Surface Morphological Study of Silicon Nanostructure Synthesized by Metal Assisted Chemical Etching method on Silicon Substrate

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Abstract: One-dimensional nanostructures have proven to be good materials for novel nanoscale optoelectronics and high-sensitivity molecular sensors. In the past few years, silicon nanowires (SiNWs) have gained extensive attention due to its unique effects on quantum confinement for developing different applied devices, including optoelectronics, biosensors and other devices. The major function is geometric control of manufactured Silicon nanostructure including their lengths, sizes and orientations. In this article we have given the etching duration of 30 minute for the N type Si having resistivity ranges from 0.001-0.1 OhmCm. Hence, the easy and practical approach in this paper to generate Silicon nanostructures (SiNSs) has been done by the metal assisted chemical etching and there characterization is done by the field emission electron microscopy (FESEM) also the average diameter of the cage like Silicon nanostructure has been calculated by imageJ software.

Keywords: Silicon nanostructures (SiNSs), Field emission electron microscopy(FESEM), chemical etching

INTRODUCTION

The current massive increase of interest in silicon nanowires is triggered by their significant potential in various technological applications such as nanoelectronic, electromechanical, mechanical, and thermoelectric equipment [1–3].

The Silicon Nanowires (Si-NW) synthesis has generated a lot of interest in these quasi-one-dimensional materials. They are presumed to have intriguing structural, surface, electronic, and mechanical properties which can be used as modeling systems to show the effects of quantum size [4–6].Researchers have successfully applied the technique of laser ablation to SiNW's manufacturing process. All the techniques used in the production of nanowires yielded Si-NW of varying diameters and orientations and although covered with an oxide sheet with just a thickness of 1–3 nm [7]. Even though the experimental results point to a crystalline core for all these nanowires, it is a concern of great importance whether the crystalline core is that of the bulk Si or has another atomic structure. It is also very probable that Si nanowires may not have a uniform nature and that a specific atomic structure may depend on both the experimental conditions under which nanowires and the size of nanowires were produced.

Calculations of the mobility in SiNWs were done by researchers by the use of two methods: direct theoretical calculations involving band structure and phonon dispersion calculations, and indirect experimental determination by measurement of I–V characteristics of SiNW device [8,9]. In addition, it was also theoretically evaluated that hole mobility is larger than or comparable to electron mobility and that, for some of the SiNWs at least, room temperature hole mobility is larger than that for bulk-Si hole mobility. In addition, many calculations involve the use of bulk acoustic and optical phonons, which can give an additional higher mobility value at the smallest SiNW diameter, than as phonon confinement is considered [10–12].

Its thermal conductivity is particularly interesting for its potential Application in thermoelectric generators or coolers at nanoscale [1,13]. Due to the greater surface-to - volume ratio and explicit surface reconstruction effects, the thermal conductivity of thin Si nanowires could differ substantially from the bulk value, which could possibly lead to phonon scattering and confinement, especially at small diameters [3,14].

However, it should be noted that the thermal conductivity for a defined thermal gradient is directly proportional to heat current flux through the nanowire. The latter derives its contributions not only from the various phonon modes but also from other possible causes; namely, modes distribution, phonon-phonon Scattering effects and group velocity [3,15].Since the confinement effect is shown only by the lowest excited phonon mode, the group velocity, mode distribution, and phonon scattering effects with the nanowire diameter are just not expected to change significantly.

The present paper also aims to solve the above-mentioned problems prompted by the advances in the bottom-up synthesis of various NW structures, which was a driving force in the realization of completely new device concepts and functional systems.The breakthroughs involve advancement of branched and hyperbranched NW structures, two NW-heterostructure-based nanocomposites , ZnO nanotetrapods bridging networks, and axial NW cross-junction architectures. These works explained the benefits of cross-junction two dimensional (2D) over bridge junction [15,16].

With a lower density, cage-like nanowires can maintain their structural stability over a wider range of strain circumstances than tetrahedral nanowires, making them a better choice for structural strength , chemical strength ,sensor, and applications for electronics under strain. That could have important implications for technology. With this work, we investigate the structural, energetic and mechanical features of Si-NW The cage like systems for Si-NW could be of lower density and similar mechanical characteristics and various electronic properties, and could therefore be beneficial for nanoscale materials and electronics[17,18].

