Abstract

For the last few years giant strides have been made in the area of nanoscience. These strides will have a tremendous impact on many different areas such as drug-sensing, IC-industry and medicinal applications. Surface enhanced Raman spectroscopy is one aspect of this, were the signal from Raman scattering can be increased many times over. This is done by creating small structures in a material and coating it in a metal. During this work a chip was created using nano-imprint lithography techniques for the creation of nanostructures on a PET wafer. Physical vapor deposition was then used to apply a metal to these structures. Finally 3D-printing was used to integrate this wafer into a chip. Both the chip and the wafers were then tested using fluorescence and Raman spectroscopy. Mean signal to noise ratios as high as 557 were observed for 50 nm Ag on top of 50 nm pillars. The study thus show promising results in using these relatively cheap methods to build small highly sensitive and selective chips for use in the detection of trace amounts of molecules.
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1 Introduction

Surface Enhanced Raman Spectroscopy (SERS) is used in different areas of molecule detection were low concentrations of a substance could be found in a large sample. Previous research has found that nanostructures can enhance the signal further making it possible to detect even single molecules.

The main purpose of this thesis was to construct and optimize a bio-sensing device in the tone of such research as [1, 2, 3, 4]. To this end, nanoimprinting lithography, Chemical Vapor Deposition and 3D-printing methods were used. Patterning at the nano-scale is a field with wide ranging applications, from sensors to catalysts. Being able to make exact patterns at this scale would contribute vastly to the current research going on not only in the field of physics, but also chemistry and medicine. With that said, making strides in this area when it comes to reproducibility, scalability and cost would generate many spin off effects.

2 Theory

2.1 NanoImprint Lithography (NIL)

The general idea of nanoimprinting is to create patterns on the nanometer-scale on a resist. For NIL this is done by mechanically deforming the substrate. For the process one needs a mold/template with a predefined relief and a substrate. The substrate must have a lower glass transition temperature than the mold. The procedure is quite simple, first the substrate is heated above the glass transition temperature, then put into contact with the template under a certain pressure and thus gets deformed by the template. The substrate (usually some sort of polymer), now should have the desired pattern [5]. A schematic of the process is shown in fig 1.

![Figure 1](image-url)

Figure 1 – A overview of the nanoimprinting process were the resist gets the pattern from a mold

Its high throughput and high resolution makes it a reliable method for patterning on the nano-scale this, in combination with a relatively low cost, makes it truly interesting [6].
2.1.1 PolyEthylene Therephthalate (PET)

Polyethylene Therephthalate, more commonly known as PET, is a cheap common material that is used during among other things in experiments. With its glass transition temperature between 67 and 81 °C well above that of room temperature and a melting temperature of around 260°C it is well suited for experiments of this kind[7]. During this experiment PET will be used throughout.

2.1.2 PolyMethyl MethAcrylate (PMMA)

PMMA is classified as glass and is more commonly known as Plexiglas or acrylic. It has a glass transition temperature from 85 to 165°C. For atactic PMMA it is about 105°C. The durability together with its higher than room temperature glass-transition temperature is why it was used for previous experiments[7, 8].

2.2 Physical Vapor Deposition (PVD)

PVD is a technique to put a thin layer of film on a substrate. There are different methods for this but the one used for this experiment was evaporation. The rates at which the materials "grow" on the target varies with the metal but can be as high as in the hundreds of Ångströms per second [9]. Higher rates mean a less uniform distribution making it preferential to have a low rate. During the deposition, impurities will be added to the film, mainly due to the vaporisation of the boat but, this will usually be small amounts. To decrease the impurities introduced the evaporation will be done in high vacuum also allowing for an approximation that the evaporated material flies in a straight line.

2.3 3D-printing

3D-printing is a method were a structure is built by adding layers upon layers. It is thus a bottom-up approach of manufacturing. Most usually, the material used, is plastic but metals are also used. 3D-printing is usually used when plastic is used and additive manufacturing is more of an umbrella term. The technique can be used in the manufacturing industry as a part of the regular process or as a fast way of producing prototypes. Studies have shown that the weight of certain bearing structures can be made lighter by using these techniques, this comes from the fact that nonbearing inner parts can be taken away instead of having a solid piece. This is said to have a tremendous impact on industries such as aeroplane design and fast prototyping. In aeroplanes the structures needs to be as light as possible while still being flexible and strong. Using a computer to optimize this gives a structure with a lot of holes in it, the famous honeycomb structure. What’s hard to do using regular manufacturing techniques is a honeycomb structure with the sizes and orientations shifting throughout the structure. With 3d-printing methods this is possible to do [10]. The recent news regarding 3D-printed houses puts the spotlight back on this report[11]. In this report the possibility of using lunar soil as material in a 3D-printer to establish a colony there is studied. When it comes to actually 3D-printing things first a model is drawn using for example a CAD program. This is then sent into
the 3D-printer that using a program called a "slicer" that creates thin layers that in turn can be produced by the printer. The slicer program also generates G-code that is a set of instruction to the printer on how to create the object wanted. The ability for a 3D-printer to construct objects from pretty much the desktop of the inventor gives it a versatility that is hard to beat.

