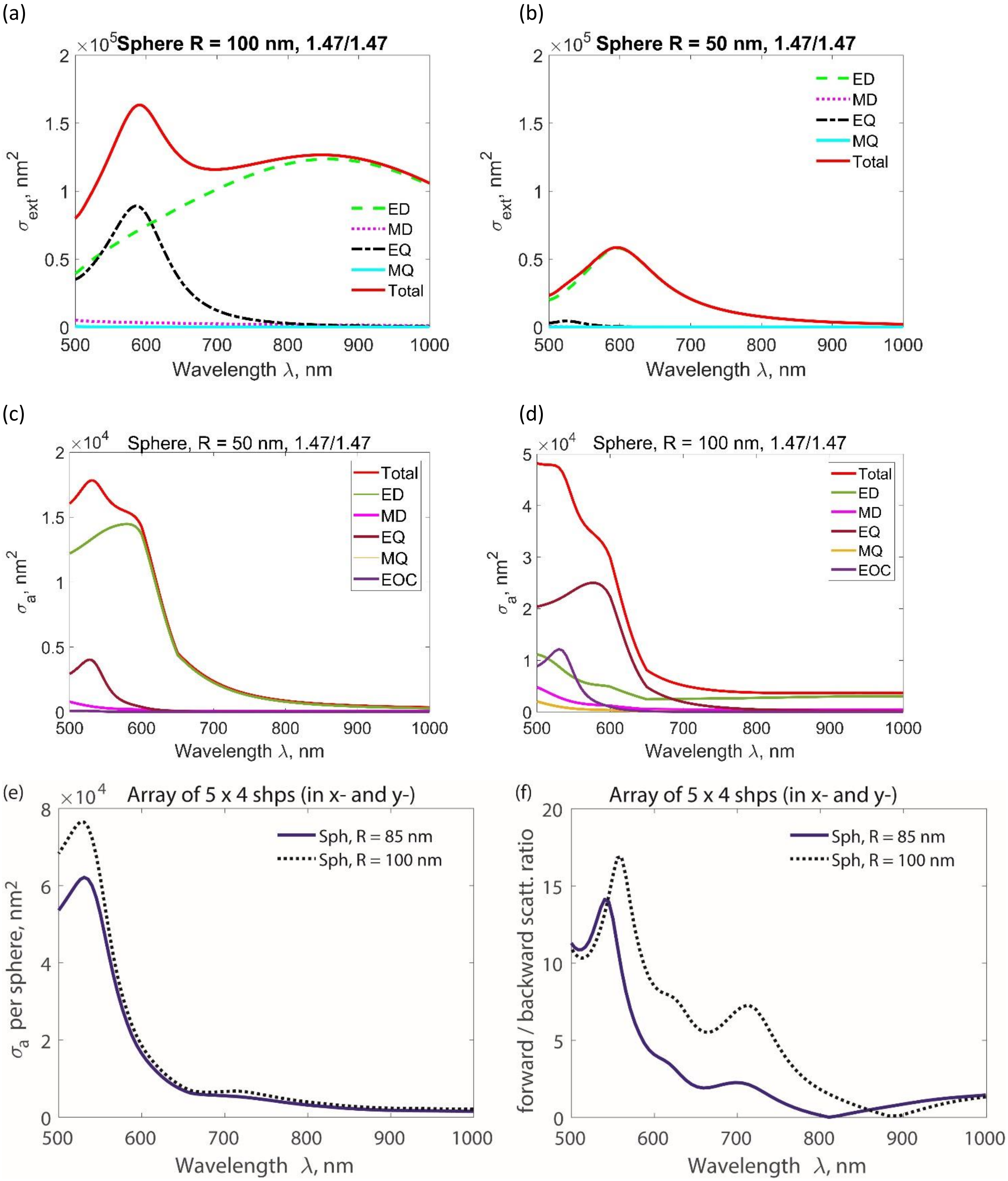

Fig. S1. (a), (b) Extinction cross-section of the sphere and its multipole decomposition calculated with Mie coefficients for the spheres with R = 50 and 100 nm. (c), (d) Absorption cross-section calculated with decomposed discrete dipole approximation and its multipole components for the spheres with R = 50 and 100 nm. (e) Absorption cross-sestion calculated with CTS Microwave Studio for the array 5 x 4 nanospheres with distances p_x = 510 nm and p_y = 250 nm. (f) Forward to backward scattering ratio from the array of 5 x 4 nanoshperes calculated the same way as (e).