Here for the synthesis of nanowire we have used the MACE method because of its beneficial properties like low cost, its simple working process cross-sectional shape and all the parameters diameter, length, orientation, doping type and doping level can be controlled easily. This is a very much flexible method and most valuable to make the higher surface to volume ratio structures. By using this method we can get the highly crystalline quality of SiNWs. There is no restriction on the size fabricated by MACE . The wire fabricated by this method can be of the diameter as small as 5nm or as large as 1 micrometer.it is one pot procedure, can be performed in a chemical lab without the use of a high cost apparatus [7,19–23].

EXPERIMENTAL DETAIL

In the first process we cut the silicon wafer of N type having resistivity ranges from 0.001 Ohm cm to 0.1 Ohm cm into a small square size shaped wafer of area 1 cm^2 . After this the cleaning of wafer has been done by the ultrasonication with the use of acetone , isopropanol alcohol (IPA),and deionized water for 15 min. Then for removing the oxide layer which is done by immersing the cleaned wafer in hydrofluoric acid for 2 minutes.

In the deposition process the SiNWs samples were prepared by metal assisted chemical etching (mace) of N-Si (100) wafer having resistivity from 0.001 Ohm cm to 0.1 Ohm cm . These wafers were dipped in solution containing 4.8 M HF & 5 mm $AgNO_3$ for one minute at room temperature to deposit Ag nanoparticles (Ag NPs). The Ag NPs deposited samples were then kept for etching in an etching solution containing 4.6 M HF & 0.5 M H_2O_2. Then etched wafers were transferred in HNO_3 acid to dissolve Ag metal present on the etched sample. Then the samples were dipped into an HF solution to remove the oxide layer .

RESULT AND DISCUSSION

Here we have used the FESEM (Field Effect Scanning electron microscopy) to study the surface morphology (SiNW diameter). FESEM solves the difficulty that arises from the images obtained from an optical magnifying lens. Similarly, it is quite sufficient to see the structure as small as 1 nm on the outside surface of the material.

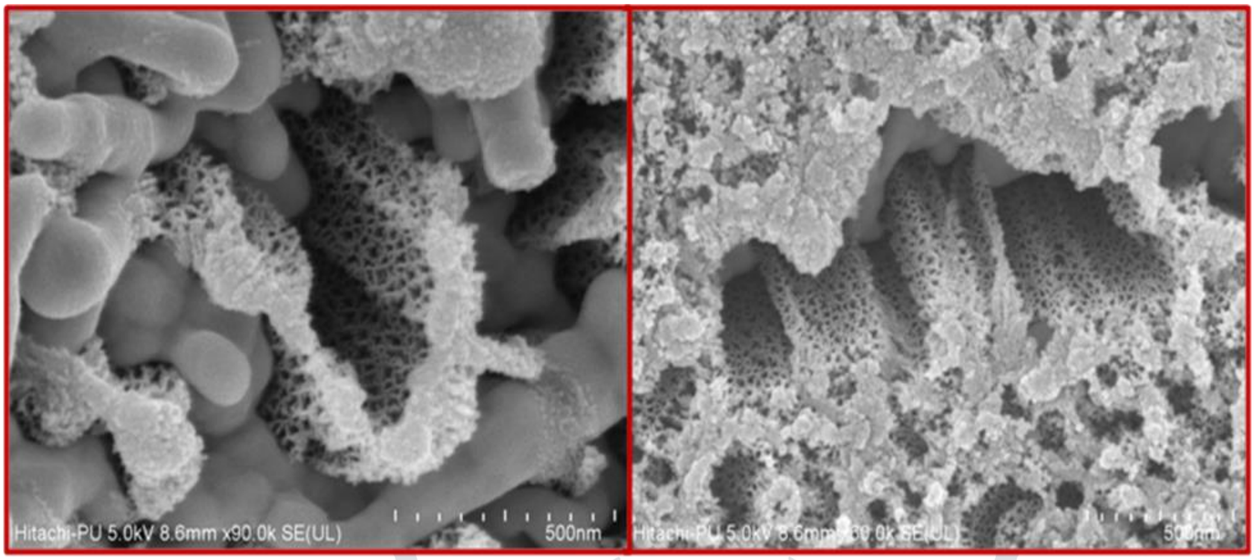

Figure 1. Top view of the N type sample having resistivity lies 0.001-0.1 OhmCm etching duration of 30 min the the resolution is 500 nm.

