

Micro- and Nanotechnology Fabrication Processes For Metals

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Many medical products are taking advantage of the developments in micro- and nanotechnology. Fabrication processes for metal products are reviewed here. Those featured include stents, surgical blades and needles, wound dressings and fluorescent labels for diagnostic testing.

Top-down versus bottom-up techniques

There are a great number of developments underway in fabrication processes utilising micro- and nanotechnology. The focus here is on processes for fabricating products made of, or incorporating, metal. Later articles in this series will address developments for other materials.

The definitions of micro- and nanotechnology are worth revisiting. Microtechnology relates to devices and structures with features in the size range from 0.1 mm to 0.1 μm . Nanotechnology relates to devices and structures with features in the size range of 0.1 μm to 0.1 nm. These structures can be produced by top-down or bottom-up process technologies.

Top-down process technologies start with bulk material and then use a variety of processes to remove material and hence fabricate the required structures. Figure 1 illustrates the evolution of the technologies. Conventional metal machining is effective down to 0.1 mm. Photolithography and etching technology can reach dimensions as small as 0.001 mm (1 μm). Extending photolithography by using deep ultraviolet radiation can enable dimensions of 0.0001 mm (100 nm) to be reached. Although photolithography is widely used in the semiconductor industry to fabricate microelectronic devices, for example, microprocessor and memory chips, it has not yet had a significant impact on medical devices. This is mainly because of the limitations on the thickness of the metal layers that can be patterned

using lithography. Generally, a 1:1 rule applies, that is, the thickness of the film can be no greater than the minimum feature size to be created. However, new developments in High Aspect Ratio Machining (HARM) technologies using new photosensitive materials are of great interest. HARM technologies rely on photolithography techniques using long exposure times, high-energy collimated beams of radiation such as synchrotron X-rays and extremely sensitive photoresist materials. The objective is to produce structures in which the height of the feature is much greater than the width; 10:1 is routine and ratios as high as 100:1 can be achieved.

In contrast to top-down technologies there are bottom-up processes. These rely on starting from the atomic or molecular level and then building up more complex structures. Figure 1 also illustrates how these techniques have evolved. There have been a num-

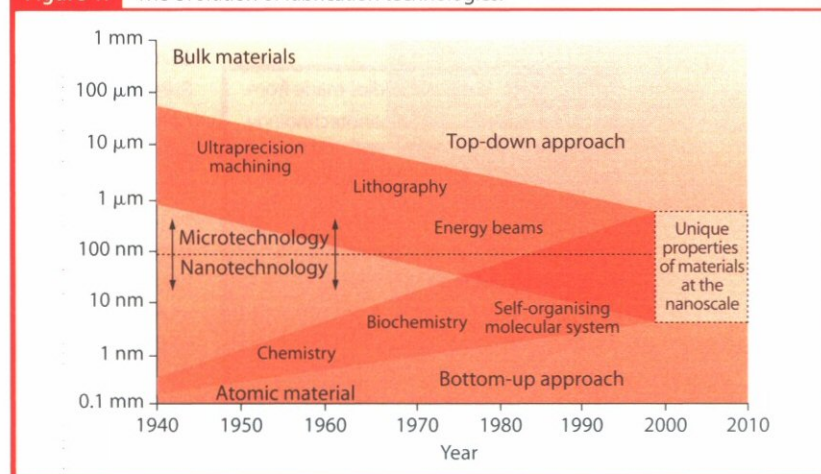
ber of challenges to be solved, including control of the particle size and finding ways to persuade molecules to organise themselves into more complex structures.

The excitement concerning nanotechnology has come from the discovery that structures with dimensions in the nanometer range (1–100 nm) can have physical properties that are dramatically different from those of the bulk material. The most commonly quoted example is that of gold nanoparticles, which do not appear metallic, but have colour ranging from yellow through to blue, depending on the particle size. Some widely used medical products are benefitting from the application of micro- and nanotechnologies and examples are explored here.

