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Bio-Nano Approaches to Fabrication of Quantum Dot Floating Gate Flash Memories

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1. Introduction

Nowadays semiconductor technology for system-on-a-chip integrates memory, logic, sensors, actuators, etc. Bio-nano techniques for device fabrication are attractive because traditional semiconductor process technology is being pushed toward its limit. Consequently, a lot of work has been done by exploring different biological materials such as DNA, virus, or protein as a tool for processing in nanometer scale.

This paper discusses the used of chaperonin 60 (GroEL) and heat shock protein 60 (HSP60) as an assembly tool for nanocrystal or quantum dot (QD) flash memory fabrication. With GroEL, we have fabricated and demonstrated both planar and vertical memory transistors [1-6]. As for HSP60, we are working on genetically engineering the size of protein unit so as to achieve more freedom in NC assembly ordering [7].

2. Chaperonin Protein-Mediated Quantum Dot Assembly as Floating gate for Flash Memory Fabrication

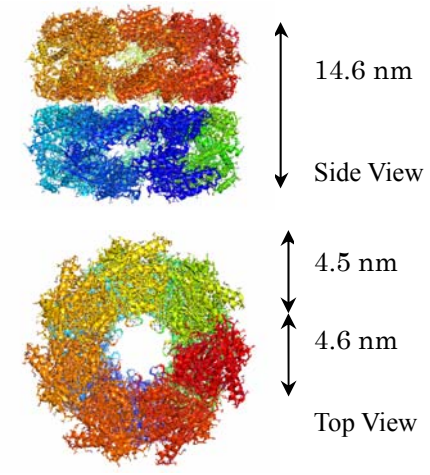

Fig. 1 Schematic illustration of chaperonin GroEL[1, 2].

Quantum dot floating gate flash memories have been demonstrated to have a lot of advantages over traditional flash memories in many aspects such as lower power consumption, better device scaling and charge retention. However, challenges still remain about how to effectively control the gate embedded dot size and spatial distribution, and minimize the electrical characteristics variation across cells. In our work, crystallized GroEL lattice was introduced as a template to assemble colloidal suspended quantum dots into 2-D arrays.

GroEL possesses two donut-shaped rings which stack together to form a double-decker structure. Each ring consists of seven protein subunits surrounding a central cavity with a diameter of 4.5 nm and a wall thickness of 4.6 nm (Fig. 1) [8]. Like many biological systems, GroEL has the property of hierarchical self-assembly through hydrophobic-hydrophobic interaction between proteins. The interior surface of GroEL's central cavitie is hydrophobic, which can trap quantum dots which are hydrophobically functionalized through hydrophobic-hydrophobic interaction [9]. Therefore we can transform the protein lattice into quantum dot assemblies. After quantum dot arrays are formed, the protein lattice can simply be removed through annealing in oxygen at 200°C or in the air at 300°C.

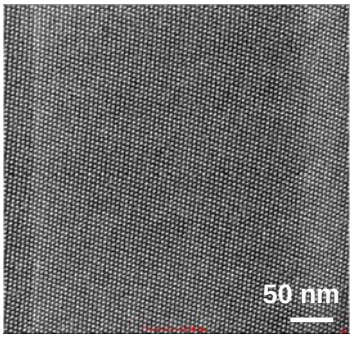

Fig. 2 STEM image of GroEL assembled PbSe quantum dots on oxide surface.

This chaperonin protein-assisted self-assembly technique has been applied to flash memory fabrication to form a uniformly distributed quantum dot array on tunnel oxide surface. STEM images show a nearly perfect 2-D ordering of quantum dots in the micron range (Fig. 2). In addition to planar transistor fabrication, we also used this technique to fabricate vertical structure devices. Our experiments prove

that GroEL can also hold the quantum dots on the side wall of vertical devices, though it cannot bring as good ordering as in planar devices (Fig. 3). Electrical data from both planar and vertical devices are promising for flash memories [1-6]. Fig. 4 shows transconductance and electrical characteristics of a vertical memory transistor.

