Growth of Si, Ge, and SiGe Nanowires

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Nanowires (NWs) are one-dimensional crystalline objects with specific physical properties due to their reduced dimensionality. The integration of Si and particularly Ge NWs in sophisticated Si electronics would be desirable, but the realization will remain on the level of research and development for years to successfully implement in the industry, as the growth and handling of NWs is a challenging task.

We focus on the controlled growth of Si, Ge, and SiGe NWs on (111)Si substrates by MBE. Hereby, solid sources of the elements, Au, Si and Ge were used. Au serves as catalyst, where the NW growth is located and take place via the VLS mechanism. Our work is targeted on arrays of doped SiGe NWs for thermoelectric devices applicable to high temperatures. NWs could be helpful to improve the figure of merit of such devices by reducing the thermal conductivity due to phonon scattering on the sidewalls and at composition changes inside the NWs.

The precise placement of gold droplets as starting points of NW growth is carried out by coordination of the Au evaporation rate and of the substrate temperature.

The distribution and movement of gold on Si and Ge surfaces varies. When cooling down the substrate, we observe small Au particles on the Si surface, beside the Au droplets. On Ge surfaces these particles are missing. We explain this behavior by a stronger Au wetting behavior, and by inhibited movement of Au atoms on Si surfaces. Moreover, residual silicon suboxide, which is more stable than germanium suboxide, serves as pinning points for Au.

The growth direction of Si and Ge NWs differs, too. Si NWs grow preferably into [111] direction forming alternating (111) and (113) micro-facets at the NWs' side walls, whereas Ge NWs grow into [110] direction with microscopically flat (111) side facets [1].

During growth, material is supplied to the Si NWs by diffusion from surface areas between the NWs and from the NWs' sidewalls. With increasing length of the NWs this process tends to be ineffective, leading to the accumulation of Si or Ge on the substrate surface outside the NWs. To protect the substrate surface from epitaxial growth during NW formation, a temporary in situ oxidation of the surface is applied.

This attempt was preceded by oxidation experiments of the as-prepared Si substrate. RHEED investigation showed that under prevailing MBE conditions a stable Si oxide is only formed when oxygen and silicon are co-deposited.

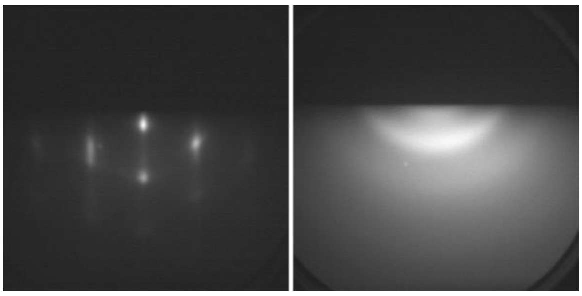

Fig. 1: RHEED images show the surface structure of a (111)Si substrate when exposed to oxygen only (left), and when silicon and oxygen are deposited simultaneously (right). The duration of both experiments was 30 min.

[1] J. Schmidtbauer, R. Bansen, R. Heimburger, Th. Teubner, T. Boeck; J. Cryst. Growth, **406**, 36 (2014)

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