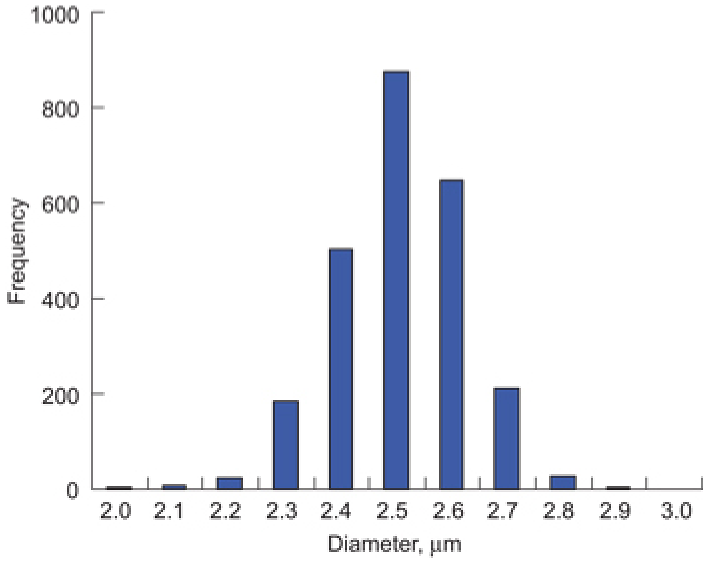
Structures Self-Assembled Through Directional Solidification

Nanotechnology has created a demand for new fabrication methods with an emphasis on simple, low-cost techniques. Directional solidification of eutectics (DSE) is an unconventional approach in comparison to low-temperature biomimetic approaches. A technical challenge for DSE is producing microstructural architectures on the nanometer scale. In both processes, the driving force is the minimization of Gibb's free energy. Self-assembly by biomimetic approaches depends on weak interaction forces between organic molecules to define the architectural structure. The architectural structure for solidification depends on strong chemical bonding between atoms. Constituents partition into atomic-level arrangements at the liquid-solid interface to form polyphase structures, and this atomic-level arrangement at the liquid-solid interface is controlled by atomic diffusion and total undercooling due to composition (diffusion), kinetics, and curvature of the boundary phases. Judicious selection of the materials system and control of the total undercooling are the keys to producing structures on the nanometer scale.

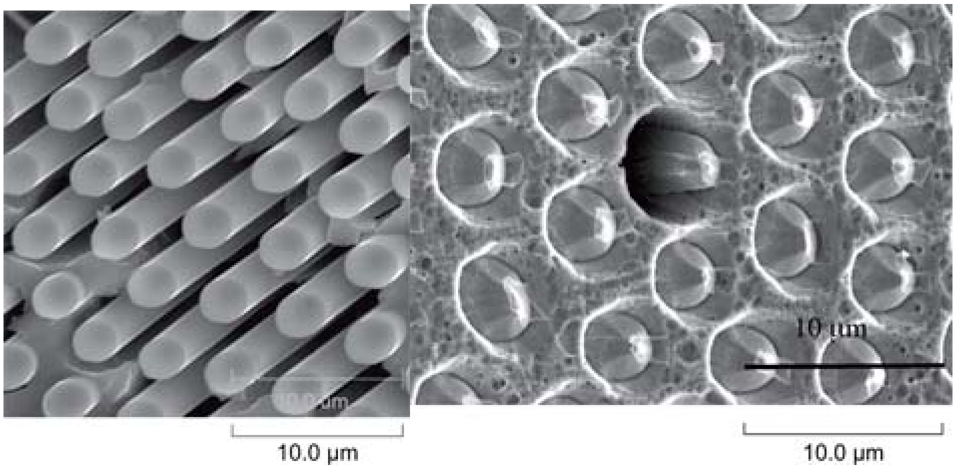
TiS_2 rods in a Si matrix.

The silicon-titanium silicide (Si-$TiSi_2$) eutectic forms a rod structure under isothermal cooling conditions. At the NASA Glenn Research Center, directional solidification was employed along with a thermal gradient to promote uniform rods oriented with the thermal gradient. The preceding photomicrograph shows the typical transverse microstructure of a solidified Si-$TiSi_2$ eutectic composition. The dark and light gray regions are Si and $TiSi_2$, respectively. Preferred rod orientation along the thermal gradient was poor. The ordered $TiSi_2$ rods have a narrow distribution in diameter of 2 to 3 µm, as shown in the following graph. The rod diameter showed a weak dependence on process conditions.



Diameter distribution of TiS$_2$ rods.

Anisotropic etch behavior between different phases provides the opportunity to fabricate structures with high aspect ratios. The following photomicrographs show the resulting microstructure after a wet chemical etch and a dry plasma etch. The wet chemical etches the silicon away, exposing the TiSi$_2$rods, whereas plasma etching preferentially etches the Si-TiSi$_2$ interface to form a crater. The porous architectures are applicable to fabricating microdevices or creating templates for part fabrication. The porous rod structure can serve as a platform for fabricating microplasma devices for propulsion or microheat exchangers and for fabricating microfilters for miniatured chemical reactors. Although more work is required, self-assembly from DSE can have a role in microdevice fabrication.



Left: Potassium-hydroxide- (KOH-) etched DSE Si-TiS$_2$. Right: Plasma-etched Si-TiS$_2$ microstructure.

Currently, aspect ratios are limited in semiconducting materials because the anisotropic etch properties are controlled by crystallography. Additional benefits of DSE include fabrication simplicity, process control of microstructure, and stability of the structure at high temperatures. Like other bottomup methods, DSE is not suitable for making complex or interconnected patterns.

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