Nanowire transistors

Jean-Pierre Colinge
CEA-LETI, Grenoble, France

After having been pushed as far as possible, the bulk CMOS transistor was recently abandoned to the benefit of FD-SOI and multi-gate 3D transistors because of insurmountable short-channel effect problems. The excellent electrostatic control of the channel region by the multi-gate architecture allows one to reduce short-channel effects well below the 20 nm node and have the potential to extend Moore's Law down to the 3 nm node. Among the different types of multi-gate FETs, the gate-all-around (GAA) nanowire FET enjoys the lowest short-channel effects.

The excellent electrostatic control in GAA nanowires has also enabled the design of novel types of transistors, such as junctionless FETs and tunnel FETs with very low subthreshold slope.

The quantum confinement of carriers in the non-transport directions gives rise to the formation of energy subbands which give rise to transconductance oscillations if both temperature and drain voltage are low enough. The energy levels and density of states depend on both the effective mass of carriers and the diameter of the nanowire. While short-channel control improves with reduced diameters and mobility increases when the effective mass is decreased, the density of states decreases at low effective masses. In addition, direct source-to drain tunneling becomes a limiting factor at low effective masses and short gate lengths.

The energy valleys depend on nanowire crystal orientation and diameter, which affects effective mass and valley occupancy. Furthermore, the energy bandgap increases when nanowire diameter is decreased. Semimetals can be viewed as semiconductors with a zero or negative bandgap energy. This energy increases in nanowires due to carrier confinement, and the design of semimetal nanowire transistors can be proposed.

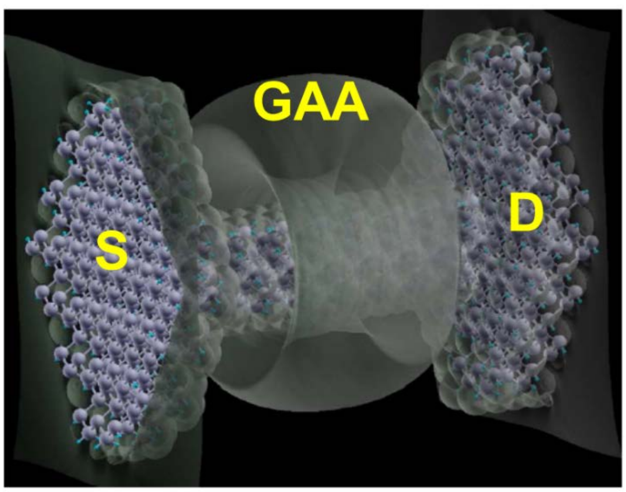

Fig. 1. Example of a semimetal nanowire GAA transistor. The small diameter channel region is semiconducting, while the wider source and drain regions are semimetallic. Each little sphere represents a tin (Sn) atom.