Fabrication of 110 Silicon Nanowire Oriented with Direct Band Gap

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Abstract. Today, the challenges of getting fast switching semiconductor device based device is the phonon generation mechanism for light-emitting by device such as diodes. The increase in efficiency of the device determine by the green light part of the emitted light spectrum. Silicon nanowire growth in the direction of 110 structure has indirect band gap, which tremendously improved the green emission efficiency at the lower Nano regime. Several band structure calculations have be predicted direct band for 110 growth silicon nanowire. Thus, the study report the fabrication of silicon nanowires with diameter between 20 to 50nm which demonstrate the direct nature of the band gap. A strong photoluminescence at wave spectrum of 597 nm with micro-second lifetime indicating it direct band gap. This study have demonstrated new nanostructure engineering based on silicon nanowire orientation which will allow new ways getting silicon nanowire functionality.

1. Introduction

Today silicon based device have offer an alternative potential in various applications and further ease through possibility to meet semiconductor size requirement in many fabrication routes for meeting transistor technologies [1-5]. The materials have show in many applications, in recent time, silicon have presented with so many applications these includes ability to produce photo luminance which show can used in low cost in photonic technologies[6]. The device can be easily fabricated with smaller dimension to be able to integrate to light sensitive micro structure. The device equally be reported for it behaviour in showing direct band[7]. Thus, The work on nanotechnology devices have attracted wider interest[8]. The technology has offered number of potentials and possibilities devices manipulations by offering different design of structures. The device can be fabricated based on either using top down or bottom up, various approaches have been applied based on first principle to understand it both electrical and mechanical properties[9]. The technology equally offered various applications of nanostructures with novel properties[10]. The technology offered two distinct opportunities which classified into Nano devices and nanomaterials. The result of putting atom in different configuration offers tremendous
opportunities to create new nanomaterials[11]. The atomic arrangement come up with entire new look in terms of structure, geometries that have influence on its electrical, mechanical properties. Many researchers have demonstrated the controlled fabrication of molecular-scale SiNWs with a small diameter array[12]. In most of these, they show that the NWs with active carriers are single crystals with little or no visible amorphous oxide down to diameters as small as 3nm[14]. The wire direction has a strong diameter dependence, with the smallest-diameter NWs are primarily along <110> and the larger NWs along <111>. Electrical transport measurement shows that these nanowires are conductive and optical studies indicate that they can exhibit visible luminescence and proposed the mechanical properties of materials, their strength, rigidity and ductility, are of vital importance in determining their fabrication and possible practical applications[15, 16]. Materials exhibit a wide range of mechanical properties ranging. In general, In the microscopic level, the arrangement of atoms in an object would be affected by the applied external forces.

2. Experimental

Two silicon wafers P-type and N-type were each group into (100), (110), and (111). Mask was designed for fabrication of sub-90nm using photography coupled with Dry etching. The fabricated nanowires were doped. The process started with first cleaning with RCA1 and RCA2 cleaning processes. The cleaned and fabricated structure were put into reactor chamber. Prior this, the wafer were cleaned with oxide buffer etcher to remove negative oxide on the surface of the silicon. Nitride was deposited with on the silicon to isolate silicon wafer with the subsequent silicon nanowire. Two dopants were use Boron and Phosphorus, prior doping with the dopant dopants gas base line is purged with diluted 1% phosphine to avoid the dopant cross-contamination at the stabilization step as recommended by the [1]. The silicon was doped in three places and the formation energies were measured.

3. Results and Discussion

The pattern formation in photolithography is the main and crucial step of the nanowire fabrication as all the subsequent process depend on the integrity of resist pattern. The figure 60 show the behavior of the resist with spin coater speed, the film the resist film thickness is inversely proportional to the spin speed of the ma-N2400 series, whereby an increase in the spin speed process leads to a decrease in the resist thickness. The formation of the thin film is an important aspect of the pattern transfer as the resist interact with and adhere to the substrate surface. Thinner the thin film the better as the uniformity depend on the resist thinness and the resist layer is preferable to produce better resolution and good resistance to the plasma etching process during RIE etching, which are crucial for obtaining nanostructures with high aspect ratios. The resulting ma-N2400 series resist film thicknesses were approximately 20–700 nm. The optimum and ideal film for pattern transfer is approximately 350nm. The thinness produced with speed of approximately 4000rpm is at maximum. This is an optimal resist thickness for exposure parameters as shown in figure1.
Figure 1. The resist thickness curve decreasing with the spin speed (rpm)

\[ t = \frac{1}{\sqrt{\omega}} \]

