Nanofabricated All-Optical Computing, Switching, and Signal Processing Devices Based on Single Photon Tunneling

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A new and important phenomenon involving single photon tunneling has been discovered recently by a multidisciplinary team of researchers at the University of Maryland. Transmission of light through nanometer-scale pinholes in a gold film covered by a nonlinear dielectric appears to saturate at a few thousand photons per second. The transmittance of such nanometer-scale holes is nonlinear with light intensity, and at the single photon level corresponds to each photon in the process of being transmitted through the hole controlling the transmittance of successive photons. This result is somewhat analogous to the Coulomb blockade observed in single electron tunneling experiments. This phenomenon was initially observed only for random nanoscale pinholes that occur naturally in thin evaporated gold films. Further work of our team has shown that the transmittance of both individual nanofabricated holes (nanopores), and arrays of nanopores, both made by focused ion-beam nanofabrication techniques, has shown not only the simple "photon-blockade" effects, but also controlled photon transmission [2]. For example, the transmittance of a nanopore or nanopore array at one wavelength λ_1, can be controlled by illumination with a second, different, wavelength λ_2.

The goal of our NIRT team is to enhance our understanding of this new phenomenon and to explore potential applications based on *fabricated* nanopores or arrays of nanopores in metal films. Such controlled single-photon light sources are being actively pursued by researchers in the areas of quantum communication and quantum cryptography. Based on our experiments so far, we expect that a detailed study of optical properties of such well controlled nanopore and other nanostructures will reveal novel quantum phenomena in nonlinear optical transmission.

Focused ion beam maskless patterning of the free-standing metal membranes appears to be an ideal tool for flexible design of nanohole arrays and other prototype photonic structures. Using FIB machine with ion beam diameter down to 5 nm, we have succeeded in fabricating

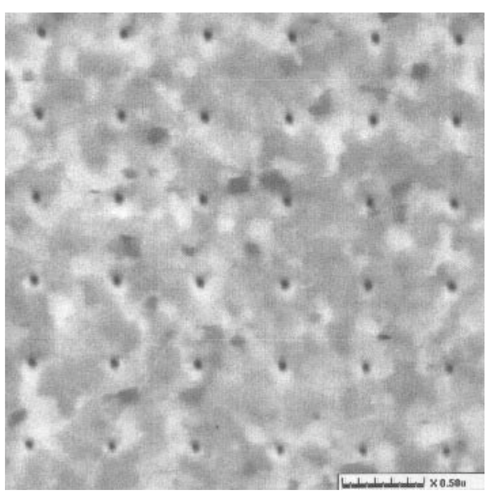

Fig.1 Array of 20 nm holes in a gold membrane.

ordered patterns of nanoholes with diameters down to 20 nm in a free-standing 400 nm thick gold film as shown in Figure 1. Photon tunneling gated by light at a different wavelength was observed in these patterns coated with non-linear optical polymer. This observation suggests that optical fields in and around nanoholes are strongly enhanced and all kinds of nonlinear optical interactions of surface plasmons should be very pronounced in these systems. The immediate goal of our NIRT team is to develop good understanding of these nonlinear interactions. Our most recent results indicate that the optical properties of nanoholes may be controlled by modest external magnetic field, which would be very attractive in quantum photonics device applications. It also appears that arrays of such nanoholes may exhibit rather prominent magnetic properties in the frequency range of cylindrical surface plasmon excitation [3]. Thus, nonlinear optical interactions of light inside the nanoholes may be described as an effective magnetic interaction, and a novel class of "magnetic light" metamaterials (Fig.2(a)) may be designed and created.

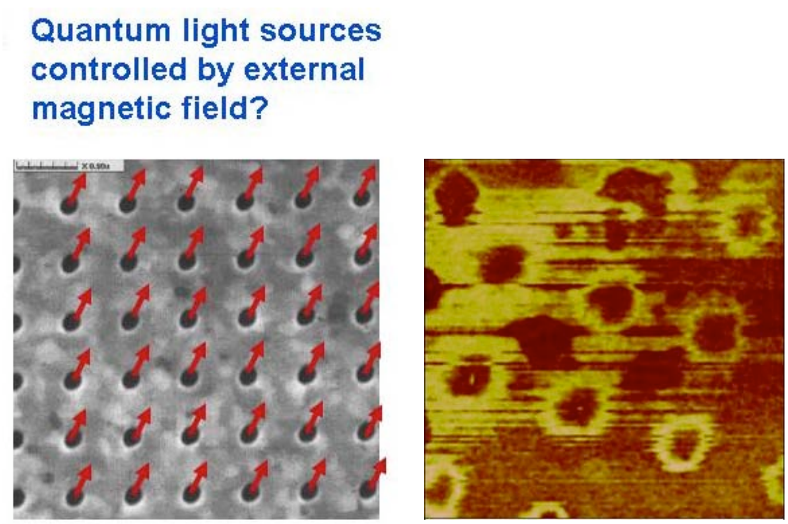

Fig.2 (a) Cylindrical plasmons in nanoholes posses magnetic moments, as indicated by the arrows.
(b) Magnetic force imaging of a nanohole array illuminated with circular polarized light.

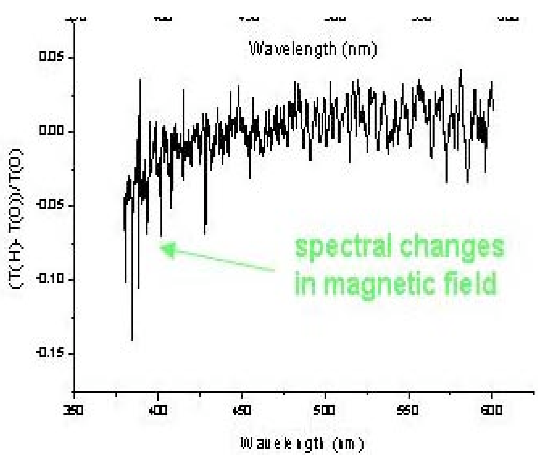

Fig.3 Changes in transmission of a 100 nm nanohole array due to external magnetic field.

Optically-induced magnetism of the nanohole arrays has been observed in spectroscopic (Fig.3) and direct magnetic-force microscopy measurements (Fig.2(b)). These observations will advance not only the field of nanophotonics, but would potentially impact such fields as mesoscopic physics and the physics of strongly-correlated electron systems.

References

[1] For further information about this project email to **smoly@eng.umd.edu**
[2] I.I. Smolyaninov, A.V. Zayats, A. Stanishevsky, and C.C. Davis, Phys.Rev.B 66, 205414 (2002).
[3] I.I. Smolyaninov, C.C. Davis, V.N. Smolyaninova, D. Schaefer, J. Elliott, and A.V. Zayats, Phys.Rev.B 71, ... (2005) "Plasmon-induced magnetization of metallic nanostructures" (in press)