POLYMERIC SYSTEMS FOR BIOMEDICAL APPLICATIONS USING NANOIMPRINT LITHOGRAPHY

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Polymers show themselves to be excellent candidates for the production of biomedical devices incorporating nanometric systems. Low fabrication costs, fast design realisation times, and, importantly, biocompatibility, are advantages that can be plundered by scientists for the production of such devices. Here, we present the patterning of polymer surfaces with nanometric structures using a nanoimprint lithography (NIL) replication technique, for use in the development of such biomedical systems. We have compared the properties of a number of commercially available polymers with a view to investigating their applicability to nanoimprint lithography.

Fabrication of the polymeric nanostructures has been accomplished using two techniques; via thin film deposition of a polymer on a suitable substrate, and via the use of a freestanding polymer film. The first NIL process involves spinning a layer of polymer from solution, onto a silicon nitride (Si_3N_4)-based substrate, using a spinner operating at approximately 6000 rpm. To imprint the polymer, the coated substrate is placed in the NIL apparatus, in contact with a patterned master stamp fabricated from the same material as the substrate (Figure 1*a*). This technique allows extremely thin films of polymer (down to tens of nanometers) to be imprinted. In the second technique, a thin piece (~100 μm thick) of freestanding polymer sheeting is sandwiched between the master and a second piece of the same material, within the nanoimprint apparatus (Figure 1*b*). The advantage of the second technique is the ability to produce a freestanding polymer containing the nanoimprinted structures that is entirely transparent, a benefit for biomedical applications.

During the nanoimprinting, in each case, the entirety is heated at a temperature above that of the polymer's glass transition temperature before pressure is applied, which forces the master into the softened polymer. After a predetermined time, the system is cooled to below that of T_g and the pressure removed. The temperature is finally allowed to return to ambient temperature and the master and the polymer are separated (Figure 1).

The masters have been fabricated by *directly milling* 1 cm^2 Si_3N_4-coated silicon wafer pieces using focused ion beam (FIB) milling apparatus [1]. The FIB uses a beam of Gallium ions to mill the substrate surface, precluding the need for any resist materials normally required for other forms of lithography. Arrays of simple structures are milled in a matter of minutes using ion doses of between 10 and 300pA. Masters with more complex or deeper structures require increased milling times, or higher ion doses. The Si_3N_4 on the master acts as an effective anti-sticking layer for the NIL process, prolonging the lifetime of the master.

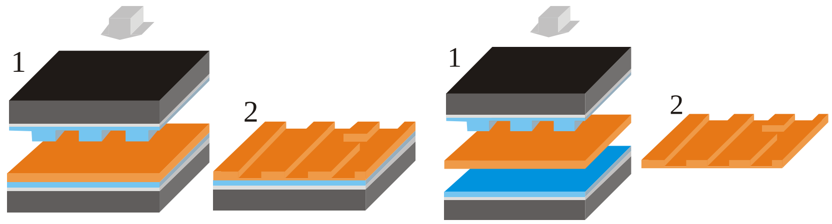
The advantages of nanoimprint lithographic pattern replication techniques using polymers include the parallel nature and potentially high throughput of the process [2]. Structures such as those presented in figures 2 and 3, nanoimprinted in poly(methyl metacrylate) (PMMA) with dimensions of 100 nm, can be easily reproduced using the spun down polymer technique, and structures such as those produced in figure 4, nanoimprinted in poly(ethylene naphthalate) with a range of dimensions, can be reproduced using the freestanding polymer technique. Consequently, if structures such as these can be replicated in biocompatible polymers, they can subsequently be used for biomedical applications.