Stents

Stents are frequently made of stainless steel, titanium or Nitinol tubes of

Figure 1: The evolution of fabrication technologies.



→ varying diameters and thicknesses. Diameters vary from 1–5 mm and tube thicknesses typically vary from 30–600 μm . Metal stents are usually cut from tubing using an Nd:YAG laser. This process tends to leave an oxide layer on the surface of the stent and remelt on the sides of the struts. Microblasting with aluminium oxide powder can remove the oxide layer and the remelt. Another technique being developed to overcome these problems is to use a water jet to guide the laser beam (Synova SA, Ecublens, Switzerland).¹ The laser beam is focussed on a nozzle through which a high-pressure water jet is delivered. The water guides the laser beam to the target by means of total internal reflection. The continuous water jet is able to cool the target and hence minimise thermal damage, thus creating a parallel, burr-free cut. Figure 2 shows the detailed structure of a stent cut using this system.

An alternative technique is to use chemical etching with the patterns

Figure 2: Detailed structure of a stent cut by water-jet laser method.

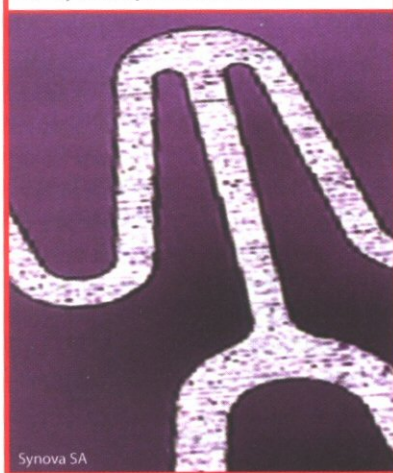
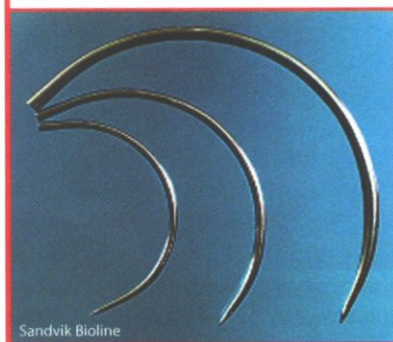


Figure 3: Surgical needles made from stainless steel based on nanotechnology.



defined by photolithography.² Producing patterns on three-dimensional structures such as cylindrical tubes is challenging and most photolithography has been developed from flat structures. An image can be focussed easily on a flat surface, but for a nonflat surface the demands on the optical system are much greater. However, the benefits in terms of lack of debris, thermal damage and the ability to batch process in high volume are providing the incentive to address these issues.

Surgical blades

The traditional material for surgical blades is stainless steel. However, the emergence of micro- and nanotechnology has enabled a new generation of surgical blades to be developed that have special shapes and can be coated with diamond on the cutting edge. GFD (Ulm, Germany)³ is producing a range of scalpels using micromachined silicon and diamond. These blades have a cutting edge with a radius of 3 nm; an average razor blade has a radius of 60–100 nm.

An alternative production technique uses focussed ion-beam milling to produce cutting edges of 37 nm in metal or ceramic (MDW Technologies, Newport Beach, California, USA).⁴ It is claimed that these blades can be cost-competitive with diamond blades. Sharper blades enable surgeons to make finer dissections and cleaner cuts leading to quicker healing.

Surgical needles

A stainless-steel material has been developed based on nanotechnology. Sandvik Bioline 1RK91 (Sandvik Materials Technology, Sandviken, Sweden) is optimal for manufacturers of suture needles for ophthalmic applications.⁵ Suture work in eye tissue, which is both sensitive and tough, requires a material that combines hardness with toughness; hardness because the point needs to be sharpened and toughness so that the needle will not break during surgery with all the disastrous consequences that would imply. Ultrahigh strength in the material enables the needles to be extremely thin, minimising tissue damage. The

level of strength depends on the amount of cold work in the material prior to thermal ageing (heat treatment), but it can be as high as 2500 MPa at room temperature. In addition, the material is pliable, which is an essential quality for this application. Tests on strip material have shown that a 90° bend in the material in the cold rolled condition can be achieved, without cracks, with a bend radius of between one and two times the thickness of the strip.