Supporting-Information Figure S2

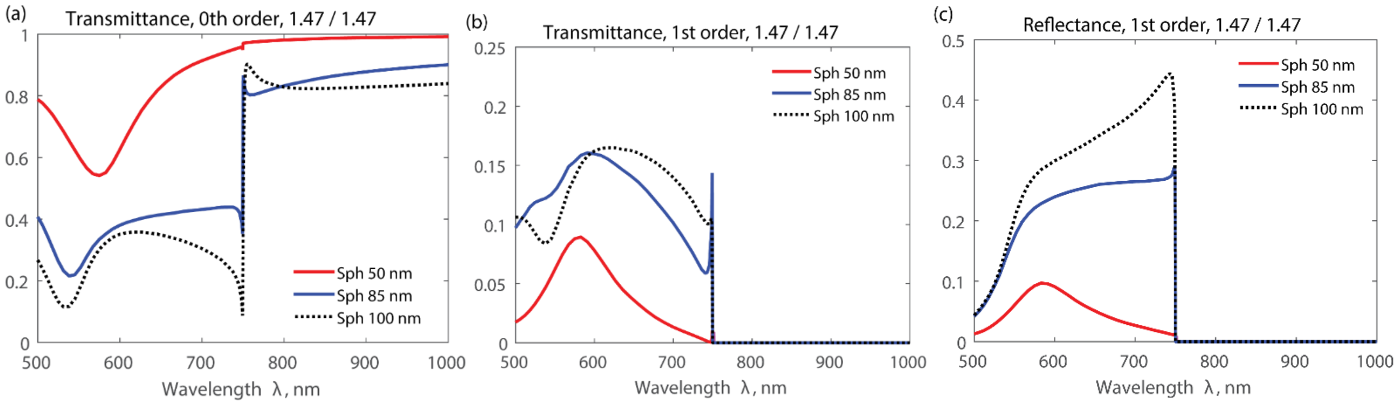

Fig. S2. Transmittance in the zeroth (a) and the first (b) diffraction orders and reflectance in the first (c) diffraction orders of the nanosphere array. Periods are p_x = 510 nm and p_y = 250 nm, the environment is homogeneous with $n = n_s$ = 1.47, and numbers denote radius R of the sphere.

Supporting-Information Figure S3

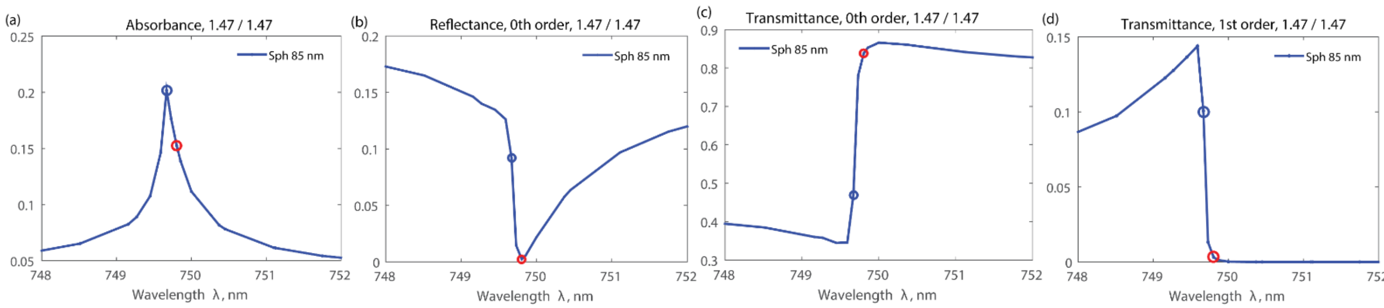

Fig. S3. (a) The absorbance of the nanoparticle array, (b) reflection in the zeroth order, transmission in (c) the zeroth and (d) the first orders of diffraction for sphere array with R = 85 nm in the homogeneous environment with $n = n_s$ = 1.47 and narrow spectral range (wavelength 748-752 nm). Periods are p_x = 510 nm and p_y = 250 nm. Blue and red circles mark the maximum of absorbance and the minimum of reflectance, respectively. One can see that that reflectance minimum and transmittance maximum almost coincide with the maximum of absorbance, where EQ lattice resonance is excited.