References:

[1] Strata 235 Dual Beam FIB apparatus produced by the FEI Company, USA

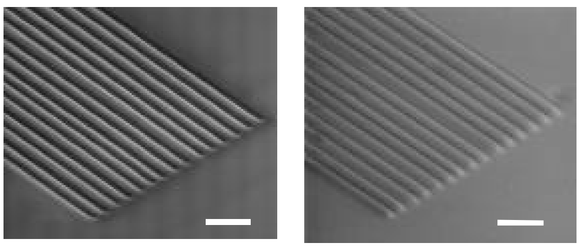
[2] J. Samitier, A. Errachid, G. Gomila, *Encyclopedia of nanoscience and nanotechnology*, ed. H. Nawala (California: American Scientific Publishers), 2003, Volume X, 1-21.

Figures:



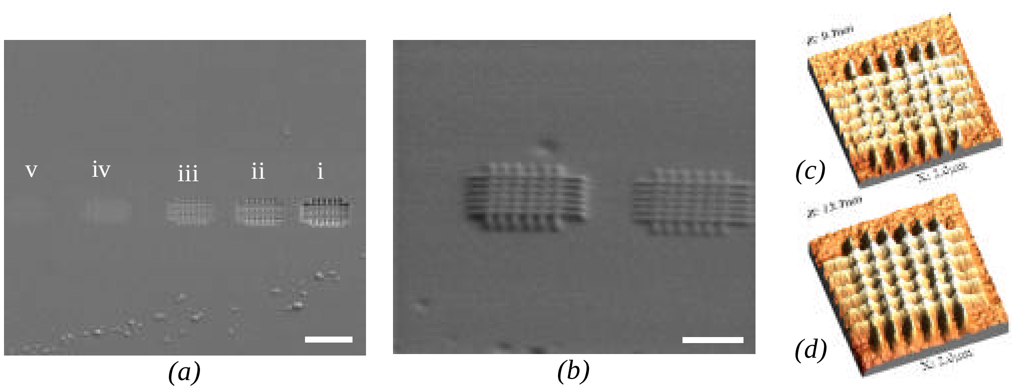
(a) *(b)*

Figure 1. Nanoimprint lithography techniques using, (*a*) polymer spin cast from solution onto a Si_3N_4 substrate and (*b*) using a freestanding polymer sheet (~100 µm thick). In (*a*) the polymer is imprinted using a Si_3N_4 master containing the nanostructures (1) to pattern the polymer on the substrate (2). In (*b*) the polymer sheet is sandwiched between the master and a second piece of master material for the imprinting (1) to produce a freestanding patterned polymer (2).



(a) *(b)*

Figure 2. Scanning electron microscopy (SEM) images of (a) a Si_3N_4 master for nanoimprint lithography containing lines milled using the FIB: dimensions of 30 µm long (not fully imaged), 100 nm wide, 100 nm deep and 400 nm period [bar = 1 µm]. (b) A nanoimprint replica of the lines in (PMMA) polymer spun down onto a Si_3N_4 substrate [bar = 1 µm].



(a) *(b)*

Figure 3. SEM images of (*a*) a Si_3N_4 master for nanoimprint lithography containing grids of lines milled using the FIB, with dimensions of 100 nm wide and 200 nm period and with depths of (i) 100, (ii) 50, (iii) 30, (iv) 10, and (v) 5 nm [bar = 2 µm], and (*b*) a nanoimprint replica of the 100 nm and 50 nm deep structures in PMMA [bar = 1 µm]. Atomic force microscopy images of the 10 nm and 5 nm deep structures replicated in PMMA are presented in (*c*) and (*d*) respectively.

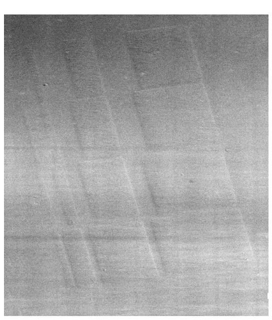


Figure 4. SEM image of rectangular structures nanoimprinted into a freestanding film of PEN using the second fabrication technique. The structures dimensions decrease from 20 µm x 20 µm to 20 µm x 200 nm, with heights of approximately 20 nm [bar = 20 µm]. The structures can simply be viewed using a standard optical microscope at high resolution due to the polymer transparency.