Morphological and electrical study of p-type silicon nanowires synthesised by Ag-assisted electroless chemical etching

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Abstract

Fabrication of Silicon nanowires (SiNWs) by electroless etching of p-type (100) Silicon wafer using silver (Ag) particles as catalyst at room temperature has been reported in this paper. Dependence of SiNWs formation on Ag electroplating and etching time was investigated. Surface morphology of SiNWs has been studied using scanning electron microscope (SEM) for different samples. The length of SiNWs increased with time of etching and decreased with electroplating time. A systematic study regarding the surface topography of fabricated SiNWs was performed using atomic force microscope (AFM). A 3D profile of the surface on a nanoscale were analysed and compared with SEM images. The average diameter of 73.9 nm for SiNWs was measured using as-obtained AFM images. Electroplating and etching time had minimum effect on the diameter of as-fabricated SiNWs. Fourier transform infrared spectroscopy was used to extract the bonding information for SiNWs. Electrical properties were evaluated using two-probe source measuring unit. Resistivity of 0.11 \(\Omega\cdot\text{cm}\) was obtained for synthesised SiNWs. A cost-effective, environment friendly electroless metal assisted chemical etching process was used to successfully develop SiNWs from the bulk Silicon wafer.

1. Introduction

Timely, research interest in 1D nano-materials has grown due to their extraordinary quantum properties and practical applications [1]. These materials comprising unique electrical, magnetic, optical, mechanical, chemical properties have diverse area of applications, for e.g., photonics, opto-electronics and medical sciences [2]. Research for cost-effective fabrication of 1D nano-materials lead to the synthesis of Silicon nanowires (SiNWs) which are environment friendly [3]. Extensive studies have been done for SiNWs due to its potential applications in the field of nano-scale electronics [4], biological and chemical sensors [5], photovoltaics [6] and thermoelectric devices [6]. Synthesis of SiNWs employs various physical (dry, i.e., electron beam lithography and reactive ion etching [7], laser ablation [8], etc) and chemical etching methods (wet, i.e., metal-assisted chemical etching [9], vapor-liquid-solid growth, etc). However, amongst the various methods listed above, metal-assisted chemical etching (MACE) has many advantages such as: (a) cost-effective as it does not require any high/low temperature and pressure parameters; (b) may be performed without power consumption [3]; (c) properties of SiNW may be controlled simply by changing reaction parameters [3, 10]; (d) fabrication of well-aligned SiNWs having uniform distribution on large scale [11]. Generally, MACE engages two stages: (a) deposition of metal particles on the Silicon (Si) surface by dipping in aqueous solution of metal salt and (b) synthesis of SiNWs by etching the metal particles deposited Si sample in suitable etchant medium.

The important factor in MACE process is the selection of metal. Gold (Au) was deposited by Peng. et. al using an aqueous solution of Potassium gold (III) chloride/Hydrofluoric acid (K\textsubscript{3}AuCl\textsubscript{6}/HF). Formation of SiNWs was seen on a small area after etching, which may be due the loose bond formation between Au particles and Si surface [12]. Peng and Lu [13] observed winding in synthesised nanowires by the application of Platinum (Pt) particles as catalyst deposited from K\textsubscript{2}PtCl\textsubscript{6}/HF (Potassium hexachloro platinate (IV)/HF) solution. Several
catalytic etchants have been proposed, however, Silver (Ag) was considered best etchant as it: (i) is a noble metal, (ii) is less expensive than Au-/Pt- based chemical compounds, and (iii) produces vertically aligned SiNWs on Si surface [14, 15]. Therefore, Ag is the most common metal used in MACE process and is deposited on Si surface by the AgNO₃/HF aqueous solution.

Fabrication of array of SiNWs using Ag particles as the catalyst by electroless etching (MACE) on p-type Si wafer has been reported here. The effect of electroplating time of Ag and etching duration for the formation of SiNWs were compared based on the characterisation: (a) morphological- by Scanning Electron Microscope (SEM) and Atomic Force Microscope (AFM), (b) chemical bonds- by Fourier Transform Infrared spectroscopy (FTIR), and (c) Electrical conduction- by source measuring unit. Calculation of the diameter of the obtained SiNWs by AFM has been explained. As per the Authors’ knowledge, the procedure to estimate the diameter of as-obtained SiNWs images from AFM has been reported here for the first time.