Here in the Fig.1 the Top view of the fabricated samples i.e FESEM images of the N type sample having resistivity of 0.001 -0.1 Ohm Cm is shown where the etching has been done for the duration of 30 min we can clearly see the cage like structures which are very much beneficial for the upcoming nanotechnology

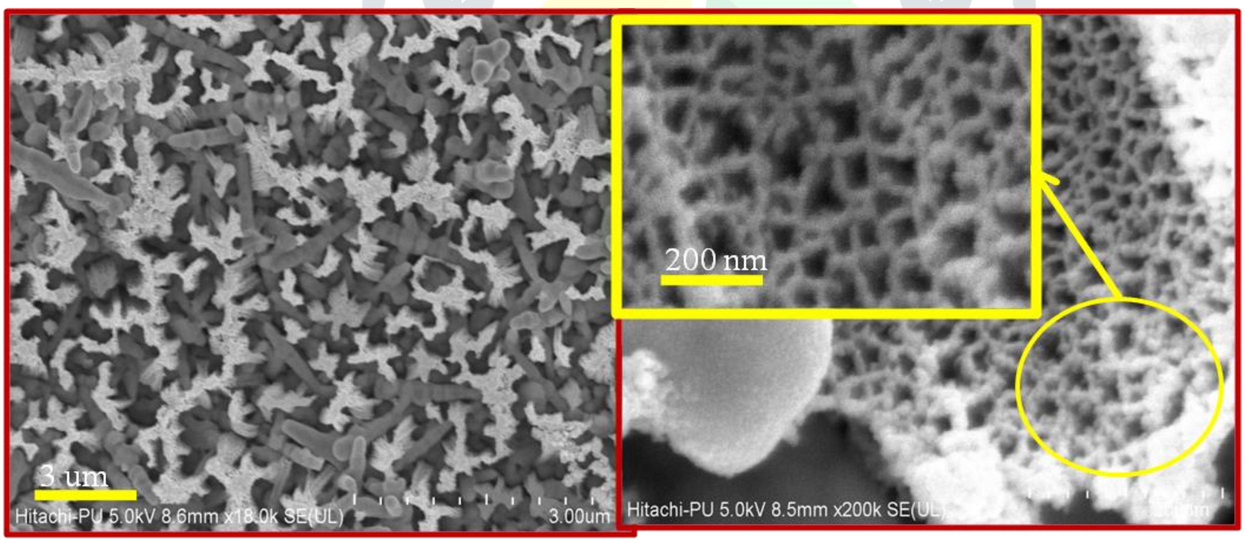

Figure 2. Top view of the N type sample having resistivity lies 0.001-0.1 Ohm Cm etching duration of 30 min the Cage like structure

Here in figure 2 the zoom view of the cage like structure has been shown in the figure. Here left hand side image is of 3 um resolution and right side of the image is with 200nm resolution which can clearly show the behavior of 30 min etching time on the N type sample of having resistivity lies between 0.001 ohm cm -0.1 ohm cm

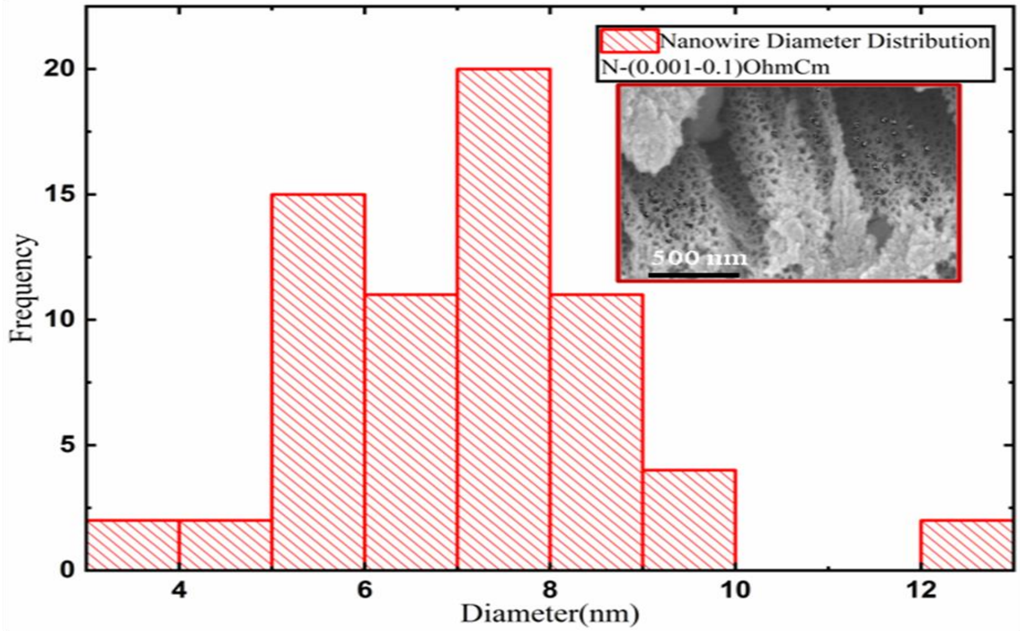

Figure 3. Nanowire diameter distribution for N type having resistivity lies 0.001-0.1 Ohm Cm also the FESEM image with data points shown in the subfigure taken to calculate data points

Figure 3 shows the nanowire diameter distribution and the subfigure which is shown inside the figure clearly shows the data point used to calculate the average diameter of the cage like structures. These structures are very much beneficial for electronics and nanomaterial applications .

