# Mass production of nanostructures

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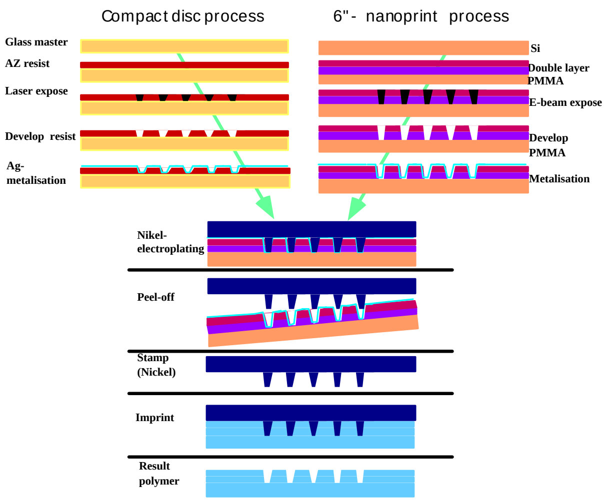
A Compact Disc manufacturing process has been used to produce nanometer-sized structures. In this paper, different process steps are studied and discussed. Stamp fabrication and CD-replication process are described in detail. In this work, 50-polycarbonate discs were replicated from one 6-inch nickel stamp with structures as small as 50nm and the result is analysed. We also show the possibility to replicate 50nm wide structures over large areas.

## Introduction:

Quantum devices whose performance is influenced by the materials being structured in the nanometer-scale e.g. single-electron devices, are promising for the coming electronic generations. Developments of nanofabrication technologies are essential for production of such nano-devices. In practice extreme e-beam lithography as well as AFM-based methods for manipulation of nano-particles[1] have made it possible to fabricate structures and patterns with dimensions down to some few nanometers. However, those techniques are working in a serial manner preventing these nano lithographies to be applied for mass fabrication of devices. However, nanoimprint lithography[2], (NIL) has the inherent potential to be a promising candidate for fabrication of such nanodevices in parallel[3] [4]. Here, a stamp patterned with a serial lithography technique, most often e-beam lithography, can be utilised for replications in a stamp-print approach' quite similar to the compact-disc (CD) manufacturing process. The CD production technique was introduced 1975, having shown it's excellent mass production capability. CD production has a total (worst case) yield better then 67% in the full area of each 6" compact disc being produced.

In this paper we will study the capability of existing CD-production technology for nanoimprint process by employing equipment and processes already used in the CD-manufacturing line. However the patterns on the stamp are defined by E-beam lithography in order to make stamp structures in the nanometer scale.




## Background to CD-production basic technique

The first step is to make a master. The master is a flat plate, on which the desired pattern is to be defined by a serial technique. The master is most commonly made from a glass plate with a diameter of 250mm and a thickness of about 10mm. The glass master is usually coated with 1000Å thick AZ-resist. A laser beam exposes the resist from the centre to the edge of the disc in a spirally formed track. The wanted pattern with structures having a forward leaning profile will be obtain after development of the resist. The track widths are about 600nm for CD and 400nm for DVD whereas the lengths of the pits depend on the recorded data. The master will then be coated with a 100nm thick silver layer by thermal evaporation. Now, the master is ready to

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be used in a galvanic process in order to grow a 300 µm thick nickel stamp. After the galvanic process the nickel "stamp", known as the "father", is peeled off the glass master. Then the backside of the stamp is polished in order to remove rough grains. The father can now either be mounted in a molding equipment for replication into polycarbonate discs, or can also be employed in a second galvanic process for making new copies of the stamp, so called "mothers". In this way, each mother can be used for an additional galvanic replication step whereby "sons" are created. From a metal base stamp can at least five new metal plates be produced without any deviation using galvanic replication. This means that the cost for making stamps is close to the cost for making the initial master, since any later defined copies are only non-expensive galvanic replications.

The next step in the CD-production line is to do either injection molding or injection compression. Those methods are both based on injection of melted polymer e.g. 250°C warm polycarbonate, into a cavity where the stamp is mounted on one side. In injection molding the melted polymer will be injected with high pressure into the cavity and in the injection compression method the melted polymer is first applied into the cavity and then compressed mechanically. The applied pressure is about 260 bar. After cooling to 60°C the polycarbonate disc is coated with a thin evaporated aluminium layer. This layer is used as the reflecting layer for the laser light reader in the CD-player.

The polycarbonate discs made with the injection molding method have more homogeneous thickness and the error rate is smaller than disc produced with the injection compression molding process.

## Experimental details: our approach

As a starting material we used a 6-inch silicon wafer. After a cleaning procedure, the sample was spin-coated by a double-layer resist. To obtain a forward-leaning profile of the patterned structures, 150nm high-molecular weight PMMA (950K) was spun on the substrate and then hard baked in 180°C for 60 minutes. Thereafter, 150nm low-molecular weight PMMA (200K) was spun on the first layer and baked in 180°C for another 60 minutes. The resulting thickness of the resist was approximately 300nm, as measured by atomic force microscope (AFM).

