Mechanical properties of individual ZnO nanowire tested via nanoprobe system

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Abstract: The individual ZnO nanowire was prepared through thermal evaporation of ZnO powder. A new test platform which contained the micromanipulator nanoprobe system installed in the scanning electron microscopy (SEM) chamber was introduced for the test of the mechanical properties of individual ZnO nanowire. A nanocantilever model was used to test the mechanical properties of the individual ZnO nanowire. And the Young's modulus was calculated based on the theoretical formula. The value of the Young's modulus for an individual ZnO nanowire was 367 GPa.

Introduction

One-dimensional nanostructures like nanobelts, nanowires, and nanorods which have fantastic properties such as electrical, optical, mechanical and potential application have attracted extensive attention in recent years[1].Especially, it is necessary to establish an effective method to measure the mechanical property of nanowires as well as the other properties. However, due to their small size, the manipulation of nanowires in testing the mechanical characterization is still a challenge[2].

ZnO is a semiconductor with a wide direct band gap (3.37eV) and a large exciton binding energy (60meV) at room temperature. it is an important member in the II-VI group semiconductors, has profound applications in optics, optoelectronics, mechanics[3]. Furthermore, the ZnO nanostructure is easy to produce. It is very important to measure the mechanical properties of ZnO nanostructures, which can be used as components for micro- and nanoelectromechanical system (MEMS and NEMS). Recently, many techniques have been developed to test the mechanical properties of nanowires. Famous experimental methods included bending, nanoindentation, and resonance.

Herein, our research group reports a new and developed method to test mechanical properties of nanowires. We use the micromanipulator nanoprobe system installed in the SEM chamber, so we can observe the position, manipulation and testing of the sample in real time[4]. This method make us easy to test the mechanical characteristics of an individual ZnO nanowire ,which is based on a nanocantilever model and get the force of bending, then calculate the Young's modulus.

Experiment

preparation of individual ZnO nanowires

The ZnO nanowires were synthesized via thermal evaporation. ZnO powder was used as the source materials and placed in the center of a horizontal tube furnace. Before heating, the tube furnace was pumped to 10 Pa to remove the oxygen in the tube, and then the temperature of the furnace was raised up to 1300˚C at the rate of 10˚C/min and held at the peak temperature for 1h under a constant pressure 250 Pa, then the system was cooled to room temperature naturally. During the course of heating and cooling, nitrogen gas was used as carrier gas with a flow rate of 75 sccm (standard cubic centimeter per minute). After taking out the sample from the tube furnace, a white product was found on the Au coated Si substrates which were placed at 10cm in the downstream of the source.

The micromanipulator nanoprobe system

In our experiment, a micromanipulator nanoprobe system with four arms manufactured by Kleindiek Company installed inside the Hitachi-S4800 SEM was used for testing the mechanical properties. We can not only observe the sample in real time but also manipulate and test the sample by this system.

The force was used to bend the individual nanowire by nanoprobe tip, which is shown in Fig.1.The tip bends the individual nanowire with a continuing increasing force and releasing the nanowire with a continuing decreasing force. The nanowire has corresponding deformation with the force. During the whole process, the tip must be moved perpendicular to the nanowire.

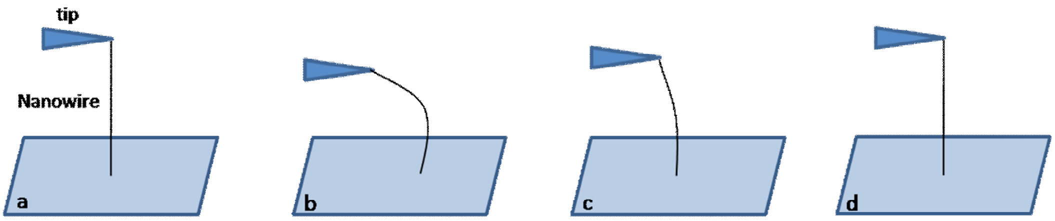

Fig.1 Schematic model of theexperiment for bending the individual nanowire by nanoprobe tip. (a) The tip just contants the individual nanowire and there is no force on the nanowire. (b) The tip is bending the individual nanowire with a continuing increasing force and the nanowire has the corresponding deformation. (c) The tip is releasing the nanowire with a continuing decreasing force and the nanowire is recovering its origin position. (d) The force becomes to zero and the nanowire returns to its origin position.