2. Experimental procedure

2.1. Chemicals used

Hydrofluoric acid (HF-40%), Hydrogen peroxide (H₂O₂-30%), Silver Nitrate (AgNO₃), Ammonia Solution (NH₄OH-25%) and Acetone (CH₃COCH₃) were purchased from Merck. Methanol (CH₃COOH) was purchased from Avantor. Ethyl alcohol, Hydrogen peroxide (H₂O₂-30%) and Acetone (CH₃COCH₃) were purchased from Merck. Methanol (CH₃COOH) was purchased from Avantor.

2.2. Experiment

P-type Silicon (100), 10 Ω-cm) wafers were ultra-sonicated in acetone for 10 min to avoid organic contamination from the bare Si substrate. Wafers were again ultra-sonicated in methanol for 5 min, followed by rinsing with DI water. Thereafter, wafers were dipped in a solution of NH₄OH, H₂O₂ and DI water to further eliminate the remaining in-organic residues. The wafers were then dipped in 1% HF aqueous solution for 2 min to remove the native oxide layer from the surface of Si wafer. Wafers were rinsed thoroughly with DI water and dried.

To form SiNW array by electroless etching process, an aqueous solution of AgNO₃ and HF (with ratio as mentioned in table 1) was prepared in a teflon beaker. The wafer was dipped in the solution for deposition of Ag particles on Si. Next, the samples were etched in an aqueous solution of HF and H₂O₂ in teflon beaker to form SiNWs. The required parameters for SiNWs formation are described in table 1. The remaining Ag particles were removed by dipping the etched samples in HNO₃ for 30 min. The samples were then rinsed with DI water and dried. All the experiments were done at room temperature. Four types of samples S1, S2, S3 and S4 were prepared. Amongst different combination of electroplating and etching time, the best result for formation of SiNWs were: (i) 20 s and 30 & 45 min (S1, S2), respectively, and (ii) 10 s and 30 & 45 min (S3, S4), respectively. The details of the experimental parameters are provided in table 1.

The morphology of the SiNWs was characterised by atomic force microscope (AFM) with Nanosurf Easyscan2 and scanning electron microscope (SEM) with JEOL MODEL-JSM-IT100 instrument. The surface texture was studied by AFM in contact mode through ConAl-G (Contact Mode AFM Probe with Aluminum Reflective Coating) tip procured from Budget Sensors with applied force of 20nN, 0 tip-voltage and P-gain of 10,000. All SEM images were taken in the scale of 5 μm with different magnification as stated in the figure 2. Analysis of the Infrared absorption spectra of samples was done by IR Affinity-1S Shimadzu Fourier Transform Infrared spectrophotometer. The Current-Voltage (I-V) characterisation was done by Keysight B2901A precision source/measuring unit (sensitivity: 100 fA) 1 ch LXI.

Table 1. Details of different etching time and electroplating time.

| Sample | Ag particles deposition | Electroless etching | Electroplating Time (s) | Etching Time (min) |
|--------|-------------------------|---------------------|-------------------------|-------------------|
| S1     | 5% 88 3% 10%            | 20                  | 30                      |
| S2     | 5% 88 3% 10%            | 20                  | 45                      |
| S3     | 5% 88 3% 10%            | 10                  | 30                      |
| S4     | 5% 88 3% 10%            | 10                  | 45                      |
3. Results and discussion

3.1. Mechanism
The entire process-steps in the formation of SiNWs and equations to explain the reaction steps are shown as a flowchart in figure 1. Growth mechanism of SiNW took place in two steps. First was the deposition of Ag particles on the Si substrate. When the Si wafer was dipped in AgNO$_3$/HF solution, the Ag$^+$ ions were plated on the Si surface. As the redox potential of Ag$^+$ ion was lower than Si, the electrons from the valence band of Si were captured by Ag$^+$ ions and were reduced to Ag as governed by the equation (1) shown in figure 1. The deposited Ag particles acted as catalyst to etch the Si substrate.[16].

The next step involves etching, through dipping the electroplated Si wafer in an aqueous solution of HF/H$_2$O$_2$. Si atoms lose electron to reduce Ag$^+$ to Ag. In presence of water, Si beneath the Ag oxidises to SiO$_2$.[3]. Subsequently, the formed SiO$_2$ layer is etched by HF as represented in equation (3). Further H$_2$O$_2$, oxidises Ag particles to Ag$^+$ as governed by equation (4), consequently oxidation of Si beneath the Ag particle occurs and the oxide layer is etched by HF, repetition of equation (1) to (4) occurs till the sample is inside HF/H$_2$O$_2$ solution as depicted by flowchart in figure 1, resulting in controlled vertical growth of SiNWs [9]. An elaborate discussion through schematic representation is depicted in scheme 1.

