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Templated Growth of Semiconductor Nanostructures through Block Copolymer Lithography

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III-V semiconductor nanostructures have the potential to revolutionize a variety of technologies such as optoelectronics, field emission and high temperature sensing. Presently, it appears that the selective area or templated growth method is perhaps one of the more promising avenues for fabrication of tailored and highly confined semiconductor nanostructures. Templated growth of semiconductor nanostructures, which involves epitaxial growth through a selective mask, allows for precise control over quantum dot size, shape, spacing and uniformity, and could potentially mitigate the nonradiative defects associated with the direct writing techniques [1,2]. Selective growth of III-V semiconductor structures, particularly gallium arsenide and gallium nitride, using a dielectric mask with micron size openings has been extensively reported in the literature. In comparison, there appears to be only few reports on the selective growth of III-V nano-structures inside sub-100 nm SiO_2 windows.

Here, we report on the templated growth of III/V nanostructures inside sub-20 nm SiO_2 windows using molecular beam epitaxy (MBE). The morphology and optoelectronic properties of these samples were characterized by AFM, SEM and high resolution TEM. Cathodoluminescence response will be evaluated. We have used block copolymer (BCP) lithography [3, 4] and reactive ion etching as a nano-patterning route to produce SiO_2 templates. In Figure 1, the principles of ordered nano-porous SiO_2 template preparation through PS-PMMA lithography and reactive ion etching are illustrated. The nanostructured templates are then used to selectively control the MBE growth of heteroepitaxially-grown III/V quantum dots with diameters less than 20nm. AFM and SEM images of templated grown quantum dots (where SiO_2 templates have been removed subsequent to growth) are shown in Figure 2. We use these techniques extensively to characterize nanostructure morphology as a function of different growth parameters, and to further quantify quantum dot size, spacing, uniformity and areal density. The latter two parameters are important metrics for the commercial viability of a templated growth process.

High-resolution TEM is also used extensively to characterize the morphology and defect structure of templated grown quantum dots. Several intriguing and unexpected results are revealed in the HRTEM micrographs shown in Figure 3. First, the quantum dot growth is initiated at the base of etch-pits which have formed below the substrate surface. Second, the quantum dot surfaces begin to facet at thicknesses above ~15 nm, but appear to be roughened below that value. And third, regardless of thickness the quantum dots contain twinned regions near the growth edges. We speculate that these regions may form as part of a deformation mechanism to accommodate local stresses arising during the growth process.

References

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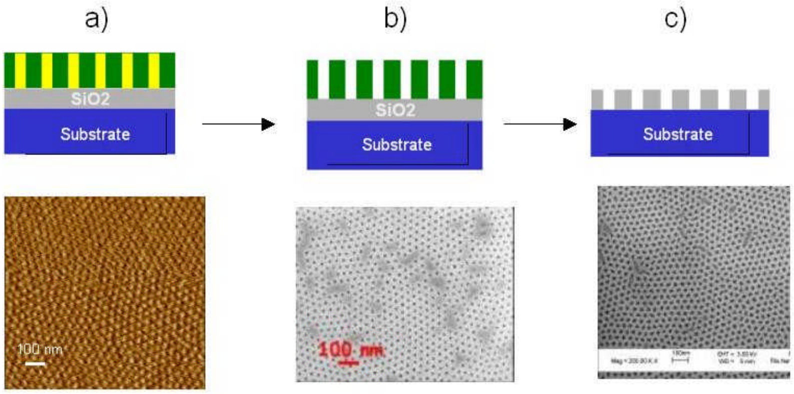

Figure 1. Principles PS-PMMA block copolymer lithography. a) Self-assembly of cylindrical forming PS-PMMA block copolymer thin films. b) Selective removal of PMMA domain. c) Reactive ion etching and pattern transfer into the oxide.

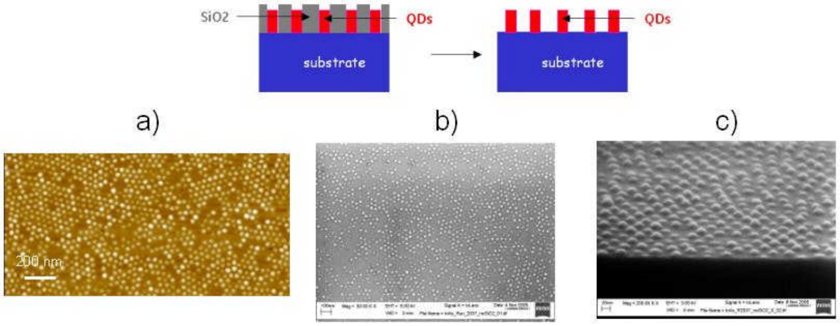

Figure 2. Selective area growth of III/V quantum dots; AFM and SEM images were obtained subsequent to oxide removal.

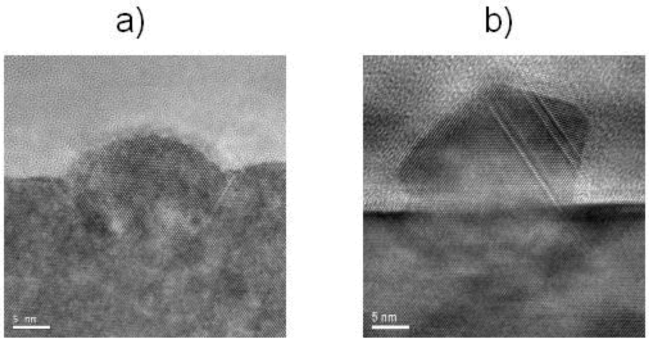

Figure 3. HRTEM images of III/V quantum dots at varying growth time conditions. Twinned regions are clearly observed a) at the dot edges and b) in the upper right corner of the dot.