Silicon quantum dots and related devices

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Quantum dot structures, where electrons are confined three-dimensionally in the sub-10 nm scale, show characteristics quite different from conventional bulk structures. Recent progress in the fabrication technology of silicon nanostructures has made possible observations of novel electrical and optical properties of silicon quantum dots, such as single electron tunneling [1], ballistic transport [2,3], visible photoluminescence [4] and high-efficiency electron emission [5].

Nanocrystalline silicon (nc-Si) particles with size less than 10 nm were prepared by VHF plasma-enhanced decomposition of silane gas. Pulsed gas plasma processing, in which the nucleation and the growth period were controlled precisely, was turned out to be effective for the preparation of monodispersed nanocrystalline silicon particles [6] (Fig. 1,2). High density integration and assembly of Si nanodots are investigated using solution methods [7,8] (Fig. 3)

Electrical properties of nanocrystalline silicon particles were investigated by employing nanoscale electrodes, both planar and vertical configurations, prepared by electron-beam lithography. Coulomb blockade and Coulomb oscillations predominantly due to a single quantum dot were readily modeled [1] as well as interactions of electrons between neighboring dots [9]. Electron transport characteristics in ensemble of surface oxidized Si nanocrystals were also studied in various device structures [10,11].

Electron transport in coupled Si quantum dots prepared by EB lithography is also investigated in detail (Fig. 4). We observed characteristic transport of triple quantum dots [12] (Fig. 5) and successfully controlled electrostatic coupling of electrons using gate electrodes [13]. RFSET fabricated on SOI structure was also demonstrated for fast operating SETs [14]. These works are important steps towards future solid-state quantum information processing.

Quantized conductance due to ballistic transport was clearly observed in vertical Si transistors. [2,3]

Single-electron memory effects were studied using a short channel MOSFET having Si quantum dots as a floating gate [15,16]. Storing of electrons in individual Si dots was evaluated by Kelvin probe force microscopy. [17] Various materials and devices are proposed and competing for post-flash non-volatile memories. More process optimization in terms of precise control of dot size and interdot distance is necessary for nanodot memory to be a candidate for future Tera-bit memory application.

We proposed novel memory devices based on Nano Electro-Mechanical Systems [18,19]. Mechanical systems are fast in nano-scale and low-power consumption. An optimized NEMS-gate which eliminate the problem of back ground charges was designed and studied using accurate 3D calculation [20]. We also prepared Si nano-bridge transistors with suspended channel structures [21] and observed unique transport characteristics presumably due to phonons confined in nano structures [22].

Photoluminescence and electron emission were observed from surface oxidized nanocrystalline silicon particles. With decreasing core Si size by further oxidation, a red light emission peak, observed at room temperature, shifts to high energy side due to quantum size effect and emission efficiency increases due to no-phonon-assisted recombination [4]. Electroluminescence was observed in stacked layers of Si nanocrystals [23] and photoluminescence efficiency was enhanced by 3D photonic crystal structures [24,25]. However, further process optimization is necessary for Si nanocrystals light emitter to be incorporated in future ULSI interconnections.

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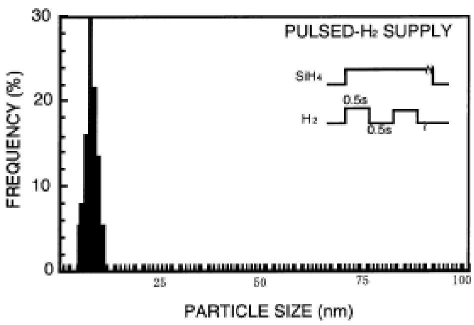

Fig. 1 Size distribution of nc-Si.

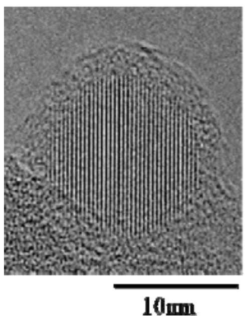

Fig. 2 TEM image.

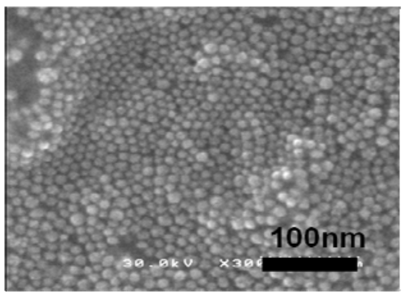

Fig. 3. 2D array of nc-Si prepared by LB film method.

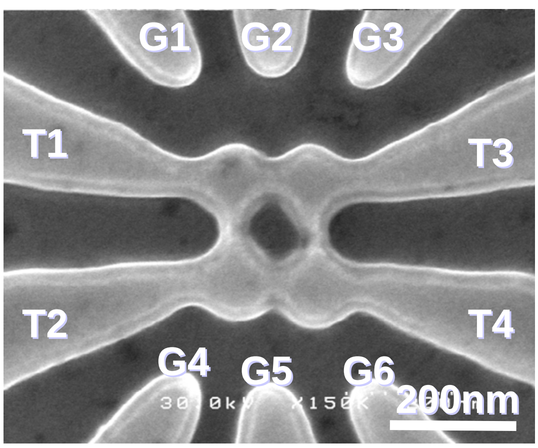

Fig. 4, Coupled 4QD structure prepared by EB method.

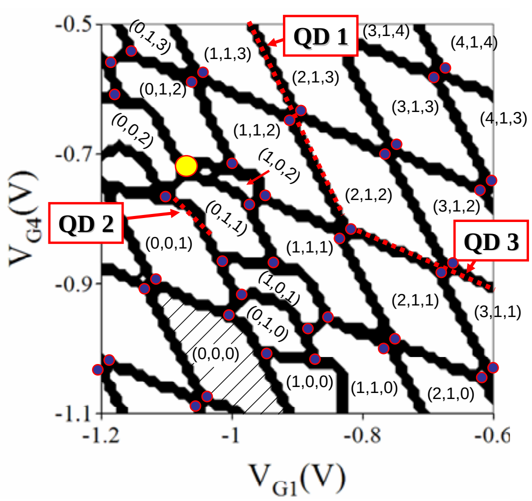

Fig. 5. Charge stability diagram for 3 QD system.