# How to tame light at the nanometer scale?

# Either shape the structure or the illumination

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## Abstract

We review our latest advances in the nanoscale control of light using plasmonic nanostructures and their application to the control of single emitters and optical cloaking.

## 1. Deterministic control of plasmon hot spots by spatial phase shaping

Reconfiguring the spatial distribution of light at the nano-scale is important to extend concepts and functionalities of macroscopic optics down to the nanometer scale. This a priori goes against the law of diffraction that prevents to independently address optically two points separated by a distance shorter than half the incident wavelength. While, plasmonic nanostructures can efficiently couple to propagating light and concentrate it into nanometer volumes; their near-field response is, however, mainly imposed by their fixed geometry. Several approaches based on ultra-short pulse shaping have recently been suggested to reconfigure dynamically plasmonic landscapes.

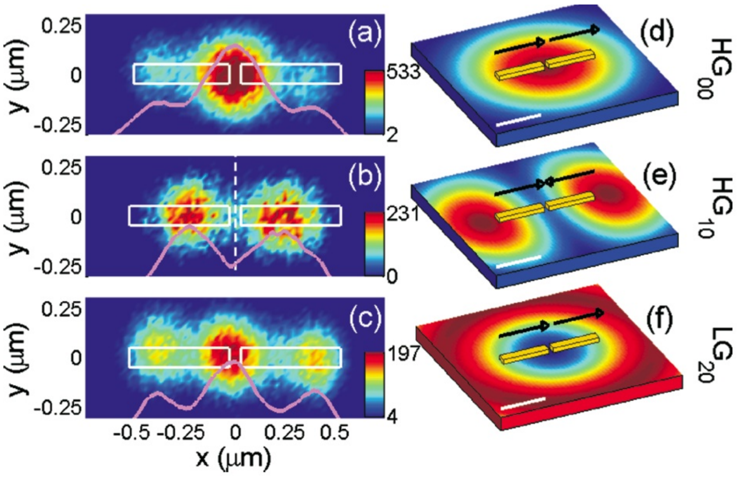

Fig 1. (a-c) Experimental Two Photon Luminescence (TPL) maps recorded on a single gap antenna (located by the white rectangles) when driven by three different incident beams (λ ) 750 nm): (a) HG00 (Gaussian), (b) HG10 and (c) LG20. The color scale gives the TPL intensity in photon counts. In map (b), the vertical dashed line locates the π-shift position of the HG10 beam. (d-f) Associated computed intensity distribution of the incident field (scale bar ) 500 nm). Each of the three beams was linearly polarized along the x-axis. The black arrows give the relative polarization orientation across the beam.

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Here we discuss an alternative approach based on spatial phase shaping (in opposition to temporal phase shaping), using continuous wave illumination to control the location of hot spots in complex plasmonic nanostructures. We first demonstrate experimentally that subwavelength phase changes at the focus of hermite-gaussian beams can be used to switch on and off the hot spots in nano-optical antennas (Fig1) [1]. We then show that this concept can be generalized into a deterministic protocol applicable to any generic plasmonic system. Based on an exact inversion of the response tensor of the nanosystem, the so-called Deterministic Optical Inversion (DOPTI) protocol provides a physical solution for the incident field leading to a desired near field pattern, expressed in the form of a coherent superposition of high order beams. We first demonstrate the high degree of control achieved on a complex plasmonic architecture and quantify its efficiency and accuracy [2].

## 2. Directive emission of a single Qdot with an optical Yagi-Uda Antenna

Nanoscale quantum emitters are key elements in quantum optics, bioimaging and sensing. However, efficient optical excitation and detection of such emitters involves large solid angles because their interaction with freely propagating light is omnidirectional. Here, we report on the unidirectional emission of a single emitter by coupling to a nanofabricated Yagi-Uda optical antenna [3]. Using advanced e-beam lithography combined with surface chemistry, we placed a quantum dot in the near field of the antenna so that it drives its resonant feed element. The resulting quantum-dot luminescence is strongly polarized and highly directed into a narrow forward angular cone upon the action of the reflector and directors elements. We observed that the directionality of the quantum dot could be controlled by tuning the antenna dimensions. Our results show the potential of optical antennas to communicate energy to, from, and between nano-emitters.

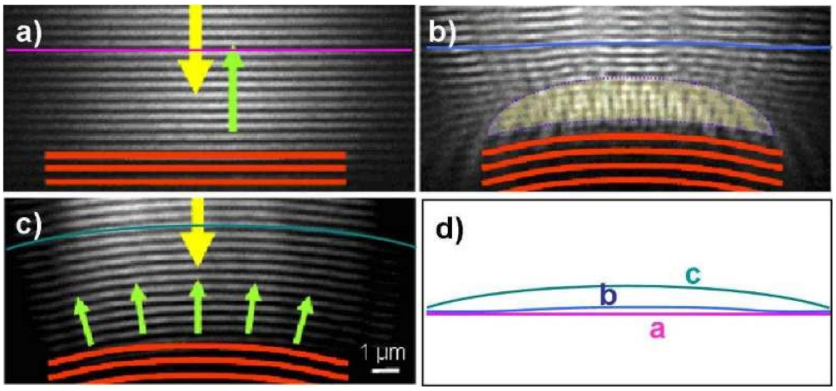

Fig. 1: Experimental image of the leakage radiation of the SPP at λ=800 nm. (a) The incident SPP (yellow arrow) hits the straight Bragg mirror (red). The interference with the back- reflected SPPs (green) results in a straight beating pattern. (c) The incident SPPs (yellow arrow) hit a curved Bragg mirror (red). The backreflected SPPs (green) have different directions due to the curved shape of the reflector resulting in the curved intensity pattern dominated by the beating of the counter-propagating SPPs. (b) Cloak is placed in front of the curved Bragg mirror. The beating pattern in reflection is clearly visible and similar to a straight Bragg reflector. (d) Averaged relative position of the interference fringes.

## 3. Hiding under a plasmonic carpet

The third and final part of this paper will discuss some of our recent advances in the application of transformation optics to surface plasmons. One of the key challenges in current research into electromagnetic cloaking is to achieve invisibility at optical frequencies and over an extended bandwidth. Here, we show that we can harness surface plasmon polaritons at a metal surface structured with a dielectric material to obtain a unique control of their propagation. We exploit this control to demonstrate both theoretically and experimentally cloaking over an unprecedented bandwidth (650-900 nm). Our non-resonant plasmonic metamaterial is designed using transformational optics and allows a curved reflector to mimic a flat mirror. Our theoretical predictions are validated by leakage radiation microscopy experiments mapping the surface light intensity at a wavelength of 800 nm (Fig2) [4].

## References

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