3.2. Characterisations of synthesised SiNWs
3.2.1. Surface morphology through SEM
The surface morphology of the nanowires grown on semiconductors has shown its importance as the performance of emerging devices depends on atomically defined surfaces and interfaces. In this regard, the as-synthesised SiNWs has been characterised by SEM to confirm the formation of the nanowires. Figure 2, represents the SEM image of the synthesised SiNWs which shows the dependency of SiNW length on the electroplating time of Ag and the etching time. The length of the nanowires was calculated using Image-J software from as-obtained SEM images. Firstly electroplating time (20 s) of Ag was fixed for samples S1 and S2 with an etching time of 30 min and 45 min, respectively, it may be seen that the length of the nanowires of sample S2 is larger than S1. Correspondingly, the same result was obtained when the samples S3 and S4 were electroplated for 10 s and etched for 30 and 45 min, respectively. Tabulation of the result obtained using Image-J software is done in table 2.

An important role is played by H$_2$O$_2$ in controlled etching of SiNWs as it affects the rate of etching, morphology and orientation of SiNWs.[11, 17]. Mechanism (refer scheme 1) indicates that longer the Ag deposited Si wafer is in contact with HF/H$_2$O$_2$ solution, the more will be the etching. The same may be noted from the SEM images as the length of the nanowire extends with the etching time. Since the electroplating time was varied and etching time was kept fixed for samples S1 and S3, it is observed that length of SiNW with low electroplating time is more as shown in table 2. This may be caused due to the deposition of low concentration of Ag particles on the surface [3, 10]. Similar results may be observed for samples S2 and S4.

Disorder in SiNW formation seen in the SEM image may arise due to the loading condition during SEM experiment. From SEM images it may be seen that the top of the nanowires is flocked. The flocking of SiNWs...
may be attributed to: (i) force of mutual attraction between the wires due to generation of electrostatic charge on the freshly formed surface and (ii) the long length of formed SiNWs [11].

3.2.2. Surface topography and estimation of diameter of SiNWs using AFM

A clear view of SiNWs formation on the top of Si surface for each sample may also be confirmed from the AFM images as shown in figure 3. The inset of each figure shows the color map (two-dimensional) obtained by selecting the scanning area ($63.1 \times 63.1 \mu m^2$) through a contact mode AFM system in air ambient. A small area ($\sim 21 \times 21 \mu m^2$) was defined for each sample, to visualise the formation of nanowires in three dimensional
mapping. A detailed study of statistical information on the topology and the diameter of the obtained nanowires for each sample has been discussed below.

The image of the as-synthesised SiNWs from SEM and AFM for sample S1 is shown in figures 4(a) and (b), respectively. The base of SiNWs has been marked with yellow in the figure. It is observed that wires stick out with a slight tilt from the Si surface. This establishes that formed nanowires are vertically aligned with slight tilt. Both SEM and AFM confirm the above stated fact. The image of the bunch of nanowires as observed in figures 4(a) and (b) seems to be different in distribution due to scaling of the images.

The surface and cross-sectional topography obtained from AFM is represented in figure 5. The position of the cantilever and the sample during horizontal surface scanning and cross-sectional scanning done with AFM is shown in figures 5(a) and (b), respectively. From figure 5(c), the surface topography may be viewed as it does not show the base of the nanowire. However, base may be seen along with the nanowire in figure 5(d) as it presents cross-sectional topography. The marked portion in figure 5(d) is the area of interest as it focuses on the

**Figure 3.** AFM image of the SiNWs formed by electroless etching method for different samples: (a) S1, (b) S2, (c) S3 and (d) S4, respectively.

