Growth of Si Nanowires on Nano Catalyst Corners

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ABSTRACT

One dimensional structures with nanometer diameters, such as Si nanowires, have great potential for understanding and testing fundamental concepts about the roles of dimensionality in optical, electrical and mechanical properties and for applications ranging from nanoelectronics to biosensing. Here we successfully grow high aspect ratio Si nanowires using Ni catalyst. At high temperature, we found that Ni catalyst layer changed to irregular starfish like structure. Detailed microscopy results showed that catalyst particle size has no relation with the diameter of Si nanowires. Most Si wires grow from the irregular catalyst tentacles. Furthermore, to understand how catalyst size and shape affect Si wires formation, we use EB writer and lift-off process to make various types of Ni nano catalyst corners.

Keywords: Si nanowires, Ni catalyst, EB lithography, SLS, lift off.

1 INTRODUCTION

Semiconductor nanowires, such as: Si nanowires, have attracted tremendous interest recently because of their potential applications as building blocks in future large scale nanoelectronics, optoelectronics and biological devices [1-3]. Si nanowires can be produced by the well known vapor-liquid-solid (VLS) mechanism [4] and solid-liquid-solid (SLS) mechanism [5]. In VLS mechanism, Si atoms in the vapor phase, supplied by gas decomposition, are absorbed on the surface of liquid droplets forming at high temperature and are solved into them, causing the super-saturation of Si in the droplets and growth of Si nanowires. In the SLS mechanism, at a very high temperature the liquid droplet of metal-Si is formed and then the Si from the substrate solves into the droplet continuously making it supersaturated with Si because of continuous diffusion. This initiates the growth of SiNW's resulting from the precipitation of Si atoms from the droplets.
Here in this work, we take advantage of SLS mechanism to grow high aspect ratio Si nanowires. EB lithography was used to pattern Ni nano catalyst. We investigated and compared the growth behavior of Si nanowires from both nano catalyst particles and nano catalyst corners.

2 FABRICATION & PROCESSING

In this work, the substrates we used were Si (100) surfaces. Ni (100Å) was evaporated on cleaned Si substrates by electron beam (EB) evaporation method. Some of samples were directly used to grow Si nanowires. In other samples, Ni catalyst layer were patterned to various nano shapes including squares and corners. The typical process flow is listed in figure 1.

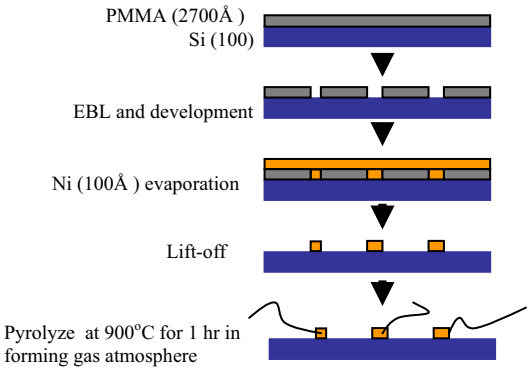
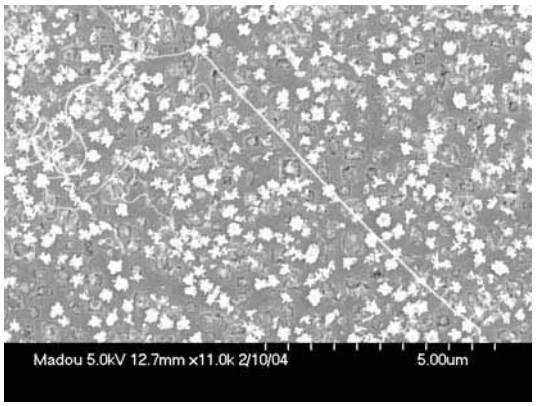


