Single-Photon Tunneling

I.I. Smolyaninov, A.V. Zayats[1], A. Güngör[2], and C.C. Davis

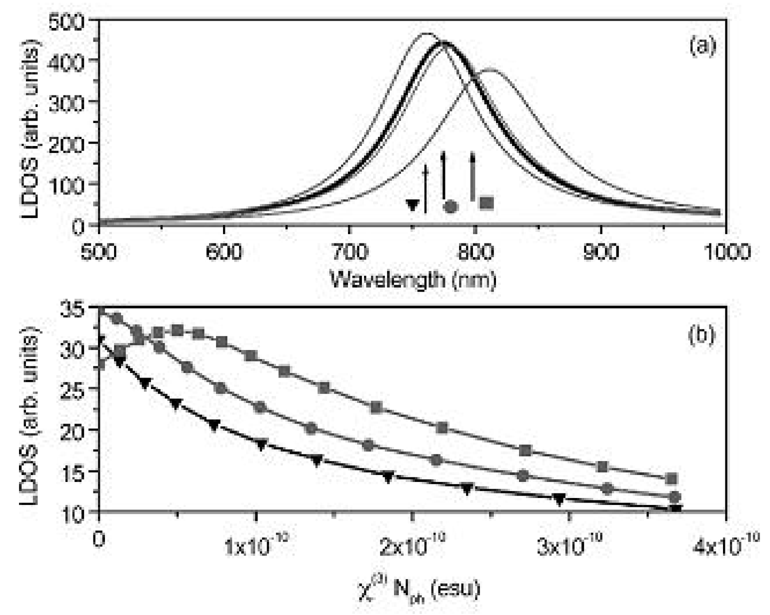
Department of Electrical and Computer Engineering