**Table 2.** Dependence of length of SiNWs on etching time.

| Samples | Electroplating time (s) | Etching time (min) | Length of SiNWs (μm) | Approx. average length from SEM (μm) |
|---------|-------------------------|--------------------|----------------------|-------------------------------------|
| S1      | 20                      | 30                 | 4.22                 | 4.70                                |
|         |                         |                    | 4.67                 |                                     |
|         |                         |                    | 5.21                 |                                     |
| S2      | 45                      |                    | 6.36                 | 6.54                                |
|         |                         |                    | 6.42                 |                                     |
|         |                         |                    | 6.84                 |                                     |
| S3      | 10                      | 30                 | 5.26                 | 5.35                                |
|         |                         |                    | 5.34                 |                                     |
|         |                         |                    | 5.46                 |                                     |
| S4      | 45                      |                    | 7.16                 | 7.26                                |
|         |                         |                    | 7.18                 |                                     |
|         |                         |                    | 7.46                 |                                     |
formation of nanowires. Three dimensional image from horizontal and vertical scanning may be seen in figures 5(e) and (f), respectively. The scaling of figures 5(e) and (f) are different as three dimensional figure 5(f) focuses only on the marked portion of figure 5(d) and consequently variation in density of nanowires has been noticed. Figure 5 is basically the comparison for the sample S3 in two different locations, which indicates the alignment of the grown SiNWs. From the reported SEM and AFM images, it may be seen that the formed nanowires are slightly tilted rather than completely vertical having a structure like group of bamboo trees.

The calculated values of average roughness ($R_a$), root mean square of roughness ($R_q$), skewness and kurtosis using Gwyddion software have been provided in table 3 for all four samples. Deviation of profile from its mean value over the entire sample surface gives the average roughness [18]. The sample S4 having 10 s electroplating time and 45 min etching time shows maximum $R_a$ and $R_q$, denoting less uniformity in the SiNWs formation compared to the rest samples. However, the values of $R_a$ and $R_q$ suffered drastic reduction for sample S2, having
20 s electroplating time and same etching time with S4. This may be due to the accumulation of more Ag particles on the surface, leading to uniform etching.

The amount of peaks or valleys, i.e., the height distribution is given by skewness. The peak represents the flocking of the top of the nanowires and valley represents the gap between the two flocked groups of nanowires.

As seen from table 3, skewness has negative values. Negative skewness indicates that the surface is covered with deep and large valleys [19]. Out of four samples, S3 has maximum number of deep and large valleys which may be confirmed from SEM images as well (figure 2). One may notice that S1 and S3 have occupied higher side of negative skewness, when compared S1 with S2 and S3 with S4, respectively. This may be attributed to the fact that, the etching time for S1 and S3 is less as compared to S2 and S4, thereby the possibility of formation of valley shaped structures are more prominent, which results in higher negative skewness value. The distribution of sharp peak is given by kurtosis. The kurtosis of sample S3 is more with respect to other samples. This may be confirmed from the AFM image of S3 in figure 3 as sharp peaks and deep valleys may be noticed.

An attempt has been done, to calculate the accurate diameter using AFM as shown in figures 6, 7, 8 and 9 for different samples S1, S2, S3 and S4, respectively. Analysis tool in the software available with Nanosurf Easyscan2 consists of tool ‘create cross-section’. A particular cross section consisting a bunch of nanowires was selected in color map (2-dimensional image) obtained by AFM. The selection done is highlighted in each color map as shown in figures 6, 7, 8 and 9 for samples S1, S2, S3 and S4, respectively. Double click on the arrow generated line graph depicting the distribution for the diameter of nanowires. A sharp peak, i.e., Lorentzian peak was selected (enclosed by red box in the figures 6–9) as it may represent a single nanowire, whereas, the broad peaks may be the collection of nanowires and may not represent the diameter of single wire. The length of the sharp peak was measured using ‘measure length’ tool available in Easyscan2 software for obtaining the diameter. Three different locations were selected for a particular sample and the respective diameter was measured. An average of the three

| Samples | Electroplating time (s) | Etching time (min) | Average roughness ($R_a$) ($\mu m$) | Root mean square of roughness ($R_q$) ($\mu m$) | Skewness | Kurtosis |
|---------|------------------------|--------------------|--------------------------------------|-----------------------------------------------|---------|---------|
| S1      | 20                     | 30                 | 0.5914                               | 0.8985                                        | −3.325  | 18.69   |
| S2      | 45                     | 0.1434             | 0.1926                               | −3.16                                         | 12.85   |
| S3      | 10                     | 30                 | 0.3684                               | 0.66                                          | −4.274  | 24.82   |
| S4      | 45                     | 1.672              | 2.085                                | −1.24                                         | 10.68   |

Figure 6. Technique to determine the diameter of nanowires for sample S1.

