Doing More with Less: Miniaturisation and Integration of Functionality

"Miniaturisation is the trend and nanotechnology is already much more widespread than most people realise," says Dr Hans Goosen , assistant professor at the Department of Precision and Microsystems Engineering (PME). "Take your phone, for example. You expect it to be better than the version you bought two years ago - to be smaller, lighter, last longer on the same batteries and use less material. In fact all these things are achievable at the very, very small scale."

Nano Engineering Research Initiative (NERI)

As part of the Nano Engineering Research Initiative (NERI), Goosen is looking into just this sort of size domain. "Nowadays things need to do more with less and in a smaller volume so both miniaturisation and integration of functionality are trends we see everywhere, not just in electronics but also in optics, mechanics and fluidics." These could be technologies for chemical synthesis and pharmaceuticals, portable medical devices and implantable systems, energy-saving systems within aerospace and car manufacturing industries – they all need to be smaller and lighter, "which means that we need to get the functionality that is done now in larger systems into these smaller volumes."

Functional Material Structures

One approach is to use Functional Material Structures (FMS), or 'Smart' materials, which can be seen as a class somewhere between materials and systems. "Traditionally, we work with a material e.g. steel or a plastic, which has specific properties that we use in design, then we shape the material and make it into a system to perform specific tasks," says Goosen. "With Functional Material Structures, the idea is to design and shape the materials at the micro-nano scale – so make little beams, little inclusions, little openings – then make many, many of them spread over a large volume to get something in between a material and a system. In this way we 'design a behaviour' of a block of material, different from the material properties and which is part of the system. In other words, by manipulating the structure at not-quite-the-material-scale but at the micro-nanoscale, we can achieve new behaviours."

In essence, this means that the Functional Material Structures can have sensing properties or unusual mechanical or thermal behaviour or any combination of these, incorporated within the material.

Dr.ir. J.F.L. Goosen
J.F.L.Goosen@tudelft.nl
+31 15 27 86 500

TU Delft

Currently Goosen is working on a way to use Functional Material Structures as actuators - components of a system that move or deform to make something happen within a system - in this case, a very small system. “A tiny actuator may only move a few microns and produce only a few nanonewtons output, which is hardly noticeable and not very useful. But if you use millions and millions of these individual components, stacking them up 1000 in a row, then suddenly the system can move five millimetres which would be much more useful.” These Functional Material actuators could be used to make small pipes that can function as pumps or valves, or extremely small devices that open and close, or switch things on and off, or clamps that move little mirrors or lenses or laser diodes. “And independent of size or shape, you can use the same ‘Functional Material’.”

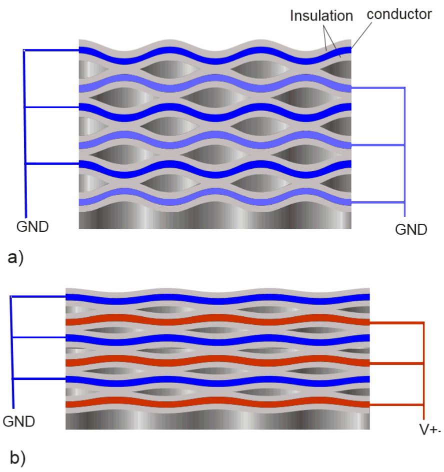
Bridging the Gap

Manufacturing at the micro-nano-scale can be approached either from the ‘top-down’ or the ‘bottom-up’, which can be challenging when trying to integrate different components of a system. Goosen: “From down-scaling, you can get to within a few millimetres, and from up-scaling, you can get to within a few hundred microns so there’s this sort of gap in the technology scale where we don’t have good solutions for designing things, or actuate and sense things where the top-down approach no longer works but before the bottom-up approach can solve the problem.” One answer to bridging this gap in technology scale would be to integrate the manufacture of all components within one system: “We’re looking at a Lab-on-a-chip, microfluidics system where the sensors and channels and everything is integrated into the same thing, as it is being made, as part of the same process,” says Goosen. “However those micro-nano-scale pumps and control devices are just not there yet - I mean as soon as you try to connect a hose the width of a human hair to another hose the width of a human hair, you have a problem! So we need to find ways to miniaturise all the parts, the whole integration technology that’s needed for the marriage between these micro- and nano-systems, as well as the link between these and larger scale systems.”

Building ‘biological’ structures

Another approach would be to use newer technologies like additive manufacture, or 3-D printing, to make essential components from the ‘bottom-up’. “For me one of the fascinating things is that nature does this all the time so the number of materials used in biological structures is very, very limited - perhaps six main materials. Which means that almost all the behaviour of different tissues - everything from shells and nails and hair to muscle and tendon and bone - is created through structure and hierarchies of structure, like hairs and fibres and bundles and weaves, which in turn, creates an enormous range of material properties and types of behaviours.”

If we were to apply a ‘biological’ approach to creating new materials and systems, suggests Goosen, and use the same type of hierarchical structures that biology is using, we could perhaps out-perform what we have now. “We’re just not there yet – we don’t have the technology to be able to manipulate and make enough volume with enough control. But these Functional Materials Structures are sort of the first step up from basic materials to small structure to large structure to final use, which is what biology does all the time. Of course we don’t ‘grow our cars’, don’t make them from the bottom up, but if we want to do it this way, we have to start thinking about different manufacturing technologies as well. So how to go about it, that’s what NERI is really about – how to bridge that gap.”



An active functional material consisting of flexible insulator (grey) shaped with tubular holes with embedded conductive material (blue/red). Figure a shows the base configuration with both sides grounded. Figure b shows the deformed structure due to a voltage on one set of electrodes (red). Func-tional materials such as these can be shaped and actuate to function as actuators, valves, pumps or tuneable particle filters.