Recording the composition and structure of the seed particle during growth of GaAs nanowires by in-situ TEM

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Semiconductor nanowires (NWs) with group III-V combinations of elements holds great promise for application in high-speed electronics, LEDs and solar cells. Common growth techniques for NWs are for example metal-organic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE), and the recently developed Aerotaxy[1] process, which provides 2-4 orders of magnitude higher growth rates and does not need expensive epitaxial support. The growth processes require temperatures ranging between 300-900°C, depending on the chosen material system, and a metallic catalyst particle (usually Au) that can dissolve at least one of the components. Despite rather well-developed theory[2], there is still a long-standing debate on whether the catalyst particle is completely in liquid or solid state[3], and the actual composition during growth. It is also unclear what effect the metal organic precursor pressure ratio has during growth. To clarify this, we have designed and constructed a CVD system connected to a high-resolution TEM.

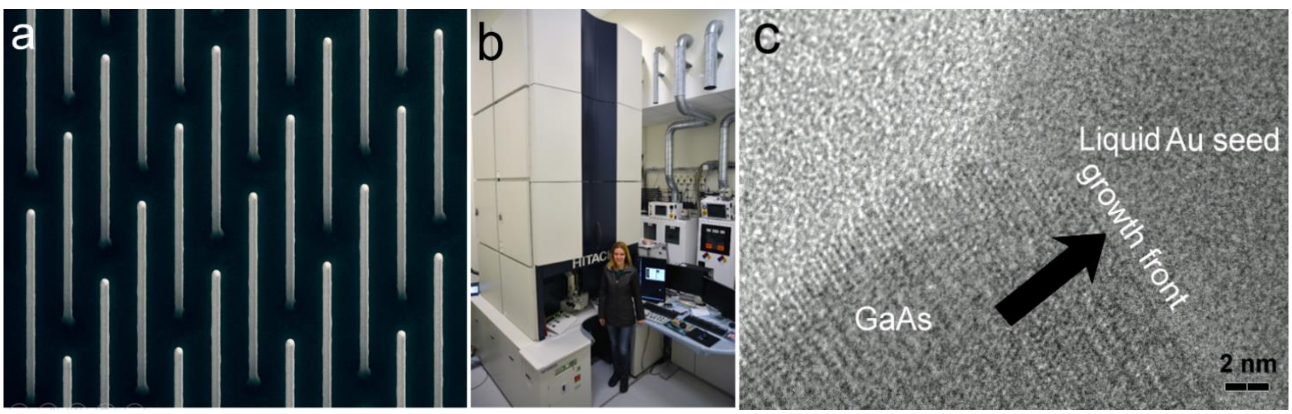

Fig.1 a) SEM image of well ordered, epitaxially grown NWs. b) The ETEM with gas cabinets in the background. c) Snapshot from a video sequence of a growing GaAs NW.

The ETEM is based on a Hitachi HF3300S ETEM with a B-COR aberration corrector, providing a >10 mm pole piece gap and a 0.86 Å point resolution. The precursor gases are lead in two separate microtubes to the specimen holder tip, where a MEMS heating chip with an amorphous SiN thin film is holding the catalyst particle specimen. X-ray energy dispersive spectroscopy (XEDS) is used for quantitative analysis during growth. The CVD gas supply system allows using 9 different gases, with pressures up to approx. 2 Pa. The gas composition inside the microscope is monitored by mass spectrometers.

We will show video recordings of growth of GaAs NWs, using Au nanoparticles and trimethylgallium (TMGa) and arsine (AsH_3) as precursor gases, which are the standard industrial gases used. The growth temperature is varied between 260℃ and 500℃.

During growth of the nanowire, the XEDS analysis of the alloy seed particle show a temperature and gas flow dependent composition of the seed particle. For fixed gas flows, Ga content in the seed particle increases with increasing temperature. For a fixed temperature, both TMGa and AsH_3 flows influence the composition, which at 420 ℃ may range from 25 to 80 atomic % Ga. Stopping the flow of precursor gases at growth temperatures results in dissolving the crystalline NW layer-by-layer at the seed particle-nanowire interface. The thermodynamically stable structure of GaAs is the zincblende structure, but varying amounts of stacking faults, and pure wurtzite structures can be induced in the nanowires. This opens up for bandgap engineering, without changing the materials system, which would be a tremendous advantage for industrial growth.

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References

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