Table 3. Roughness of SiNWs as measured from AFM.
measured diameters for each sample was considered and the same is reported in table 4. One may notice that the average diameter of nanowires for each sample are in the range of 70–77 nm, which dictates that the electroplating and etching time has minimum effect on the diameter of the synthesised SiNWs.

3.2.3. Fourier transform infrared spectroscopy (FTIR) of SiNWs

Figure 10 presents the FTIR spectra of S1, S2, S3 and S4 samples. The peak at 680 cm\(^{-1}\) is attributed to the vibrational mode of Si-Si bond [20]. Further, the peak at 1200 cm\(^{-1}\) corresponds to the symmetric stretching of
Figure 9. Technique to determine the diameter of nanowires for sample S4.

Table 4. Measured value of the diameter of as-synthesised nanowires from figures 6, 7, 8 and 9 for samples S1, S2, S3 and S4 respectively as obtained from AFM.

| Samples | Diameter of nanowires (nm) | Average Diameter (nm) | Samples | Diameter of nanowires (nm) | Average Diameter (nm) |
|---------|---------------------------|-----------------------|---------|---------------------------|-----------------------|
| S1      | 67.5                      | 71.28                 | S3      | 56.8                      | 69.63                 |
|         | 71.26                     |                       |         | 69.31                     |                       |
|         | 75.09                     |                       |         | 82.79                     |                       |
| S2      | 75.09                     | 77.02                 | S4      | 71.24                     | 77.67                 |
|         | 75.11                     |                       |         | 75.11                     |                       |
|         | 80.86                     |                       |         | 86.66                     |                       |

Figure 10. FTIR spectra of SiNW array for samples S1, S2, S3 and S4.
Si-O-Si bond [21]. This indicates the occurrence of surface oxidation during chemical etching [3]. The absorption band at 1742 cm\(^{-1}\), 2363 cm\(^{-1}\) and 3000 cm\(^{-1}\) for C-O and C-H bond may be from surface contamination [3]. A broad peak at about 3700 cm\(^{-1}\) may be attributed to the O-H stretching bond due to water adsorbed by the surface [3, 21].

3.2.4. Current conduction mechanism of SiNW

Figure 11(a), depicts a schematic of the configuration for electrical measurement of SiNWs. The different parts are labelled in the figure with a consideration that Si was not etched completely and therefore a series combination of SiNWs and un-etched Si is proposed. The necessary equivalent circuit of figure 11(a) is represented in figure 11(b). The corresponding comparison of the conductance curve for SiNW with bulk Si is shown in figure 11(c). The existence of knee voltage (\(V_T\)) and negligible current flow in reverse bias may be observed for bulk Si, whereas the presence of nanowires changes the diode like behaviour and hence the conduction characteristic becomes Ohmic-like in nature [22]. This gives rise to the series resistance \(R_s\) and the contact resistance \(R_c\), as shown in figure 11(b).

The current density–voltage (J-V) characteristics for samples S1, S2, S3, S4 and bare Si substrate are depicted in figure 12. For the J-V measurement, two gold contact probes as electrical contact with keysight source measuring unit with gold coated chuck as a sample holder were used. Figure 12(a) represents the J-V characteristics for samples S1 and S2, having same electro-plating time (20 s) whereas etching time were 30 and 40 min, respectively. The J-V characteristics for S3 and S4 samples with equal electroplating time (10 s) however

Figure 11. (a) Depiction of electrical measurement configuration for SiNWs, (b) an equivalent circuit of SiNWs during electrical measurement and (c) comparison of threshold voltage of bulk Si and SiNWs.

Figure 12. Comparison of J-V characteristics of different samples along with bare Si substrate: (a) S1 and S2, (b) S3 and S4, (c) S1 and S3 and (d) S2 and S4, respectively.

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different etching duration of 30 and 40 min are depicted in figure 12(b). Comparison of the J-V characteristics of samples S1 and S3 comprising 30 min etching time with different electroplating time (10 s and 20 s), and similarly, for samples S2 and S4, with etching time 45 min and electroplating time (10 s and 20 s) are shown in figures 12(c) and (d), respectively. In all the figures, the J-V profile for Si wafer is shown for comparison.

