Silicon nanochains: fundamental properties and applications

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Silicon nanochains are amongst the promising materials for potential applications in future nano-electronic devices because of its structure. The nanochains consist of a series of silicon nanocrystals of few nm in diameter, separated by silicon dioxide regions. It is difficult to achieve such structures with top down fabrication techniques. Further, the physical properties of grown nanochains can be defined at the time of synthesis as control over the dot size and separation is possible [1]. Therefore the morphology of the nanochains can be tailored, according to the proposed application.

Here, the silicon dioxide necks may act as tunnel barriers for electron tunneling between the silicon nanocrystals (islands), forming a multiple tunnel junction system. The tunnel-coupled nature and nanoscale size of the silicon nanochains makes these structures promising candidates for the fabrication of single-electron transistors operating at room temperature. The structure is also of interest to study the charge storage for future flash memories and investigation of electron transport in a nanoscale 1-D system. Further, the study of electrical and optical properties of the nanochains may lead to other device applications such as field effect transistors and information processing devices.

In contrast to silicon nanowires that have been studied extensively, hardly any attention has been paid in understanding the electrical properties of silicon nanochains. We are investigating the electrical and optical properties of individual silicon nanochains. The nanochain devices were defined on silicon-on-insulator (SOI) material with approximately 50 nm thick silicondioxide capping layer, grown thermally on the top-Si layer of the SOI material. The heavily doped top-Si layer formed a conducting back plane with the potential to form a back-gate. Initially, an array of Cr/Au alignment marks was fabricated by electron beam lithography on the silicondioxide capping layer. Next, hexamethyldisilizane vapour treatment of the surface was used as an adhesion promoter for nanochains. Nanochains, dissolved in IPA (0.1 mg / 3 ml IPA) using ultrasonic tip agitation for 5 minutes, were then spun onto the sample at 5000 revolutions per minute. Individual nanochains were then selected with reference to the alignment marks, by scanning electron microscope inspection. Finally, 20 nm Ti / 75 nm Al contacts were evaporated on to the nanochains, after wet etching of the silicondioxide layer around the nanochain in the contact regions [2].

Multiple step coulomb staircases were observed in current-voltage (*IV*) characteristics of these devices at room temperature [2]. The Coulomb staircase characteristics can be understood qualitatively, using single-electron Monte Carlo simulations [3]. We use a multiple tunnel junction (MTJ) circuit to model the nanochain devices, assuming equal junction capacitances. Our observation of a Coulomb staircase suggests a strong asymmetry in the junctions along the MTJ, and we include the effect of this by means of a random variation in the tunnel junction resistances. Such a variation may be caused by our observed variation in SiNC separation. There is also likely to be an associated variation in junction capacitances, although we neglect this in our analysis for simplicity. MTJ simulations require significant stray capacitance to reproduce both the low observed values of threshold voltage and the wide step widths in the Coulomb staircase. The simulations suggest that as stray capacitance increases, threshold voltage reduces and the clarity of the staircase improves. Simulated *IV* characteristics agree with experimental results. Experiments are underway to

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[2] Rafiq *et. al.*, to be published in J. Appl. Phys. (2008)

[3] Single-electron circuit simulator 'SIMON', see C. Wasshuber, H. Kosina, and S**.** Selberherr, IEEE Trans. CAD **16**, 937 (1997).