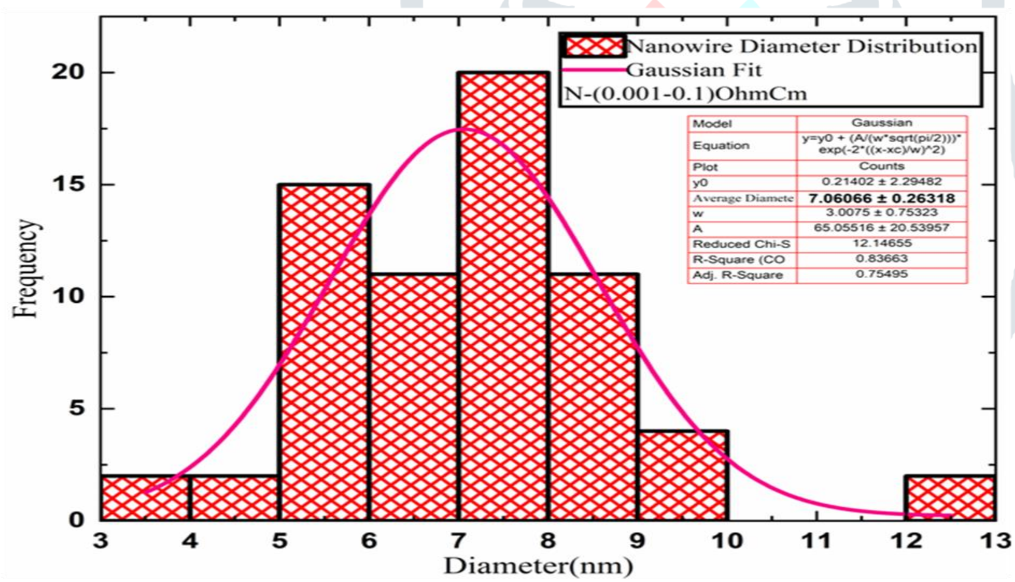

Figure 4. Nanowre diameter distribution for N type having resistivity lies 0.001-0.1 OhmCm also the Gaussian curve shows the Average diameter.

The above figure clearly shows the Gaussian curve fitting of the nanowire shown in the cage like structure which reveals that for the N type sample having resistivity lies between 0.001 ohmCm-0.1 Ohm Cm for the etching duration of 30 minute we have the average diameter is 7.06 nm (Approx.)

CONCLUSION

The size (diameter) of the SiNW synthesized by MACE technique on the Si substrate having a resistivity lies in the range of 0.001 ohm cm -0.1 ohm cm for N type Wafer having etching time of 30 min is 7.06 nm and that came out by the use of Image J software. We have investigated the mechanism formation of SiNW during the MACE technique. The use in the electronic industry comes from these one-dimensional nanostructures, which is a change of light energy to electrical energy. Sensors such as biosensors, gas sensors can be made by use of SiNWs, also it can work as a building block for the next generation electronics . There is much material that is based on SiNWs like in batteries based devices . As they wear properties of high aspect ratio which makes them highly sensitive to use in sensing purposes.

REFERENCES

[1] E.K. Lee, L. Yin, Y. Lee, J.W. Lee, S.J. Lee, J. Lee, S.N. Cha, D. Whang, G.S. Hwang, K. Hippalgaonkar, A. Majumdar, C. Yu, B.L. Choi, J.M. Kim, K. Kim, Large thermoelectric figure-of-merits from SiGe nanowires by simultaneously measuring electrical and thermal transport properties, Nano Lett. 12 (2012) 2918–2923.

[2] D. Li, Y. Wu, P. Kim, L. Shi, P. Yang, A. Majumdar, Thermal conductivity of individual silicon nanowires, Appl. Phys. Lett. 83 (2003) 2934–2936.

[3] I. Ponomareva, D. Srivastava, M. Menon, Thermal conductivity in thin silicon nanowires: Phonon confinement effect, Nano Lett. 7 (2007) 1155–1159.

