Fabrication of ZnO Nanowire Device Using Top-Down Approach

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1. Abstract

ZnO nanowire devices were fabricated from top-down using optical lithography. The nanowires are formed from anisotropic etch of 100 nm Filtered Cathodic Vacuum Arc (FCVA) deposited ZnO thin film. The nanowires are characterized using SEM and Raman spectroscopy via image mapping. The current-voltage characteristics showed a typical ohmic behaviour after contact annealing, reflecting the influence of the lowering of contact barriers between the ZnO nanowire device and the Al metal electrode.

2. Introduction

ZnO nanowires are considered to be one of the most important semiconductor nanomaterials with applications such as optoelectronics, electronics and sensors due to their wide and direct bandgap energy (3.37 eV), large exciton binding energy (60 meV) and high thermal stability[1-3]. To date, a lot of research is done to produce high quality nanowires from bottom-up approach [4]. Top-down method using electron-beam and focused-ion-beam lithography [5-6] have also made great impact to investigate the basic properties of nanowire devices but their use on a large scale is a challenge due to high cost.

Recently, polycrystalline silicon nanowires are patterned using top-down optical lithography which was used in biosensor applications [7]. In this work, we have demonstrated a top-down silicon compatible process to create ZnO nanowire devices and experimentally verified its Ohmic conductivity.

3. Experiment

Figure 1 shows the process steps of the ZnO nanowire fabrication process. The process starts with an n-type Si sample and a layer of 400nm SiO_2 is thermally grown on the substrate. The SiO_2 trench is formed by photolithography pattern transfer and reactive ion etching (RIE) based on CHF_3-Ar gas mixture. The etched depth of the SiO_2 trench is 100 nm. A layer of 100 nm thick ZnO is deposited on top of the trench structure using Filtered Cathodic Vacuum Arc (FCVA) method, as shown in the SEM of Figure 2(a). The ZnO

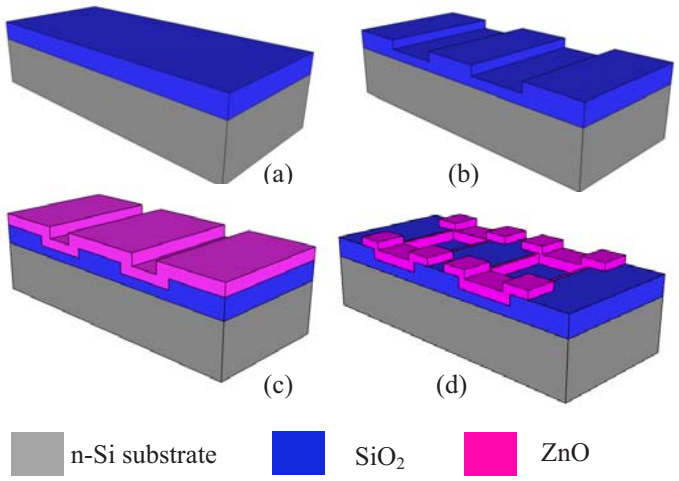


Fig.1: *Diagram illustrating the fabrication process of the ZnO nanowire (a) thermal SiO_2 deposition, (b) SiO_2 patterned and etched using RIE (c) ZnO FCVA (d) ZnO nanowire formed at the spacer after RIE etch*

film is then etched anisotropically using RIE to form the nanowire structure as shown in Figure 2(b). The etch gas used was CHF_3 and the RF power is varied from 100W to 200W to determine the best selectivity between ZnO and SiO_2. The etch pressure was 20 mTorr and the gas flow rate was set at 25 sccm. The etch rate results are shown in Figure 3.

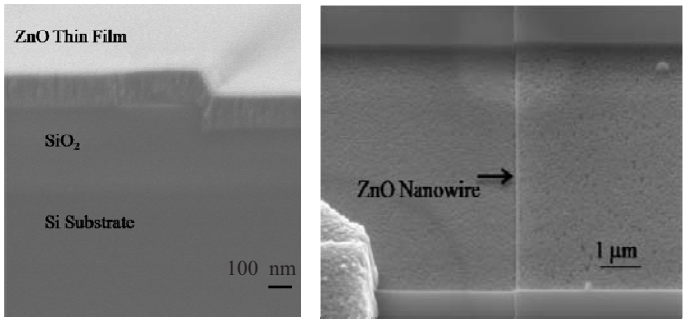


Fig.2: *SEM images of (a) ZnO thin film on SiO_2 trench. (b) ZnO nanowire formed at the SiO_2 spacer*

The etch rate results demonstrating highest etch rate of 1.64 nm/min for RF power of 200 W, followed by 0.72 nm/min and 0.3 nm/min for RF power of 150 W and 100 W, respectively.

