Fabrication of mono-electronic devices by AFM manipulation of silicon nanocrystals

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The size of electronic devices has been steadily decreasing using the top-down design approach. Transistors with channel length as short as 6 nm have already been fabricated [1]. With such small dimensions, quantum phenomena such as Coulomb blockade and/or resonant tunneling cannot be neglected and such effects should be studied in more detail. On the other hand, nano-objects such as carbon nanotubes and silicon nanocrystals (nc-Si) are very promising because there is no inherent scaling limit to the bottom-up approach to device fabrication. Transistor [2] and memory [3] devices incorporating nc-Si have already been demonstrated. However, up to now, no technique allows precise positioning of nano-objects in the active area of a device. We have developed three various AFM (atomic force microscopy) nanomanipulation techniques that allow i) placement of nc-Si with a precision of 10 nm [4]. It is then also possible to select the nc-Si we want to study (e.g. its diameter). Using these techniques, we have connected two metallic electrodes (drawn by electron beam lithography, lift-off and Ti/Au deposition) having 20 nm of separation with 1-3 nc-Si. After nc-Si manipulation, I(V) characteristics can be measured in the test structure indicating the injection of electrons through the nanocrystal(s). At room temperature, I(V) curves exhibit resonant tunneling peaks that can be attributed to discrete electronic levels in the nc-Si. At a constant drain to source voltage, drain current versus gate voltage exhibits oscillations that are related to the Coulomb blockade effect in the nanocrystal(s). As well, our test structure shows single electron transistor (SET) behavior. Using AFM under ultra high vacuum conditions, we show that we electrons can be injected into individual nc-Si and subsequently detected with a precision of 1 electron. For example, the injected charge in a 15nm-diameter nc-Si saturates at 12 electrons for a given charging field. Coupling SET fabrication by mean of AFM nanomanipulation with precise determination of the injected charge in an individual nc-Si close to the SET channel should allow us to design a single electron memory.

[1] IBM, IEDM 2003 [2] Choi et al., Appl. Phys. Lett. 73, 3129 (1998) [3] Tiwari et al., Appl. Phys. Lett. 68, 1377 (1996) [4] S. Decossas et al., nanotechnology 14, 1272 (2003)

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