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SEM AND STM INVESTIGATIONS OF NANOWIRES

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1. Introduction

Nanostructures have attracted much attention in recent years [1-6]. New methods have been developed to fabricate a large variety of structures [3, 4, 6] whose particular features depend on the precise growth conditions, substrates, and catalysis. Especially, self-assembled nanowires (NWs) offer a large variety of interesting and unique properties since they turned out to grow in rather excellent quality even in relatively easily controllable processes and to become nearly strain-free under these conditions. In particular, ZnO NWs have attracted renewed attention in recent years due to their peculiar optical properties [2, 6, 7]. This material system is a promising candidate for short-wavelength optoelectronic devices. The attention on ZnO has considerably enhanced since the first report on p-doped ZnO light-emitting diodes was published [8]. Many room-temperature applications have already been shown, such as single-NW field-effect transistors, light-emitting diodes, laser diodes, logic gates combining both n-type and p-type NWs, solar cells, and sensors [1, 5, 8]. Self-organized ZnO NWs have substantial advantages compared to other material systems (no surface oxidation, high exciton binding energy, ferromagnetic properties when doped with transition elements). A key property of these material systems is the unique versatility in terms of geometrical dimensions and composition. However, for any application a detailed knowledge of the optical properties, their microscopic origin, surface morphology and cross-section, which is influenced by e.g. growth methods or the geometry of nanostructures, are of fundamental importance. In this paper we report on investigation of vapor phase epitaxy grown ZnO NWs on a Si substrate by scanning electron microscopy (SEM) and scanning tunnelling microscopy (STM).

2. Experiment

Experiments were carried out in SEM and STM. The pressure inside SEM is ~ 10^{-7} mbar and STM – 10^{-11} – 10^{-12} mbar. During the operation the tilt of the stage in SEM system is 52^{o}. For SEM imaging the diameter of the electron beam is 1 nm, the applied acceleration high voltage is 20 kV and current 0.4 nA. ZnO NW samples were grown on a Si substrate by the VPE

technique [2]. After growth (~ 30 min) a huge number of single-crystalline NWs were obtained. The geometrical structure of the obtained NWs depends strongly on the growth conditions. Of main influence are both temperatures at the source material as well as at the substrate, the pressure and the gas flow. Due to the fact that individual wires of the as-grown ensemble cannot be directly addressed by a focused laser beam or SEM, single NWs have to be extracted from the ensemble. This was achieved by sonication in a dissolver bath. The optical properties of ZnO single and ensemble NWs were investigated by L. Wischmeier, et al. [7]. For surface characterization of ZnO NWs by SEM and STM samples with high densities of NWs were fabricated.

3. Results and Discussion

In the following we present the results of the SEM and STM investigation of the VPE-grown ZnO NWs on the Si substrate to answer the question whether the NWs are perfect or non-perfect. SEM and STM images of ZnO NWs are shown in Figs. 1, 2, 3 and 4.

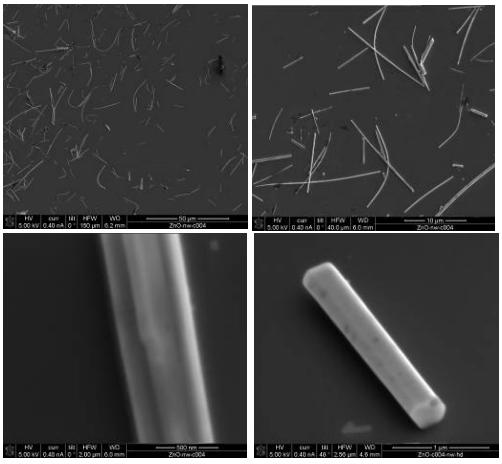

Fig. 1. SEM images of ensemble (above) and single (below) perfect ZnO NWs on Si substrate.