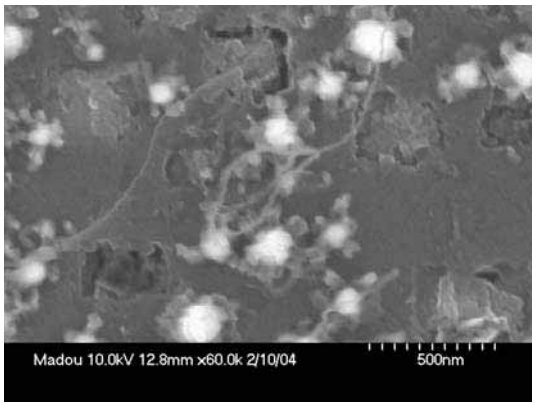
Figure 1: Fabrication details for Si nanowires grown on catalyst corners. (a) PMMA film of 0.27μm thickness was spin-coated on Si; (b) patterning the PMMA by electron beam, then developing it; (c) evaporation of Ni (100 Å) by EB evaporation; (d) making Ni nano patterns by lift-off method; and (e) pyrolyzing the samples at 900°C in forming gas environment.

3 RESULTS & DISCUSSION

Figure 2 (a) and (b) shows typical SEM images of as-grown nanowires from Ni (100 Å) layer. EDX investigation confirmed that the nanowires were composed of amorphous Si. In Figure 2(a) it can be seen that the Si nanowires originate/terminate with the star-fish shaped Ni catalyst islands. The Ni film appears to break down into several catalyst islands of Ni of around 0.1-0.5µm. These islands act as a starting point for the growth of the Si nanowires following the SLS mechanism since Si substrate is the only available source for the continuous diffusion of Si . The wires were found to be



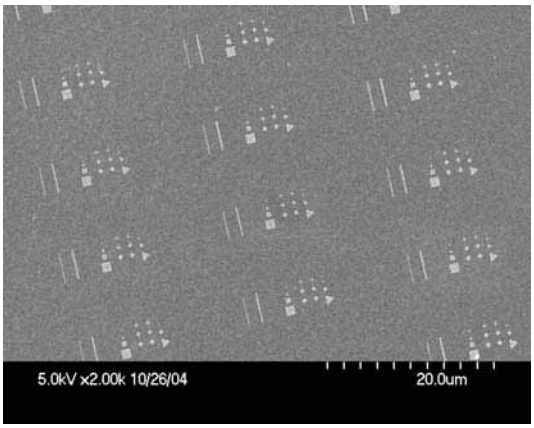
(a)



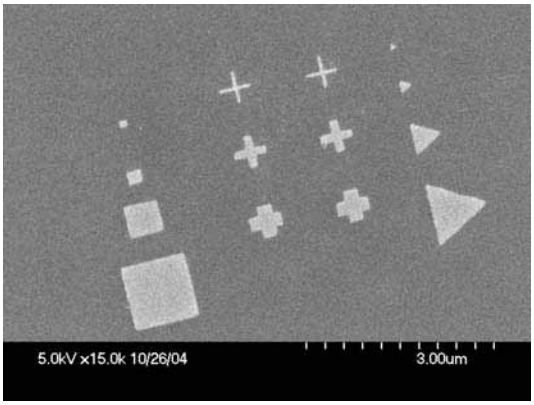
(b)

Figure2. Typical SEM images of Si nanowires grown on Si (100) with Ni (100 Å) catalyst layer.

about 20-50nm in diameter and extending upto more than 5µm. Figure 2(b) shows a higher magnification SEM of the Si nanowires. The catalyst islands can be seen clearly to form a star-fish shaped structure. It can also be seen that three separate nanowires are interlocked to one wire. There are a lot of etch pits on Si substrates.