2.3.1 Bio-applications

Using 3D-printing in bio-applications has been studied to both restore function to organs or make new ones altogether[12, 13]. The first attempts at 3D-printing using biological materials was done using regular 2D-printers with just a simple change of what was in the ink cartridge, from ink to biological material. Nowadays, of course, a biological 3D-printer is a specialized piece of machinery optimized for the task of printing biological material[13]. As seems to be the case for all technologies, not surprisingly, the easiest way is to go through 2D over into 3D. This seems to be the case here as well since researchers predict that in the near future skin grafts using 3D-printing should be viable while more complex organs are in the distant future[13].

2.4 Microfluidics

Microfluidics is the science of controlling fluids in the range of $10^{-6}$L and less. These small volumes allows for less material to be used e.g reagents blood, saliva etc. Making it possible to make more experiments in case these are expensive to do or reagents hard to come by. The study of microfluidics in conjunction with nanoscience to form devices requiring small amounts of reagents is a fast emerging field. This combination can be used in different sensor applications and as in situ point of diagnosis care.

In microfluidics the flow can be described by Reynolds number which is given as

$$Re = \frac{Lv_{avg}\rho}{\mu}.$$ (1)

With L being the length of the channel $\mu$ is the viscosity of the fluid $\rho$ the density and $v_{avg}$ is the average flow velocity. In microfluidics this usually gives a small Reynolds number which means laminar flow. Laminar flow is predictable making it possible to predict the fluid flow. Using this fact one could in principle quite easily determine how any fluid behaves in a small chip. An aspect of this is that when it comes to mixing it would be needed to add something that creates turbulence. This could be done by making the fluid go through something that disrupts the flow some kind of "forest".

2.5 Metal Enhanced Fluorescence (MEF)

MEF is a process wherein the fluorescence is enhanced by nearby metal particles. The metal particles act like optical antennas which increases the rate of fluorescence. If a few free electrons (plasmons) are considered, they will due to an external field be made to oscillate coherently. This effect is called Localised Surface Plasmon Resonance
(LSPR). At hotspots the enhancement can be hundredfold [14] using nano-structures of silver. Hotspots are where the EM field interferes coherently, this happens when the nano-structures are in close proximity to each other. Nano-structures of different shapes enhances the fluorescence more or less with different thicknesses of the layer also playing a part [14].

2.6 Surface Enhanced Raman Scattering (SERS)

Raman scattering is scattering of light where the scattered light has a wavelength different from the incoming. This effect is due to the excitation of the materials ro-vibrational states, after a short while a photon will be sent out with either a lower (Stokes) or higher (anti-Stokes) energy. The process for this can be seen schematically in fig 2.

![Figure 2](https://via.placeholder.com/150)

**Figure 2** – Raman scattering in an energy diagram were the molecule is excited to a virtual vibrational state and then sends out a photon

Stokes Raman scattering is much more common than anti-Stokes since for anti-Stokes the material needs to be in a higher energy state. Fluorescence and Raman scattering is tightly connected but, should not be confused as the same thing. Raman scattering is different from fluorescence in that it is a scattering whereas in fluorescence, the photon is completely adsorbed. The time scales for the two are also widely different, almost instantaneous in the case of Raman, as opposed to nanoseconds, in the case of fluorescence. SERS is a spectroscopic method that uses Raman scattering, that is in turn enhanced by metallic and/or nanostructures (LSPR). In the extreme cases the enhancement can be as much as $10^{15}$, the incredible enhancement could allow for single molecule detection [1] [15] [16] [17]. This technique thus intrigues the medicinal community, as it can be applied to point of care diagnosis systems. What it gives in enhancement factor has to be paid in reproducibility though the largest enhancement factors only occur at certain
"hot-spots", since this is of lesser importance a good overall enhancement factor is more important [15, 16, 17]. The scattering cross section of Raman spectroscopy is in the order of $10^{-30} \text{cm}^{-1}$ and for fluorescence about $10^{-15} \text{cm}^{-1}$. These can be seen as probabilities that a scattering will occur. As mentioned previously SERS could increase the intensity with a factor of about $10^{15}$ which is enough to make Raman and fluorescence comparable in terms of probabilities. The main reason for using SERS instead of fluorescence is that the sample needs less preparation using SERS.

