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A study of future scope of silicon Nano wires (SiNWs)

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Abstract

Over the last few years silicon nano wires have come under intensive research due to their promising physical properties and potential as active materials in future electronic and optoelectronic applications. This article reviews various bottom-up growth methods of silicon nanowires. Various catalysts, including gold and other metals, as well as non-catalyst initiated growth methods are discussed in detail by comparing recipes including important parameters such as growth temperature, catalyst deposition methods, silicon nanowires diameter obtained, surface quality etc. This is expected to allow for an easier selection of a suitable growth method for a desired application. In addition, this article briefly reviews some of the developments in the field of silicon nanowire electronics and optoelectronics, including theoretical and experimental determination of charge carrier mobilities, visible photoluminescence, as well as a few recent examples of photodetectors and solar cells using silicon nanowires.

Keywords: Photo detectors, PSi or SiNWs, MACE method, presurface treatment

Introduction

Intensive research activity has been targeted on the development of texturization of silicon, a novel method in the semiconductor industry for large scale use in reducing the reflectance of silicon especially in the solar cells. This can be done either by texturing the silicon through mechanical grooving or acid etching. But these methods are not capable of reducing the mass to enhance the absorption capability. Thus new method has been developed to overcome this difficulty. The dissolution of silicon in hydrofluoric acid is very effective in texturing the silicon in atomic level through which silicon nano structures such as PSi or SiNWs can be fabricated. These silicon Nano structures exhibit unique properties which are useful in many fields such as photonics, opto electronics, solarcells etc.

Different methods have come up to fabricate either PSi or SiNWs. Among these wet chemical etching method called metal assisted chemical etching (MACE) is recognized as the simple and low cost method to fabricate silicon nano structures like PSi and SiNWs. MACE enables the fast growth of nano materials even at room temperature. The main factors of MACE method include the type of noble metal, oxidizing agent and etching time. Preferentially Ag nano particles are preferred in MACE as Ag assisted chemical etching has high controllability over growth of SiNWs compared to other. Hydrogen peroxide (H_2O_2) is commonly used oxidizing agent as the electrochemical potential of H_2O_2 is more than the other oxidizing agents and also silicon. Thus PSi and SiNWs were fabricated by MACE with Ag as catalyst and H_2O_2 as an oxidizing agent and studied the fabrication with the variation of etching time.

The work has been started with the synthesis of PSi by Ag assisted chemical etching at room temperature. The Ag nano particle deposition was systematically studied with the variation of deposition time. The diameter of Ag nano particle increased with the deposition time. The optimum deposition time fixed was 40 sec for further continuing the experiment. Later the etching of Ag deposited silicon has been carried out in the etchant solution at different etching timings. The synthesized PSi was characterized for its structural, optical and wettability properties. The XRD spectrum of PSi exhibited predominant orientation peak at $2\theta = 69.230$ corresponding to si (100) along with a small peak. The grain size has been calculated by sherrer's formula and found that the crystalline size decreased with etching time and minimum value of grain size was obtained for 120min etched sample.

The porosity and pore depth of PSi with the variation of etching time was studied through the SEM analysis.

The porosity was determined by geometry method through SEM analysis and found that the porosity increased with etching time and maximum porosity (83%) was obtained for 120 min etched sample. The pore depth also showed the linear variation with etching time and maximum pore depth obtained was 23 μm after 240 minutes etching. The refractive index of the porous silicon was calculated using Looyenga effective approximation method and studied the refractive index variation with etching time. It was found that the refractive index was function of porosity. The roughness of PSi was found to be very high compared to bare silicon wafer. The optical properties like optical reflectance, absorbance and photo luminescence of PSi were studied at different etching time. It was found that the optical reflectance decreased with the increase of etching time. The maximum attenuation of 5% was obtained for 120 min etched sample. The PSi showed the enhancement in the absorbance with the increase of etching time. The PSi exhibited photoluminescence (PL) after 180 min etching. PL spectrum of PSi showed two shoulder peaks along with maximum intensity peak. The intensity of the PL peak decreased with the increases of etching time. The wettability of PSi is studied through contact angle measurements. The water contact angle was measured by using 1 μL water drop. It was found that the contact angle of PSi increased with etching time from 60 min to 240 minutes. The maximum contact angle obtained was 143° after 240 min etching. 143° contact angle value was almost near to superhydrophobic surface contact angle 1500.