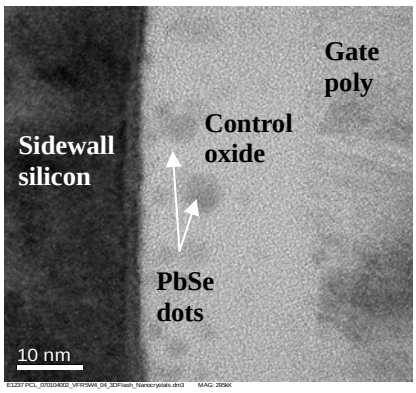

Fig. 3 Cross-sectional Tunneling Electron Micrograph of PbSe QDs embedded in the gate-stack on mesa sidewall [6].

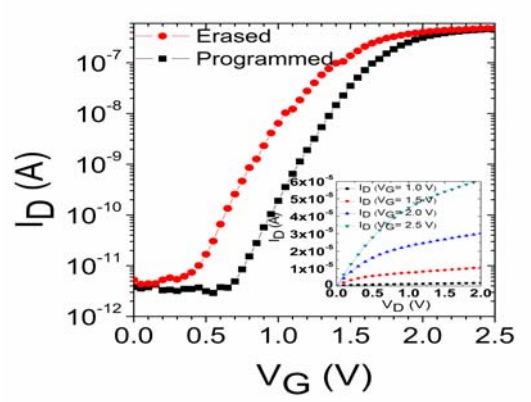

Fig. 4 Transconductance characteristics with a memory window of ≈ 0.3 V in the non-optimized vertical devices, and (inset) drain [6].

3. Genetic Engineering of HSP60 for Cavity Size and Density Control

Although the cavity size of GroEL can be modified in the presence of Mg^{2+}, K^+ and ATP (adenosine triphosphate) through conformational change [9], the dimension of change is very small (1 or 2 nm). In other words, the flexibility of trapping QDs with different size is highly limited. To solve this problem, one way is to genetically engineer the protein to obtain control over cavity size.

HSP60 are a group of chaperonins consisting of two stacked rings with 7, 8 or 9 subunits. Funtionalized with peptide sequence, additional subunit can be joined to the protein termini by binding inorganic materials or by fusion to binding or catalytic proteins, which makes it possible to obtain arbitrary ring length and highly ordered assemblies [7].

Our preliminary experiments were aimed at assembling the HSP60 subunits into protein rings with a cavity diameter of 9 nm and using them for quantum dot trapping. Fig. 5 shows gold QDs assembled at the presence of HSP60. With a higher HSP60 concentration, the density of gold QDs trapped on sample surface significantly increased, which indicates the effectiveness of QD trapping by the protein cavity. It also shows that the density of QDs on the surface can be modified by the deposition temperature.

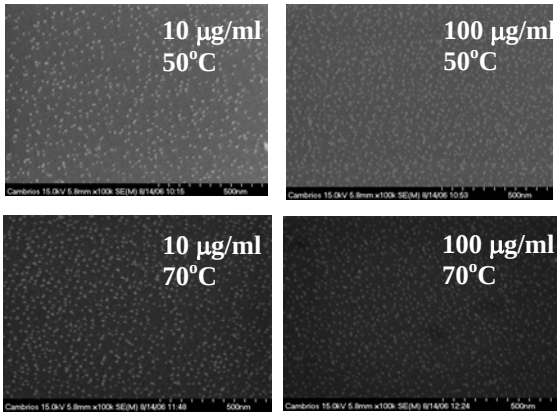

Fig. 5 SEM images of Au QDs on SiO_2 surface after HSP60 removal.

4. Conclusions

Using chaperonin protein as an assembly tool for quantum dot floating gate flash memory fabrication has been demonstrated to be feasible in both planar and vertical devices. Genetic engineering of protein to allow more flexibility for device process is still under investigation.

Acknowledgements

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