

# Focusing of Light by a Nano-Hole Array

Fu Min Huang,<sup>1</sup> Yifang Chen,<sup>2</sup> F. Javier Garcia de Abajo<sup>3</sup> and Nikolay Zheludev<sup>1</sup>

<sup>1</sup>EPSRC Nanophotonics Portfolio Centre, School of Physics and Astronomy, University of Southampton, SO17 1BJ, UK

<sup>2</sup>Central Microstructure facility, Rutherford Appleton Laboratory, Didcot, Oxon, OX11 0QX, UK

<sup>3</sup>Instituto de Optica, CSIC, Serrano 121, 28006 Madrid, Spain

**Abstract:** We report the first demonstration of light focusing by a nano-hole array. The quasi-crystal arrangement of holes “focuses” light a few tens of microns from its surface, creating bright “focal spots” of sub-wavelength energy concentration.

©2005 Optical Society of America

OCIS codes: (100.6640) Superresolution; (110.1650) Coherence imaging

We show for the first time that an array of nano-holes in a metal screen can “focus” light at distance of about ten microns from the screen. When a purposely designed quasi-crystal array of sub-wavelength holes is illuminated with coherent light it produces bright hot-spots of energy concentration that are separated by a few microns from neighbouring spots in the “focal plane”. Using a laser at 660 nm and a hole array containing 14,000 holes 200 nm in diameter we observed sub-wavelength “focusing spots” smaller than 290 nm in diameter.

This new phenomenon of “lensing” by a nano-hole array results from the partial reconstruction of the array’s field far away in the diffraction zone. This resembles the classical Talbot effect observed with periodic gratings, where diffraction leads to the reconstruction of the grating’s field at periodic distances from the grating. However, in the effect reported here the quasi-periodic hole array shows only a partial reconstruction at certain distances from the array. At these distances only sparsely distributed hot-spots appear, thus concentrating the energy transmitted through a large number of holes into a small number of well-isolated foci.

The subwavelength foci were observed using a transmission scanning near-field optical microscope (SNOM). The array had approximate 10-fold symmetry and was manufactured by electron beam lithography in a 100 nm aluminium film on a silica substrate. In the proximity of the sample, the optical field concentrates at the holes. Further away from the array well defined hot-spot patterns appear at specific, irregular distances wherein the hot-spots are separated by a few microns from neighbouring spots (see Fig. 1).

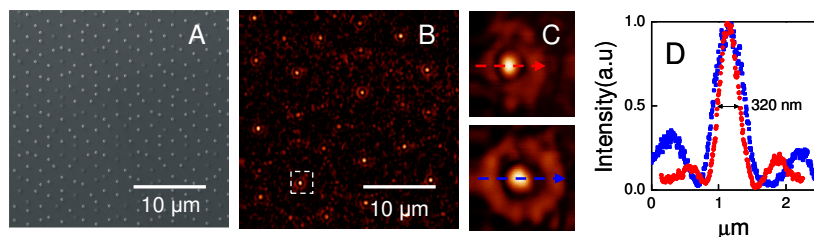


Fig. 1 Subwavelength hot-spots created by an array of quasi-crystal subwavelength holes: A) SEM image of a fragment of the quasi-crystal hole array; B) subwavelength hot-spot pattern observed by SNOM at a distance of 12.5  $\mu\text{m}$  from the array, when it is illuminated by a 660 nm laser; C) images of an individual hot-spot (indicated on figure B) at the “focal” distance of 12.5  $\mu\text{m}$  (upper), and when slightly “defocused” at 14  $\mu\text{m}$  from the array (lower); D) profiles of the hot-spot at distances of 12.5  $\mu\text{m}$  (red dots) and 14  $\mu\text{m}$  (blue dots) from the array, indicating a peak width of 320 nm in the “focal” plane, which corresponds to a hot-spot diameter of less than 290 nm after deconvolution to account for the SNOM probe aperture size.

With such high localization and brightness, imaging with subwavelength resolution can be achieved by scanning the object under investigation against the focal spot. Similarly, a single hot-spot, appropriately isolated by a mask, may be used as a “light pen” in high resolution photo-lithography.