Synthesis of Silicon nano wires (SiNWs) with presurface treatment

SiNWs were fabricated by metal assisted chemical etching with Ag as catalyst, with and without pre surface treatment. The mechanism of fabrication of SiNWs follows the PSi fabrication with MACE. In MACE the deposition Ag plays an important role in fabricating the uniform SiNWs. Thus prior to the deposition of Ag, a pre surface treatment is necessary. The pre surface treatment is the immersion of cleaned silicon wafers in the solution containing H_2SO_4 and H_2O_2 in the ratio 3:1 for 10 minutes. The mechanism of presurface treatment has been studied in depth. The deposition of Ag has been carried out with and without pre surface treatment. The deposition of Ag was studied through SEM analysis. It was found that without pre surface treatment silver flakes have deposited whereas with pre surface treatment the Ag nano particles deposited as spherical nano particles. The coverage area of Ag was less on the silicon with presurface treatment compared to the silicon without presurface treatment. The Ag deposited samples after etching in the etchant solution, SiNWs were obtained which was confirmed through SEM analysis. It was found that the uniformity of the SiNWs obtained with pre surface treatment was high compared to without pre surface treatment. The aspect ratio of SiNWs was calculated. The aspect ratio of SiNWs was found to be 53 and 75 without and with pre surface treatment respectively.

Study of the properties of fabricated SiNWs surface with hydrogen plasma treatment through ECR device:

The fabricated SiNWs were exposed to hydrogen plasma through ECR device which is a versatile and solution free

method for the surface modification. The modification of SiNWs surface through hydrogen plasma was carried out at constant temperature. The microwave power was optimized and properties of SiNWs were studied with 800 watts and with 600 watts microwave power. The hydrogen plasma exposure through ECR device on SiNWs started with 800 watts microwave power at different plasma exposure times. The SEM data of the plasma exposed samples from 5 minutes to 30 minutes exposure revealed that the agglomeration of SiNWs decreased with the plasma treatment. The diameter of the SiNWs decreased with the increase of plasma exposure time. The aspect ratio of SiNWs was measured before and after plasma treatment and was found to be high with plasma treatment. The roughness analysis has been carried out through optical profilometer. The roughness of SiNWs was found to be 0.54 μm and 0.52 μm without and with plasma exposure for 5 minutes respectively. The wettability of SiNWs was studied through contact angle measurements. It was found that the water contact angle on the SiNWs surface was 86° without plasma treatment and with 5 minutes plasma treatment the contact angle decreased to 22.6°. Up to 15 minutes plasma exposure time the surface exhibited the hydrophilic nature with the contact angle less than 90° and later it exhibited hydrophobic nature with the contact angle more than 90°. After 30 minutes exposure the contact angle was found to be 143°.

The SiNWs surface exhibited hydrophilic at the lower exposure times and converted to hydrophobic at the longer exposure times. The DC conductivity of SiNWs was measured with and without plasma treatment at different exposure times. It was found that the DC conductivity of SiNWs was 0.41 $\times 10^{-6}$ S/cm and after 5 minutes plasma treatment it was found to be 12.21 $\times 10^{-6}$ S/cm. At the higher exposure times it was observed that the enhancement in the conductivity was less. The optical reflectance of plasma treated SiNWs was measured and it was found that the reflectance of SiNWs surface increased with the increase of plasma exposure times. The further study is required in analyzing the optical reflectance with the plasma exposure time.