[1] Queen's University of Belfast, UK [2] Fatih University, Istanbul, Turkey

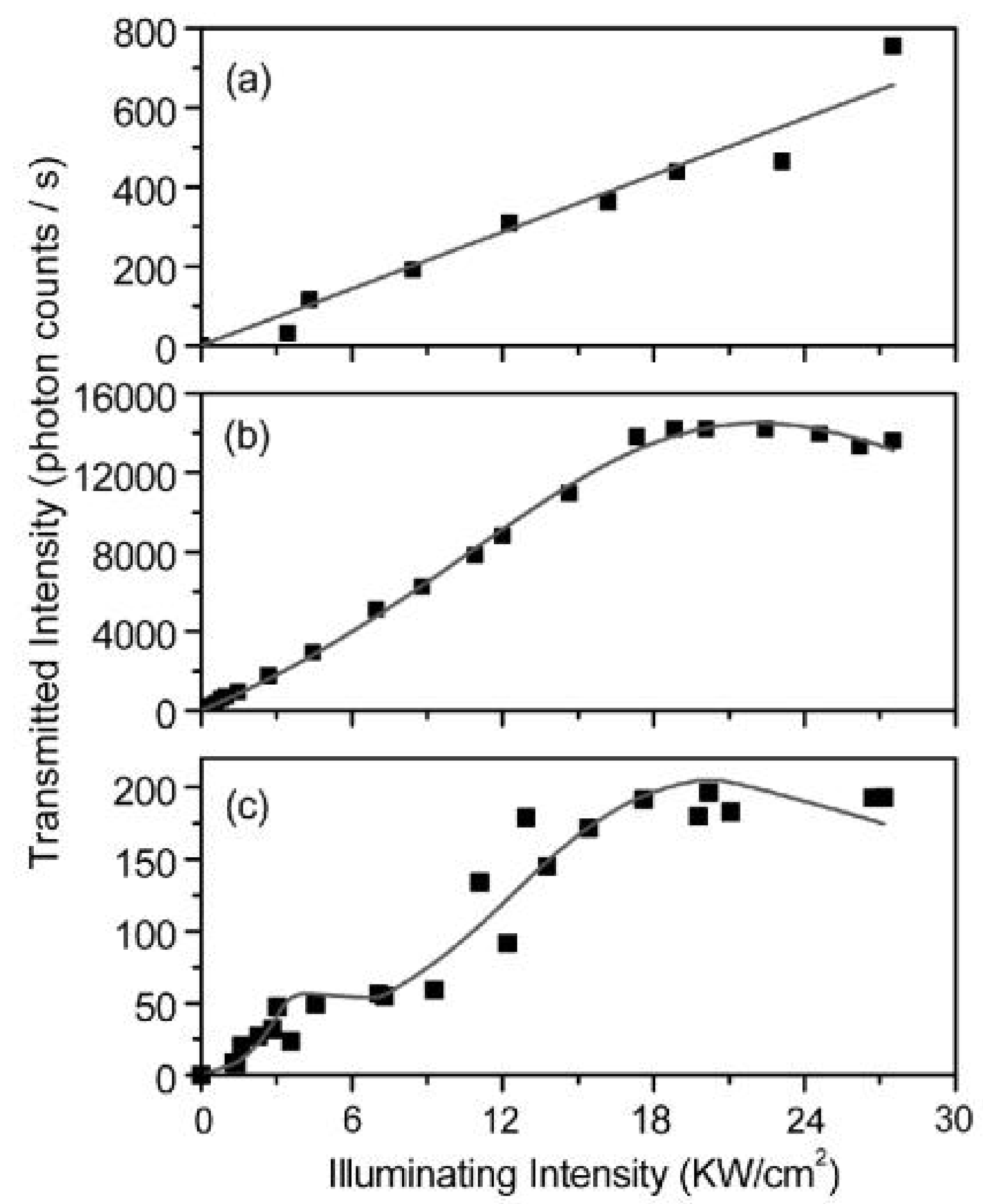
The Maryland Optics Group

Abstract

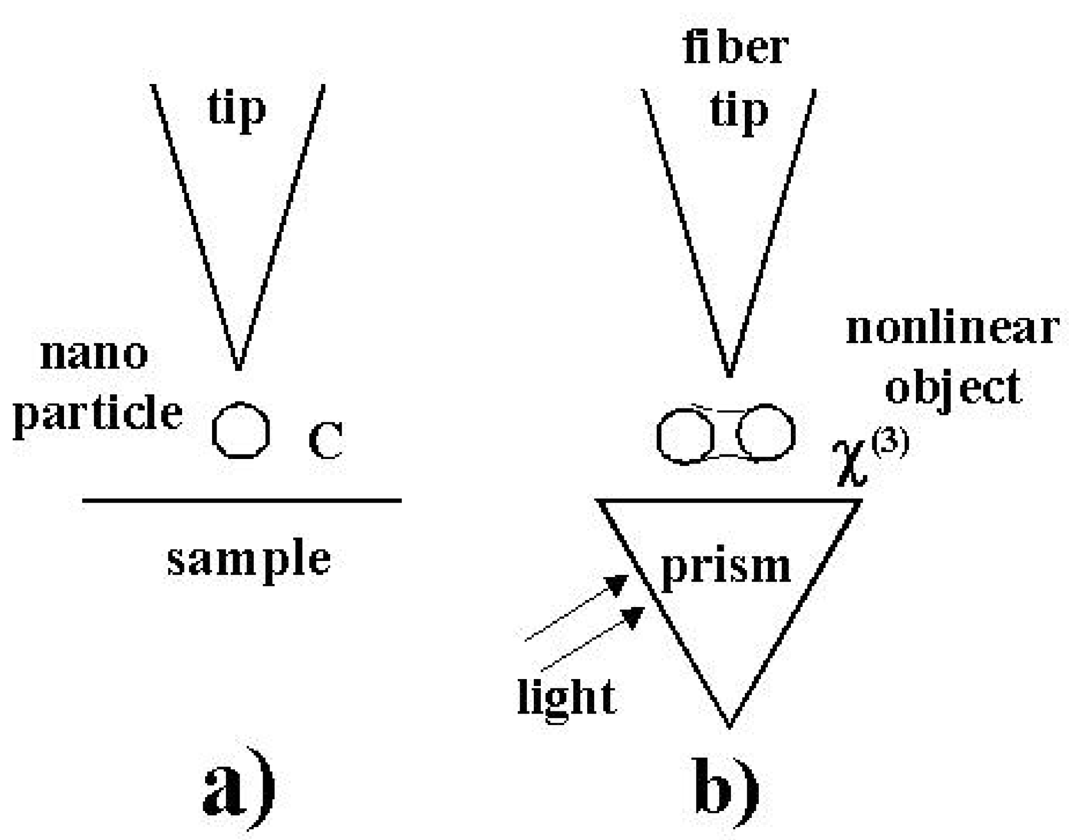
Strong evidence of a single-photon tunneling effect, a direct analog of single-electron tunneling, has been obtained in the measurements of light tunneling through individual subwavelength pinholes in a thick gold film covered with a layer of polydiacetylene. The transmission of some pinholes reached saturation because of the optical nonlinearity of polydiacetylene at a very low light intensity of a few thousands photons per second. This result is explained theoretically in terms of "photon blockade", similar to the Coulomb blockade phenomenon observed in single-electron tunneling experiments. The single-photon tunneling effect may find many applications in the emerging fields of quantum communication and information processing



