Marie Curie Career Integration Grants (CIG)

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"Light-Matter Interaction in Smart Optical Materials"

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It is well accepted that the future progress in many areas such as optical telecommunications, nonlinear optics, optical imaging, and light emission devices will sensitively rely on the availability of novel and/or strongly improved optical materials. Here, metamaterials have recently opened an exciting gateway to reach unprecedented physical properties and functionality unattainable from naturally existing materials. The artificial "atoms" and "molecules" in metamaterials can be tailored in shape and size, the lattice constant and inter-atomic interaction can be precisely tuned, and "defects" can be designed and placed at desired locations. The recent demonstration of negative refraction in bulk optical left-handed metamaterials is only one excellent example of new exciting physics arising from these materials. Yet such demonstrations are only the tips of the iceberg of what might possible with artificially engineered optical materials.

Our project explored the revolutionary physics of optical metamaterials, covering nonlinear optical phenomena and wave dispersion engineering, adaptive polarization control of waves using metamaterials with real time reconfigurations, metasurfaces, and modification of light emission. The unique properties of metamaterials arising from their specific spatial configurations opening up exciting new venues for device development in the fields of all-optical data processing, optical meta-nanocircuits, light collection for solar energy harvesting, superlenses for perfect imaging, perfect mirrors, and novel nonlinear optical elements.

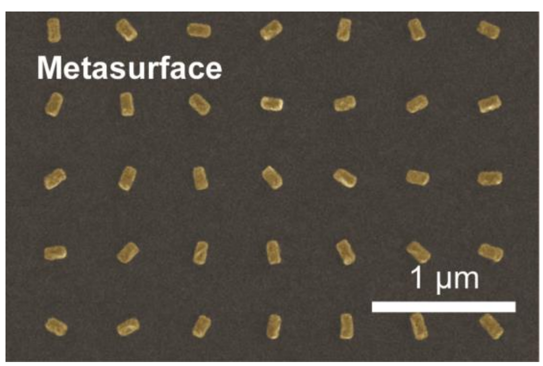

Figure 1: Scanning electron microscopy image of a metasurfaces with plasmonic gold nanorods.

The project in particular focused on the design and realization of novel optical effects due to the interaction of light with only a thin film of artificially structured materials on top of a traditional material surface, the so-call metasurfaces. Such metasurfaces are very promising candidates for future light manipulation devices since they are relatively easy to manufacture with state-of-the-art nanofabrication methods (like in the semiconductor industry) and they are ultrathin, allowing a high vertical integration of functionalities within small volumes or areas. During the first part of the project we therefore developed a concept of phase manipulation for light based on small plasmonic nanostructures. With our concept we were able to demonstrate that the local phase of light can be easily tailored when passing through the surface. We like to note that this effect does not arise from an accumulated phase during the propagation but an abrupt phase change due to a polarization change of the light. Hence, the technique works over a large range of wavelength and ultrathin film.

With this technique we demonstrated the potential of this concept with three-dimensional holographic imaging based on the phase change at the metasurfaces. The technique even has some practical advantages compared to traditional methods since it allows very high resolution, wide field of view and broadband operation while avoiding problems like twin image generation inherent to most holographic techniques.

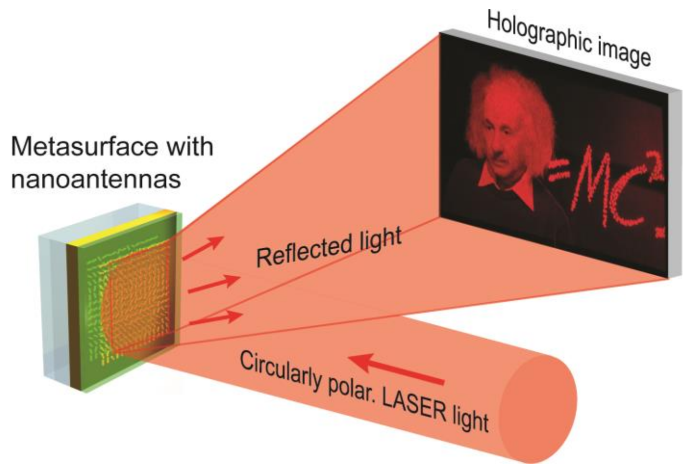

Figure 2: Schematic illustration of the holographic image generation from a metasurfaces hologram.

Furthermore, we extended this concept to the nonlinear regime to generate a local nonlinear polarization source which results in the generation of new frequencies with a particular phase. Based our design we were able to demonstrate that an ultrathin layer of well-defined plasmonic nanoantennas with only a fraction of the thickness of the used wavelength of light can introduce a desired local phase during the harmonic generation. In this context we were also able to proof that the selection rules for nonlinear processes in natural materials are valid for mesoscopic systems consisting of nanostructured surfaces. We believe that such a direct tailoring of nonlinear process can lead to completely new optical elements for all-optical devices. This knowledge was meanwhile transferred to new students and other groups within the department to develop this concept even more.

Another part of the project was investigating the possibility of tailoring the excitation of particular surface wave along a metal film, the so-call surface plasmon polaritons. Here, we were able to demonstrate a novel plasmon coupler that can excite these surface states with particular phases simply be changing the polarization state of the incident light. With our design we were able to change the direction of the surface wave (amplitude) and phase at the same time. Such a technique might become handy for future on-chip applications were surface plasmons have to be launched with certain properties.

The project's main goal of investigating the possibilities of enhanced light-matter interaction and novel nonlinear optical processes in metamaterials has been successfully demonstrate. We were able to show the high potential of such new material systems for nano-optical devices and applications.