Epitaxy of ordered arrays of semiconductor nanostructures on substrates patterned by EUV interference and e-beam lithography

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On the one hand side typical applications within nanoelectronics for semiconductor nanostructures, like quantum dots and nanowires, require precise control of the position, size and composition of the nanostructures. On the other hand side, commonly used bottom-up technologies for the fabrication of nanostructures, like self assembly, lead to arbitrary nucleation sites and a rather broad distribution of island sizes. Moreover, epitaxy of nanowires frequently involves the vapour liquid solid growth mode, employing metallic catalysts which potentially contaminate the semiconductor. Here we investigate the nucleation of nanostructures on predefined locations on the substrates. The patterns are produces by either EUV interference or by e-beam lithography. Two examples are presented, namely the growth of Ge quantum dots and quantum dot crystals on templated Si substrates and the growth of GaAs/AlGaAs core shell structures on GaAs/SiO_2 substrates.

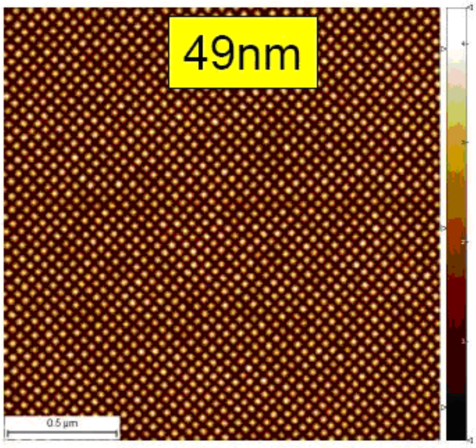
Interference lithography using EUV light at a wavelength of λ=13.5 nm allows the fabrication of periodic patterns with a pitch of less than 20nm [1]. Using this technology Si (100) substrates have been patterned with 2-dimensional hole patterns with periodicities ranging from 35 to 100 nm. After EUV exposure and resist development the pattern was transferred to the Si substrate by reactive ion etching (RIE). Typically the holes were etched to a depth of 6-8 nm. Subsequently low temperature Molecular beam Epitaxy of a thin Si buffer layer was performed followed by the growth of a stack of Ge quantum dot layers separated by thin (5-10 nm) Si spacer layers. Fig. 1 shows AFM images of the top surface of quantum dot crystals (QDC) with lateral periodicities of 49, 42 and 35 nm fabricated by this technology. The QDC exhibit excellent ordering of the Ge dots and a very small size distribution as manifested by AFM, TEM as well as X-ray diffraction measurements. Moreover intense photoluminescence has been observed, which persists up to room temperature. Model calculations are in agreement with the structural and optical properties. These calculation indicate vertical and horizontal coupling of electronic states of neighbouring dots in the QDC.

In the second example presented in this study, GaAs (111) substrates have been coated with SiO_2 films. The SiO_2 film was patterned by means of e-beam lithography and subsequent RIE to open small windows with typical diameter of 50 nm into the SiO_2 . These patterned wafers were subject to MOVPE growth using a selective mode to grow ordered arrays of GaAs nanowires. After the deposition of the GaAs wires the growth mode was switched by switching the precursors and a AlGaAs shell was deposited. Embedding a n-doped layer into the AlGaAs shell aims to the fabrication of a modulation doped 1-dimensional GaAs wire. Fig. 2 shows a) schematically of the structure of the grown core-shell structures and b) an SEM image of the MOVPE grown modulation doped AlGaAs/GaAs core-shell structures. First experiments on the transport in these wires are reported.

References:

[1] Y. Ekinci, H.H. Solak, C. Padeste, J. Gobrecht, M. P. Stoikovich, and P.F. Nealey, Microelectronic Engineering 84, 700 (2007).

