Watching Nanowires Grow

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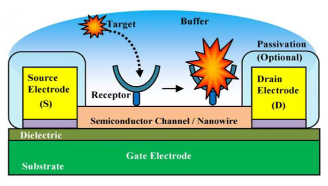
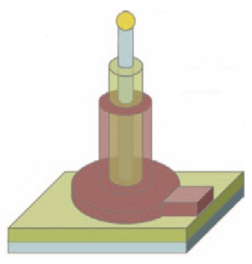
Applications



Sensing

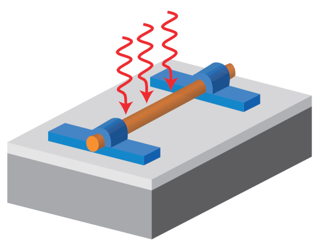
Chen et. al., Nano Today 6,131



Transistors

(gate-all-around FET)

Thelander et. al., Materials Today 9,28



Light absorption

(solar cells)

Cao et. al., Nature Materials 8,643

Bottom-up VLS growth

- A (sub)eutectic metal-semiconductor droplet acts as a collector and reservoir for the nanowire growth material. This material crystallizes at the liquid-solid interface, giving rise to a nanowire with diameter mostly equal to that of the droplet.
- Nanowires tend to adopt an energetically favorable droplet-nanowire interface. Hence, for most systems, the interface is formed by a single {111} plane. This results in preferential <111> growth direction.

Experimetal details:

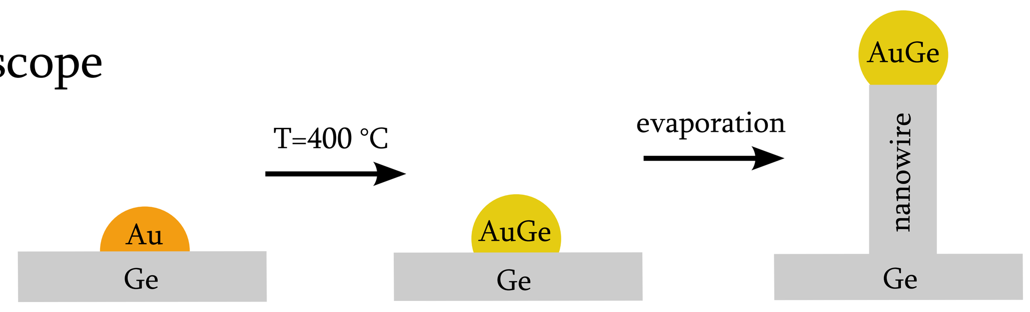
environment: 10^{-4} Pa inside scanning electron microscope

