

Block Copolymer Lithography

– A Novel High-Resolution Approach to Growing Exceedingly Thin Nanowires

Herein we describe how the frontiers of resolution and pattern density of nanoscale features can be pushed beyond the limits of conventional fabrication techniques. We demonstrate how large-scale arrays of very thin semiconductor nanowires (NWs) can be implemented in a quick and cost-effective way by using an emerging method called block copolymer (BCP) lithography. This enables the fabrication of e.g. the next generation of high-performance transistors but can also cut the cost of producing high-efficiency solar cells.

In this MSc thesis a method of fabricating large arrays of sub-20 nm NWs, i.e. large areas with regularly spaced long thin pillars with diameters <20 nm, was developed. Key is harnessing the potential of molecular self-assembly i.e. the ability of certain molecules to spontaneously form organized 3D structures.

Here, the molecule in question is a *block copolymer* – a ‘long’ chain-like molecule composed of two types of smaller repeating units linked together in a structure reminiscent of a pearl bead necklace. The repeating units are arranged into two separate blocks e.g. block ‘A’ and ‘B’, see Figure 1 a).

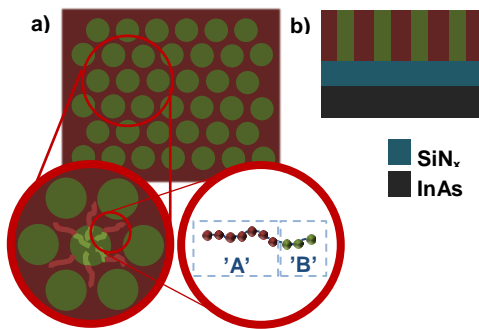


Figure 1: a) Schematic molecular structure of the BCP and a top-view of the self-assembled pattern it forms. b) A cross-sectional view of the BCP film showing cylinders oriented perpendicular to the SiNx/InAs substrate.

The blocks do not like mix, analogous to oil and water, and this is fundamental to the self-assembly process. In a heated polymer sample, containing countless BCP chains, the molecules will spontaneously rearrange themselves in such a way that block ‘A’ (and ‘B’ respectively) from different chains will nestle together to form a separate *phase*. However, unlike a mixture of oil and water that consists of different types of molecules that simply can separate into two layers the blocks cannot since they are linked together with a strong chemical bond that prevents this type of large-scale phase-separation. Instead a compromise is struck where blocks from neighbouring chains form separate but identical nm-sized domains. Zooming out we see that all the BCP chains will have arranged themselves in this way, generating a highly organized repeating pattern.

The exact nature of the pattern depends on the volume ratio between the blocks in the BCP chain. The BCP used in this project spontaneously adopts a pattern consisting of densely packed cylinders, composed of only blocks of type ‘B’, in a surrounding consisting of the ‘A’ blocks, see Figure 2 Figure 1.

If the polymer is applied to a substrate (i.e. a hard surface) this pattern can be used in creating other features of similar size. As the pattern will self-assemble, the size of the features can be made far smaller (<10 nm), denser and quicker than otherwise possible with conventional techniques.

Here, the BCP film was applied on top of a *silicon nitride* (SiNx) layer which in-turn rested on an *indium arsenide* (InAs) surface, see Figure 1 b). The BCP pattern was transferred into the SiNx-layer and ultimately used as a template for depositing an identical array of gold particles onto the exposed InAs, see Figure 2 a) and b).

The purpose of the gold particles was to act as seeds/catalysts during the growth of the NWs i.e. NWs will only grow on the spot where a gold particle is located. The properties of BCP and its processing hence dictate the diameter, spacing and location of the final NWs.

The controlled process of growing crystalline semiconductor structures on a crystal surface (the exposed InAs here) is referred to as *epitaxy*.

The novelty in this work is the definition and fabrication of the array of gold seeds. Our method can achieve higher resolution, pattern density and cost-effectiveness than the lithography techniques used presently by industry.

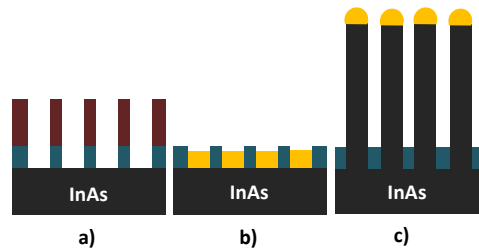


Figure 2: a) After selective removal of the cylinder-forming blocks of the BCP and pattern-transfer into the underlying SiNx-layer. b) After complete polymer removal and gold deposition. c) After epitaxial growth of InAs NWs using the gold particles as catalytic ‘seeds’.