Researchers create the world's smallest Christmas record

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Measuring only 40 micrometers in diameter, researchers at DTU Physics have made the smallest record ever cut. Featuring the first 25 seconds of the Christmas classic "Rocking Around the Christmas Tree," the single is cut using a new nano-sculpting machine—the Nanofrazor—recently acquired from Heidelberg Instruments.

The Nanofrazor can engrave 3D patterns into surfaces with nanoscale resolution, allowing the researchers to create new nanostructures that may pave the way for novel technologies in fields such as quantum devices, magnetic sensors and electron optics.

"I have done lithography for 30 years, and although we've had this machine for a while, it still feels like science fiction. We've done many experiments, like making a copy of the Mona Lisa in a 12 by 16-micrometer area with a pixel size of ten nanometers. We've also printed an image of DTU's founder—Hans Christian Ørsted—in an 8 by 12-micrometer size with a pixel size of 2,540,000 DPI. To get an idea of the scale we are working at, we could write our signatures on a red blood cell with this thing," says Professor Peter Bøggild from DTU Physics.

"The most radical thing is that we can create free-form 3D landscapes at that crazy resolution—this gray-scale nanolithography is a true game-changer for our research."

**Nanoscale Christmas record, in stereo**

The Nanofrazor is not like a printer adding material to a medium; instead, it works like a CNC (computer numerical control) machine removing material at precise locations, leaving the desired shape behind.
In the case of the miniature pictures of Mona Lisa and H.C. Ørsted, the final image is defined by the line-by-line removal of polymer until a perfect gray-scale image emerges. To Peter Bøggild, an amateur musician and vinyl record enthusiast, the idea of cutting a nanoscale record was obvious.

"We decided that we might as well try and print a record. We've taken a snippet of 'Rocking Around The Christmas Tree' and have cut it just like you would cut a normal record—although, since we're working on the nanoscale, this one isn't playable on your average turntable. The Nanofrazor was put to work as a record-cutting lathe—converting an audio signal into a spiraled groove on the surface of the medium. In this case, the medium is a different polymer than vinyl.

"We even encoded the music in stereo—the lateral wriggles is the left channel, whereas the depth modulation contains the right channel. It may be too impractical and expensive to become a hit record. To read the groove, you need a rather costly atomic force microscope or the Nanofrazor, but it is definitely doable."
High-speed, low-cost nanostructures

The NOVO Foundation grant BIOMAG, which made the Nanofrazor dream possible, is not about cutting Christmas records or printing images of famous people. Peter Bøggild and his colleagues, Tim Booth and Nolan Lassaline, have other plans. They expect that the Nanofrazor will allow them to sculpt 3D nanostructures in extremely precise detail and do so at high speed and low cost—something that is impossible with existing tools.

"We work with 2D materials, and when these ultrathin materials are carefully laid down on the 3D landscapes, they follow the contours of the surface. In short, they curve, and that is a powerful and entirely new way of 'programming' materials to do things that no one would believe were
possible just fifteen years ago. For instance, when curved in just the right way, graphene behaves as if there is a giant magnetic field when there is, in fact, none. And we can curve it just the right way with the Nanofrazor," says Peter Bøggild.

Associate professor Tim Booth adds, "The fact that we can now accurately shape the surfaces with nanoscale precision at pretty much the speed of imagination is a game changer for us. We have many ideas for what to do next and believe that this machine will significantly speed up the prototyping of new structures. Our main goal is to develop novel magnetic sensors for detecting currents in the living brain within the BIOMAG project. Still, we also look forward to creating precisely sculpted potential landscapes with which we can better control electron waves. There is much work to do."

Postdoc Nolan Lassaline (who cut the Christmas record) plans to create "quantum soap bubbles" in graphene. He will use the Nanofrazor to explore new ways of structuring nanomaterials and develop novel ways of manipulating electrons in atomically thin materials.

"Quantum soap bubbles are smooth electronic potentials where we add artificially tailored disorders. By doing so, we can manipulate how electrons flow in graphene. We hope to understand how electrons move in engineered disordered potentials and explore if this could become a new platform for advanced neural networks and quantum information processing," says Lassaline.

The Nanofrazor system is now part of the DTU Physics NANOMADE's unique fabrication facility for air-sensitive 2D materials and devices and part of E-MAT, a greater ecosystem for air-sensitive nanomaterials processing and fabrication led by Prof. Nini Pryds, DTU Energy.