Ultrasound for Imaging and Sensing at the Nanoscale

"Ultrasound is widely used at the macroscale," says Dr Gerard Verbiest, assistant professor at the Department of Precision and Microsystems Engineering (PME), "but it's not really used at the nanoscale - yet ultrasound is the only way to obtain non-destructive information about a sample's subsurface structure. So here I'm working on two lines of research: using ultrasound to detect nano-sized features below the surface of a material, and using graphene for sensing displacements, vibrations and ultrasound."

Imaging under the surface with ultrasound

Ultrasound - sound waves with frequencies above 20kHz and too high for humans to hear - is widely used in medical imaging and non-destructive testing of products and structures. "Ultrasound is used to scan babies in the womb or beating hearts, both of which are in the order of tens of centimetres," says Verbiest, "but if you want to make an image at the very small nanoscale, you encounter a lot of problems because the wavelength of ultrasound is larger than the structures you're trying to measure."

It's long been a goal of both science and industry to be able to look at nanoscale structures below the surface and to this end, Verbiest has been working on combining ultrasound with very high-resolution microscopy, specifically a type of scanning probe microscope known as an Atomic Force Microscope, or AFM. "An AFM has a microscopic cantilever and the tip of this cantilever has a very sharp end, around 20 nanometres, which 'feels' the surface of the sample. As this tip moves over a surface, it is deflected and you can measure how far the cantilever is deflected," explains Verbiest. In this way, you can reconstruct the topography of the surface of a material.

The challenge then was to integrate ultrasound into an Atomic Force Microscope, and use the tip of the cantilever to gain lateral resolutions "so that you can really pinpoint at the nanoscale the vibration amplitude of your surface, which also contains information about what's inside," says Verbiest. By using ultrasound at similar frequencies as those used in medical diagnostics, that is around 10 MHz, Verbiest was able to get good quantitative images from below the surface. "We buried gold nanoparticles roughly 90 nm under the surface of a polymer and we could pinpoint exactly where they were using this technique."

One major application of this technique would be within the electronics and semi-conductor industry, allowing a quicker and more accurate diagnosis and adjustment of any issues encountered in the manufacturing of microchips. "And another important application would be in biology," adds Verbiest, "allowing researchers to look inside living cells and understand how, for example, cell fission takes place."

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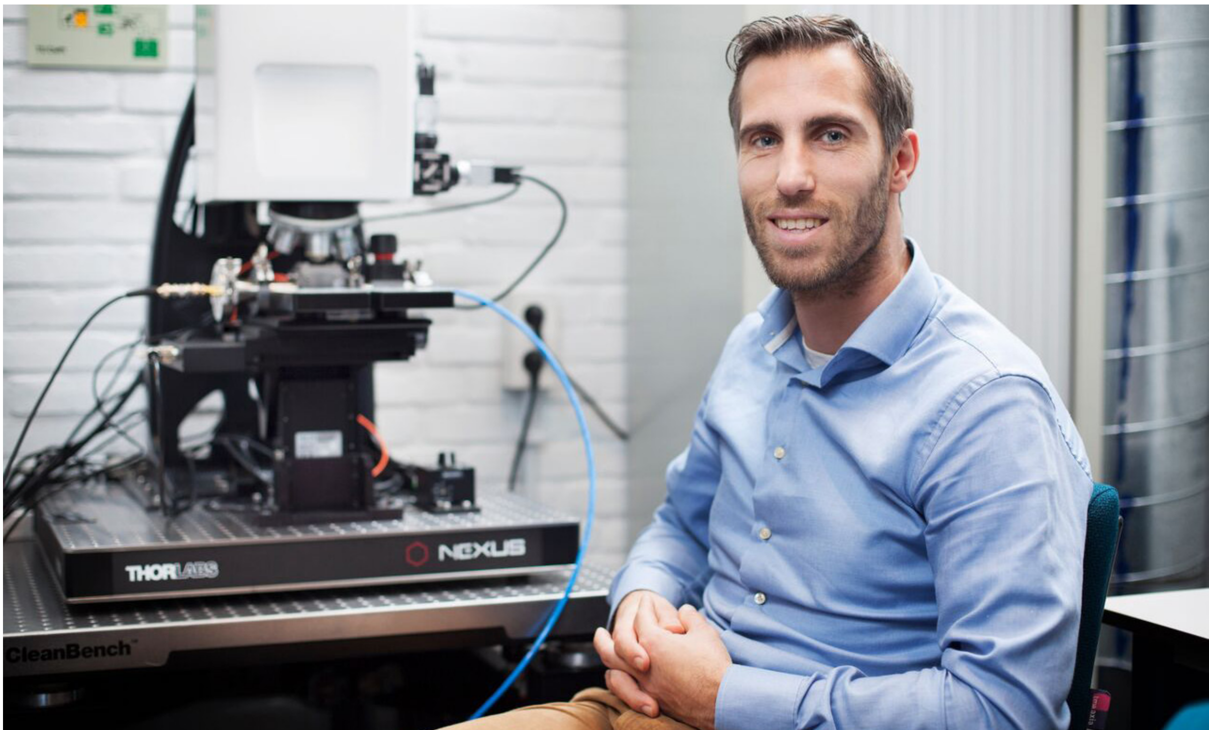