2.7 Signal to Noise Ratio (SNR)

SNR is a tool used in many different applications, with different ways of calculating it for each. In spectroscopy it is a measurement tool for how accurate and precise a method is for finding a solute. There are a few different ways of calculating it, even in spectroscopical circumstances, the one used in this report is according to LCGC specifications [18].

![Figure 3](image)

**Figure 3** - A picture showing how the SNR is calculated. The dotted line is the baseline, the noise is given by the difference between the highest and lowest peak around the baseline. The height of the big peak is then measured from the baseline.

What is first done is to establish a baseline, some part around the peak under consideration that is "flat". Around the baseline the noise is found, by definition the difference
between the highest and lowest peak, all this can be seen in fig 3. The values found from fig 3 can then be used to calculate the SNR from

\[ SNR = \frac{H}{h}. \]  

(2)

The value that comes from eq (2) should ideally be as high as possible but \( SNR \approx 10 \) is typical [18, 19].

2.8 Scanning Electron Microscope (SEM)

SEM is a type of microscopy. It differs from regular microscopes that instead of light electrons are used to "view" the specimen. This can of course not be done directly but requires detectors for the backscattered electrons. These can then be reconstructed using a computer to get a topographic view of the sample. One of the advantages with SEM is the great resolution which can be as high as 0.5nm. Some disadvantages are that the sample has to be prepared for vacuum and that it has to be conductive. The conductive part can be done using aforementioned PVD for example with a thin layer of metal, if it is not already conductive. These restrictions make it impossible to view living things but make it well suited for the metallic wafers used in this experiment.

3 Experimental

3.1 Nanoimprint lithography

To create the patterns necessary to enhance the signal, nanoimprint lithography was used with a Nano-imprinter (Obducat NIL2.5). The molds used were made from PDMS and the properties of them can be seen in table 1.

<table>
<thead>
<tr>
<th>Diameter of pillars [nm]</th>
<th>Spacing, center-to-center [nm]</th>
<th>Height of pattern [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>780</td>
<td>365</td>
</tr>
<tr>
<td>85</td>
<td>300</td>
<td>175</td>
</tr>
<tr>
<td>50</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

This was done in a cleanroom under ISO 5 standards [20]. The substrate used was PET that was first cleaned using a sonicator. By first putting the PET wafers in acetone in the sonicator then isopropanol and finally, water all steps were done for 5 minutes. After this they were put into the nanoimprinter and the recipe was put in according to table 2.
Table 2 – The recipe for the nanoimprinter. The first row is show how long the specimen should be subjected a certain temperature and pressure. The last line is telling when the specimen should be released

<table>
<thead>
<tr>
<th>Temperature [Celsius]</th>
<th>Pressure [Bar]</th>
<th>Time [Sec]</th>
<th>UV</th>
<th>Air cooling [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>190</td>
<td>30</td>
<td>120</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

After this the wafers were checked under a microscope (Olympus BX51) to see if they had islands of pillars. In order to keep track of the different wafers they were put in petri dishes using double sided tape.

3.2 Physical Vapor Deposition (PVD)

The PVD was done using a thermal evaporator (Kurt J. Lesker Company PVD 75). The process is done as follows: first the metal, that is to be evaporated onto the target, is placed into a "boat", a vacuum is then created, the metal is then heated, by a current going through the boat, and evaporates onto the target. The boat is made of tungsten (wolfram) because of its high melting temperature. During this work deposition rates of about 1 Å/s were used as to ensure a uniform distribution on the substrate. Two different thicknesses for the silver deposit was made, one with a thickness of 50 nm and one with 85 nm. For each and every combination, at least 3 samples were made, as to ensure some statistical reliability.

When gold was deposited the same procedure was used as for silver with another boat. Since Au is so expensive pieces of PET was put up around the evaporation chamber, collecting the gold, to be used in later experiments.

