

FORMATION OF NANOCRYSTALLINE SILICON QUANTUM DOT ARRAYS

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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, ballistic transport, visible photoluminescence and electron emission. Nanocrystalline silicon particles with size less than 10 nm have been prepared by VHF plasma decomposition of silane gas. Pulsed gas plasma processing, in which the nucleation and the growth period are controlled precisely, is turned out to be effective for the preparation of monodispersed nanocrystalline silicon particles [1]. Electrical properties of nanocrystalline silicon particles have been investigated by employing nanoscale electrodes, both planar [2] and vertical [3] configurations, prepared by electron-beam lithography. Coulomb blockade and Coulomb oscillations predominantly due to a single quantum dot are readily modeled as well as interactions of electrons between neighboring dots. Single-electron memory effects are studied using a short channel MOSFET having Si quantum dots as a floating gate [4]. Oxidation process of nanocrystalline Si particles is studied intensively in order to fabricate Si dots with size less than 5 nm. Visible photoluminescence [5] and high-efficiency electron emission [6] have been observed from surface oxidized nanocrystalline silicon particles. We have proposed a novel material NeoSilicon in which both particle size and interparticle distance of nanocrystalline silicon (nc-Si) quantum dots are precisely controlled [7].

We developed a method of making the nc-Si dot dispersion solution and assembling the nc-Si dots from the solution by using the drop & evaporation technique. Methanol was found to work best as a suitable solvent for nc-Si dots. The nc-Si dots were assembled successfully in the two-dimensional manner on the hydrophilic SiO₂ surface via the lateral capillary meniscus force. By making the evaporation process slower with use of isopropanol as a solvent, densely packed layered structures were formed with an areal dot density as high as 9.4×10^{11} dots/cm². In addition, we examined the assembly of

the nc-Si dots on the patterned SOI substrates with nanoscale electrodes with a gap of as small as 20 nm and succeeded in fabricating the nc-Si dots cluster bridging between the electrodes. Combining the top-down nanolithography and bottom-up self-assembly, this technique may provide a new method to fabricate nanoscale Si structures for the future quantum information device applications.

References

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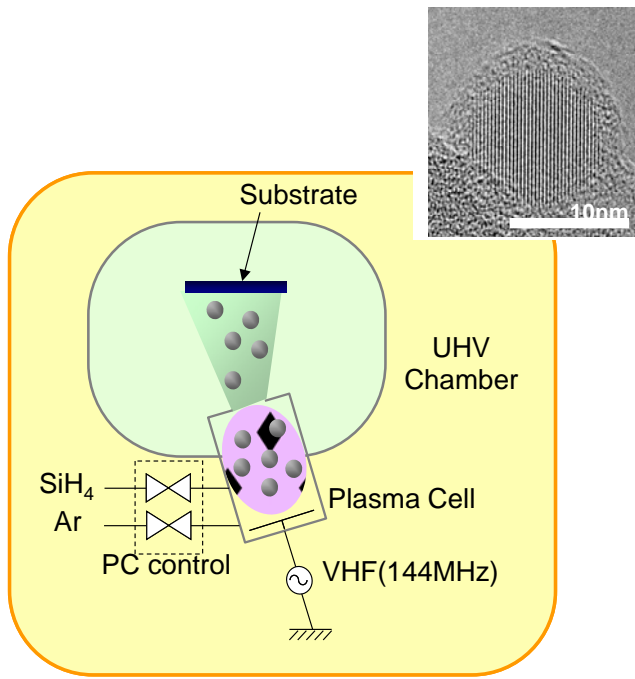


Fig. 1. A schematic diagram of the fabrication system of nanocrystalline silicon dots using plasma cells and a TEM image of a nc-Si dot.



Fig. 2. A schematic flow-chart of the drop & evaporation process.

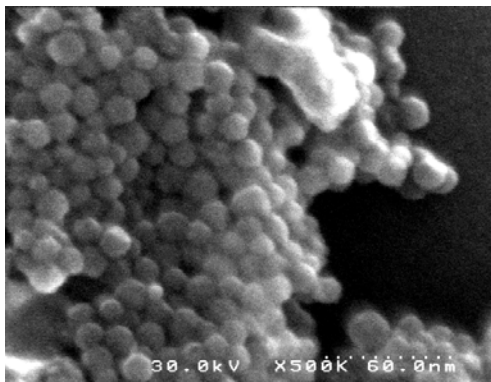
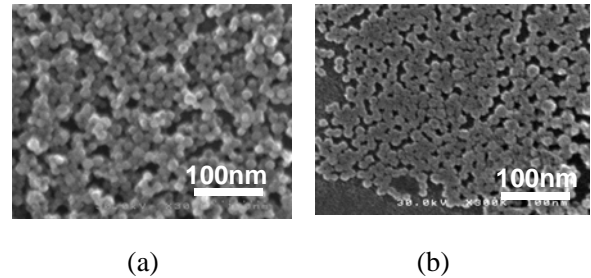


Fig. 3. SEM image of the nc-Si dots assembled with the drop & evaporation method.



(a) (b)
Fig. 4. SEM images of the nc-Si dots assembled at room temperature with the drop & evaporation method using methanol solvent on Si (a) and SiO₂ (b) substrates.

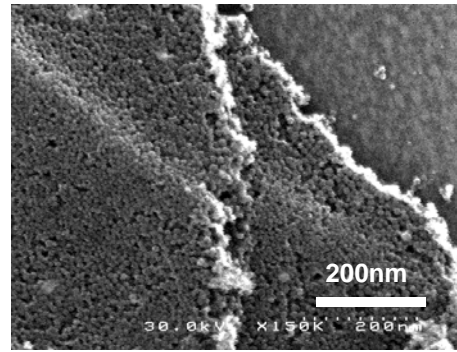
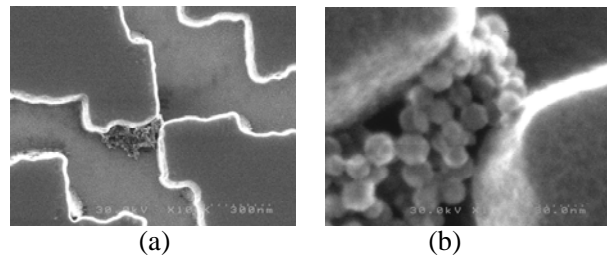


Fig. 5. The nc-Si dots assembled by using the drop & evaporation method using isopropanol solvent on the SiO₂ substrate. The observed steps were probably formed when two (or multiple) assembled flat regions were pushed against each other by the lateral capillary force. The conditions on evaporation should be optimized for further improvement of the assembly process.



(a) (b)
Fig. 6. SEM image of the nc-Si dots assembled on the SOI wafer with patterned nanoelectrodes (a) and the blow-up of the nanogap region (b).