Supporting-Information Figure S4

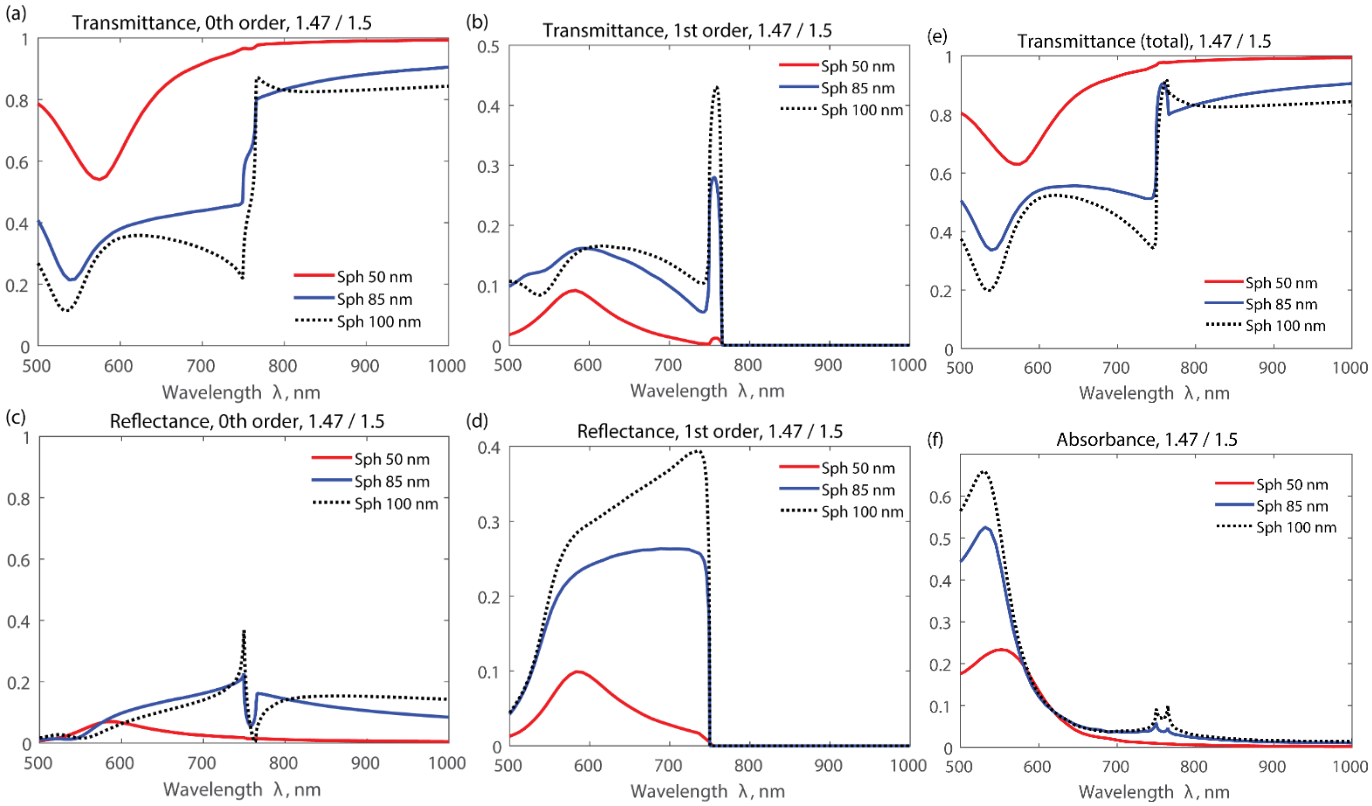

Fig. S4. Nanosphere array in the non-homogeneous environment: transmittance in the zeroth (a) and the first (b) diffraction orders and reflectance in the zeroth (c) and the first (d) diffraction orders; (e) total transmittance; (f) Absorbance. Periods are p_x = 510 nm and p_y = 250 nm. The refractive indices of the superstrate and the substrate are n_s = 1.47 and n = 1.5, respectively. Numbers denote the sphere radius.