3.3 CAD

In making the CAD models that were later to be 3D-printed both FreeCAD and Inventor was used. In fig 4 a few CAD pictures are shown made using FreeCAD and Inventor.
Figure 4 – CAD models for the 3D-printer and a finished chip. 4a is one of the first produced using FreeCAD without a square for the chip. 4b was done using Inventor and had a square for the chip as well. In 4c we can see one of the tries to have a chip working using capillary forces. A finished chip is seen in 4d. The chip is molded into PDMS on top of a glass wafer.

In fig 4a we can see one of the first tries for a CAD chip. This was then improved upon as can be seen in figs 4b and 4c. In fig 4b one see a square for the chip to be integrated into with a slight elevation to accommodate for the size of the chip. In 4c we see a try to make a chip using capillary forces to drive the liquid. During the printing it was found that sharp edges usually put enough force on the plastic to make it curl upwards. Due to this sharp edges were avoided to make it easier to print.

3.4 Microfluidic device

The microfluidic device was constructed using a 3D-printer (Ultimaker 2+). First a solid version of the channels were made these were then covered in PDMS. The solid version of this can be seen in fig The whole device was then put into an oven to harden the PDMS. After the PDMS had hardened, the plastic from the 3D-printer was taken away leaving channels. This chip can be seen in figure 4d.

After this, Raman spectroscopy was carried out both with the chip and on a simple glass slide for comparison.
3.5 Surface Enhanced Raman Spectroscopy (SERS)

SERS measurements were done using a \textit{RENSHAW inVia confocal Raman microscope}. The microscope can be seen in figure 5. This microscope has a maximum power of 500mW and the wavelength used was 738nm.

![Figure 5 – The Raman microscope used](image)

The microscope was focused on the crystals of the material under observation. During the experiment the power was turned from low to high, in order to not "burn" anything with the higher powers. The order went like so 0.1, 0.5, 1, 5 percent of maximum power.

3.6 Fluorescence

For the fluorescence a \textit{TECAN Infinite M Nano} plate reader was used with the \textit{Magellan} software. Throughout the experiment the top-reading mode was used and the plates loaded with the chips used can be seen in fig 6a. The chips were preordered and then using PVD techniques with a PVC mask the gold stripes were created.

![Figure 6 – Pictures showing two stages of fluorescence testing. In 6a we can see the chips before going into the microplate reader. 6b shows preparation of the samples for another fluorescence test](image)
In 6b we can see the specimens being treated to be tested using another fluorescence machine. During this testing phase they had first been treated overnight and then again with another treatment 30 minutes prior to the test began.

3.7 Scanning Electron Microscope (SEM)

After the substrates had a coating of silver they were checked under a SEM microscope. This was done in order to see how the pattern turned out.

4 Results

4.1 Working towards a microfluidic chip

In fig 7 we can see a schematic of the process of building a chip.

![Flowchart of chip building process](image)

Figure 7 – Short schematic of the work-flow for creating a chip

4.2 Scanning Electron Microscope (SEM)

Looking first at how the nanoimprinting turned out for the 50 nm pillars in a SEM microscope. One can see from fig 8 that the nanoimprinter was able to make very sharp edges. It is also possible to see some structure to it, but there seems to be more like diamond shapes than the expected pillars in the 50 nm case. There is also no real periodicity to the structure as opposed to what was wanted.
Figure 8 – An overview of the SEM pictures from the 50 and 85 nm pillars. In 8a shows the clear edge of the nanoimprinter. b) is an overview of the 85 nm pattern. c) and d) are zoomed in pictures for the 50 and 85 nm respectively.

Now looking at fig 8b one can see the difference between the 50 and 85 nm pillars. In fig 8d which shows an enlarged view of the pillar structure in 8b, it is clear that the pillar structure is more pronounced. For the 400 nm fig 9a is part of a quite large structure that could be seen by the naked eye. In fig 9c one sees defects running through the otherwise quite periodic structure.
Figure 9 – SEM pictures for 400 and 100 nm pillars. a) shows the large structure for 400nm with a zoomed in picture in c). In b) and d) we can see a previous experiment with 100 nm pillars done on PMMA under comparable conditions and the same equipment.

4.3 Raman

Looking at fig 10 the Raman spectra for the chips covered in a 4-ATP solution is seen. In this section blank means a blank silver surface, and pillars and islands are used interchangeably. In fig 10a the Raman spectra for 50 nm pillars with a coating of 50 nm Ag is seen. It is clearly seen, that the spectra, for when the laser is aimed at pillars, is higher than when it is aimed at blank. The peak at 1600 cm$^{-1}$, using eq (2), has a signal to noise ratio of 212 for the blank and 557 for when the laser is aimed at the pillars. Doing the same for fig 10c 14 and 520 is the SNR for blank and pillars respectively. Finally for 10b the signal to noise ratio is 139 for the blank and 400 for the islands.

