Nanoimprint Lithography for Molecular-Motor-Based Devices

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Molecular motors are large biomolecules that act as mechanical machines. They are found within each of our cells. Molecular motors can be extracted from cells and integrated engineered surfaces [1]. These surfaces are for example being pursued as a future computation technology that may be able to solve important mathematical problems that cannot be solved with the technology available today [2]. To enable future large scale fabrication of these surfaces, a fabrication method with high throughput is needed. Therefore, a technique called nanoimprint lithography, which is fast and cost effective, has been tested in this project, as a replacement for previously used fabrication methods.

Within cells, molecular motors are needed for transportation of material. This ability can be utilized for carrying out new tasks outside the cell. They operate at a scale of a few tens of nanometers, which is why the structures in the devices are around this order of size as well. To host and control molecular motors, topologically and chemically patterned surfaces, are used. [3]

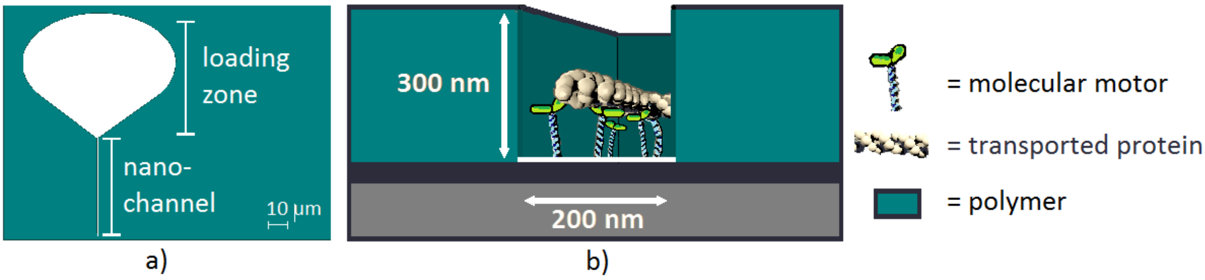

Figure 1: Illustration of the structures of a molecular-motor-integrated surface. a) Top view of a loading zone, leading to a nanochannel. b) Cross section of a nanochannel with polymer walls and molecular motors attached to its floor. The figure also illustrates a protein being transported by the molecular motors.

Selected structures of this type of device was fabricated to test NIL. The pattern included 80 μm wide structures called loading zones and 200 nm wide nanochannels, illustrated in Figure 1a). The loadingzones and nanochannels are structures with walls and floors, but no roofs. The floors of the structures are covered with attached molecular motors. The molecular motors can interact with a specific type of protein, if they come in direct contact with each other, and will push these proteins around. This is illustrated in Figure 1b). These proteins are added at the loadingzones, and are from there guided into the nanochannels.

The patterning of this type of surfaces has previously been conducted by a technique called electron beam lithography (EBL). [3] However, in this project another fabrication method called nanoimprint lithography (NIL), has been tested. The two techniques can be compared to the example of putting down your signature by using a pen (EBL) or by using a stamp (NIL). With EBL, the electron beam sweeps across the substrate surface (as a pen) to define a pattern. [4] The surface is made of a polymer (a plastic) which is sensitive to the bombardment of electrons, which makes it possible to remove polymer at desired locations. In NIL, a nanopatterned stamp is instead pressed into a ductile polymer which conforms to its relief. [5] In contrast to the example with the signature, both EBL and NIL results in a topological pattern. [4][5] Making a NIL-stamp is rather time consuming and is not very practical if the aim is to make one device. However, to fabricate a thousand copies, a stamp is much more time efficient to use. [5]. The purpose of using NIL is thus to open up for future large scale fabrication of molecular-motor-based devices.

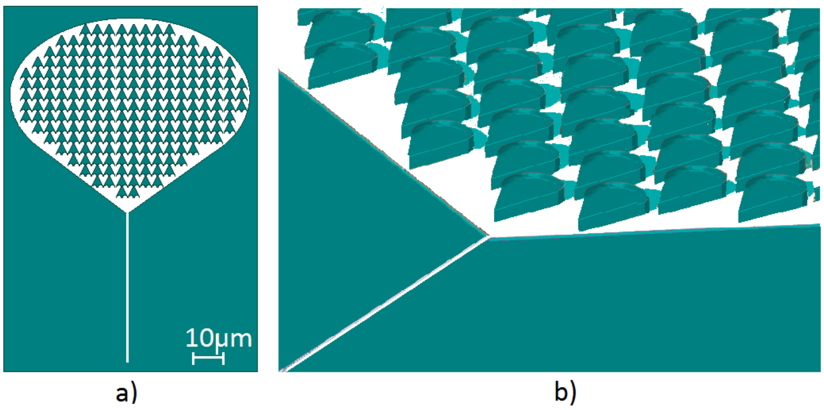

Figure 2: Illustration of patterned loading zones. a) Top view of a patterned loadingzone b) Illustration showing the topography of a patterned loading zone (not to scale).

The pattern to be imprinted with NIL, contained structures with a size difference of a factor 400. This causes no problem with EBL [4], in which the indents in the surface are created by removing polymer where needed. In NIL, the polymer is instead dislocated by the stamp. To make large indents, a lot of polymer needs to be dislocated, compared to smaller indents. The difference in how much, and how far, the polymer needs to be displaced, causes unwanted accumulations of material at certain points. Due to this, the imprint is likely to become uneven. Some structures of the pattern might even be completely missing at large structure-size differences. [5] Therefore this issue had to be addressed, which was done by modifying the design of the loading zones.

The modification consisted of adding structures into the open space, as illustrated in Figure 2 a) and b). Many different patterns were made and the loading behavior of proteins for differently patterned loading zones was simulated in Matlab by a collaborator, Till Korten (TU Dresden). The simulations showed that by varying the pattern, the loading speed could greatly be varied as well, in addition to making NIL possible. This ability to customize the loading speed, was an important result, which can be useful in future device designs.

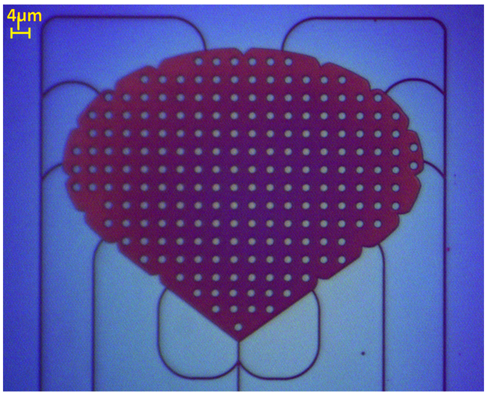

Figure 3: Image of a patterned, loading zone imprinted in TU7. The blue areas are TU7, while the darker areas show the underlying material.

A polymer called TU7, which is compatible with NIL, was evaluated in material tests to determine if it was suitable to use in this application. This was to find a replacement to the previously used polymer which is adapted for EBL. TU7 was confirmed to be compatible with the biomolecules used. Thus, the imprints were made in TU7. The microscope images of the imprinted structures, showed well resolved loading zones and nanochannels, as can be seen an example of in Figure 3.

Thus, this work has supported the possibility to use NIL in the fabrication of this type of molecular-motor-based devices.

References

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