Effects of visible light illumination on the conductance of Al/AlO_x single-electron transistors

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Recently, significant attention was attracted to single photon detectors employing quantum dots for trapping of photon-excited carriers and detecting those carriers using ultra sensitive electrometers such as single-electron transistors (SETs). The SETs can also be used to investigate the so–called "blinking" behavior exhibited by semiconductor dots and nanowires. This blinking phenomenon is described as random periods of photoluminescence ("on") from the blinking objects followed by periods of darkness ("off") where no light is emitted despite continuous light excitation of the nanoscale structures. The process of "blinking" is believed to be associated with the charge redistribution within the structures, and SETs are excellent sensors to detect these charge changes. To accurately detect these charge fluctuations the SET detectors itself must be protected from direct illumination to avoid detection of unrelated photon-excited effects. To achieve this goal, metal shields can be used, and the efficiency of shielding in turn has to be characterized along with other parasitic effects promoted by light illumination. Using high resolution e-beam lithography we fabricated SETs protected from direct access of photons by means of metal shields, as well as unshielded devices which are used as a reference. Figure 1(a) shows an SEM micrograph of one of the studied SETs before the fabrication of the top insulator and metal shield; Fig. 1(b) shows the fabricated array of the SETs covered with metal shield separated from the devices with thin layer of dielectric; and Fig.1(c) shows the performance of the typical SET at different temperatures. We study the effects of light illumination on the behavior of the SETs fabricated using Ti-Au shields of different thickness, different dielectrics separating devices from shields, as well as different device geometries and substrate materials. Figure 2 shows several effects on the SET conductance caused by the light illumination: smearing of the CBOs (Fig. 2a), drastic increase of the electrical noise (Fig. 2b) and reduction of CBO amplitude with the presence of light (Fig. 2c) in unshielded devices; and the change in the periods of the Coulomb blockade oscillations (CBOs) in a shielded device (Fig. 2d). We believe that the observed effects could be separated into two major categories. The first is attributed to light induced charge excitations of nearby traps, and the second is related to charge excitations in the Si substrate. We are currently investigating the details of the possible mechanisms of charge interaction with the light to optimize the performance of the detector for best sensitivity to incoming photon flux while at the same time minimizing the parasitic effects.

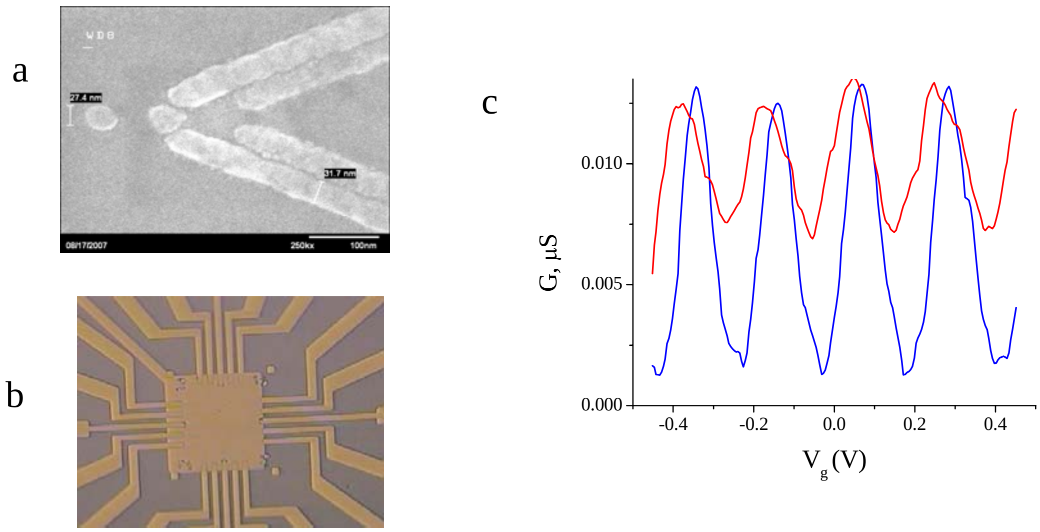

Figure 1 (a) Electron Micrograph of a Single Electron Transistor (b) Optical micrograph of an array of shielded SETs (the shield is in the square in the center, 50×50 μm^2) (c) Coulomb oscillations of the fabricated SETs measured at 9K (red curve) and 4.2K (blue curve).