Supporting-Information Figure S5

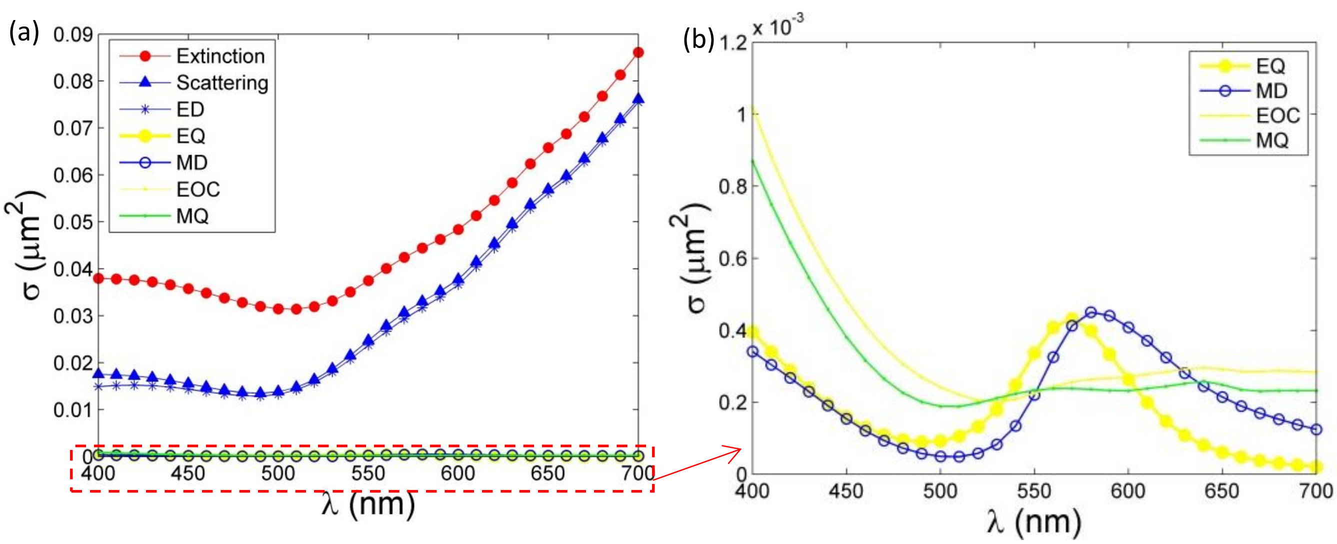

Fig. S5. (a) Total scattering cross-sections and its multipole components of the nanodisks with R_d = 85 nm and H = 50 nm in a homogeneous environment with $n = n_s$ = 1.47 calculated using a decomposed discrete dipole approximation. (b) An enlarged view of EQ, MD, EOC, and MQ, which have much smaller value than ED.