Figures:



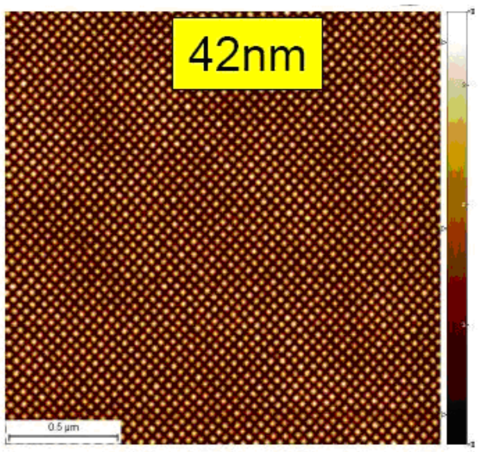
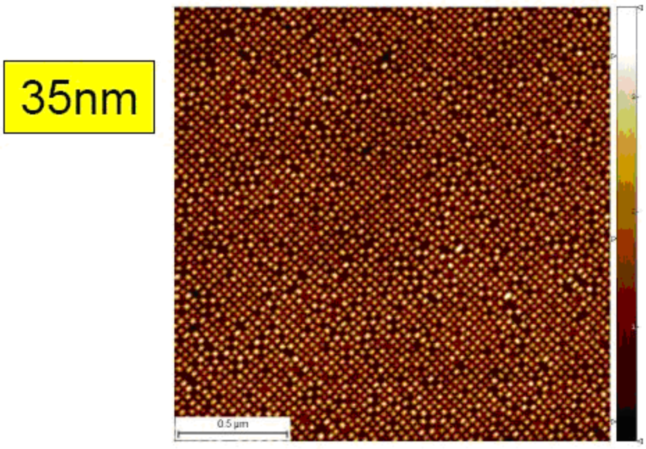


Fig. 1: AFM images of the top surface of Ge/Si quantum dot crystals with lateral periodicities ranging from 49 to 35 nm. MBE growth of Ge dots was performed on templated Si substrates prepatterned by EUV interference ithography.



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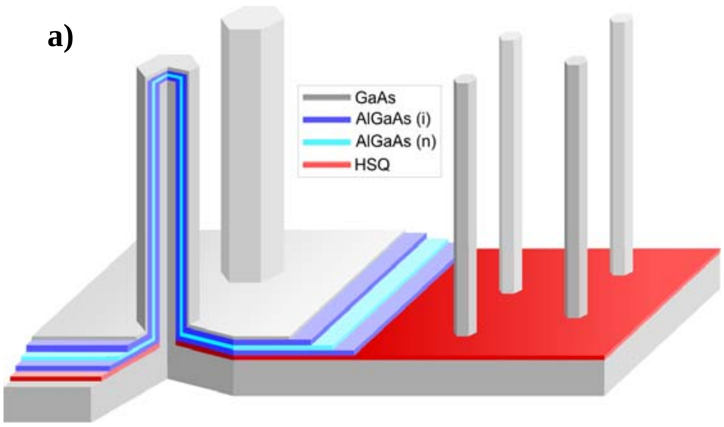

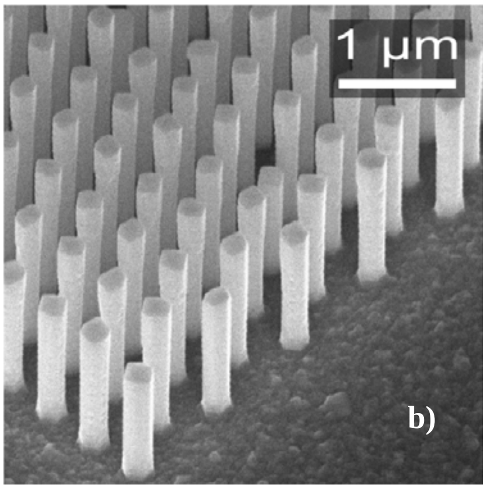

Fig. 2: a) schematic view nad b) SEM image of GaAs/AlGaAs core-shell structures grown by MOVPE on GaAs (111) substrates. The nucleation of the GaAs wires was initiated in small windows opened in a SiO_2 layer at the surface of the GaAs substrate.