A series of SEM pictures were captured to record the position of the tip and the nanowire, as shown in Fig.2. Therefore, the corresponding deflections of the nanowire could be obtained and the force could be calculated. Fig.2(A) shows the tip just contacts the nanowire and the red rectangle frame shows the individual nanowire. Fig2.(A) to Fig2.(D) show the tip increase the force to the nanowire and the nanowire had the corresponding deformation. Picture D shows the maximum deformation of the nanowire. Fig.2(E) to Fig.2(H) shows the releasing process, the nanowire was recovering its origin state with the force releasing, indicating that the deformation of the individual ZnO nanowire is elastic deformation

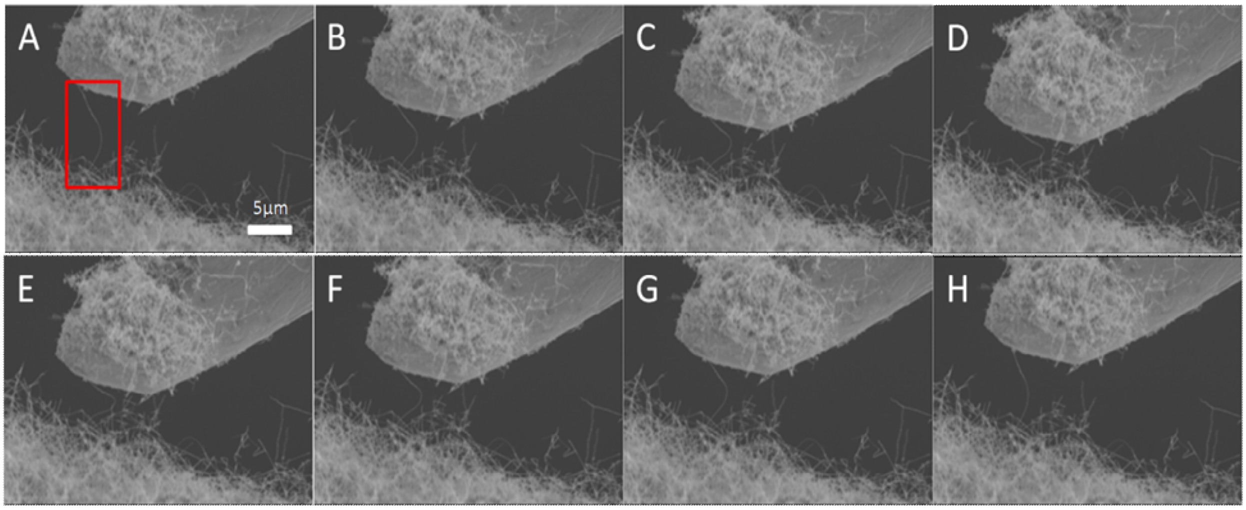

Fig.2 A series of SEM images of an individual ZnO nanowire after continuously exerting the force, A→B→C→D was shown the loading process, while E→F→G→H was the releasing process.

A series of data of the forces and the deflections based on all the SEM images was got by Force Measurement Analysis (FMA) software as shown in Table 1

Table 1 The data of the force and the deflection of the individual nanowire

F(μN)	**d(nm)**
0	0
0.9835	62.41
1.7621	141.25
2.2513	180.8
2.6426	214.7
2.9863	231.72
3.3286	259.96
3.6726	276.91
2.966	293.85
4.3102	310.96

F-d curve was shown in Fig.3 based on the Table 1.The slope of the F-d curve was 13.28N/m. The length (L) and the diameter (D) of the individual nanowire was 12.3μm and 260nm respectively. Therefore Young's modulus (E) could be calculated to 367GPa.This value can't be compared to the Young's modulus of ZnO (c_{33}=210 GPa and c_{13}=104 GPa),due to the shape of the nanowire and the anisotropic structure of ZnO are convoluted in the measurement[5].

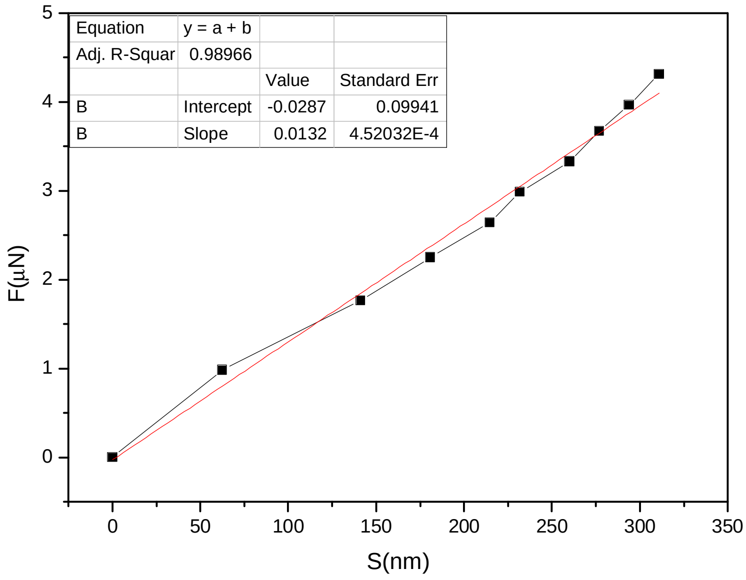

Fig.3 F-d curve of the individual ZnO nanowire

Conclusions

The ZnO nanowire was synthesized via thermal evaporation and the mechanical properties of the individual nanowire was tested by the micromanipulator nanoprobe system installed in the SEM. The deformation of the ZnO individual nanowire was elastic deformation and Young's modulus was calculated to 367 GPa.

Acknowledgments

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