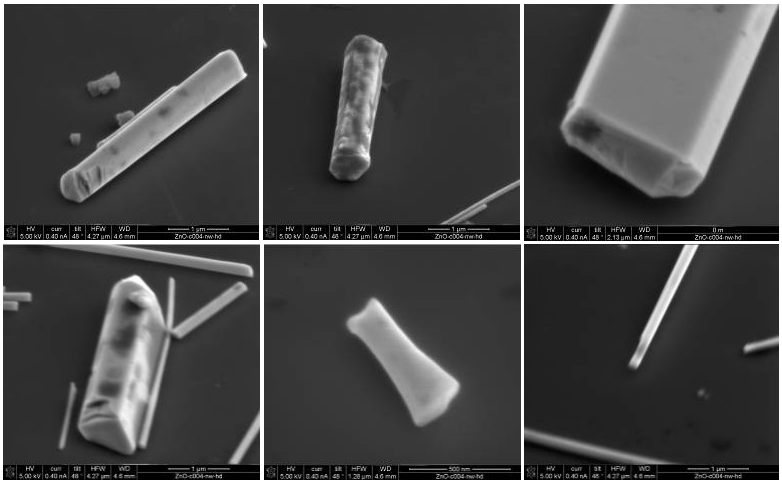

Fig. 2. SEM images of ZnO non-perfect single NWs on Si substrate.

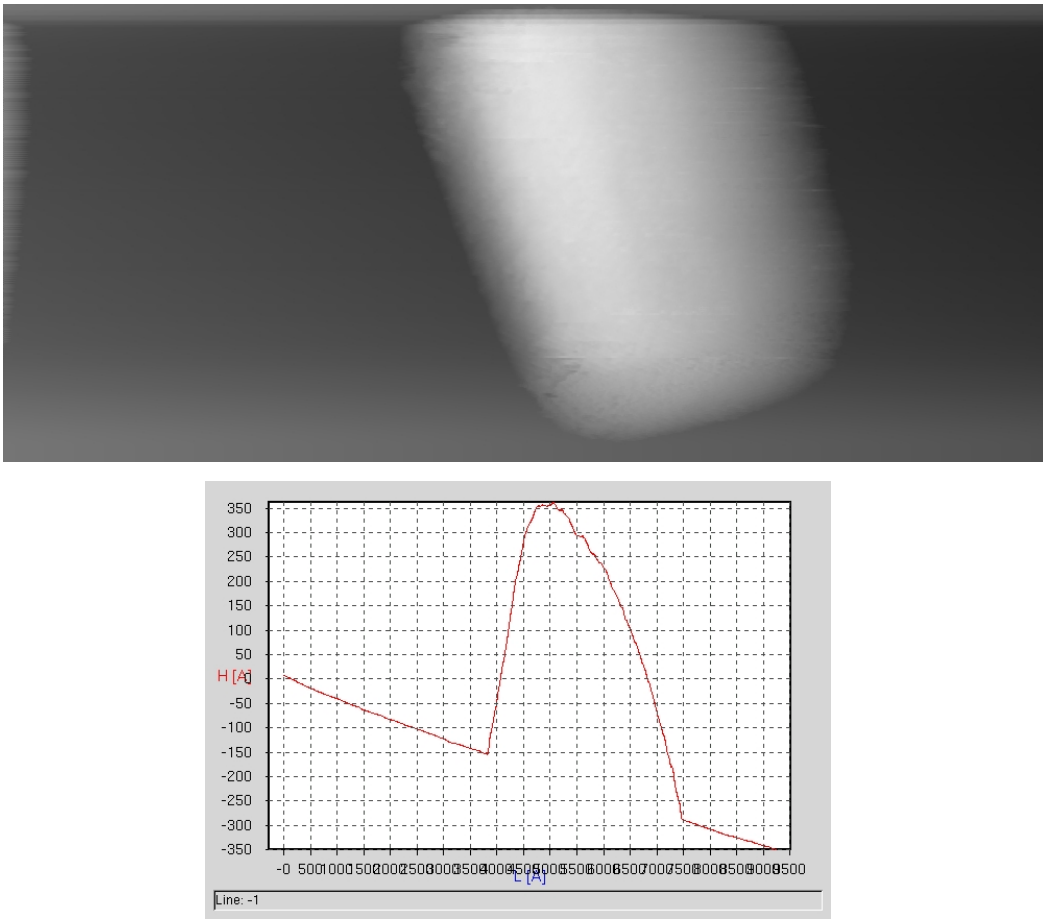

Fig. 3. SEM image of ZnO of NW grown on Si substrate and height profiles of them in two directions. The scan area is 1000 nm x 560 nm.

