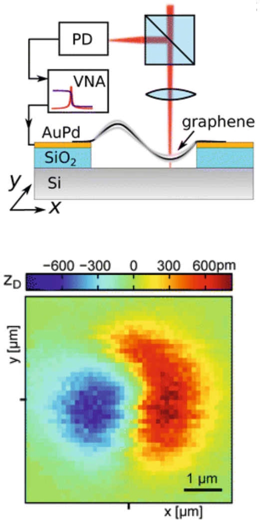
Hybrid micro/nano architectures: the best of two worlds

Over the past decades, scientists have uncovered that by making systems so small that the dimensions approach those of single molecules or atoms, exciting new functionalities and possibilities emerge that larger systems cannot offer. The scale where this happens is the scale of the nanometer (a millionth of a millimeter). Now, this research area is at an exciting stage where actual every-day applications are slowly coming within reach. Moving from nano-science to nano-applications requires a nano-engineering step, says Prof.dr. Peter Steeneken, head of the Dynamics of Micro and Nanosystems group at TU Delft. He worked for 15 years in high-tech industry and now combines his professorship at the Department of Precision and Microsystems Engineering with a part-time affiliation at the Kavli Institute of Nanoscience, also at TU Delft.



Optical characterization of the dynamic motion of a graphene membrane at 23 MHz.

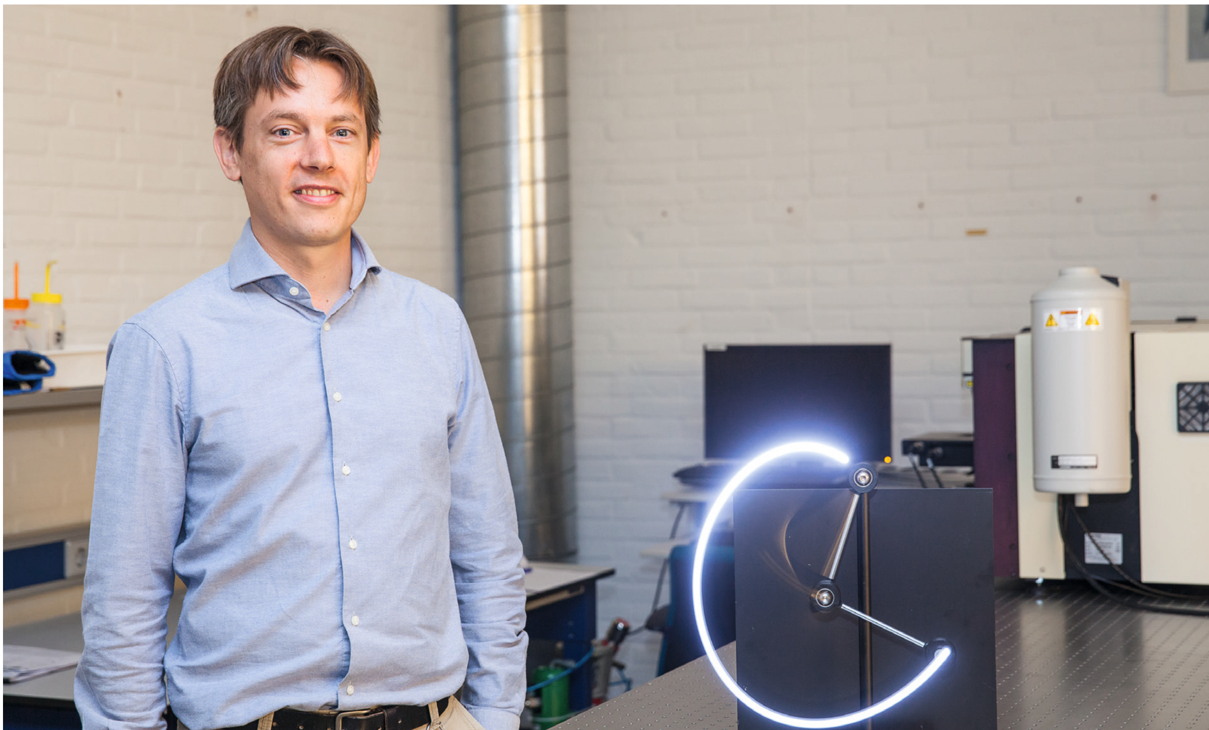
High-throughput material and device characterization

This engineering step not only involves the design of new nanoscale systems. "We should also determine how to best fabricate such tiny systems. How can we guarantee the quality of each component when they're so small?" If industry is to mass-produce systems that involve nanoscale components, it needs to make sure that very large quantities of identical tiny parts of the highest quality can be fabricated reliably. The crucial first step is to have full knowledge of and control over the material properties on these small scales. Conventional characterization techniques often can't deal with materials of which one or more dimensions are in the nanometer range, such as ultrathin layers of graphene. To develop new characterization methodologies, Steeneken and his team make clever use of those material properties that set ultrathin -sometimes as thin as a single atomic layer- layers apart from thicker counterparts, such as their non-linear dynamics. By modelling a suspended graphene membrane's non-linear dynamics, the researchers recently determined a crucial material parameter, called Young's modulus, which is a measure of the stiffness of the material. In contrast to conventional methods to determine this modulus, Steeneken's method is fast, contactless, and provides a platform for high-throughput characterization. The next step is to put this and other characterization methods to use and investigate large numbers of nanomaterials and nanodevices, checking for uniformity and reproducibility, parameters that are essential for future mass-production techniques.