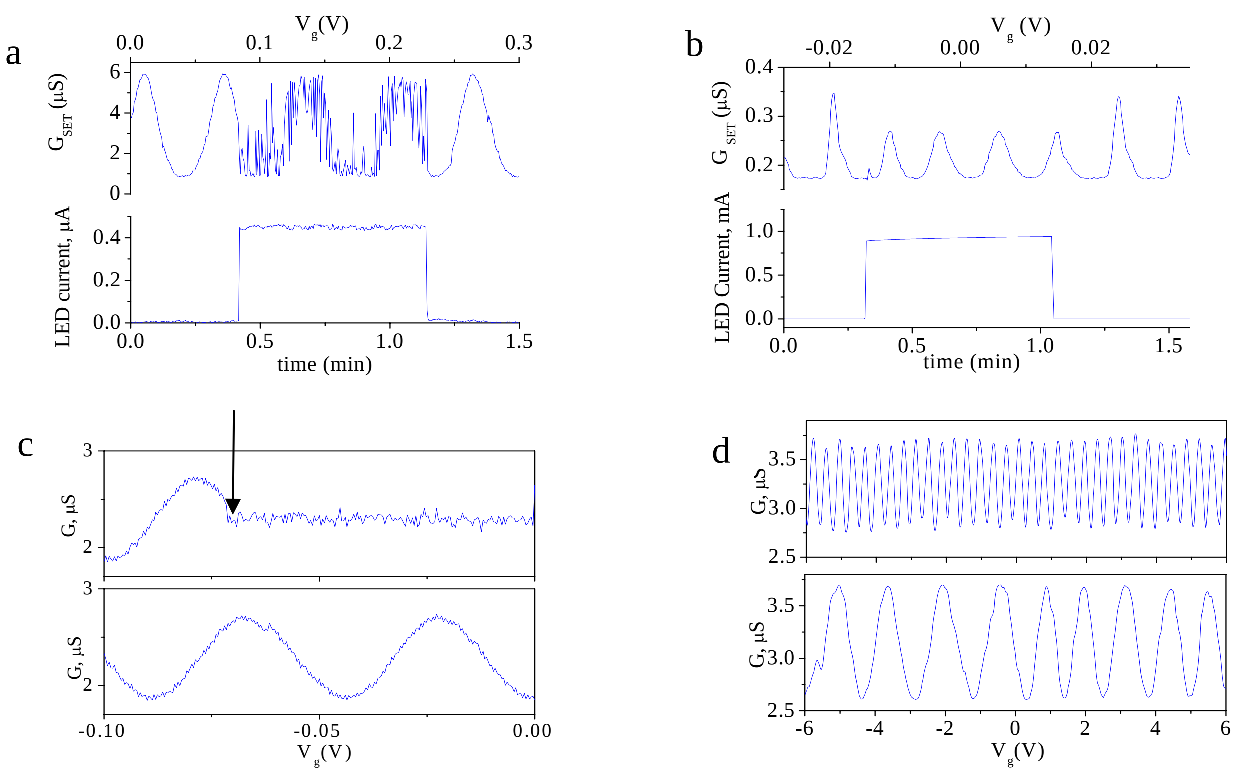

Figure 2. Response of the SET conductance to red LED illumination. (a) Noise appearance as small photon flux (I_{LED}=0.5 μA) is applied. Bottom curve shows light pulse in time. (b) Light induced peak lowering at higher light intensity (I_{LED}=1 μA). (c) Smearing of the CBOs for larger size SETs I_{LED}=40 μA, arrow point to the instance when light is applied. (d) Change in the period of oscillations. Top curve is measured at I_{LED}=200 μA, bottom curve is measured in the dark.