[4] S.K. Saxena, V. Kumar, H.M. Rai, G. Sahu, R. Late, K. Saxena, A.K. Shukla, P.R. Sagdeo, R. Kumar, Study of Porous Silicon Prepared Using Metal-Induced Etching (MIE): a Comparison with Laser-Induced Etching (LIE), Silicon. 9 (2017) 483–488.

[5] K.A. Gonchar, A.A. Zubairova, A. Schleusener, L.A. Osminkina, V. Sivakov, Optical Properties of Silicon Nanowires Fabricated by Environment-Friendly Chemistry, Nanoscale Res. Lett. 11 (2016).

[6] S.K. Saxena, G. Sahu, V. Kumar, P.K. Sahoo, P.R. Sagdeo, R. Kumar, Effect of silicon resistivity on its porosification using metal induced chemical etching: Morphology and photoluminescence studies, Mater. Res. Express. 2 (2015).

[7] W. McSweeney, H. Geaney, C. O'Dwyer, Metal-assisted chemical etching of silicon and the behavior of nanoscale silicon materials as Li-ion battery anodes, Nano Res. 8 (2015) 1395–1442.

[8] K.A. Salman, K. Omar, Z. Hassan, The effect of etching time of porous silicon on solar cell performance, Superlattices Microstruct. 50 (2011) 647–658.

[9] A. Kaya, K.G. Polat, A.S. Mayet, H. Mao, Ş. Altındal, M.S. Islam, Manufacturing and electrical characterization of Al-doped ZnO-coated silicon nanowires, Mater. Sci. Semicond. Process. 75 (2018) 124–129.

[10] H. Han, Z. Huang, W. Lee, Metal-assisted chemical etching of silicon and nanotechnology applications, Nano Today. 9 (2014) 271–304.

[11] K.Q. Peng, S.T. Lee, Silicon nanowires for photovoltaic solar energy conversion, Adv. Mater. 23 (2011) 198–215.

[12] M. Shao, D.D.D. Ma, S.T. Lee, Silicon nanowires - Synthesis, properties, and applications, Eur. J. Inorg. Chem. (2010) 4264–4278.

[13] D. Dvila, A. Tarancón, M. Fernndez-Reglez, C. Calaza, M. Salleras, A. San Paulo, L. Fonseca, Silicon nanowire arrays as thermoelectric material for a power microgenerator, J. Micromechanics Microengineering. 21 (2011).

[14] V. Kashyap, N. Chaudhary, N. Goyal, K. Saxena, Cost effective synthesis of semiconductor nanowires, AIP Conf. Proc. 2162 (2019) 1–4.

[15] D. Ma, H. Ding, H. Meng, L. Feng, Y. Wu, J. Shiomi, N. Yang, Nano-cross-junction effect on phonon transport in silicon nanowire cages, Phys. Rev. B. 94 (2016) 1–10.

[16] Y. Li, J. Dykes, T. Gilliam, N. Chopra, A new heterostructured SERS substrate: Free-standing silicon nanowires decorated with graphene-encapsulated gold nanoparticles, Nanoscale. 9 (2017) 5263–5272.

[17] A.S. Togonal, L. He, P. Roca I Cabarrocas, Rusli, Effect of wettability on the agglomeration of silicon nanowire arrays fabricated by metal-assisted chemical etching, Langmuir. 30 (2014) 10290–10298.

[18] G. Editors, D. Nocera, D. Guldi, 2009 Renewable Energy issue, Chem. Soc. Rev. 38 (2009) 165–84.

[19] L. Qiao, A. Shougee, T. Albrecht, K. Fobelets, Oxide-coated silicon nanowire array capacitor electrodes in room temperature ionic liquid, Electrochim. Acta. 210 (2016) 32–37.

[20] S.D. Hutagalung, M.M. Fadhali, R.A. Areshi, F.D. Tan, Optical and Electrical Characteristics of Silicon Nanowires Prepared by Electroless Etching, Nanoscale Res. Lett. 12 (2017).

[21] S. Ngqoloda, Vertically aligned silicon nanowires synthesised by metal assisted chemical etching for photovoltaic applications, (2015).

[22] P.J. Linnros, Metal-assisted etching of nanopores in silicon, Master Thesis. (2014).

[23] R. Liu, F. Zhang, C. Con, B. Cui, B. Sun, Lithography-free fabrication of silicon nanowire and nanohole arrays by metal-assisted chemical etching, Nanoscale Res. Lett. 8 (2013) 155.