펄스레이저 증착법을 이용한 실리콘 나노와이어 합성

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Synthesis of silicon nanoeires by pulsed laser deposition in furnace

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Abstract : Si nanowires (NWs) were fabricated in vacuum furnace by using a Nd:YAG pulsed laser with the wavelength of 325 nm. Commercial p-type Si wafer is used for target, and any catalytic materials are not used. Scanning electron microscopy (SEM) images indicate that the diameters of Si NWs ranged from 10 to 150 nm. Si NWs have various size and shape with a substrate position inside a furnace, and their morphologic construction is reproducible. The formation mechanism of the NWs is discussed.

Key Words : Si Nanowires, Vapor-Solid Mechanism pulsed laser deposition (PLD)

1. Introduction

One dimensional nanoscale structures have attracted a great deal of attention in recent years because of their great potential for fundamental studies as well as applications in functional nanodevices. Controlled growth of the nanowires in their morphology, orientation, for example, is the key to success both for characterization of physical properties and exploration of device application of the nanowires; however, it is extremely difficult to realize. In most of previous reports for growth of NWs by using PLD, deposition times are over 60 min. The target which is induced by laser beam during the deposition forms many cone-like structureson the surface. This cone-like structures change plume direction and distribution of the particle size, which cause the decrease of deposition rate [1] and aggravation of film quality [2]. Here, we fabricated Si NWs by laser ablation of rotating Si target to avoid the formation of cone-like structures. Moreover, we used the commercial boron doped p-type silicon wafer with target. Neither additional deposition of catalyst metal layer nor fabrication of target including catalyst materials was required.

2. Experimental

Si NWs were synthesized by using pulsed laser ablation in alumina tube placed inside a furnace. Target was put on the rotational holder inside the center region of the tube and the substrates were placed upstream from center of the tube as shown in Fig. 1(a). The names of the samples were determined by their position in the furnace tube as shown in Fig. 1(b).

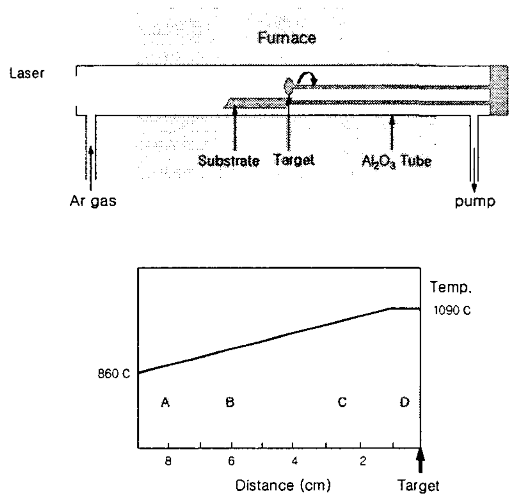

Fig. 1. (a) Schematic diagram of the laser deposition apparatus for nanowire growth, (b) temperature incline with substrate position inside a furnace and sample names at the local sites.

When the pulsed laser beam was focused, the indicated furnace temperature was kept at 1200℃. The temperatures measured by IR thermometry at substrate holder was changed from 860℃ to 1090℃ depending on local position from target. The morphology of synthesized Si NWs were measured by SEM. The crystalline phase was investigated by X-ray diffraction (XRD) with a Ni-filtered CuK (λ=0.15406 nm) as radiation source.

3. Result and discussion

Typical images of obtained Si NWs are shown in Fig. 2. The shape of the Si NWs varied with substrate positions. After cooling down to room temperature, a dark gray-colored deposit was found on the surface of the substrate. In the sample A, the curved NWs were observed as shown in Fig. 2(a). The diameters of these curved NWs ranged from 10 to 20 nm. The NWs observed in the sample B seemed to be straight as shown in Fig. 2(b). The average length of the straight NWs was greater than 1 ㎛. In Fig. 2(c), the straight NWs were also observed in the sample C. The diameters of these wires ranged from several tens to hundreds of nanometers. In the case of the sample D, the substrate was found to be covered by raspberry-like structures with the size about 1.5 ㎛, as shown in Fig. 2(d).