In using eq (2) a problem arose from the drift of the baseline around the peak at 1600 cm$^{-1}$. Since no clear baseline was found the dip slightly to the left of this peak was used as a baseline, and the noise taken from there.

Looking at fig 10d, which is the Raman spectra of the chip seen in fig 4d, when there is a
4-ATP solution on the chip. One sees, that the highest count comes from when the laser is aimed at an island. Thereafter, when it is aimed at silver and the lowest count comes from when it is aimed only at PDMS. The SNR were not calculated for this sample due to the noisiness of the signal.

![Figure 10](image)

**Figure 10** – Figure showing the Raman spectra. For each sub-picture it is shown for when the laser is pointed at islands and blank. In 10a) the mean value for all the pillars with 50 nm pillars and 50 nm Ag are seen. In 10b and 10c the ones for 85 50 and 85 85 respectively. In 10d we can see the Raman spectra of the device when the laser is pointed only at PDMS on an Island and at only a blank spot on the silver surface.

For all of these plots the machine seems to have an anomaly going on at about 950 cm\(^{-1}\) to around 1400 cm\(^{-1}\). The area in question becomes much thicker and with abrupt spikes at the end most prominently at around 1400. This phenomena is most easily seen in fig 10a where the noise of the signal at around 1200 cm\(^{-1}\) makes the line quite thick for the island spectra.

### 4.4 Fluorescence

The results from the fluorescence are summarized in table 3.
Table 3 – Mean of the different values for the fluorescence test. A,B,C are just different places where tests were carried out on the chips

<table>
<thead>
<tr>
<th>Mean counts/Point</th>
<th>Gold-coated chip</th>
<th>Blank chip</th>
<th>No chip</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15851</td>
<td>8086</td>
<td>6786</td>
</tr>
<tr>
<td>B</td>
<td>14817</td>
<td>8781</td>
<td>6857</td>
</tr>
<tr>
<td>C</td>
<td>14875</td>
<td>8886</td>
<td>6773</td>
</tr>
</tbody>
</table>

As is seen in table 3 counts for the gold-coated chips are higher, as was to be expected from the theory.

5 Discussion

5.1 Nanoimprinter

The recipe for the nanoimprinter was found, in previous studies, to be a good one, but as can be seen from fig 11, the nanoimprimer was not able to keep the pressure constant. Since the pressure releases way above the glass-transition temperature, it is hard to say if the structures had time to form. This may very well cause problems when it comes to reproducibility. It would be nice too be able to do some imprinting, then directly go to SEM look at how it turned out and continue from there. This way, when you later move on, you are sure that the steps building up to it are in some sense, correct. The way it is done now, seems a bit like doing everything at once, not making sure the first part is in order before moving on. The wafers that were used were far from clean and scratched, so they had to be cleaned beforehand. Maybe the traces of tape were interfering with the Raman spectrum? Something that could be worth looking into is, the durability of the nanopillars. That is, for example, look into the making of the defects seen in fig 9c are they from defects in the mold? Or from the handling of the PET? There seems to be quite a big difference in how well the PMMA and PET turns out from the nanoimprinter therefore the use of PET should be tested even further. On a cheerful note, looking at both the SEM pictures and the Raman spectra it seems like with a bit of optimization that this method could work very well.
What is a bit puzzling is if the large difference to how PET and PMMA plastic turned out is due to them being different plastics? Or if it is due to the nanoimprinter acting up? Whichever it is further experiments are required.

5.2 3D-printing

3D printing things is an easy way of doing a first prototype, or a proof of concept. It is also good for when parts have to be replaced somewhere remote or otherwise inaccessible. To this end, I think it worked well and with some more time different device prototypes could have been produced. There were some optimization that needed to be done when it came to printing the channels. These were mostly things like, how hot the plastic should be, how hot the bed should be, printing speeds etc. Then a few had to be printed in case the printer was misbehaving. Usually there were strands left from the printing if this was the case they were removed using a scalpel under microscope.

