New record in materials research: One terapascals in a laboratory

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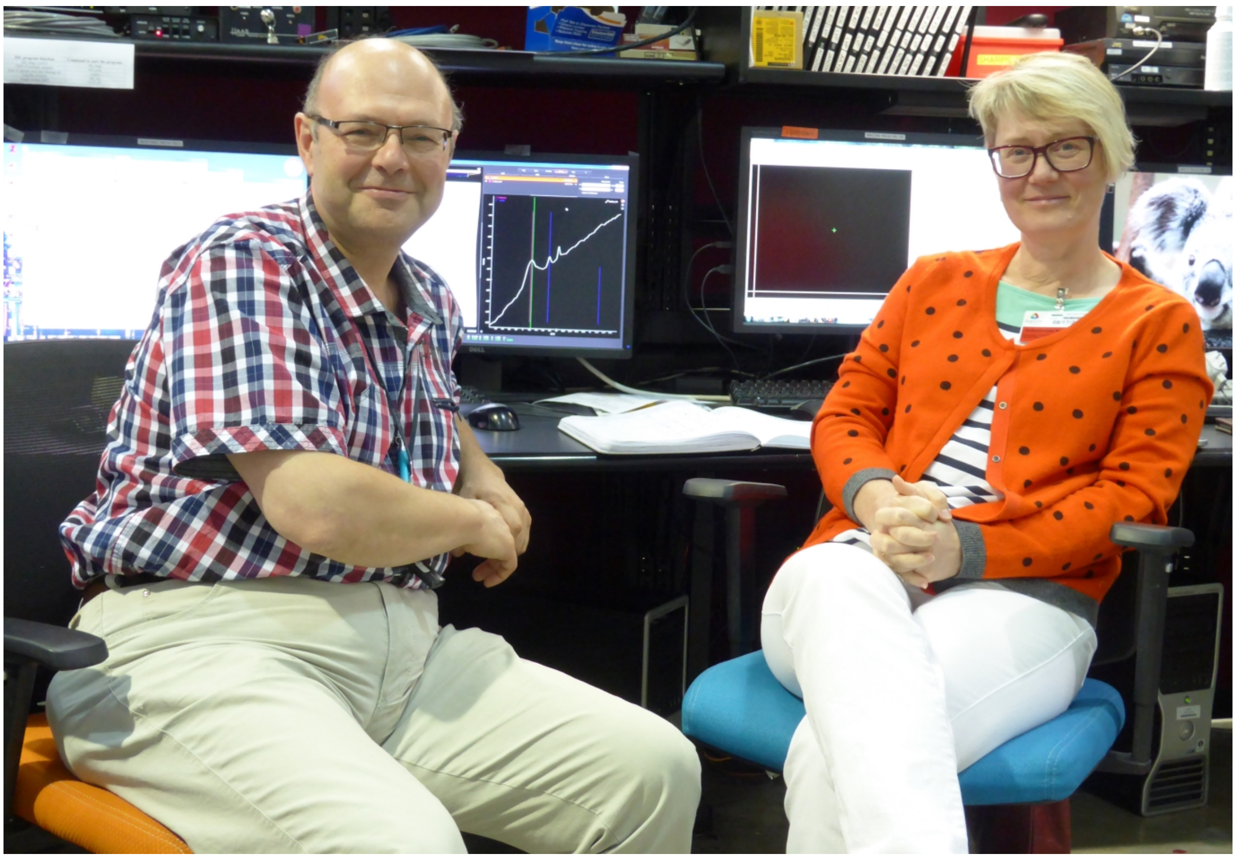

Prof. Dr. Leonid Dubrovinsky and Prof. Dr. Natalia Dubrovinskaia in the Argonne National Laboratory in Chicago. The monitor in the background displays the measurement in excess of 1 terapascal.

An international team of researchers headed by Prof. Dr. Natalia

Dubrovinskaia and Prof. Dr. Leonid Dubrovinsky of the University of Bayreuth has succeeded in creating a pressure of 1 trillion pascals in a laboratory. A study published in *Science Advances* is opening up new research prospects in physics, solid state chemistry, materials science, geophysics, and astrophysics.

The extreme pressures and temperatures that can be achieved and controlled with great precision in a laboratory are ideal objects of investigation in physics, chemistry, and materials science. They allow the structures and properties of materials to be explained, new materials to be synthesized for industrial applications, new material states to be discovered, and a deeper understanding of materials to be achieved, thereby yielding insights into the structure and dynamics of Earth and other planets. For this reason, scientists around the world have a strong research interest in continuing to increase the amount of pressure generated in laboratories for purposes of material analysis.