Supporting-Information Figure S6

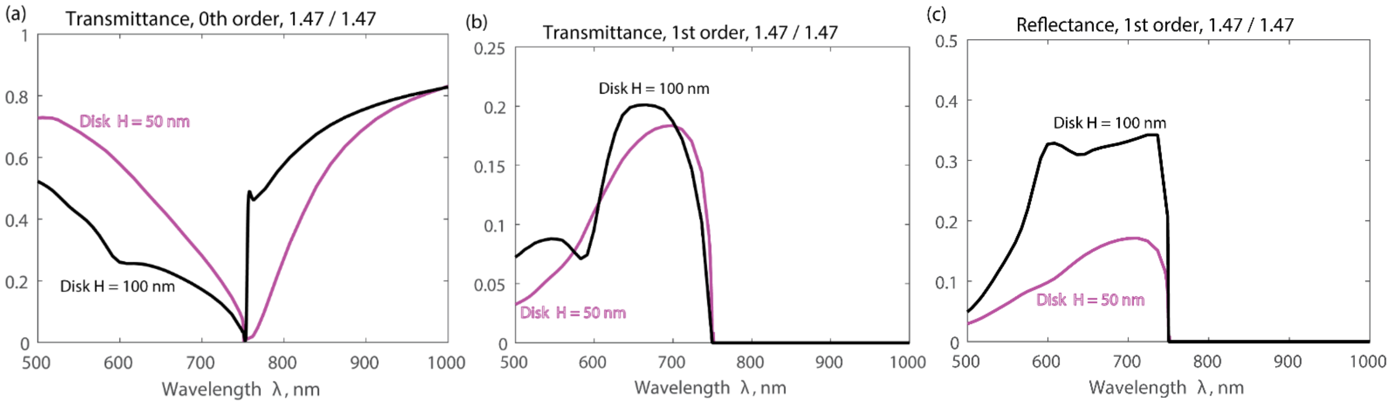

Fig. S6. Transmittance in the zeroth (a) and the first (b) diffraction orders and reflectance in the first (c) diffraction orders of the nanodisk array. Periods are p_x = 510 nm and p_y = 250 nm, the environment is homogeneous with $n = n_s = 1.47$, height H of the disk is either 50 or 100 nm, and its radius R_d = 85 nm.