5.3 Device

Using PDMS to be able to see through it and holding the chip in place at the same time seems like a bad idea. It seems like a better idea to look through the other side (through the glass) and use the PDMS to hold the chip in place, and for the channels of course. For this to be a viable method, the Raman spectra should be checked so that the glass doesn’t interfere too much. It also feels like a cumbersome way of doing things as of now, so other methods should be conceived, or this one markedly improved. The signal to noise ratio was not even calculated due to the noisiness of the spectra.
5.4 Raman

Looking at the plots for the Raman spectra, it seems as if the highest peak at about 1600 cm\(^{-1}\) in general comes from the 85 nm pillars with 85 nm Ag as seen in fig 10c. What seems strange here is, that the blanks on that sample are so very low it is almost as if they are non-existent. Looking at the individual plots supports this, that is not the mean, small peaks can be seen but still the highest one is only 710 counts. This can be compared to the highest peak seen in 10 of above 20000 counts. What caused this odd and strangely consistent behavior is hard to know. Could it be that this thickness of silver is just the right amount to somehow make destructive interference? Moving on to look at 10a, we can see that even though the SEM pictures weren’t looking very good for these pillars, they still came out on top with a clear difference from the blank ones on the same substrate. The same is true for 10b but with a lower signal to noise ratio. The problem with using SNR here is that the drift for the baseline is quite large and therefore ill-defined. For future experiments the same definition of a baseline should therefore be done in order to correctly compare the results. According to [18] values for SNR are usually around 10.

5.5 Fluorescence

The fluorescence part went well with results as expected higher for the gold-coated parts of the chip. As is also seen in table 3 the mean counts for the blank chip is still higher than when no chip is present. This effect can be explained by reflection due to more interfaces. The effect is not always prominent but sometimes went up to 20 – 25% one should therefore be aware of it.

What could have been nice to see is the difference it would have made on the results if silver had been used instead of gold. Since gold is so much more expensive silver would be preferable compared to gold from an economical viewpoint.

5.6 Outlook

Seeing as we only have finite resources, taking care of the ones we have seems like a brilliant idea. Thus, using less resources per test and with higher selectivity means earlier treatment of patients and the usage of less resources to that end as well. The more we learn about nanoscience, the easier all of these things will become with an even more exact production of nanoscale objects. This will in turn, generate even more inventions of things that may seem far-fetched now. There seems to be a promising future for the whole field of nanoscience and to be able to construct things in bulk with exact specifications at this scale will take a tremendous effort. It is fascinating to think, that the same principle employed by Gutenberg in the 15th century, and in China even earlier, can still be used in the field of nanoscience. My belief is, if we overcome this first obstacle, we will be granted access to a world we have previously only glimpsed at, to quote Feynman "There is plenty of room at the bottom".
References

In vivo tumor targeting and spectroscopic detection with surface-enhanced Raman nanoparticle tags  
Nature Biotechnology. vol 26 pp 83-90

Nanoimprinted patterned pillar substrates for surface enhanced Raman scattering applications  
ACS appl. mater. interfaces 2015,7 pp 22106-22113

A 3D-printed device for a smartphone-based chemilumininescence for lactate in oral fluid and sweat  
Analyst, 2014, 139, 6494

Low cost lab-on-a-chip prototyping with a consumer grade 3D printer  
Lab Chip, 2014, 14 ,2978

Imprint Lithography with 25-Nanometer Resolution.  
Science. 272 (5258): 85-7

Nanoimprint Lithography: Methods and Material Requirements  
Adv. Mater. 2007, 19 , 495-513

[7] Ashby, M. F.  
Materials Selection in Mechanical Design  

Materials science and engineering (Ninth edition)  

[9] Kurt J. Lesker (No date found)  
Sputtering Rates  
Retrieved 22 May 2017 from  
https://www.lesker.com/newweb/ped/rateuniformity.cfm

Additive manufacturing in unmanned aerial vehicles (UAVs): Challenges and potential  
Aerospace Science and Technology Vol 63 (2017) 140--151
Building components for an outpost on the Lunar soil by means of a novel 3D printing technology
Acta Astronautica Vol 93 (2014) 430--450

A bioprosthetic ovary created using 3D printed microporous scaffolds restores ovarian function in sterilized mice
Nature Communications vol 8, (2017)
doi:10.1038/ncomms15261

3D bioprinting of tissues and organs
Nature Biotechnology VOL 32 NUMBER 8 Aug 2014 773--785


[18] John W. Dolan (1/1-2006)
NanoLab

[19] ICH HARMONISED TRIPARTITE GUIDELINE
VALIDATION OF ANALYTICAL PROCEDURES: TEXT AND METHODOLOGY Q2(R1)
Nov 2005

[20] Roushdey Salh (No date found)
NanoLab