19th INTERNATIONAL CONFERENCE ON DIFFUSION IN SOLIDS AND LIQUIDS
DSL2023
HERAKLION, CRETE | GREECE
26-30 JUNE 2023

ABSTRACT:

Diffusion in nano-objects observed *in-situ* in the transmission electron microscope

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Observing atomic diffusion *in situ* in the transmission electron microscope (TEM) is possible directly in some specific cases like graphene edges [1]. When considering other nano-objects, like nanowires or nanoparticles, the geometry makes it more challenging to image single atoms: there is no sharp edge and the bulk material makes it difficult to avoid a background noise in the images, excluding single atom visualisation. Diffusion fluxes can however be deduced from the observations in real time of growth fronts or phase boundary migrations, which allow in turn to quantify diffusion at the nanoscale. Here, we present several examples of such measurements, performed in the "NanoMAX" prototype environmental TEM, with such objects as semiconductor and Ni-silicide nanowires (NWs) [2] . We emphasise the Ni-silicide case, where NW growth takes place when exposing a pure Ni film to a mixture of silane and hydrogen at 400°C. Interestingly in this system, the NW phase characterised *ex situ* is most often *not* the phase crystallising during growth. A phase change takes place at the end of growth, through the migration of a phase boundary (see figure). The migration velocity, together with composition measurements (by energy-dispersive X-ray spectroscopy), directly leads to the value of the flux of Ni atoms and to their nanoscale diffusion coefficient.

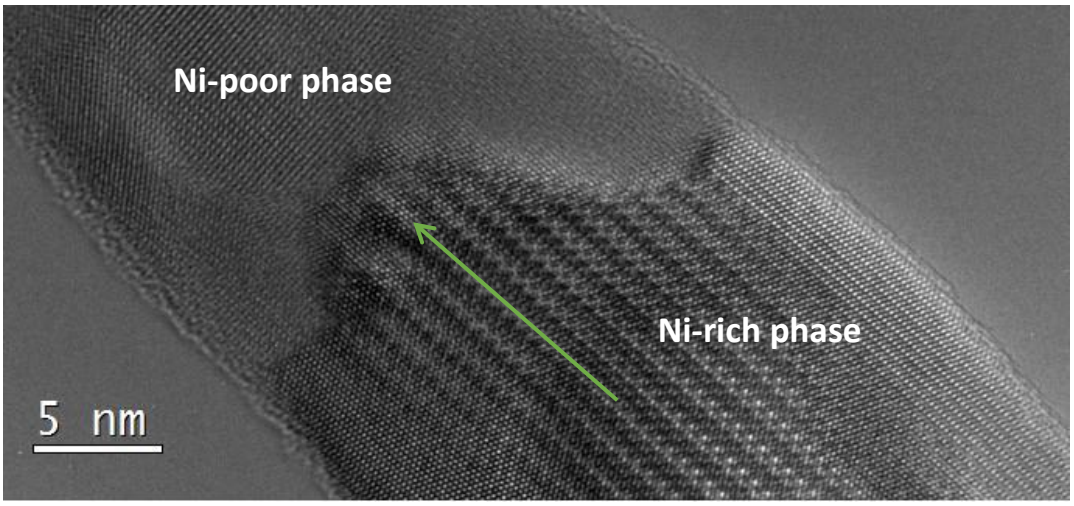

Figure: advancing phase boundary in a Ni-Si NW

[1] X. Yang, *et al.*, *Single-atom catalytic growth of crystals using graphene as a case study*, npj 2D Materials and Applications **5**, 91 (2021), https://doi.org/10.1038/s41699-021-00267-4
[2] É. Ngo, *et al.*, *Liquid-assisted vapor–solid–solid silicon nanowire growth mechanism revealed by in situ TEM when using Cu–Sn bimetallic catalysts*, J. Phys. Chem. C **125**, 19773-19779 (2021), https://doi.org/10.1021/acs.jpcc.1c05402