Electron beam exposure was performed in a commercial scanning electron microscope (SEM), equipped with a pattern generator and a beam blanker. The accelerating voltage and the electron probe current were 35 kV and 100pA respectively. The double layer PMMA was developed at 20°C in a 1:3 mixture of methylisobutylketone and isopropanol for 60 seconds. The test pattern consisted of 50 and 100nm lines and 50nm dots in 100µm by 100µm areas.

This e-beam defined "master" was then was coated with a 50nm thick silver layer by thermal evaporation The silver layer served as the cathode in the subsequent galvanic process where a nickel-father was made. Thickness measurement showed that the fabricated 6-inch nickel stamp was 250µm thick. The nickel stamp was then used to fabricate polycarbonate discs in a injection compression equipment.

## Result and discussion

In total about 50 polycarbonate discs were produced using the nickel-father as the stamp. Optical measurement methods revealed that all discs showed good pattern transfer. We have chosen randomly one of the polycarbonate discs for a more detailed study using SEM.

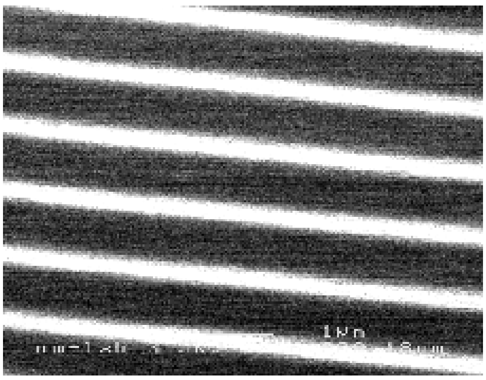

Figure 1: 100nm lines in Double layer PMMA resist

Figure 2:50nm thick Silver coated PMMA

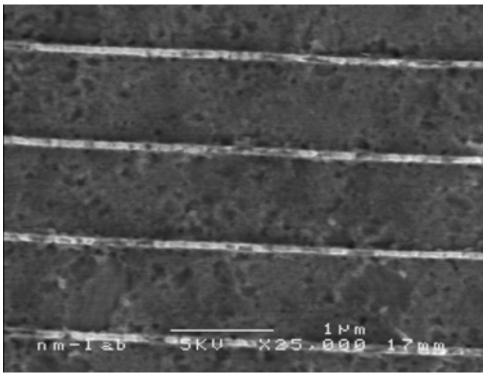


Figure 3: 100-nm lines on the nickel stamp.

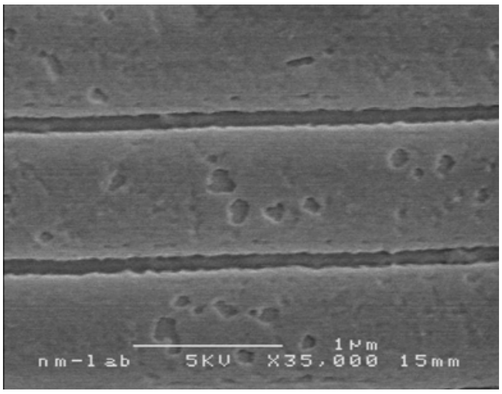


Figure 4: Imprinted polycarbonate

In figure 1 is displayed the 100nm lines in the double layer resist, looking top down onto the lines with the SEM. As can be seen, the lines definition is quite good. After thermal silver evaporation the surface does not like that good (see figure 2). There is a large granularity found and there is lot of large features between the lines. However, although having that kind of bad surface for the galvanic "sead"-layer the galvanically defined nickel stamp (figure 3) did show a quite nice and smooth surface. Then after fabrication of the polycarbonate disc the line definition in the plastic is good (see fig. 4). By comparing the lines in figure 3 and 4 that are from identical locations on the stamp and replica, one can conclude that the line transfer is very good.

The patterns in the different locations on the 6" nickel stamp were compared with the polycarbonate disc. It showed that all structures were copied into polycarbonate disc and no loss of structures were observed. We observed at some locations small defects between the lines on both the nickel stamp and the polycarbonate discs. These small defects were of similar size as was fond on the silver-coated PMMA after evaporation (see fig. 2, 3 and 4).

In order to study the molding process and pattern transfer ability, we have chosen an area on the stamp to examine in high resolution and we found exactly the same area on the polycarbonate discs. This is shown in figure 5 and 6.

