URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Molding the flow of light with metasurfaces

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Metasurfaces are built from a collection of scatterers deposited on a surface; they can be used to produce unusual optical effects that cannot be realized with conventional optical elements. In that presentation, I would like to both give some general background on their functioning principles and share some of our recent work to realize metasurfaces using different types of nanotechnologies.

When light impinges on a flat surface, it is reflected and transmitted following the mere lows of refraction. The corresponding change of direction encountered by the incident plane wave can be understood in terms of a phase gradient being added to the incident light as it progressively hits the surface, and bends its propagation direction, as illustrated in Fig. 1(a). This phenomenon has been used for well over two centuries in diffractive gratings, where the phase gradient is simply produced by the periodic corrugation of the surface.

Resonant optical structures also produce a phase that can be added to the incoming light: when the frequency of light is lower than the optical resonance the scattered field is in-phase with the excitation; when the frequency is higher than the optical resonance, the scattered field is out-of-phase with the excitation. Plasmonic nanostructures are especially well suited to produce this effect and have been instrumental to design metasurfaces with extraordinary optical properties. In that context, a fundamental question is the amount of phase a resonant structure can produce: the conventional laws of physics limit this amount to a phase change of π upon resonance; however, I will show that by engineering the resonant system or modifying its environment, it is possible to extend this phase much beyond that modest value.

While a grating produces only a very simple phase gradient, a metasurface can be designed in ways such that extremely complex phase distributions are added to the incoming light, thus producing complex light flows. Furthermore, in metasurfaces, the phase gradients can strongly depend on the illumination frequency, leading to effects that cannot be obtained with conventional gratings. Such a metasurface is illustrated in Fig. 1(b): it is composed of a collection of different Fano-resonant nanostructures that redirect the incident light into different directions depending on its frequency (e.g. blue light will bend to the right, while red light will bend to the left, an effect that cannot be realized with a conventional grating). Mastering the fabrication of nanostructures is key to the realization of efficient metasurfaces and I will share some of the technologies we have developed to this end, including on-going work where we use alloys of gold and silver to extend the parameter space that can be used to design metasurfaces, Fig. 1(c).

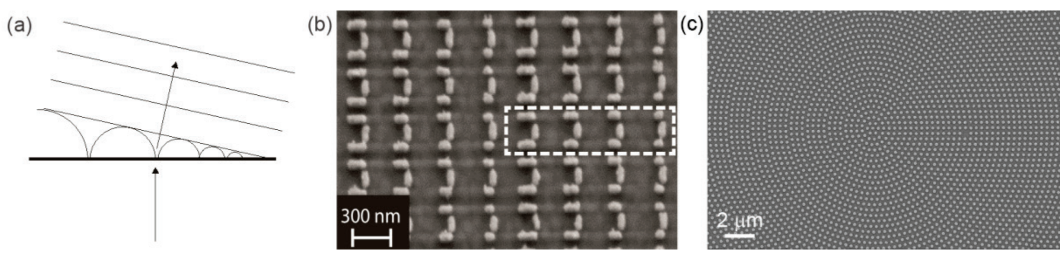

Figure 1. (a) Principle of bending the flow of light by adding a phase gradient. Two examples of metasurfaces operating at optical frequencies: (b) a Fano-resonant metasurface made in silver for colour routing and (c) a metalense made from gold-silver alloyed nanostructures: the nanostructures visible here are made from two different alloys with different compositions.