Coherent control of nanoscale light localization: positioning a hot-spot at will

Tsung Sheng Kao[1,*], *Stewart D. Jenkins*[2], *Janne Ruostekoski*[2] *and Nikolay I. Zheludev*[1]
[1]*Optoelectronics Research Centre and Centre for Photonic Metamaterials, University of Southampton, SO17 1BJ, U.K.*
[2]*School of Mathematics and Centre for Photonic Metamaterials, University of Southampton, SO17 1BJ, U.K.*
**Email: tsk@orc.soton.ac.uk , web: http://www.nanophotonics.org.uk/niz/*

Abstract: A new paradigm for achieving prescribed nanoscale energy localization at subwavelength scale is demonstrated in this paper. Well isolated energy hot-spots as small as λ/10 can be created and positioned at will on the metamaterial landscape.

In 2002 Stockman et.al suggested a method, which was based on tailoring phase modulation of ultrashort optical pulses in the time domain to achieve coherent control of spatial distribution of the excitation energy in complex inhomogeneous nano-systems. Here we suggest a new paradigm for achieving prescribed localization of optical energy with nanoscale accuracy.

The method, does not depend on a transient redistribution of energy between nano-objects and may be implemented with *continuous coherent optical sources*, making pulse excitation unnecessary. Implementation of the method requires only widely available instrumentation (a spatial light modulator and a continuous laser) that can be retrofitted to a conventional microscope. Moreover, it does not require the nanoscale system to be spatially inhomogeneous (such as a rough surface) and works with periodic, regular planar array of identical nano-objects opening the opportunities for *microscopy, lithography and data storage applications* which will be discussed below. It is based on tailoring the spatial variation of the phase in the driving far-field to achieve the prescribed coherent control of localization and depends on the interactions between individual nano-objects. This idea has a clear mechanical analogy in two coupled identical oscillators (modelling nano-objects) that may be driven to vastly different amplitudes by setting up a phase delay between otherwise identical coherent mechanical forces driving them. We demonstrate this approach in a planar metamaterial, a two-dimensional array of nanoscale subwavelength meta-molecules excited with spatially phase-modulated optical beam. We show that a given meta-molecule can be “fired-up" so near-field energy is localized at it while a group of neighbouring meta-molecules remain unexcited. Now by simply adjusting the excitation beam spatial phase profile the nanoscale hot-spot can be moved at will from one meta-molecule to another thus achieving the Holy Grail of nanophotonics: a prescribed nanoscale energy localization at a subwavelength scale. We demonstrate that controllable nanoscale localization of optical energy can be achieved at an artificial nanostructured metamaterial surface, an array of altimetrically split ring plasmonic resonators when such structure is illuminated with a coherent continuous light wave (a laser) those spatial variation of the phase at the metamaterial plane can be tailored.

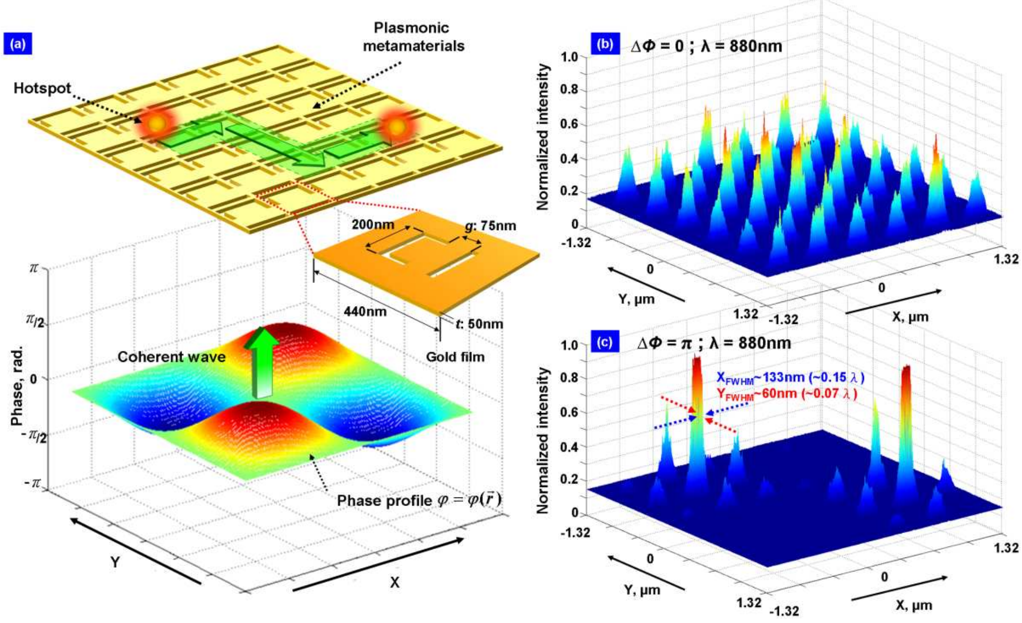

Figure 1. (a) A schematic diagram of the gold split-ring metamaterial and the applied sinusoidal phase profile of the incident wave. The wavelength of incident wave is 880nm and the maximum phase difference is denoted as $\Delta\varphi_{max}$. In (b) the applied phase is flat ($\Delta\varphi_{max} = 0$), and the energy distribution is homogeneous across different unit cells. With a large phase difference $\Delta\varphi_{max} = \pi$, the energy is concentrated in only a few of the unit cells, giving strongly localised peaks (c).