Supporting-Information Figure S7

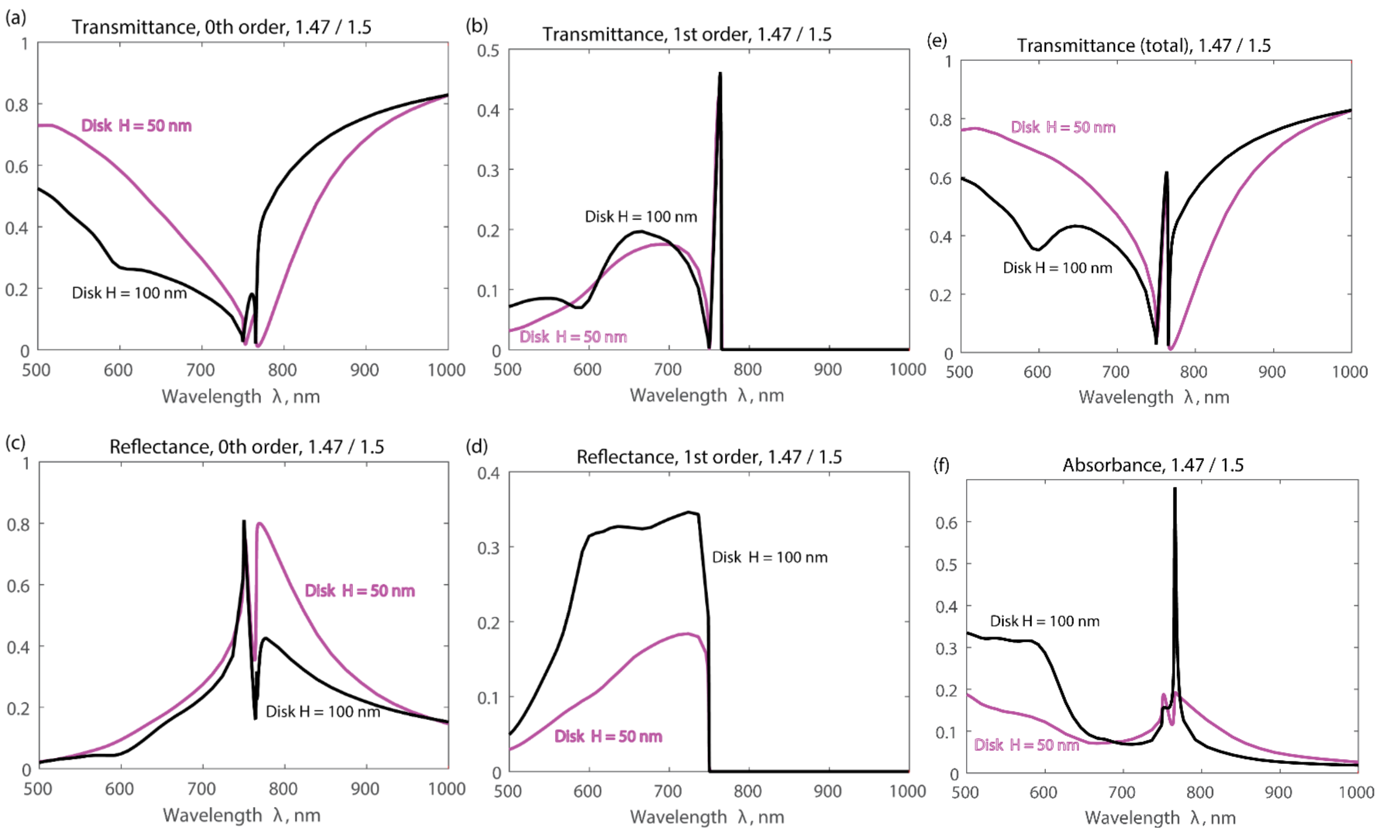

Fig. S7. Nanodisk array in the non-homogeneous environment: transmittance in the zeroth (a) and the first (b) diffraction orders and reflectance in the zeroth (c) and the first (d) diffraction orders; (e) total transmittance; (f) Absorbance. Periods are p_x = 510 nm and p_y = 250 nm. The refractive indices of the superstrate and the substrate are n_s = 1.47 and n = 1.5, respectively. Height H of the disk is either 50 or 100 nm, and its radius R_d = 85 nm.

Nanoparticle array in the non-homogeneous environment:

1) In the first diffraction order of transmission, the peak is broader and more pronounced;
2) In the zeroth diffraction order of transmission, the resonances are weaker and smeared out;
3) In the zeroth diffraction order of reflection, the feature is broader and stronger;
4) In the first diffraction order of reflection, there is no feature.

Supporting-Information Figure S8

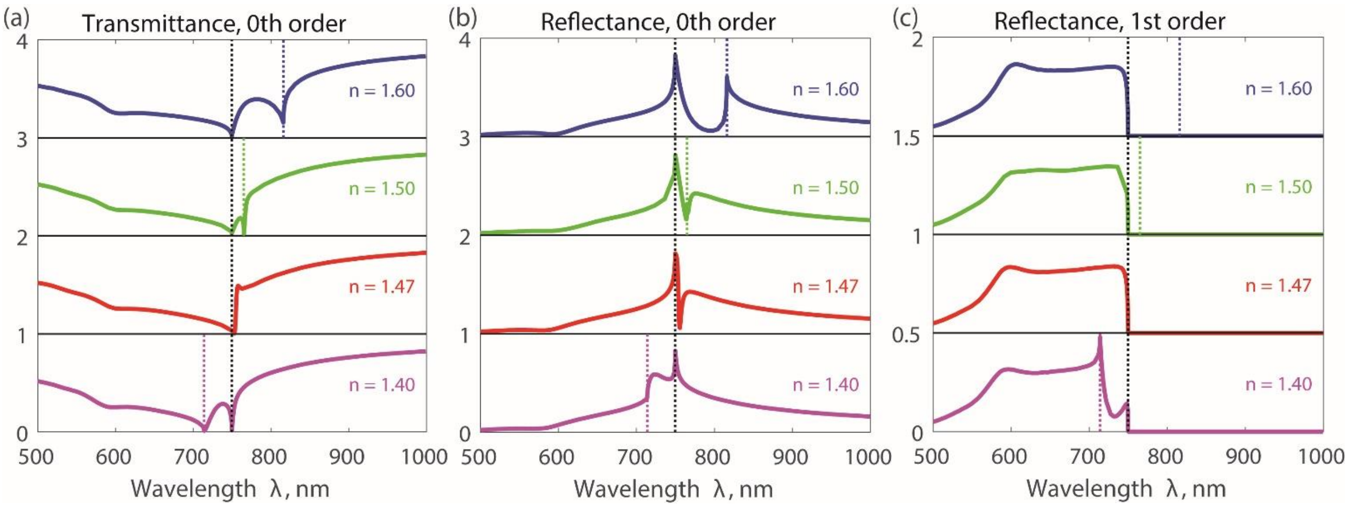

Fig. S8. (a) 0th order transmittance, (b) 0th order reflectance, and (c) 1st order reflectance for nanodisks with R_d = 85 nm and H = 100 nm (see more results in Fig. 8). Periods are p_x = 510 nm and p_y = 250 nm, n_s = 1.47. The dotted color lines mark a wavelength where the resonances in the substrate are expected, i.e. $\lambda_{RA} = np_x$, and the dotted black line corresponds to the resonance in superstrate, i.e. $\lambda_{RAs} = np_{xs}$. Each plot is shifted by either 0.5 or 1 with respect to the previous one.