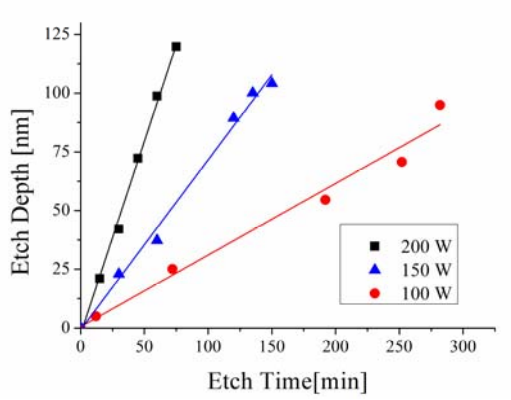


Fig.3: *The etch rate of ZnO film with pressure=20mTorr and CHF_3=25sccm*

We have selected RIE power of 200W not only due to its highest etch rate but at this power, highest selectivity was achieved compared to the SiO_2 layer beneath the ZnO film. Finally, Al contact pad was e-beam evaporated on top of the nanowire structure and annealed in Rapid Thermal Annealing (RTA) process at 350°C for 12 mins. The nanowire device structure with Al pad is shown in the optical microscopy image in Figure 4(a). The nanowires fabricated have length range from 2 µm to 20 µm. The width and height of the ZnO nanowires are around 100 nm. These dimensions can be controlled by adjusting the thickness of the ZnO layer and the height of the SiO_2 trench. Figure 4(b) shows 16 identical wires across the two Al electrodes demonstrating ZnO nanowire arrays were successfully formed at the side of the oxide spacers.

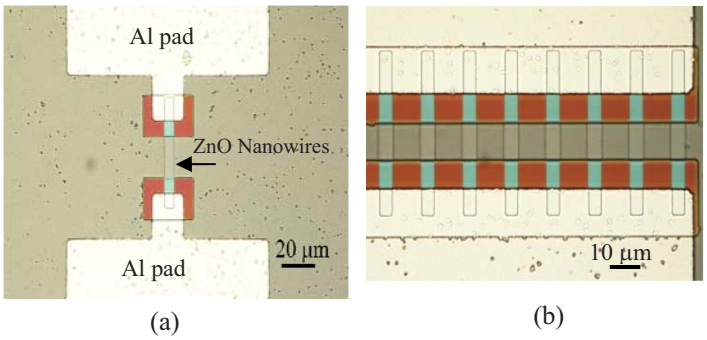
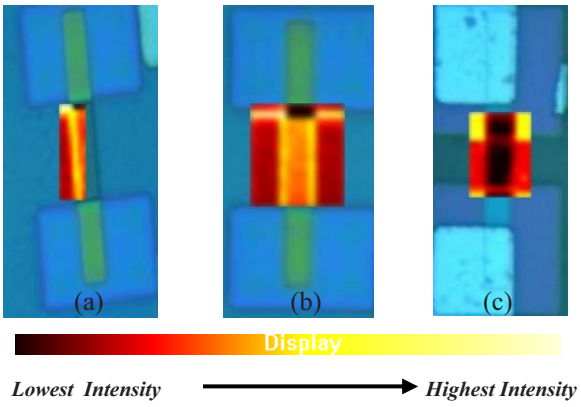
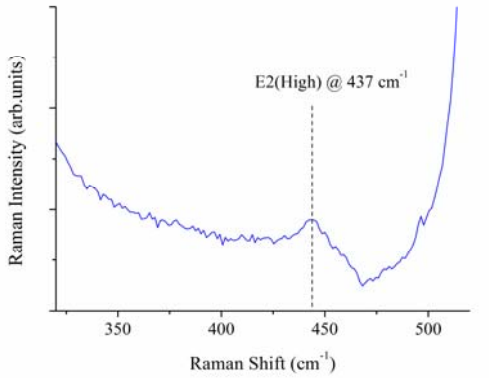


