A New Structure of nanodisk (Stacked Nanodisk) fabricated by bio-nano-process and defect-free neutral beam etching

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1. Introduction

It is indispensable to increase the miniaturization of conventional MOSFET as year goes by. However, the miniaturization would suffer serious problems, such as leakage current and power consumption, in the near future. Quantum effect devices are highly expected to overcome these problems. In many application, such as electron pump, leakage current and power consumption, in the near future. miniaturization would suffer serious problems, such as conventional MOSFET as year goes by. However, the

2. Experiment

The details of the bio-nano-process for the fabrication of stacked nanodisk were based on previous literature. Here we briefly describe the sample preparation procedure. Multilayered films were fabricated sequentially as followings: a 1.4-nm-thick SiO2(1st) was grown by rapid thermal oxidation on a p-type Si(100) wafer; amorphous silicon (a-Si) layer was deposited on the SiO2(1st) using electron beam deposition and crystallized to form 3-nm-thick poly-Si(1st) by heat treatment in nitrogen atmosphere; a 1–2-nm-thick SiO2(2nd) was grown on the poly-Si(1st) by NBO; a 3-nm-thick poly-Si(2nd) was deposited by the same process as poly-Si(1st); finally, the surface of the sample was naturally covered by surface oxide (SiO2(3rd)). After film deposition, the etching mask was deposited onto the sample by using recombinant ferritin molecules. The ferritin protein shell was removed by heat treatment in oxygen atmosphere to extract the 7-nm-diameter iron oxide core as etching mask. Alternative etching of N2 gas/hydrogen radical (N2 treatment) and defect-free neutral beam (NB) etching was performed to precisely remove SiO2 and poly-Si layers, respectively. The diameter of stacked nanodisk was controlled by the N2 treatment time in the first etching step. We also investigated the diameter control by high energy NB etching. In order to optimize the etching condition, Si 2p regions of XPS spectra were measured after each etching step.

3. Results and discussion

Figure 1 shows the XPS spectrum of each optimized etching step. Initially, as shown in Figure 1-(a), the chemical shift was about 4eV before etching, which implies that the SiO2(3rd) was similar to the thermal oxide due to the heat treatment for removing protein shell. After 1st NF3 treatment with 30 minutes, as shown in Figure 1-(b), the surface of the sample was the poly-Si(2nd) due to smaller chemical shift with about 3.6eV and much weaker intensity of oxide peak. Figure 1-(c) shows the larger chemical shift and stronger intensity of oxide peak, as shown in Figure 1-(d), were similar to the one after 1st NF3 treatment due to the sample surface of poly-Si(1st). Finally, as shown in Figure 1-(e), the chemical shift and intensity of oxide peak became larger again, which indicates that the SiO2(1st) was preserved after 2nd NF3 treatment. The SEM images, as shown in Figure 2, show the evolution of each etching step corresponding to the XPS spectra. After 1st NF3 treatment, as shown in Figure 2(a)-(i), the image shows rough surface and the disk shape is not clear. After 1st NB etching, the disk shape, as shown in Figure 2(a)-(ii), could be recognized. Then, the disk shape is more obvious after 2nd
NF₃ treatment, as shown in Figure 2(a)-(iii). At the end, the stacked-nanodisk was clearly shown in Figure 2(a)-(iv) and the surface of remained SiO₂(1st) was very smooth. Figure 2(b) shows the cross-sectional scanning transmission microscopy (STEM) image of stacked-nanodisk. The stacked-nanodisk with alternative layers of nanodisks and tunnel junctions was clearly observed.

Diameter of stacked nanodisk was controlled by the 1st NF₃ treatment (the following etching conditions were the same). We also performed higher energy of NB etching to investigate the controllability of diameter. Figure 3 shows the result of diameter control. By changing the NF₃ treatment time, the diameter could be controlled. As the NF₃ treatment time increases, the diameter of stacked nanodisk decreases. The controllable range is from about 14 to 12 nm. By using the high energy NBE, the controllable range could be extended to about 11 nm.

I-V characteristics of stacked nanodisk were taken using JEOL JSPM-4500A scanning probe microscope and an AFM probe coated with doped diamond at room temperature. Figure 4 shows an example of the I-V for a stacked nanodisk. Coulomb staircase was observed. Figure 5(a) and (b) show the diameter dependence and SiO₂(2nd) thickness dependence of Coulomb staircase. The staircase width highly depends on the SiO₂(2nd) thickness due to the change of tunnel probability. On the other hand, the staircase was almost independent of diameter because the nanodisk works like a quantum well[12].

4. Conclusions

In summary, a stacked-nanodisk with two nanodisks connected in a series by coupling of three tunnel junctions was successfully fabricated by bio-nano-process. By utilizing XPS spectra, the etching depth could be precisely detected and the etching condition could be optimized as well. The SEM and TEM images clearly show the evolution of the shape of the stacked-nanodisk after each etching step and the alternative structure of stacked-nanodisk, respectively. The diameter of stacked nanodisk could be controlled by different etching condition. The Coulomb staircase was observed in I-V measurement at room temperature. The staircase width was almost independent of diameter. By varying the thickness of tunnel junction of SiO₂(2nd) by our developed NBO, the characteristic of Coulomb staircase could be controlled.

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