From figures 12(a)–(d), negligible current during reverse bias compared to forward bias may be observed for un-etched cleaned Si wafer which shows a typical Schottky nature for a semiconductor-metal junction. However, for all SiNW samples the trend of J-V curve with positive and negative applied bias shows drastic increment of reverse and forward current, which indicates that formation of nanowires on Si surface transforms the semiconducting nature of Si towards the metallic behaviour. The probable reason for the same may be due to: (i) propagation confinement through the nanowires and (ii) reduction of scattering of charge carriers during applied bias. This leads to the dominance of ballistic transport in conduction mechanism. Ballistic transport is a phenomenon where charge carriers travel with less scattering. Ballistic transport is determined by the structure of semiconductors and is observed in quasi 1D structure, e.g., nanowire. With increase in length of the nanowires, electrical conductivity increases, which is an observable phenomenon for ballistic transport regime [23]. For the above reason, it may be noted that the current in case of sample S4 is maximum with respect to other samples as observed from figure 12. Between samples S1 and S2 (etching time: S2 > S1), one may notice in figure 12(a) that the current is higher for sample S2, as the average length of the nanowires for S2 is longer than S1. The same may be observed between samples S3 and S4 from figure 12(b). It may be inferred that with increase in etching time/length of nanowires, more metallic property may be gained. Also, from figure 11(c), one may notice that the threshold voltage decreases for SiNWs as compared to bulk Si, which further confirms the shift of semiconductor nature towards metallic nature.

Comparison between S1 and S3 in figure 12(c) infers that S3 has higher current value than S1 in forward bias condition. This may be due to the fact that the average length of S3 is larger than S1 as explained in the SEM characterisation section. The above observation is also valid for S2 and S4. However, it is observed that the difference between S2 and S4 is less as compared to S1 and S3. The probable reason may be due to the influence of bulk wafer conductivity rather than nanowires conductivity, i.e., diffusivity may be dominant over ballistic transport.

The resistance of the SiNWs is effectively due to the series combination of two segments, i.e., nanowires and the unetched part of the Si wafer (as shown in figure 11(a)). As the structure is considered to be hybrid of unetched Si and SiNWs, the equivalent resistance (R) will be given by:

\[
R = R_e + R_n
\]

\[
R = R_e + \frac{\rho_{SiNW}}{NA} L
\]

\[
RNA = \frac{R_n NA + \rho_{SiNW}}{L}
\]

Where, \(\rho_{SiNW}\) is the resistivity of SiNW, L is the length of the nanowire, A is the area of contact and N is the total number of nanowires covered by top contact. As \(R_e\), N and A are constant, equation (7) may represent a straight line equation with slope \(\rho_{SiNW}\) which provides the value of resistivity of SiNWs.

Using equation (7), product of equivalent resistance and the area of contact (RNA) versus the length of SiNWs for all samples to calculate the resistivity of the SiNWs is shown in figure 13. \(R^2\) represents the regression of the fitting. The resistivity is obtained from the intercept of the slope. The dynamic resistance for each sample
was calculated in forward bias. The equivalent resistance is noticed to be decreasing with the increase in the length of SiNWs (etched surface) due to ballistic transport of charge carriers through SiNWs which results in the negative slope as shown in figure 13. Electrical resistivity of the SiNW samples is found to be 0.11 \( \Omega \cdot \text{cm} \) from figure 13.

4. Conclusion

This paper reports the synthesis of slightly tilted SiNWs on p-type Si wafer using an electroless etching method at room temperature. The ability of Ag particles influence the etching of the underlying Si in the down direction randomly, which may be the reason of the disordered SiNWs observed. The formation of the nanowires not only depend on intrinsic catalytic property of Ag but also the arrangements of Ag particles on the top of Si surface.

- The morphology of the synthesised SiNWs were observed by SEM. The average length of the sample S4 was found to be maximum (7.26 \( \mu \text{m} \)) as measured by Image J software. The length of SiNW increased with time of etching.
- AFM characterisation revealed the topology, diameter and roughness of the SiNWs. The average diameter of 73.9 nm as calculated by AFM was found to have minimum effect of electroplating and etching time.
- FTIR confirms the presence of required bonding for SiNWs.
- The resistivity of formed SiNWs was found to be 0.11 \( \Omega \cdot \text{cm} \), which is less than the resistivity of the wafer used to synthesise the SiNWs.
- It may be concluded that less electroplating time and higher etching time results in the better morphology of SiNWs as well as conductivity.

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