Fig.4 *Optical images of (a) ZnO nanowires formed at the SiO_2 spacer (b) Array of ZnO nanowires*

4. Characterization

In this section, we characterize the ZnO nanowire by using Raman spectroscopy and its Ohmic characteristics. The Raman spectroscopy is done by mapping the ZnO nanowire at the side of the SiO_2 trench as shown in Figure 5. Figure 5 (a) shows bright yellow region, indicating the presence of ZnO and this is verified by the Raman spectrum shown in Figure 5(d). The laser source used for the Raman spectroscopy map was 532 nm. If the incident light was exactly normal to the surface, only the E_2 phonon modes and the A_1(LO) phonon mode can be observed in ZnO [8] The peaks at 437 cm^{-1} should be assigned to the vibration modes of E_2. The E_2 mode was related to band characteristics of the wurtzite phase, and it can be shifted due to residual stress in the nanowire. Figure 5(a) of Sample 1 and Figure 5(b) of Sample 2 show high intensity (yellow) at the side of the oxide trench, which indicate the existence of ZnO nanowires. Meanwhile Figure 5(c) of Sample 3 does not show peaks at E_2 mode near the oxide trench which suggests the ZnO film has been overetched.





(d)

Fig.5: *Raman image mapping at E_2 phonon mode (a) Sample 1 (b) Sample 2 (c) Sample 3(d) Raman spectra obtained from one of the mapped point along ZnO nanowire device*

The electrical characterization is done using a semiconductor parameter analyzer HP4155. Figure 6 shows the I-V characteristics of the ZnO nanowire device measured before and after contact annealing in RTA. The current-voltage characteristics were measured in room temperature. The nanowires measured were 10 μm long. The voltage is biased from -1V to 1V. Before annealing, the ZnO nanowire device show asymmetrical behaviour with máximum current of $1x10^{-8}$ A at 1V. This result indicates the existence of surface barriers between the ZnO nanowire device and the Al metal electrode. The black curve shows the same nanowire device after contact annealing with RTA in vacuum. The curve shows a distinctive characteristics of Ohmic behaviour from the symmetric I-V result. Contact annealing also improves the current of the ZnO nanowire device by three-fold in magnitude with máximum current achieved at 1V is 2 $x10^{-5}$ A. This result using Al electrode is comparable to results produced using Ti/Au metal [2][9]. This is due to the dissociation of the ZnO at the surface región and strong reaction between Al and O in the ZnO layer with the annealing process. As a result, the n-type barrier heights is being lowered. [10]

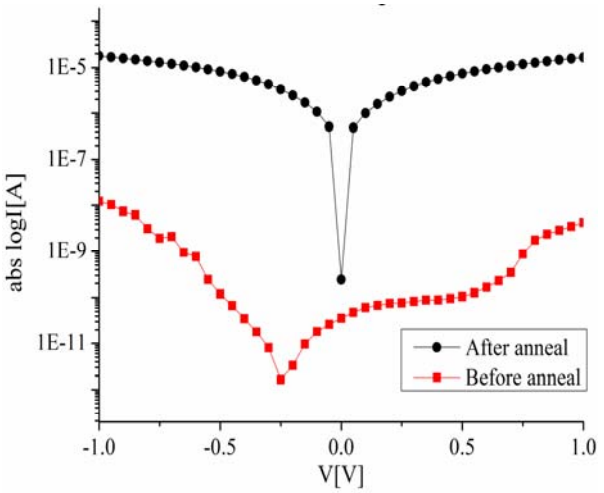


Fig.5: *The I-V characteristics of Al-ZnO Nanowire Before and After Contact Anneal*

5. Conclusions

ZnO nanowire structures were fabricated using top-down approach and characterized using Raman spectroscopy and its Ohmic behavior is studied. This fabrication produces large scale ordered nanowire devices and its process is compatible with Silicon CMOS process flow. We demonstrated that the dimensions and positions of the nanowires can be controlled. The fabricated ZnO nanowire device shows high intensity Raman peaks along the SiO_2 spacer which is a good indication of the existence of ZnO material. The Ohmic characteristic after the RTA annealing improves with current enhanced by three fold order in magnitude. Thus, we have successfully demonstrated that this technique is a very promising method and can be directly extended to the fabrication of nanowire field-effect transistor.

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