Solvatochromic spectroscopy of metamaterials

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Abstract: For the first time, it is shown theoretically and experimentally, that immersing metamaterial into liquids with different refractive indices enables spectroscopy capable of distinguishing between different multipole contributions to metamaterial's transmission and reflection spectra.

The solvatochromic spectroscopy presented here relies on the fact that efficiency of light emission by different multipoles depends differently on the ambient refractive index. Indeed, a simple calculation shows that, for example, emission efficiency of an electric dipole antenna will scale linearly with ambient refractive index (n), whereas in case of magnetic or toroidal dipole antennas, the scaling would be with third and fifth powers of n, respectively (see Fig. 1a). Here, we will apply these scaling laws to distinguish various multipole excitations induced in nanophotonic devices, such as metamaterials.

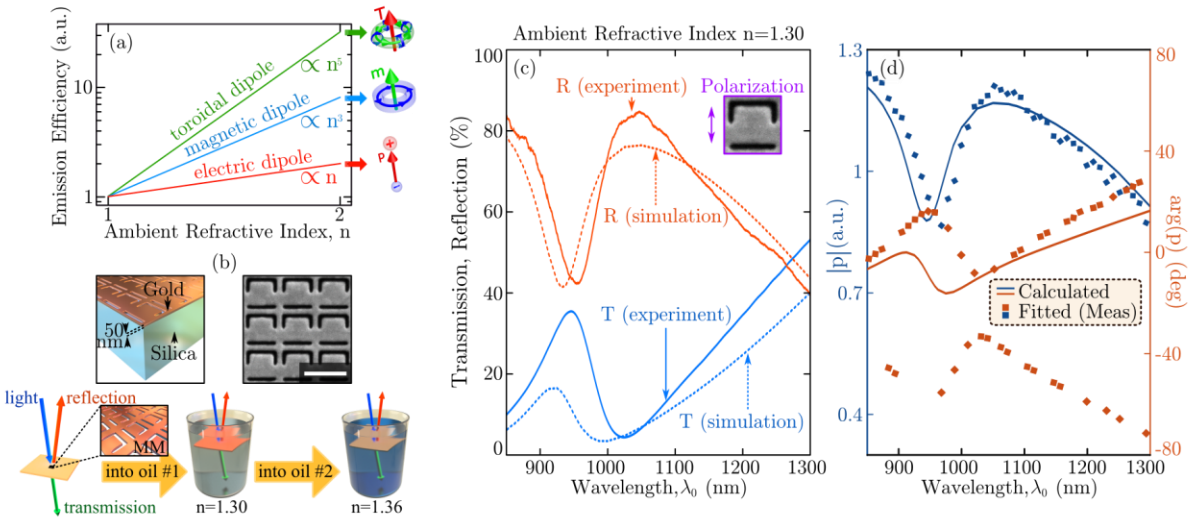

Figure 5. Solvatochromic spectroscopy of metamaterials. **(a)** Sketch of the emission efficiency of the three electromagnetic dipoles as a function of ambient refractive index (n). **(b)** Top Half: The geometry of the tested metamaterial: a 50nm thick gold film on thick glass substrate patterned using focused ion beam. Bottom Half: the experimental technique. The reflection and transmission of the metamaterial is measured in one refractive index oil, then in another one, with slightly different refractive index, etc. **(c)** Transmission and reflection of the metamaterial (shown in (b)) measured (and modelled) under the immersion in refractive index oil with n=1.30. **(d)** Electric dipole induced in the metamaterial (amplitude & phase). Solid lines show results of the simulation (labelled as 'calculated'), scatter points show the results extracted from the solvatochromic spectroscopy (labelled as 'fitted').

The general phenomenon of change in electromagnetic response of chemicals as a result of being placed into different environments is known as solvatochromism – the dependence of chemical's colour on the host-solvent. A related phenomenon has also been considered in atomic physics [1], where, ignoring local fields, it has been calculated that rates of spontaneous decay of atoms and molecules scale linearly with ambient refractive index in case of electric dipole transitions, and as the fifth power of refractive index in case of toroidal dipole transitions.

In our talk, we shall present the first application the solvatochromism in reverse, i.e. identifying multipole transitions based on the scaling of emission efficiency with ambient refractive index. We will show numerically that the difference in scaling can be used to differentiate between electric and toroidal dipoles, and thus detect the presence of dynamic anapoles, under realistic conditions. We shall also present an experimental demonstration of the new spectroscopy. In experiment, illustrated in Fig. 1b-d, the reflection and transmission of the metamaterial was measured in series of refractive index oils. The change in transmission/reflection as a result of changing ambient index was then used to extract both amplitude and phase of the electric dipole excitation induced in the metamaterial (Fig. 1d).

[1] E. V. Tkalya, "Spontaneous electric multipole emission in a condensed medium and toroidal moments", Phys. Rev. A 65, 022504 (2002)