The transmittance band between the anomalies for $n > n_s$ is associated with the transmission into the first diffraction order of the substrate (blue and green lines), and when this diffraction order disappears, the total transmission decreases. For $n < n_s$, the strong transmittance band does not exist between the Rayleigh anomalies. The spectra of the total reflection basically repeat the spectra of the zeroth diffraction order beam into the superstrate. Only in the case of $n < n_s$ the reflection into the first diffraction order can be significantly increased due to disappearing of the first diffraction order of the transmission (for n = 1.40).

Supporting-Information Figure S9

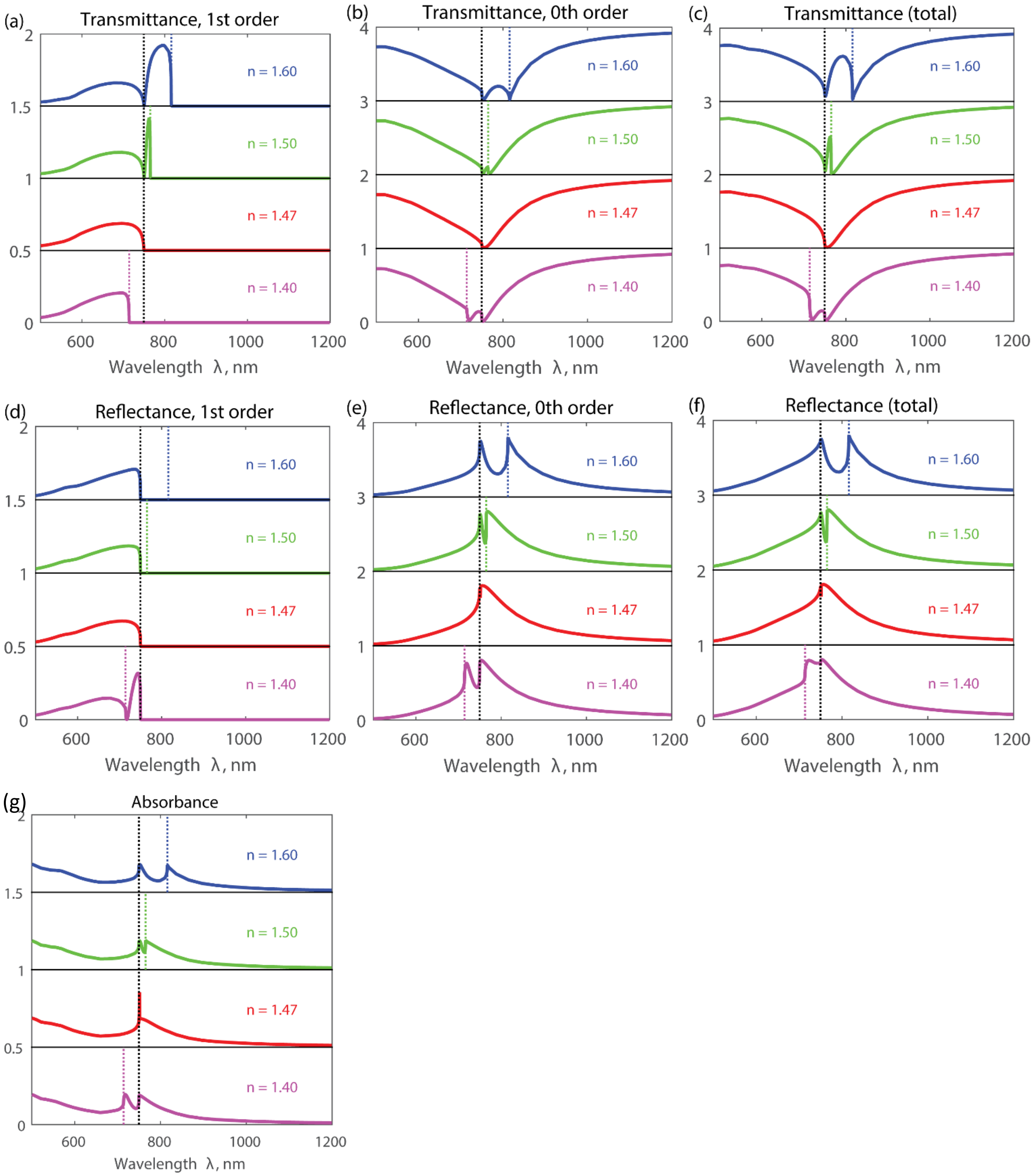

Fig. S9. (a)-(c) Transmittance, (d)-(f) reflectance, and (g) absorbance of the array of nanodisks (R_d = 85 nm and H = 50 nm) for different n denoted on the plots. Periods are p_x = 510 nm and p_y = 250 nm, n_s = 1.47. The dotted color lines mark a wavelength where the resonances in the substrate are expected, i.e. $\lambda_{RA} = np_x$, and the dotted black line corresponds to the resonance in superstrate, i.e. $\lambda_{RAs} = np_{xs}$. Each plot is shifted by either 0.5 or 1 with respect to the previous one.