LDOS spectra (a) and intensity dependencies (b) of LDOS at the wavelengths indicated by arrows calculated for the 10 nm spherical silver particle placed at 1 nm over a silver film coated with a nonlinear material. The LDOS spectra correspond to different changes of the refractive index of a nonlinear material: (from left to right) Δn = -0.03, 0, 0.01, and 0.1. Dielectric constants of silver are taken from (20), the linear refractive index of the nonlinear material (n_0 = 1.7) is chosen close to the refractive index of BCMU polydiacetylene



Experimentally measured transmission of selected sub-wavelength pinholes at 632 nm. Saturation of transmission due to the optical nonlinearity of polydiacetylene at a very low light intensity of a few thousands photons per second has been observed. Solid lines are the fits in the model of the intensity dependent LDOS resonances.



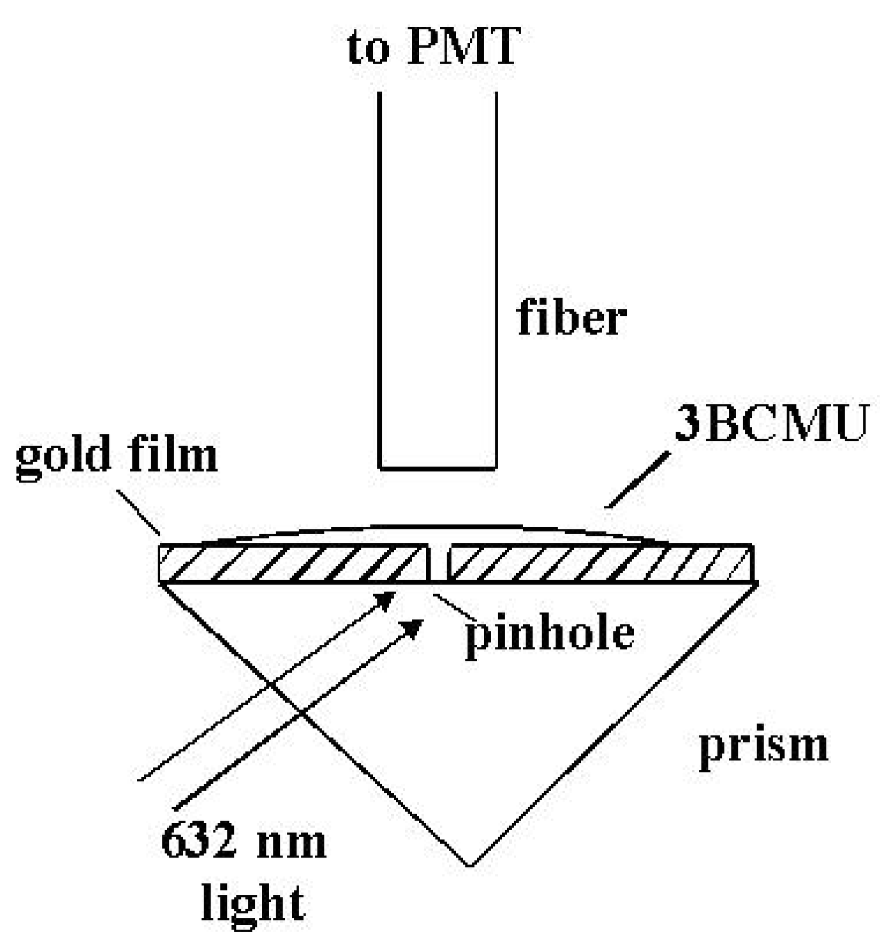
Single-electron tunneling:

charging energy $e^2/2C$ of the capacitance C is much larger than the thermal energy k_BT and the quantum fluctuation energy $\hbar\nu$ with $\tau = RC$ (where R is the resistance of the tunnel junction)

Single-photon tunneling:

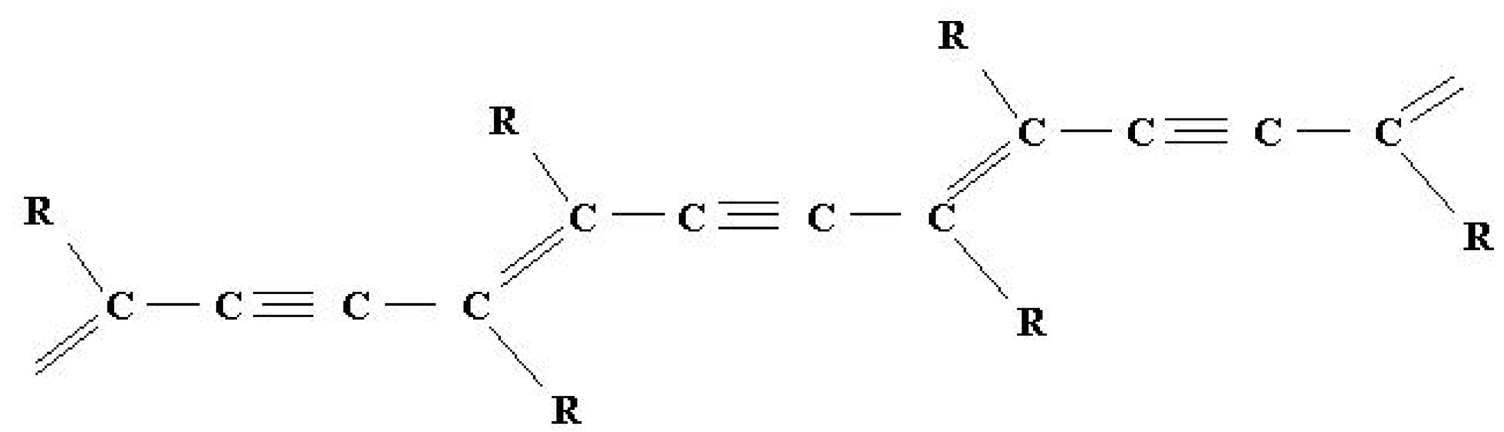
The electric field of the excited localized mode E_L induces local changes in the dielectric constant ε of the nonlinear optical material:

$\varepsilon = \varepsilon_0 + 4\pi\chi^{(3)}|E_L|^2$



Schematic view of our experimental setup.

Molecular structure of poly-4-butoxy-carbonyl-methyl-urethane (poly-4BCMU)



R= $(CH_2)_4OCONHCH_2COOC4H_9$

$\chi^{(3)}_{1111}(\omega;\omega,0,0) \sim 1.69 \times 10^{-10}$ esu