Sensors

Steeneken works on a range of nanosystems he enthusiastically tells about. One example is a tiny sensor to register gas pressure or detect specific types of gases such as CO_2. "If we could make such sensors small enough to be incorporated into mobile phones, then everyone could check the air quality outside and inside." In designing the new nanoscale sensors, Steeneken once more exploits the fact that ultrathin layers display dynamical and mechanical properties not offered by thicker layers, such as a very high resonance

Professor Peter Steeneken
P.G.Steeneken@tudelft.nl
+31 15 27 89 545



TU Delft

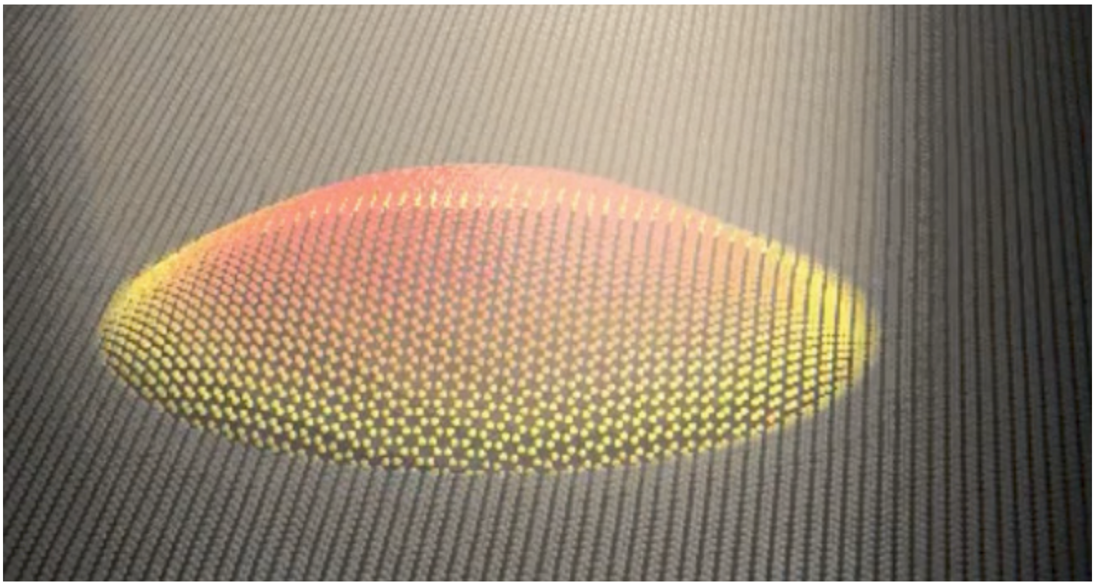
frequency, a low weight and extreme flexibility. “By using layers with nanometer thickness, we have created pressure sensors that are much smaller and yet much more sensitive than their micrometer-sized counterparts. The thinness of the layers also allows us to create nanometer-sized holes, which can be used to sieve the air and selectively test for the presence of specific molecules.” By using physical sensors that do not rely on chemical reactions, Steeneken and his team aim to extend the reliability and lifetime of the devices, in order to meet consumer-electronics requirements.

Best of both worlds

When can we expect such novel nanosystems? Steeneken: “The development is not easy. Take graphene. It has fascinating properties and lots of potential. At the same time, we are facing significant challenges in making graphene-based systems so small: fabrication gets harder, the tiny readout signals get buried in background noise, etc. As with any new material, it will take at least 10-15 years before a completely new graphene-based device on the nanoscale will be mass-produced. That’s why I’m working to find intermediate steps in between today’s microscale devices and tomorrow’s nanoscale devices. Hybrid micro/nano architectures could have an impact on a shorter term.” “My vision is that the nanoscale components and structures in hybrid micro/nano devices will enable novel and improved functions for monitoring and controlling processes, like molecular sieving, osmosis, catalytic reactions and nanoparticle dynamics. Ultimately, this will lead to new sensors and actuators that can find widespread applications in air quality control, chemical industry, drug delivery, metrology, water sensors and health monitoring.” Steeneken concludes: “Making a step-by-step transition to nanotech is a very promising route.”

Pay-off

What will be the role of TU Delft’s Nano Engineering Research Initiative (NERI) in facilitating this transition? Steeneken has high hopes. “I think TU Delft offers an innovative way to look at design and fabrication challenges; an expertise that could be of use to industry. While we are already collaborating with various companies, NERI is a platform to intensify this collaboration. It’s important we look beyond specific challenges arising from a specific industrial process. If we identify common issues, we can join forces with companies from various backgrounds to find far-reaching, fundamental solutions. I’m convinced we will come up with innovations that serve not just a single product. Take, for example, the principles of non-linear dynamics: these don’t just play role on the nanoscale - they affect systems at all scales, up to enormous wind turbine wings. A joint effort in this area could have an unsuspected pay-off.”



Graphene

One of the materials Steeneken uses to build nanoscale components is graphene. Graphene is a thin layer of carbon atoms in a hexagonal honeycomb lattice. It has many unusual properties: it is the thinnest compound known to man at one atom thick, the lightest material known, the strongest compound discovered, the best conductor of heat at room temperature and also the best ductor of electricity known. No wonder the material has taken the world by storm, culminating in the 2010 Nobel Prize for Physics for graphene pioneers Geim and Novoselov. Recently, Steeneken was part of the Delft team that discovered bubbles of graphene that change colour as they expand and contract. The researchers envision that, one day, these ‘mechanical pixels’ could be used for displays.