Transmission in the first diffraction orders is either suppressed for $\lambda_{RAs} < \lambda < \lambda_{RA}$ and $n < n_s$ or has a peak for $\lambda_{RAs} < \lambda < \lambda_{RA}$ and $n > n_s$. As a result, both the zeroth diffraction order and the total transmittance for all $n \neq n_s$ under consideration have two minimums, i.e. at λ_{RAs} and λ_{RA}. The first diffraction order of reflection has two features at $\lambda = \lambda_{RAs}$ and $\lambda = \lambda_{RA}$ and $n < n_s$ and it is suppressed at $\lambda_{RAs} < \lambda < \lambda_{RA}$ and $n > n_s$, which altogether causes two peaks in reflectance, the zeroth diffraction order and total, at λ_{RAs} and λ_{RA} for all n.

Supporting-Information Figure S10

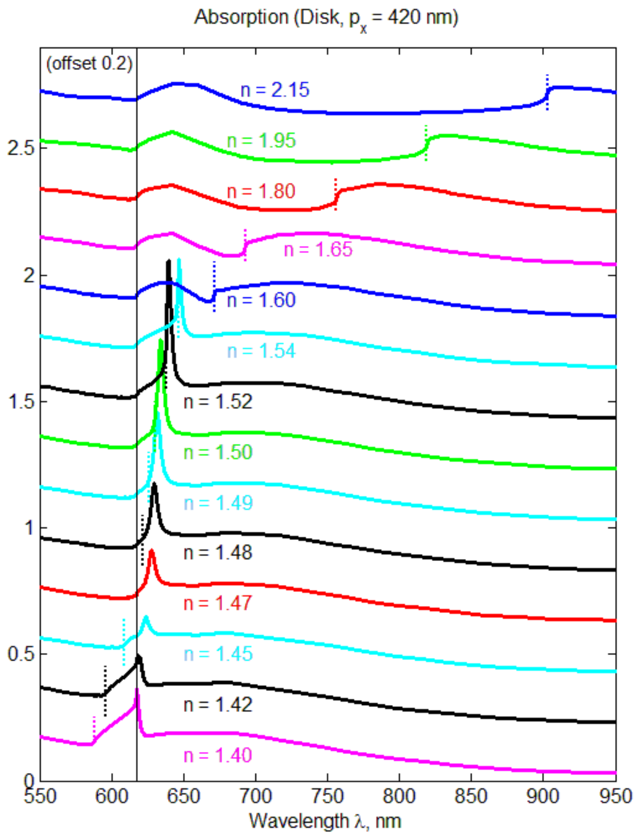

Fig. S10. Absorbance for various n. Periods are p_x = 420 nm and p_y = 250 nm, a disk with R_d = 85 nm and H = 50 nm, and n_s = 1.47. The dotted color lines mark a wavelength where the resonances in the substrate are expected, i.e. $\lambda_{RA} = np_x$, and the solid black line corresponds to the resonance in the superstrate, i.e. $\lambda_{RAs} = np_{xs}$.