Until now, the 1-terapascal mark – i.e. 1,000,000,000,000 (one trillion) pascals – was considered a magic threshold. That's three times higher than the pressure found in Earth's core. As a point of comparison, it can be thought of as the pressure that would be exerted on a single penny if 100 Eiffel Towers were stacked on top of it.

It is this threshold which the international team of researchers headed by Prof. Dr. Natalia Dubrovinskaia and Prof. Dr. Leonid Dubrovinsky of the University of Bayreuth have now reached and even exceeded. The scientists have now revealed how they were able to break this record in the research magazine Science Advances.

International Research Cooperation

In addition to the Bavarian Research Institute of Experimental Geochemistry & Geophysics (BGI) and the University of Bayreuth's

Laboratory of Crystallography, numerous other research partners were involved: the Center for Advanced Radiation Sources at the University of Chicago, the European Synchrotron Radiation Facility in Grenoble, the University of Antwerp, the Karlsruhe Institute of Technology (KIT), and the Immanuel Kant Baltic Federal University in Kaliningrad. Key experiments were carried out by Bayreuth scientists at the Argonne National Laboratory, a research institute in Chicago under the leadership of the US Department of Energy.

Synthesized in the lab: ultra-hard diamond spheres

Spherical nano-crystalline diamonds have opened a door to a new dimension of materials research. Researchers at the University of Bayreuth synthesized these transparent spheres, each with a diameter of 10-20 micrometres, in a laboratory. As it turns out, they exhibit a highly unusual resistance to pressure due to their unique texture. They are extremely robust when external pressures are exerted on them.

The members of the research team exploited this property for the purpose of creating pressure in excess of 1 terapascal for experiments in materials science. Using a focused ion beam, they first split the ultra-hard diamond spheres in two. The two halves were then installed in a double-sided diamond anvil cell. With the material samples wedged in between being exposed to increasing pressures, they were x-rayed at the electron synchrotron facilities in Chicago. The diffraction pattern yielded by these technologically demanding investigations revealed that the threshold of 1 terapascal had been reached and even exceeded.

Inside the diamond anvil cell: materials tested at extremely high pressures

Diamond anvil cells have been used in high pressure and high temperature research for quite some time. In such research, the sample of the material to be investigated is placed between the two diamonds. These diamonds squeeze the material sample together from both sides resulting in pressure of up to 250 gigapascals.

A few years ago, this research technique was extended in a crucial way at the Bavarian Research Institute of Experimental Geochemistry & Geophysics (BGI) and the University of Bayreuth's Laboratory of Crystallography. The double-sided diamond anvil cell constructed here enables much higher pressure levels to be achieved. This is due to the half nano-crystalline diamond attached to each of the two diamonds in the cell. The heads of the hemispheres are positioned exactly opposite one another. This allows them to transfer the extreme pressures exerted on them from the outer edges of the larger diamonds to the material samples between them without being destroyed. The key feature of this two-step process is that the pressure transferred to the material sample is multiplied. For the heads of the hemispheres that touch the material sample have a considerably smaller surface than their circular lower surfaces with which they are attached to the larger diamonds.

A key source of pressure resistance in nano-crystalline diamonds is their particle size. The nano-crystalline diamonds with which compression pressure in excess of 1 terapascal was achieved in two-step cells are between 2 and 15 nanometres.

Liquid and gaseous samples also investigated

The research finding that have now been published do not open up new possibilities in physical, chemical, and geo-scientific materials research solely in virtue of having exceeded the 1-terapascal mark. Special seals the scientists installed in the double-sided diamond anvil cell allow not only solid bodies, but also material samples in their original gas or liquid states to be analysed at pressures in excess of 1 terapascal.

Future research prospects

"We are very pleased that we – together with our research partners – were able to contribute to international high pressure and high temperature research in this way," Prof. Dr. Natalia Dubrovinskaia said. The newly published research findings are expected to be highly relevant to many different branches of research, especially physics, solid state chemistry, materials science, geophysics, and astrophysics. Industry is also expected to benefit from the findings, for example in the development of new hydrogen technologies or high-performance superconductors.

From 4 to 9 September 2016, the European High Pressure Research Group (EHPRG) will convene at the University of Bayreuth for the organization's annual conference. "New research prospects will, of course, also be a topic at the conference," Prof. Dubrovinskaia said.

More information: N. Dubrovinskaia et al. Terapascal static pressure generation with ultrahigh yield strength nanodiamond, *Science Advances* (2016). DOI: 10.1126/sciadv.1600341

Provided by University of Bayreuth