High-Density Assembly of Nanocrystalline Silicon Quantum Dots

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The bottom-up approach to form nanometer-scaled silicon structures is attracting more attentions as an alternative way of developing future quantum nanoelectronics devices since maintaining the conventional top-down miniaturization trend is getting harder due to fundamental physical and technological limitations as well as of the economical limitation. Nanocrystalline silicon (nc-Si) quantum dots [1,2] are particularly a promising material and various new device applications have been explored based on their unique electronic and photonic properties. In this paper we report on a new bottom-up technique of high-density assembly of the nc-Si quantum dots based on natural aggregation of the dots in the solution. We previously studied how the nc-Si dots deposited on the Si substrate get mobile in the hydrofluoride (HF) solution by simply dipping the substrate with the nc-Si dots on into the HF solutions [3]. We demonstrated the HF solution droplet evaporation method that utilizes aggregation of the dots when we evaporate a solution droplet applied onto the nc-Si dots randomly deposited on the Si substrate. It was shown that the nc-Si dots are assembled in a droplet of the HF solution, resulting in various regular patterns locally on the substrate. In the present study we examined to use various other solvents for making the nc-Si dispersed solution more suitable for achieving highly dense nc-Si assembly.

Nanocrystalline Si dots with a diameter of 8±1 nm were deposited on the Si substrates by using VHF plasma decomposition of pulsed SiH_4 gas supply. The samples were immediately (within one minute) put into pure water, methanol and cyclohexane (C_6H_{12}), and ultrasonic cleaning was conducted for 5 minutes. We then observed by SEM how well the nc-Si dots were come off from the substrate. After that we concentrated the solution by heating and dropped a small volume of condensed solution onto a new substrate as shown in Fig. 1. After drying the solution droplet, we observed the assembled nc-Si dots by using SEM. For all three solvents we observed that the nc-Si dots were removed from the substrate to a large extent. After the drop & evaporation process, we could observe the assembled nc-Si dots only for the methanol solvent. The capillary meniscus interactions [4] are supposed to work between the nc-Si dots immersed partially in the methanol, resulting in the dot aggregation. Figure 2 shows the SEM image of the assembled nc-Si dots. We could achieve the areal dot density of approximately 7×10^{11} cm^{-2} which is fairly close to the close packing of the spheres with a diameter of 10 nm. Quasi-regular patterns of the dots are also recognized locally in the assembly (Fig. 2).

References

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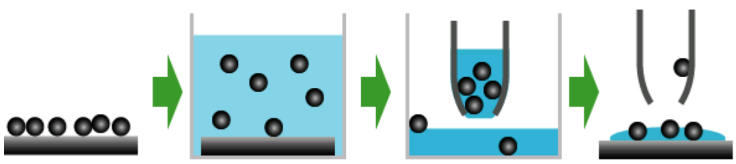

Fig. 1 Nanocrystal Si dots deposition, removal & condensation in the solvent and dripping of the nc-Si solution

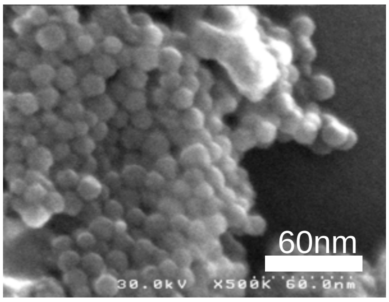

Fig. 2 SEM image of assembled nc-Si dots obtained by using methanol solution drop & evaporation method

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