The spin speed is one of the main parameter to produce or determine the pattern integrity. The range of spin speeds is important as it defines the range of thicknesses that can be achieved from a given designed pattern. As can be seen above in figure 1, the spin coating able to produce uniform films from 1000 rpm upwards, although, it has been reported that good film quality can be achieved down to around 500 or 600 rpm. Most common spin coaters will also reach a maximum speed of 6000 to 7000 rpm as indicated in this study. As such, a normal range of working spin coating rpm might span a factor of ten 1000 rpm to 8000 rpm) which in turn means a maximum variation in film thickness of around a factor $\sqrt{10} \approx 3.2$. From this factor the thickness of the entire pattern can be determined. The lower the thickness, the better the pattern exposure to the mask aligner and the resist development.
which as the size increase the band gap decrease, for atomic interaction exponent $\alpha$ is equal to 2 as the fitted curve and C is fitting coefficient as proposed by [24]. It is interesting to note that when the wire diameter increases, the band gap decreases. Furthermore, it can be observed that for different size as it increase, it show that band energy decease, this implies that the Si-NWs when interact exhibit strong interaction between atom to atom to create collision, this create phonon Fig.1. Generally from the literature, for the Si-NWs, the interaction of atoms results in increase electron group velocity, which increase collision and collection effect in the elastic deformation which decreases the lattice atomic interaction which in turn decrease the band gap. The energy gap exhibited as a results from interaction of Si atoms at edge of SiNWs. Large value of the energy gap is related to the quantum restriction (quantum confinement) of charge carriers. The nanowire behaviour of band gap can be explained by the increase in the resistance in the band structures of silicon nanowires. Due to the collision of atoms, the effective bond length in the band gap is shorten and this decrease the band gap in silicon nanowirer. The band with more smaller size shows energy shift due to the quantum restriction. These features of the band gap of quantum silicon nanowires can be a basis for many application in semiconductor industry especially.

To study dopants in the nanowires, the formation energy is very important. The formation energy $E_{\text{formation}}$ of the impurity which include B and P is generally defined as the energy needed to insert an atom B and/or P into the nanowire which represented by the equation below:

$$F_i = E(\text{doped SiNW}) - E(\text{SiNW}) + (n + m)\mu_{\text{Si}} - n\mu_{\text{B}} - m\mu_{\text{P}}$$

Where the notations are $n$ and $m$ are the number dopants B and P, $\mu_{\text{Si}}$ is the chemical potential of Si and $\mu_{\text{B/P}}$ the chemical potential of an atom of the impurity which are Boron B and phosphorous P. It is clear that the position labelled 2 in figure 3. is the preferential position for the dopant in both B and P doped. The formation energy for P doping is smaller
than for B doping. It is also clearly seen the formation energy for orientation <111> both dopants are highest compared formation energy for the <001> and <110>. The interaction between the dopants, which enlarges the formation energy in <111> orientation as confirmed by [25]. Shows the top and cross section view FESEM image of the nanowires during the dry etching process. The profile indicates that the silicon wires were formed with good uniformity, high resolution and good pattern placement. The width of the silicon wires is approximately 2.2µm. The cross-sectional revealed that the wire exhibits clear rectangular cross sections, the image shows the profile features to be approximately 2.2µm in width and 45nm in height. Compared with the resist pattern. The silicon wires increased in width by approximately 0.1µm after the oxidation before dry etch process. Thus, the results indicated that dry etching process could produce silicon wire with more surface précised manner and width. The uniformity of the device is one of the most important parameters for it electrical response.

4. Conclusion

The study successfully, demonstrated the behaviour of the nanowire conductance, resistance and band gap with size, the results show that the energy gap, resistance and conductor are all higher at the lower nanosize, the value of band gaps were 4.3 eV, 4 eV and 3.7 eV for (111), (110) and (100) respectively with the nano size of the 1 to 6nm, the nanowire is shown super conductance at lower regime and gradually decrease as the size increase, this is due to the surface of the device. Thus, the effect of the aforementioned parameters was successfully established. As the Nanowire reduces, the mechanism of inducing partial charge through interaction equally revealed.

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