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Epitaxial growth of III-V nanowires on Si(111) microheaters using an environmental transmission electron microscope

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Gold-catalyzed III-V nanowires are grown epitaxially on microfabricated silicon microheaters in an environmental transmission electron microscope (ETEM). The study contributes to the fundamental understanding of crystal growth at nanoscale as well as the fabrication of future microdevices. The study includes both design, fabrication and characterization of microheaters integrated into a silicon on insulator (SOI) chip suitable for specialized ETEM holders. The setup is used for *in situ* nucleation and growth studies of gold-catalyzed III-V nanowires at different growth parameters on the silicon microheaters, which also work as substrate with a (111) crystal orientation.

Microheaters have previously been used for epitaxial growth of silicon nanowires [1]. Observing nanowires bridging from one microheater to another *in situ* TEM has resulted in unique studies of contact formation [2] and electrical characterization of single nanowires [3] resulting in nanowire based microdevices. The setup has also led to important fundamental results for nanowire growth measuring the surface tension of gold-catalyzed silicon nanowires [4]. The present study extends the previous observations with an extra dimension by studying gold-catalyzed III-V nanowire growth live in a unique ETEM with a purpose built gas handling system for metal-organic vapor deposition [5].

Silicon microheaters have been fabricated based on previous designs [6]. For silicon nanowires, the growth rate can be used to determine the temperature profile of the microheaters [6], but using more complex compositions such as III-V nanowires, other methods are used to determine the temperature profile for the microheaters including simulations with COMSOL Multiphysics®. Au-nanoparticles are introduced as catalyst particles using aerosol deposition. A good contact between the Au-nanoparticles and the silicon microheaters is important to get epitaxial growth. This is encouraged by annealing the microheaters on a hot plate in a nitrogen atmosphere right after gold deposition. Another important interface besides that of Au-catalyst and Si-substrate is the contact between the catalyst and the surrounding precursor gases. An oxide layer is formed on the surface of the catalyst and removing this is a part of the nucleation studies. Once the nanowires are growing, the suspended nanowire growth is investigated including the growth of crystal phase heterostructures. By changing gas flows, the crystal structure of the GaAs nanowire can be deliberately tuned from hexagonal wurtzite to cubic zincblende [7].

Microheaters prepared as described above are loaded into the ETEM. Applying a current to the device lead to resistive heating of the microheaters (figure 1a). The eutectic point of gold and silicon is found, when the gold particle forms a liquid alloy with the silicon substrate (figure 1b).

As an AuSi liquid is formed and oxide has been removed from the catalyst surface, epitaxial growth is achieved (figure 1c), which is being confirmed by diffraction patterns (figure 1d-e). The epitaxial growth is used to study the effect of changing gas flows on crystal structure as control of the changing crystal structure can allow for formation of crystal phase heterostructure (Figure 2).

In conclusion, the present study investigates the growth of gold-catalyzed III-V nanowires on resistive heated microfabricated Si(111) cantilevers. It demonstrates different growth behaviors of the suspended nanowires by changing growth parameters.

Figure 1: Silicon microheaters integrated into a silicon on insulator chip hanging into vacuum (a). Applying a current will heat up the microheaters forming a liquid AuSi alloy. TEM images of AuSi alloy achieved at temperatures above the eutectic point (b) and an epitaxially growing nanowire (c). The epitaxial growth is verified by diffraction patterns (d) of both silicon microheater and GaAs nanowire (e).

Figure 2: Nanowire growing at different applied gas flows from one video sequence going from wurtzite (a) structure to introducing sections with zincblende structure (b). The snapshots are taken as the nanowire grows.

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