Novel Device Concepts and Strategies Basing on SiGe Nanostructures

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The development of the CMOS technology in the last decade has shown that classical materials in CMOS technology materials and device principles have been exhausted, long before the ultimate physical limits have been reached. As a consequence, some materials such as HfO_2 as gate dielectrics and Cu as interconnect metal, which have been off limits only a few years ago, have already entered the major Si device fabrication facilities. Today, additional materials are being investigated, with a particular emphasis on hybrid systems as well as on surfaces and interfaces. While further downscaling in combination with intensified research on hybrid systems will permit the continuation of the CMOS technology path for the next 10 to 15 years, radically new approaches are required for the “beyond-CMOS” scenarios, including device principles and matching architectures.

The introduction of Ge into Si technology permits the modification of the structural, mechanical and electrical properties. Thus the implementation of Ge into Si technology leads to the design of novel devices as well as to new routes for the fabrication of nanostructures. A central challenge for nanotechnology aiming towards nanoelectronics, nanomechanics, biochemical sensors and nanophotonics is to implement exact control in the positioning and size of semiconductor nanostructures. Here, we focus on the templated self-assembly of SiGe nanostructures and discuss two pathways for the fabrication of them.

Templated self-organization of Ge dots is achieved by patterning Si substrates by extreme ultra-violet interference lithography (EUV-IL) using diffractive optics. This method offers fast large area exposure of templates with close to perfect periodicity. Si substrates have been patterned with 2-dimensional hole arrays using EUV-IL and reactive ion etching. Subsequently, molecular beam epitaxy was employed to grow Si/Ge quantum dot stacks. This process allows the fabrication of 2- and 3-dimensional quantum dot crystals containing Ge dots in a Si host crystal of unmatched structural perfection as proven by X-ray diffractometry. The Ge dots exhibit a remarkably narrow size distribution and close to perfect ordering. 2-d ordered quantum dot arrays with lateral periodicities of 50 – 100 nm as well as stacking of those quantum dot arrays into 3-d quantum dot crystals with a vertical periodicity of < 10 nm have been investigated. The results were interpreted by comparison with model calculations using nextnano3.

In the second approach Si/SiGe as well as Si/SiGe/Cr hybrid layered structures are patterned by standard lithographic techniques into mesa structures. Underetching of the mesa structures leads to a scrolling of the layer stacks into nanotubes, nanospirals and other 3-d objects due to the strain. Thus, by this technique nanostructures are produced from templates in a self-assembled fashion. The mechanisms controlling the scrolling process were analyzed in detail and their dependence on the shape, the orientation and the size of the mesa pattern was determined. Moreover, the mechanical properties of tubes, spirals and rings have been studied. Individual structures have been cut off from the substrate by micromanipulation and were subject to analysis.

Possible applications for quantum dots and scrolled nanotubes for nanoelectronic devices and nano-electromechanical systems will be discussed.