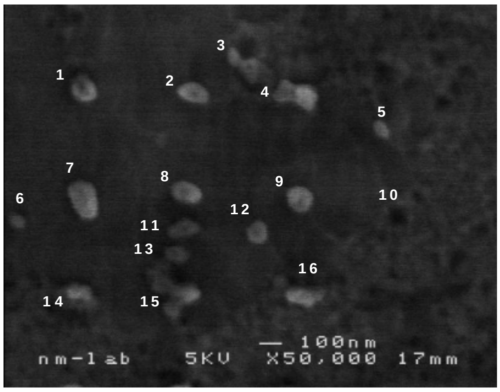


Figure 5: Dots in the nickel stamp

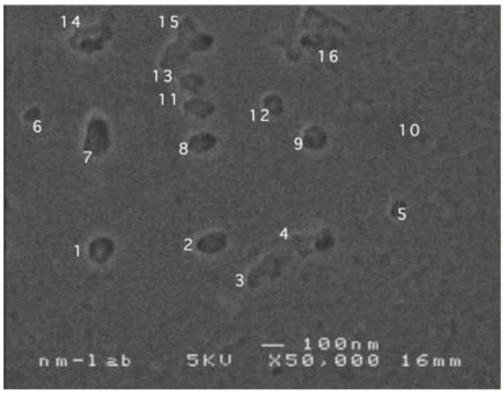


Figure 6: Imprinted dots in the polycarbonate disc

The dots have been numbered to make the comparison. As can be seen from fig. 6, the defects in the nickel stamp are also transferred to the polycarbonate disc. The dot 1 in the nickel stamp (fig. 5) contains a small hole, clearly visible as a small dot also in the hole at location 1 in the polycarbonate (fig. 6). Compare as well the defect no. 6, which is approximately 50nm in diameter for both the nickel stamp and the polycarbonate disc (fig. 5 and 6).

The conclusion from this study is that it is possible to replicate fairly small features, (<50nm), on large scale using CD-fabrication technology. The limitations found in this study is obviously coming from the formation of the metal sead layer. This can be concludes by comparing the surface of the PMMA after development with the some surface after silver evaporation, see figure 1 and 2 respectively. An AFM investigation of the thermally evaporated silver layer revealed that the surface was unacceptably rough. This rough surface negatively effects the structures with the small line width. This will be the main limitation for using CD technology directly when the structure size is reduced to a few nano meters in size.

Generally metal particle size found on the evaporated layers depends on the kind of metal as well as the coating method. In order to compare coatings methods, we coated two substrates, one with 40-nm thick thermal evaporated silver and another with 30 to 40-nm thick sputtered nickel layer. AFM studies shows that the nickel-coated surface has a finer surface structure as compared to the silver-coated surface.

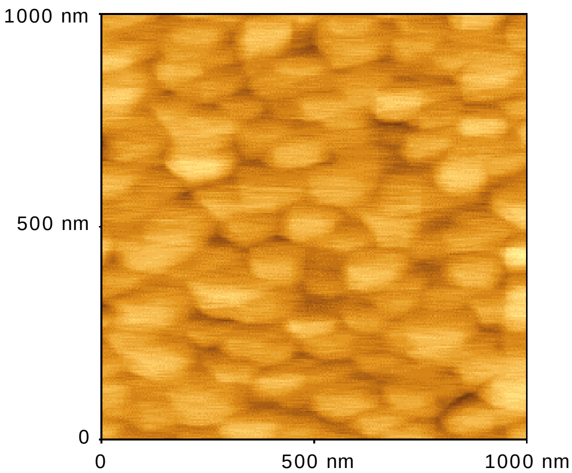

Figure 7: Thermally evaporated Ag on Si

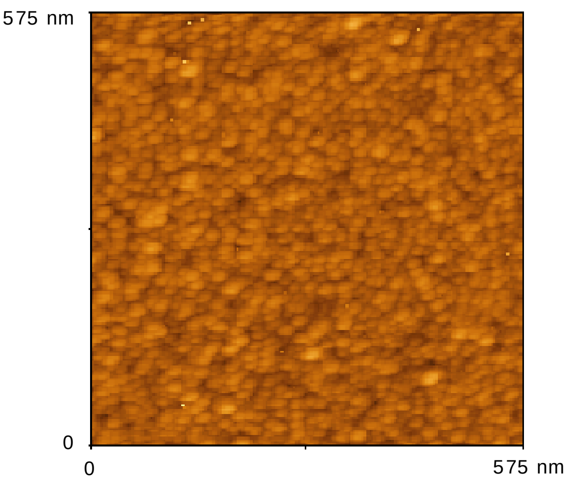

Figure 8: Sputterd Ni on Si

## Conclusions

This work has clearly shown the possibility to replicate nano structures using compact disc technology. Furthermore, we have identified that the most critical step for having a successful pattern transfer at the nanoscale using CD-technology is the metallization stage when defining the stamp. The reason being that a smooth sead layer for the galvanic process is needed in order to fabricate stamps with resolutions in the nanometer scale. Here, we showed that a sputtered nickel surface is much smoother, having a finer structure than a thermally eveporated one. Stamp production flexibility assesses generation of multiple stamps with same resolution. The CD-production background demonstrates the dimensional stability during long-term use of single stamp.
This article has reviewed many of the considerations when implementing CD-process for nano-structure production. It is evident that this technology is an effective low coast mass production technique with a capability for production of structures smaller then 50nm over as large as 6-in areas. This means that Nanoimprint processes being applied for 6-in semiconductor technology hold great promise and might very soon be available.

## Reference:

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