UV nanoimprint lithography and mold replication for the site-controlled self-assembly of Si/Ge islands

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The Stranski-Krastanow growth mode provides a method to fabricate nanostructures via strain-driven self-assembly. As this self-assembly is a statistical process, the nanostructures typically nucleate on random positions. However, in the germanium-on-silicon (Ge-on-Si) system it has been demonstrated that the nucleation sites of Si/Ge islands can be controlled by pre-structuring the Si substrate [1], allowing the growth of ordered and addressable Si/Ge islands. For applications relying on addressability, island ordering on chip-sized areas and, thus a fast and inexpensive patterning method suitable for large areas and sub-100 nm structuring is required.

Therefore we introduce UV nanoimprint lithography (UV-NIL) for the pit-pattering of molecular-beam epitaxy (MBE) substrates. Our quartz nanoimprint mold (1" x 1") contains a pillar pattern on four fields, each extending over a continuous area of 3 x 3 mm^2. By a two-fold replication process using the ORMOCER® material from microresist technology GmbH, we fabricate a replica mold (Fig. 1.a.). Imprinting the replica mold into the resist, transfers the pillar pattern to a hole pattern (Fig. 1.b.). Mold replication extends the lifetime of expensive nanoimprint molds and thus is of crucial importance for a cost-efficient application of the imprint technology. In our work, we investigate the influence of the mold replication on the imprint quality and on the quality of the Si/Ge islands grown on the structured templates subsequently.

After the residual resist layer etch, the hole pattern is transferred into the Si substrate by reactive-ion etching. The resulting pits have a depth of 45 nm and a diameter of 200 nm with a period of 400 nm (Fig. 2.a.).

Six monolayers of Ge were deposited at 690 °C by MBE. Atomic force microscopy (AFM) images show extremely well-ordered Si/Ge islands (Fig. 2.b.). For comparison, Fig. 2.c. shows the random and bimodal growth distribution of pyramids and domes on the planar substrate area [2]. Statistics based on 18 AFM images taken evenly distributed on one patterned field show a highly uniform island formation with an apparent height of 8.15 +/- 0.37 nm and a base length of 137.5 +/- 4.0 nm. To the best of our knowledge, these island arrays represent the largest areas so far reported in literature with coherently ordered Si/Ge islands, which are addressable by a second lithographical step.

The homogeneous island growth results in a significant improvement of the photoluminescence (PL) signal (Fig. 3.). The PL emission lines are narrowed and a splitting into two peaks is now observable. In spatially resolved PL experiments, we observe no variation in the PL peak position and line width, revealing a uniform island distribution, which is in accordance to the AFM statistics.

Our results suggest that pit-patterning by UV-NIL opens a cost-efficient route to define high-density Si/Ge island arrays (sub-100 nm period) over large areas with excellent and homogenous properties

[1] Z. Zhong et al., Appl. Phys. Lett. 82, 4779 (2003)
[2] M. Stoffel et al., Appl. Phys. Lett. 83, 2910 (2003)

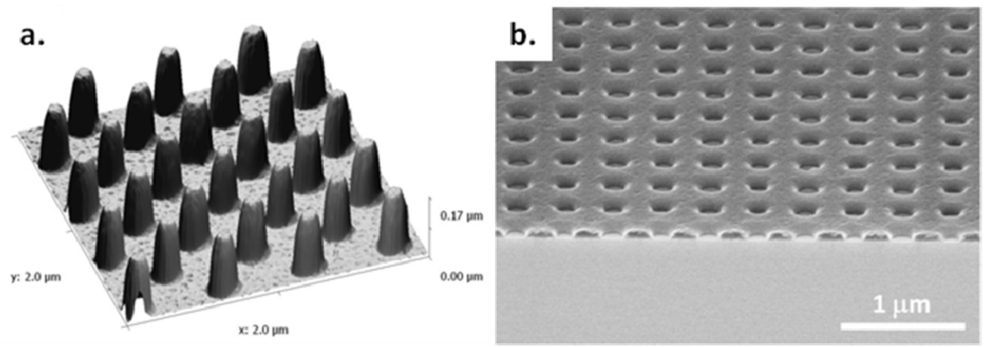

Fig. 1. a. AFM image of replica mold with a pit-period of 400 nm and b. SEM image of the pit-patterned resist after residual layer etch.

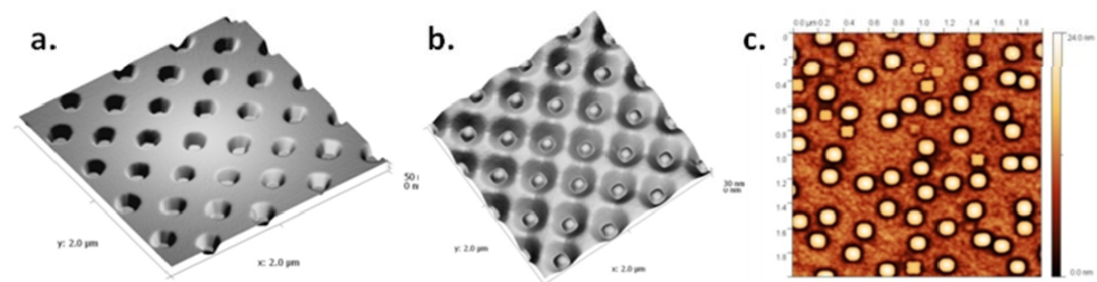

Fig. 2. AFM images of a. a pit-patterned Si substrate with a period of 400 nm and b. Si/Ge islands grown with 6 monolayers of Ge at 690 °C on the pit-patterned Si substrate in a.; c. the planar substrate area, showing pyramids (P) and domes (D).

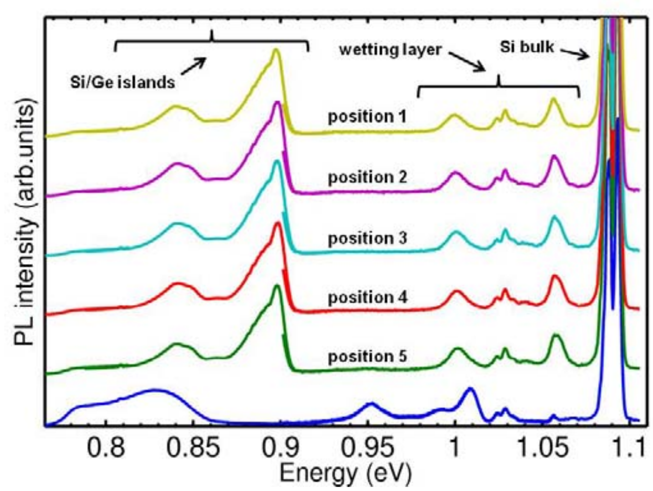

Fig. 3. PL spectra measured at 7 K, an excitation intensity of 20 W/cm^2 and wavelength of 514 nm for Si/Ge islands grown with 6 monolayers of Ge at 690 °C and a pit-period of 400 nm (position 1 - 5) and on the planar substrate area (lowest PL spectrum).