metal: Au

nanowire: Ge by evaporation

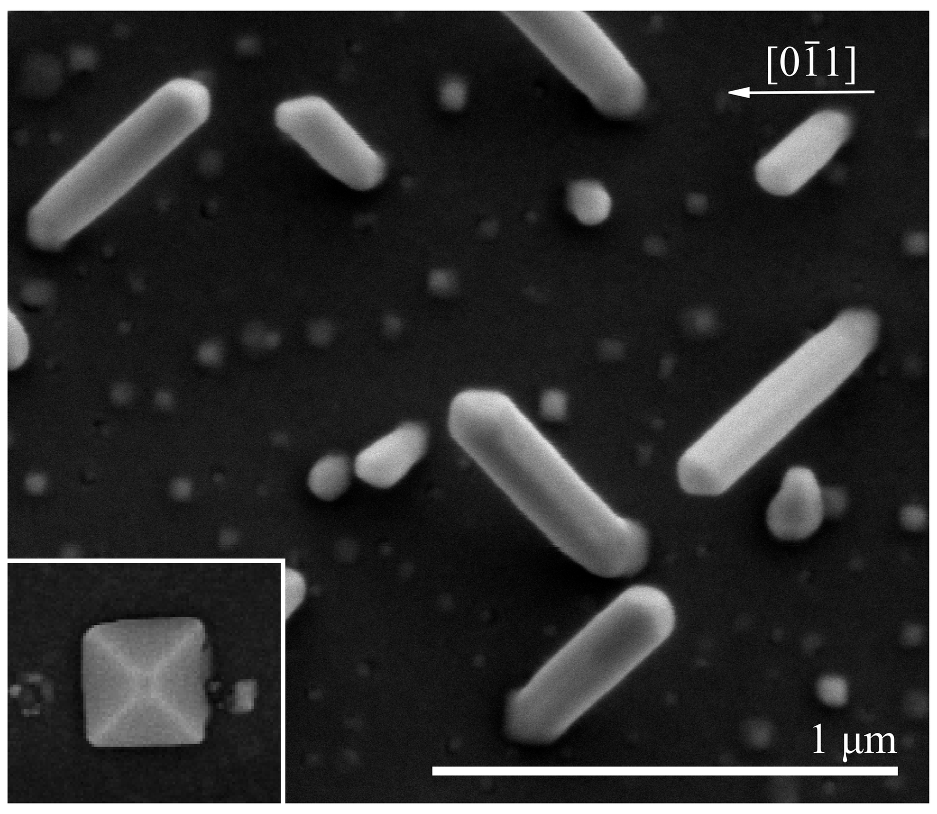
temperature: 400 °C

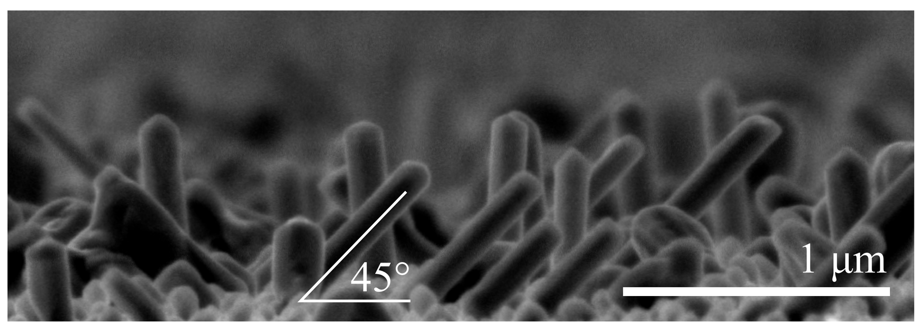
growth rate: 3 Å/min - 12 Å/min



In our work using in-situ electron microscopy we show that the growth orientation can be altered by controlling the supersaturation in the droplet.