PSi and SiNWs were found to be the most promising materials in the opto electronics and photonics. Synthesis of PSi and SiNWs has been carried out by MACE with Ag as catalyst. Also the hydrogen plasma treatment was carried out on the fabricated SiNWs surface. The Ag nanoparticle diameter and pore depth was found to be increased with the increase of deposition time and etching time respectively and found to be in good agreement with the previous reports. The XRD spectrum of PSi concluded the crystalline nature of si (100) of PSi with the sharp peak at 69.24° shows that the PSi exhibits the crystalline nature. The pore depth and porosity were increased with the increase of etching time. The refractive index of PSi was found to be less compared to the bare silicon. The optical reflectance of porous silicon was suppressed to almost 10% which was very effective for enhancement of optical absorption and in the preparation of antireflecting coatings. The suppression in the reflectance can be attributed that the increase of pore depth. The static water contact angle measurements showed that increase of etching time results in the increase of contact angle. This result concludes that there is possibility of achieving superhydrophobicity on the PSi surface.

SiNWs were fabricated by MACE with Ag as catalyst. The pre surface treatment was carried out on the silicon wafer before MACE and it was found that the uniformity and aspect ratio increased with pre surface treatment. The fabricated SiNWs were exposed to hydrogen plasma through ECR device at the microwave power of 800 watts and at different exposure times. Through the hydrogen plasma exposure, the tremendous change observed on the roughness of the SiNWs surface which was found to be decreased with the hydrogen plasma treatment. This decrease in the roughness can be attributed that the passivation of silicon surface through hydrogen plasma exposure which makes it smoothen. The wettability of SiNWs was studied and was found that the SiNWs showed the transformation from hydrophilic nature to hydrophobic with the increase of plasma exposure time. In the second part of hydrogen plasma treatment, the fabricated SiNWs were treated with hydrogen plasma at 600 watts microwave power. The plasma treatment time was varied from 0 minutes to 30 minutes. The structural, electrical, wettability and optical properties of SiNWs were studied in depth with the variation of plasma exposure time. The structural properties concluded that the diameter of the SiNWs decreases with the increase of plasma exposure time. The crystalline size decreases with plasma treatment. The roughness is found to be less at the lower exposure times and it was increased at the higher exposure times. The wettability properties concluded that the transition of hydrophilic to hydrophobic was possible with the increase of plasma exposure time.

The conductivity measurements concluded that for the SiNWs surface DC conductivity was enhanced with the hydrogen plasma treatment and this enhancement was more pronounced at the lower exposure time compared to higher exposure time. The optical reflectance studies concluded that the optical reflectance slightly increased with the hydrogen plasma exposure time. In conclusion metal assisted chemical etching (MACE) with Ag as catalyst was observed to be a better tool for the synthesis of PSi and SiNWs. The decrease of reflectance and increase of contact angle with the increase of etching time makes the PSi to act as anti reflecting coatings and self cleaning surfaces. The hydrogen plasma treatment on the fabricated SiNWs was observed to be a versatile method in studying the surface modification of SiNWs through the study of different properties.

Future Scope of The Work

- The optical properties in correlation with microstructure of the PSi are to be studied in detail to fabricate the Solar cell by using the porous silicon as anti reflecting coating.
- The results conveyed that the conductivity of SiNWs was enhanced with the hydrogen plasma treatment. In this connection, the influence of hydrogen plasma exposure time on the electrical properties of as fabricated SiNWs has to be studied further in detail in order to use SiNWs as anode material in Lithium ion batteries.
- The decrease of diameter of SiNWs was observed with the hydrogen plasma treatment. Hence a detailed study on the diameter of the SiNWs has to be carried out further by varying the plasma parameters in order to study the electron field emission from the SiNWs.

- The switchable wettability from hydrophilic to hydrophobic nature of SiNWs was observed with the hydrogen plasma treatment. Hence a further detailed study on the hydrophilic nature of SiNWs with the hydrogen plasma exposure has to be studied to make use of SiNWs for the bio molecular purification.
- The SiNWs exhibited hydrophobic nature at the higher plasma exposure times. Hence an influence of plasma exposure time on the hydrophobicity /superhydrophobicity of SiNWs have to be studied further in depth in order to utilize hydrophobic /superhydrophobic SiNWs as self cleaning surfaces in the solar panels.

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