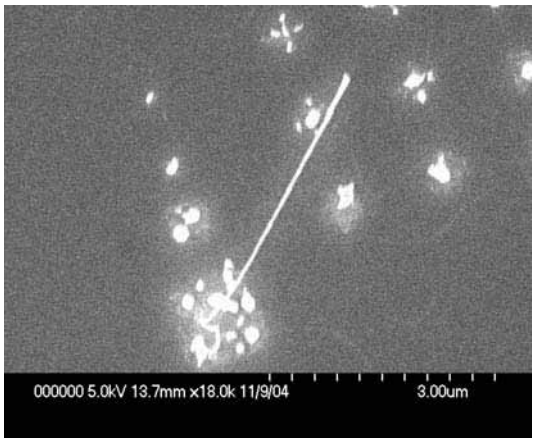
(a)



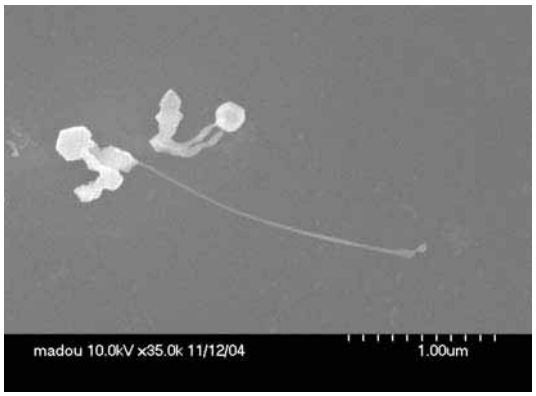
(b)

Figure 3. Typical SEM images of Ni nano structures (100 Å thick) fabricated by EBL as catalyst on Si substrate (100).

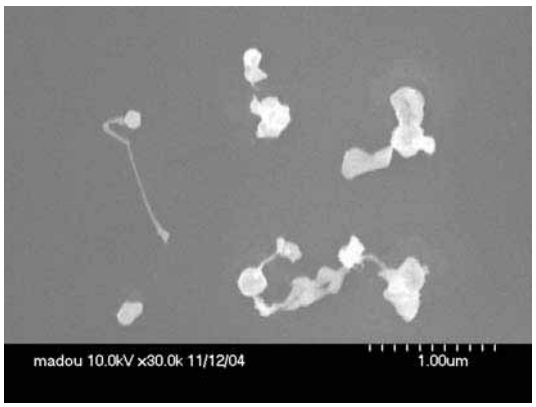
Next in order to see if the nucleation sites of Si nanowires happens on nano corners or not, we made catalyst nano corners by EBL before Si growth. Figure 3 (a) shows the SEM image of various nano-corner pattern arrays which were patterned with the EB lithography. Figure 3(b) shows a high magnification SEM image, in each array, the patterns had various nano shapes like triangles, squares, cross, lines. Their sizes ranged from 100nm to 1µm.



(a)



(b)



(c)

Figure4. Typical SEM images of Si nanowire grown from nucleated Ni catalyst nano-corners.

Figure 4 (a) shows the SEM image of the pyrolysed sample at 900^{o}C in forming gas environment. We find that the catalyst pattern broke down into much smaller Ni irregular domains at the size of typically around 10-400nm. One high aspect ratio nanowire grows from one nano-domain and connects several irregular nano domains. From the high magnification SEM images as shown in Figure 4 (b) and 4 (c), it is observed that nanowires in different length grow from the broken nano domains without any relation to the original Ni nano corners. In a word, unlike the wire growth from starfish type tentacles shown in Figure 2, here artificially made nano tentacles didn't contribute to the nanowires growth. Further detailed studies will be done.

4 CONCLUSIONS

In conclusion, we successfully grow high aspect ratio Si nanowires using Ni catalyst and SLS mechanism. Detailed microscopy results showed that in our case catalyst particle size has no relation with the diameter of Si nanowires. At high temperature, we found that Ni catalyst layer changed to irregular starfish like structure. Most Si nanowires grew form the irregular catalyst tentacles. In order to understand how catalyst size and shape affect Si wires formation, we use EB writer and lift-off to make various types of Ni nano corners. It is found that artificially made nano tentacles didn't contribute to the nanowires growth.

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