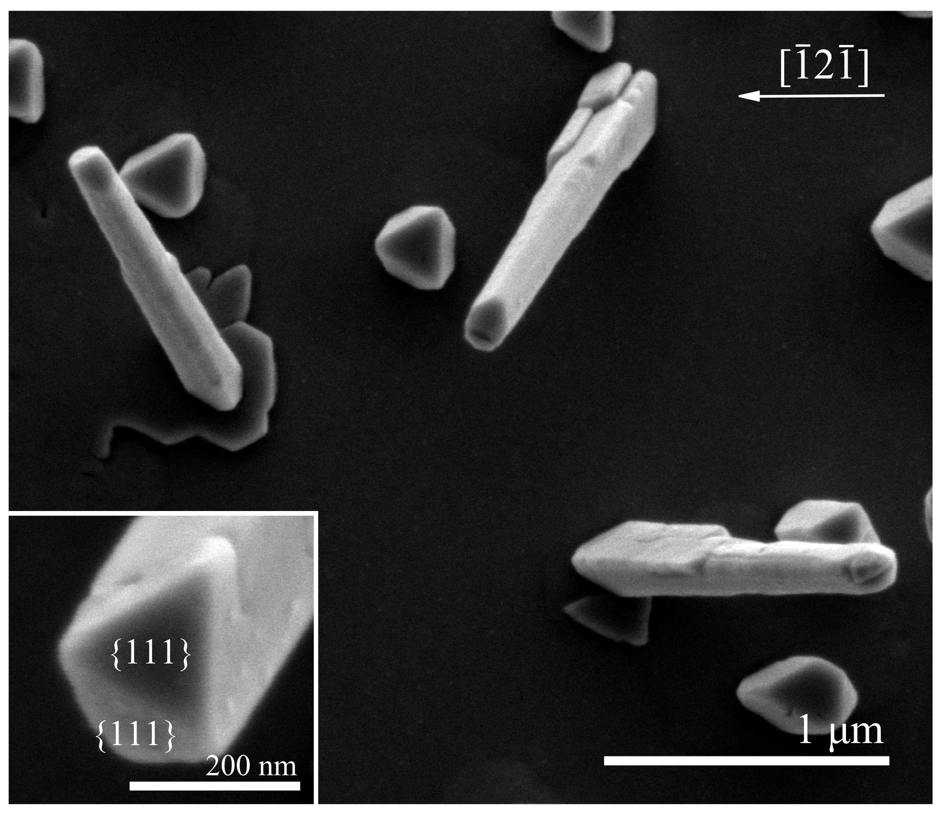
Growth results

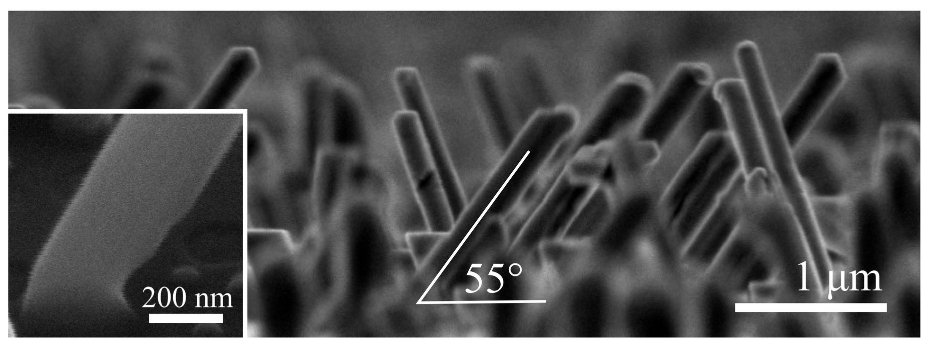




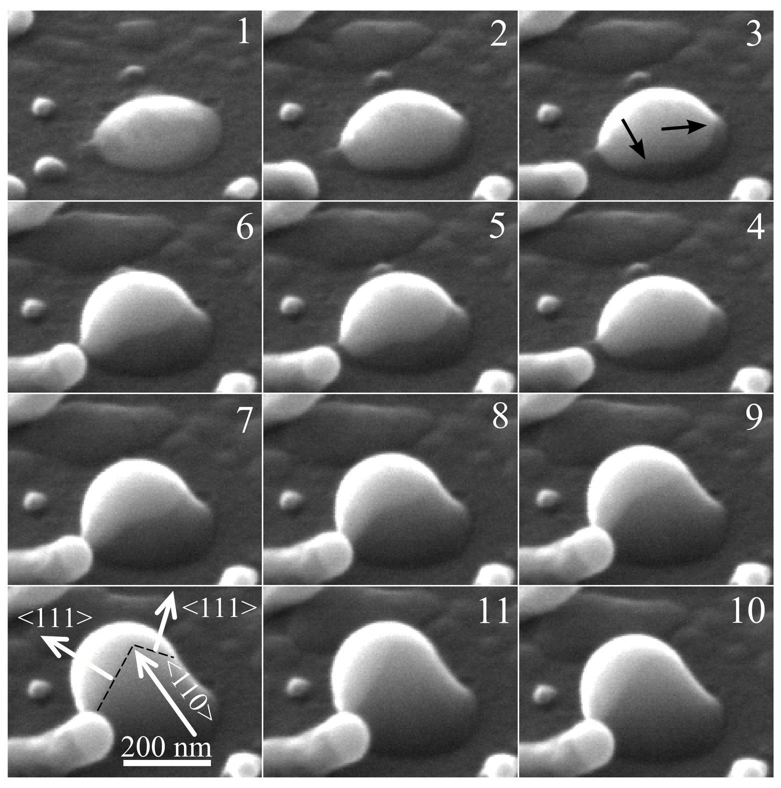
Ge(100) ⟵ substrate orientation ⟶ Ge(111)