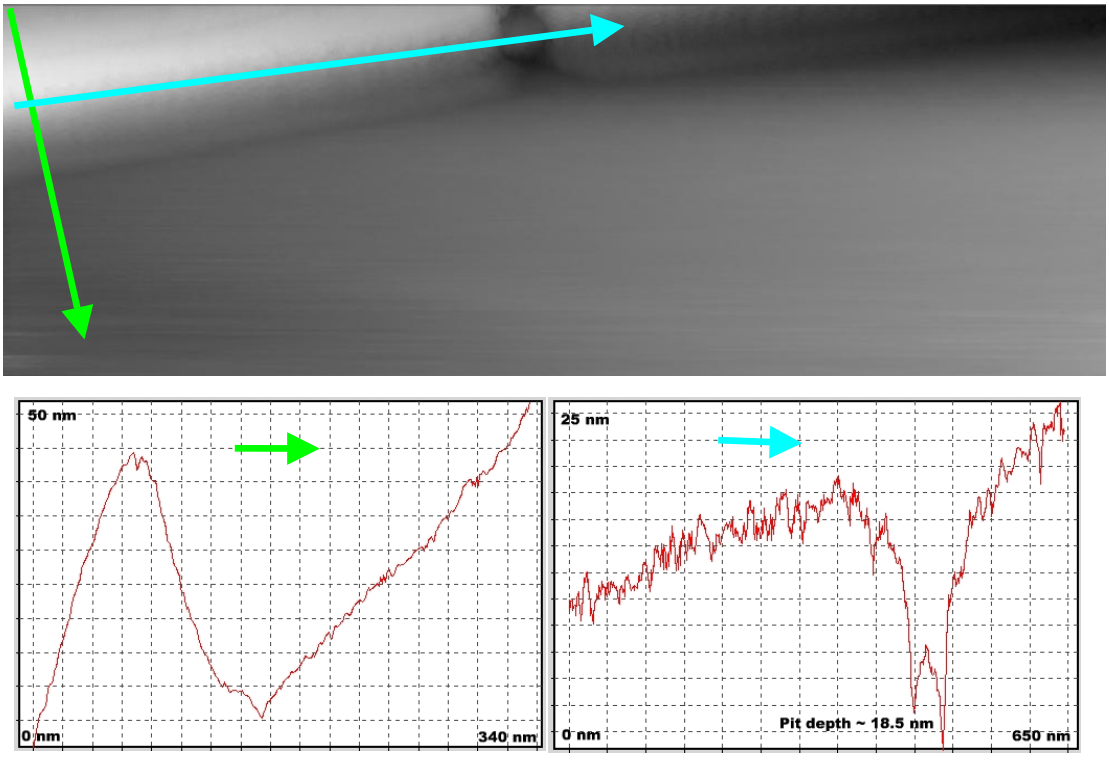

Fig. 4. SEM image of ZnO of NW grown on Si substrate and height profiles of them in two directions. The scan area is 1000 nm x 340 nm.

There are ensemble (Fig. 1) and single NWs (Fig. 2, 3 and 4), among which we found straight and bend, as well as perfect (with regular facets and smooth surfaces) (Fig. 1 and 3) and non-perfect (with irregular facets, not smooth surfaces, variable width, damages and particles) (Figs. 2 and 4) ZnO NWs. The heath profiles of NWs allow determining the height and width of NWs (Figs. 3 and 4) and spots on the NWs (Fig. 4). The sizes of the NWs were determined: the length is about 2-24 μm, and the width and height are about 200-500 nm. The depth of NW is 18.5 nm. The hexagonal facets of the NWs were observed on SEM images, which emphasize the good crystalline quality of the NWs (Fig. 1).

4. Conclusion

Thus, we investigated vapor phase epitaxy grown ZnO NWs on a Si substrate by SEM and STM. SEM investigations show that there are single NWs and ensembles of NWs, among which we found straight and bent, perfect (with regular facets and smooth surfaces) and non-perfect (with irregular facets, not smooth surfaces, variable width, damages and particles) NWs, as well as NWs with clean surfaces and surfaces with the dark spots and features. The hexagonal facets of the NWs were observed on SEM images, which emphasize the good crystalline quality of the NWs. The sizes of the NWs were determined: the length is about 2-24 μm, and the width and height are about 200-500 nm.

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