Hardness and toughness are normally two opposing properties in material physics, with more of one leading to less of the other. Ultrahigh strength and good formability cannot be easily combined, but this is possible using nanotechnology. This material contains small particles that measure 1–10 nm and are called quasi crystals. Quasi crystals have a structure in between crystalline and amorphous, which can stop dislocations and thereby act as reinforcement. They form during heat treatment and strengthen into a tough matrix that gives rise to the exceptional material properties. The material is suitable for a range of medical tools including various types of surgical needles, bone drills and dental instruments. Figure 3 shows fine surgical needles made from the material.

Wound dressings

Since the the Middle Ages, silver has been used as a preservative for water because of its antibacterial properties. Recently, there has been renewed interest in the material because of the rise in drug-resistant bacteria. The effectiveness of silver as an antimicrobial agent can be improved by changing the size of the silver particles. Conventional silver is composed of large crystals, which dissolve slowly in contact with body fluid. Silver particles of a small size that dissolve more rapidly when moistened and begin antimicrobial activity almost immediately have been developed (Nucrust Pharmaceuticals, Wakefield, Massachusetts, USA).⁶ Many organisms are killed within 30 minutes. When incorporated in wound dressings, the particles are also suitable for sustained release over periods of up to seven days.

Table I: A summary of the advantages of new devices and manufacturing processes compared with conventional approaches.

Product	Existing manufacturing	New method	Advantages
Stents	Nd:YAG laser cutting and microblasting with aluminium oxide	3D photolithography or water-jet laser	<ul style="list-style-type: none"> • No surface oxide layer created • No thermal damage • Reduces risk of particulate waste
Blades	Precision metal stamping and etching	Micromachining	<ul style="list-style-type: none"> • Blades that are sharper, smaller and more functional • The blades exhibit uniformity and durability and last longer than blades made by other methods
Needles	Standard stainless steel	New nanostructured alloys	<ul style="list-style-type: none"> • New alloys provide ultrahigh strength, toughness, good formability and corrosion resistance
Wound dressing	Conventional wound dressing with antibiotics	New material with nanocrystalline silver ions	<ul style="list-style-type: none"> • Provides antimicrobial activity immediately and kills many organisms in 30 min, faster than other forms of wound dressing with antibiotics • Can deal with drug-resistant bacteria
Fluorescent particles	Conventional dyes	Quantum dots	<ul style="list-style-type: none"> • Colour can be tailored depending on particle size • Small inorganic crystals can withstand more excitation cycles than organic dyes • All colours can be excited with one wavelength source

Fluorescent labels

Conventional organic dyes need to be excited with a particular wavelength of light and only emit light at one specific wavelength corresponding to the band-gap energy. Quantum dots are particles with dimensions in the nanometer range that have extremely interesting optical properties. Like semiconductors, they absorb light at all wavelengths shorter than the wavelength corresponding to the photon energy of the band-gap. However, the wavelength that is emitted (its colour) depends on the size of the dot. The size can be tailored by the fabrication process and hence a single type of semiconducting material can yield an entire family of distinctly coloured labels.

A further advantage of the quantum dot is that the inorganic crystals used to make them can withstand significantly more cycles of excitation and light emission than typical organic dyes can, which soon decompose. This allows researchers to track the behaviour of cells and tissue for longer intervals. Quantum Dot Corp. (Hayward, California, USA)⁷ has described how quantum dots can be used in a variety of

applications, including immunohistochemistry, flow cytometry, western blotting and plate-based assays.

Improved performance

Micro- and nanotechnology are already being used to improve the performance of many medical products. Table I summarises the advantages of these new devices and manufacturing processes compared with the conventional approach.

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