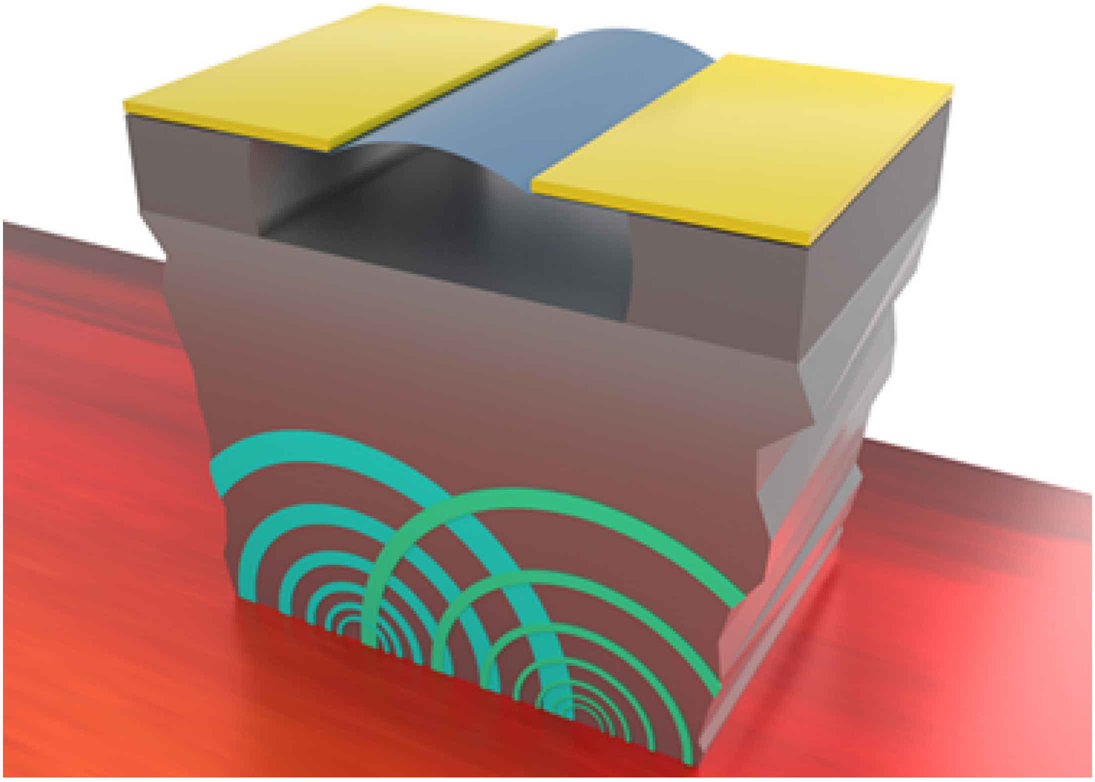
TU Delft

Graphene-based sensors for vibrations and ultrasound

In another line of research, Verbiest is exploring better ways to use ultrasound to sense and detect displacements and vibrations at the nanoscale particularly for use in commonly used and increasingly miniaturised micro-electrical systems. He is specifically interested in using graphene, a recently discovered form of carbon with an exciting array of potentially very interesting properties. “A graphene membrane is one atomic layer thick so it doesn’t cost energy to bend it. It also has a high resonance frequency and is very sensitive to change in mass or in spring constant – which is exactly what you want for sensing,” says Verbiest. “For example, if a particle lands on your graphene membrane or you pull on it a little bit, this has a huge effect on the resonance frequency and you can measure that electrically, which is another nice property of graphene. You can easily measure displacements and vibrations and therefore it lends itself well to being used in electrical sensing schemes like we have in our phones and computers. For example, accelerometers are used in your phone for the automatic screen rotation, and in cars, to trigger the airbags.”

Verbiest sees a future in which graphene plays a major role in such applications. “Accelerometers now, for instance in your mobile phone, are around one centimetre squared which is really big! But you could envisage using graphene to make them 100, or even 1000 times smaller whilst still maintaining the same good resolution. So I’m interested in developing these micro-electromechanical systems for highly sensitive measurements at the high frequency range.”

Working at NERI in a multidisciplinary team and with a wealth of contacts across various industries, Verbiest feels that he’s in a good place to push ahead with his twin goals: “to really push this ultrasound detection with AFM and to get it to a state where people can start using it at the nanoscale, in a similar way to how medical imaging is being used now at the macroscale. And secondly, I would really like to develop this graphene-based sensing for displacement, vibrations, ultrasound into a real application but there’s also room to look into the fundamental properties because of all the questions that have to be answered.”



Graphene

A graphene resonator (blue) on a silicon substrate (gray) was fabricated in such a way that the device could be mounted onto an ultrasound transducer (red). For the first time, this allowed a research team led by Verbiest to measure the responds of a graphene resonator to ultrasound propagating through the substrate [Nano Letters 2018, 18, 8, 5132-5137]. They achieved a resolution of 7 pm/√Hz by making use of the unique properties of graphene. The new insights are very useful for numerous sensing applications at the nanoscale, which are currently developed by Verbiest.