Building complex semiconductor nanowires via *in situ* growth experiments

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Semiconductor nanostructures can be grown while under observation in a transmission electron microscope by flowing chemical vapor deposition precursor gases over a heated substrate. Video-rate observations, where tens or hundreds of images are obtained per second, provide a unique view of the physics of the self-assembly process that generates the individual nanostructures. Morphology, crystal structure and growth kinetics can be measured, including the response of the growth process to changes in parameters such as pressures and temperature [1]. We have used this technique to examine the epitaxy and self-assembly of Si, Ge, GaAs and GaN nanowires. These nanowires are grown from nanoscale metallic catalytic droplets that act to accelerate growth at the catalyst/nanowire interface (the *vapor-liquid-solid* growth mode), thereby forming an elongated crystal.

We find that the VLS growth mode allows quite complex nanowire-based structures to be grown controllably if we obtain a detailed understanding of the mechanisms at work. We first describe the formation of "nanocrystal-in-nanowire" structures, achieved by supplying metals such as Ni or Mn sequentially to the catalyst during Si nanowire growth [2]. We discuss the range of structures that can be achieved in other materials such as Ge and GaAs. We next consider the opportunities for crystal engineering in III-V nanowires. GaAs, for example, can grow in nanowire form in both the zinc blende crystal structure, which is the equilibrium phase, and the non-equilibrium wurtzite structure, allowing crystal phase heterostructures to be formed. *In situ* microscopy allows the mechanism of this phase selection to be clarified [3]. Finally, we describe nanowires grown into bridges between macroscopically large contacts. Electrical transport through such nanowires can be correlated with their structure and the morphology of the junctions at either end, also measured and controlled *in situ* [4], and electric fields can be used to control nanowire growth directions [5]. This is potentially useful for device integration. We conclude with a perspective on multi-modal experimental probes that may provide the promise of correlating nanowire surface chemistry with structure and properties measured *in situ*.

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