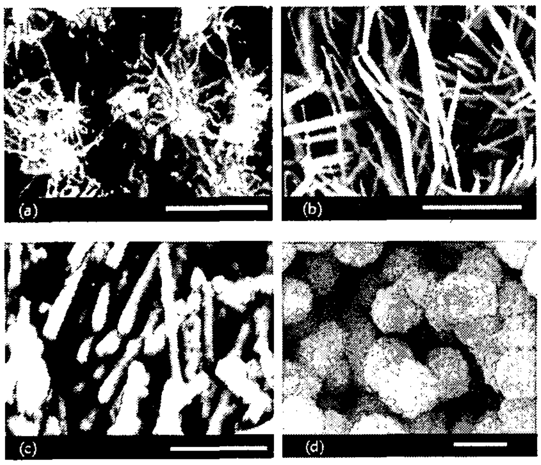

Fig. 2. SEM images of various Si NWs at different local site in furnace. (a) sample A, (b) sample B, (c) sample C, (d) sample D. Scale bar: 1.5 ㎛.

However, when we precisely observed the sample D at higher magnification, NWs were observed in several parts of the sample as shown in Fig. 3(a). We scratched one piece of the raspberry-like carpet from the substrate and observed the microstructures of it. It showed that the film consists of fine free-standing wires of very high density, as shown in Fig. 3(b). The deposition rate was larger in close site from target. The difference of deposition rate formed the exposed substrate surface of the sample A which is not covered with NWs, and raspberry-like structures of the sample D. Moreover, the temperature gradient shown in fig. 1(a) seems to be having an important role of formation of various structures.

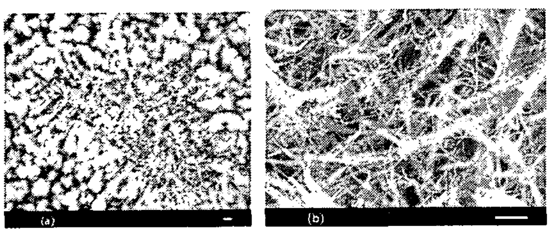

Fig. 3. SEM images sample D in in any other region. Scale bar: 1 ㎛.

Figure 4 shows a XRD spectrum of the sample B. The peaks of the Si (111), and (220) were observed with high intensities which indicated that the Si NWs were the well crystalline structure. The (111) plane has the lowest surface energy in the planes of silicon and plays an important role during the growth of nanowires. Notably, some additional peaks were observed. It was suggested that the peaks were related to crystalline silicon oxide. The peaks can be attributed to the surface silicon oxide, since Si NWs were oxidized upon exposure in air. The growth mechanism of Si NWs has been ascribed to the vapor-liquid-solid reaction assisted by the metal catalyst [3]. However we did not use the metal catalyst. N. Wang et al. reported that silicon oxide plays an important role in growth of nanowire [4]. The nucleation of nanoparticles is assumed to occur at the substrate by different decomposition of silicon oxide. We plan to verify this mechanism with more systematic investigation in further sturdy.

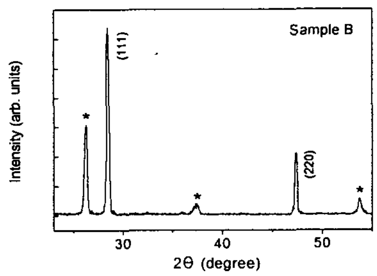

Fig. 4. θ-2θ X-ray diffraction patterns of sample B.

4. Conclusion

In summary, Si NWs were grown on a Si substrate without using any catalyst metal successfully by laser deposition. The various shapes of Si NWs were observed. The NWs fabricated by laser ablation have the diameter ranged from 20 to 150 nm. The present results provide simple approach for nanostructure preparation.

Acknowledgements

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References

[1] Y.E. Touloukian, R. K. Kirby, R.E. Taylor, P.D. Desai, IFI/plenum, (1975) 12.

[2] R. Kelly, andJ. E. Rothenberg, Nucl. Instrum. Meth. Phys. Res., **B7/8** (1985) 755.

[3] A. M. Morales and C. M. Lieber, Science, 279 (1998) 208.

[4] N. Wang, Y. H. Tang, Y. F. Zhang, C. S. Lee, I. Bello, S. T. Lee, chem.. Phys. Lett., **299** (1999) 237.