Zinc oxide nanorods grown from solutions: What is next?

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Synthesis of nanoscale building blocks of controllable dimensions, morphologies, and materials is central to nanoscience and nanotechnology. A great deal of interest has been recently directed towards the design of new devices using one-dimensional (1D) semiconductor nanostructures such as nanowires and nanorods (NRs). The research into 1D nanostructures has been motivated not only by their unique electrical and optical properties but also by the fact that their high aspect ratio allows for a full relaxation of elastic strain without the development of extended defects. This opens the door for the integration of different material platforms onto a given substrate, which is one of the key challenges faced by the semiconductor industry.

The question of how the 1D nanostructures grow has long fascinated scientists. While most of the NRs of classic semiconductors, such as Si, Ge, GaAs, InP, and InAs, is grown catalytically by vapor-liquid-solid (VLS) or vapor-solid-solid mechanisms, the NRs of wide bandgap semiconductors, such as GaN and ZnO, can be grown by catalyst-free methods. The catalyst-driven growth mechanisms, and particularly the vapor-liquid-solid (VLS) mechanism, have received considerable attention. On the contrary, the mechanisms of the nucleation and growth by catalyst-free methods are not deeply understood and the growth technology strongly relies on empirical results.

In this presentation, we take a critical look at the research progress in the growth of ZnO NRs from solutions. We discuss the selection, the surface treatment, and the fabrication of suitable substrates and seed layers for a particular application. We show that in conventional batch reactors the solution supersaturation varies with time. The growth rate of ZnO NRs is thus not constant over time and decreases as the growth proceeds due to the depletion of the solution in reactants. The variation of the supersaturation and of the growth rate results in the variation of incorporation of dopants, impurities, and structural defects along the NRs. Moreover, with a different level of supersaturation, the growth mechanism can be altered. We propose a solution to this issue, the so-called continuous-flow reactors, and discuss their design. We further point out key chemical and physical phenomena taking place during the growth and propose approaches to model them. To deeply understand the nucleation and growth phenomena, we developed lithographic techniques using focused electron and ion beams, which allow us to prepare highly uniform arrays of upright-standing ZnO NRs on different substrates and seed layers. Finally, we demonstrate methods of how individual nanorods and their heterojunctions can be electrically characterized with a nanoprobe installed in the scanning electron microscope.