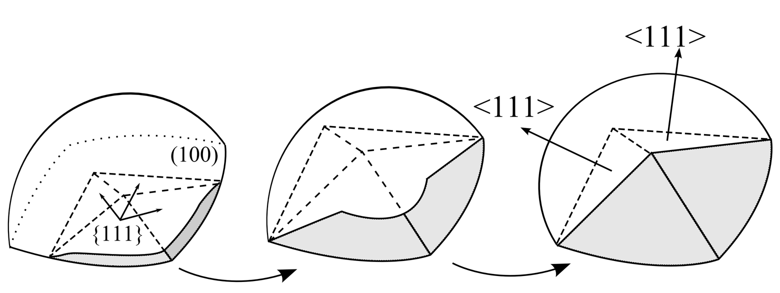
- for small evaporation rates the nanowires growth direction is <110>, independent on substrate orientation
- growth interface is formed by two {111} planes, inclined by 110°, independent on substrate orientation
- in between nanowires small islands are formed, having pyramidal (on Ge(100)) or triangular (Ge(111)) shape
- all <110> oriented nanowires on Ge(111) exhibit <111> oriented pedestal





Initial growth stage: in-situ observation

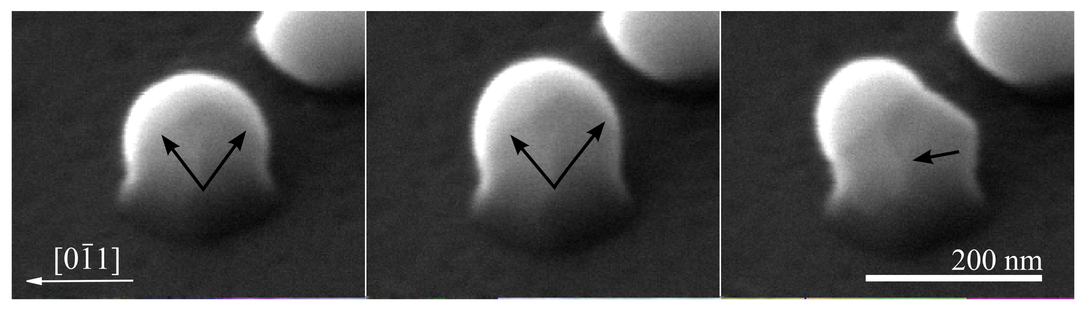


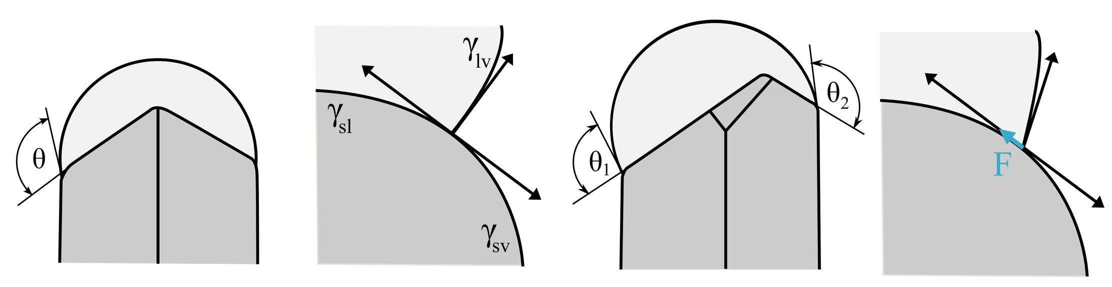


- Image 1: 13 minutes after evaporation start. The droplet collects the deposited atoms.
- Image 2: 36 minutes after growth. The droplet height increased due to the formation of nanowire nucleus at the droplet-substrate interface.
- Images 3-12 are taken in 3 minute steps. The droplet dewetts the nanowire sidewalls until stable position is reached. The growth interface consisting of two {111} planes is established. Further on, the growth proceeds in <110> direction.

Nanowire kinking

If the deposition rate is increased, nanowire kinking towards <111> direction occurs very often. The droplet changes its contact angle and pins to different edges. The growth interface is formed by a single {111} plane.





The growth direction of nanowires can be controlled by the growth rate, which is directly related to the supersaturation in the droplet. If high growth rates are achieved (as is usual in CVD), <111> growth direction is preferential. If the growth rate is significantly decreased, the growth interface is formed by multiple facets and the preferential growth direction becomes <110>.