Ecole Doctorale des Sciences Fondamentales

Title of the thesis: Physics and design of gap-plasmon metasurfaces

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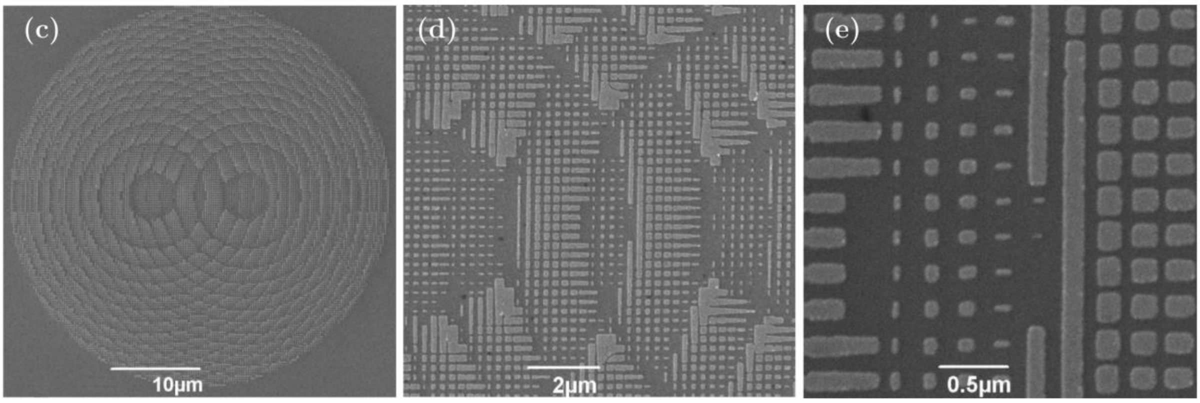
Summary :

Metasurfaces are bi-dimensional arrangements of optical resonators, generally metallic and then plasmonic (in the sense that they owe their properties to the electron gas they contain). The individual response of each resonator can be summarized by two values : the amount of light which is radiated and the change in the phase that occurs when the radiation interacts with the resonator. Theoretically, well enough chosen and placed resonators allow to entirely control the wavefront, including polarization. It is then possible to design holograms or devices that can behave as lenses as well as surface wave launchers (see figure). More simply, metasurfaces allow to control the color which is radiated locally.



For now, the design and the fabrication of such structures is still quite a challenge despite the amazing devices that have been realized. First, it is difficult to consider that resonators do not interact – and when they do, their optical response changes. Such a complexity has to be taken into account. Second, the realization of such structures requires the use of lithography techniques which are very expensive, reducing the number of potentially successful applications.

Part of the problems come probably from the fact that the resonators are actually quite "open". These are patch antennas, i.e. metallic nanostructures deposited on a dielectric layer, itself deposited on a another metallic layer. With such a (relatively) thick spacer, resonators are not ultimately miniaturized as plasmonics would allow to do.

The advantage thick layers provide is that light is much less absorbed by the resonator – however the interaction between neighboring resonators has a much larger impact and the resonators are much larger compared to the wavelength.

The goal of the project is to deterrmine what the potential of gap-plasmon resonators with a much lower spacer thickness (around 5 nm) truly is. In this regime, gap-plasmon resonators do absorb much more light, as the cavity under the patch for the gap-plasmon is much more “closed”. Meanwhile, the importance of the interaction between resonators is reduced, and the gap below each patch being so small, any change in the properties of the material within this gap will have a much larger impact on the optical response of the resonator. Finally, other fabrication techniques are available in such a regime, so that lithography is not the only way to realize them. Recent results suggest that these resonators can be used in transmission, which offers new perpectives for biosensing – i.e. the sensing of biomolecules of interest.

The constraints associated to this kind of optical resonators may be important, but being able to overcome them may open new perspectives. This subject is obviously mixing the fundamental physics of these resonators with design problems, both domains influencing each other. While design constraints may influence the functioning regime of the resonators to look for, design techniques can maybe help overcome the drawbacks of these resonators.

This project will be carried on in collaboration with teams in Marseille, for the experimental part and in Sophia-Antipolis (CRHEA and INRIA) for the theoretical and numerical parts of these complex but quite fascinating objects.

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[2] Antoine Moreau, Cristian Ciracì, Jack J Mock, Ryan T Hill, Qiang Wang, Benjamin J Wiley, Ashutosh Chilkoti, and David R Smith. Controlled-reflectance surfaces with film-coupled colloidal nanoantennas. Nature, 492(7427):86–89, 2012.
[3] Escoubas, L., Carlberg, M., Le Rouzo, J., Pourcin, F., Ackermann, J., Margeat, O., ... & Berginc, G. (2019). Design and realization of light absorbers using plasmonic nanoparticles. *Progress in Quantum Electronics*, *63*, 1-22.

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