A material that superconducts continuously up to extreme pressures

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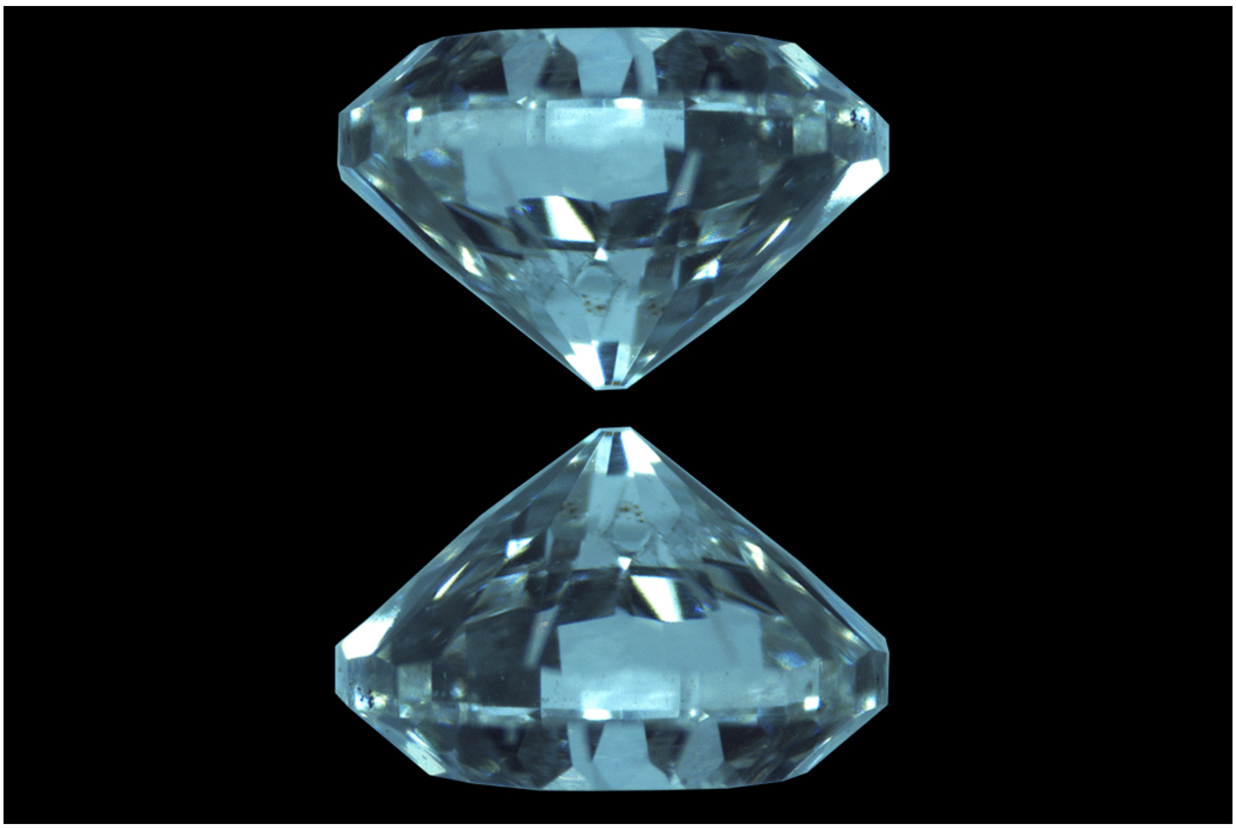

A rendering of the HEA sample being squeezed between the culets of two diamonds. Credit: Liling Sun

Researchers have discovered a metal alloy that can conduct electricity with zero resistance, or superconduct, from ambient pressure up to pressures similar to those that exist near the center of the Earth. The material, which is likely the first to show this kind of robust superconductivity, is described in a paper in the December 12, 2017, edition of the *Proceedings of the National Academy of Sciences*.

The material is a member of a new family of metal alloys known as high-entropy alloys (HEAs), which are composed of random atomic-scale mixtures of elements from the block of "transition metals" on the periodic table. HEAs are interesting in multiple ways, including structurally. They have simple crystal structures, but the metals are arranged randomly on the lattice points, giving each alloy the properties of a both a glass and a crystalline material.

The HEA studied in this work is unique in that it can superconduct continuously from low to high pressures – even when subjected to pressures akin to those that exist at the outer area of our planet's core. This discovery was made by a group of scientists from the Institute of Physics at the Chinese Academy of Sciences and the Chemistry Department at Princeton University. The HEA they studied is composed of the metals tantalum (Ta), niobium (Nb), hafnium (Hf), zirconium (Zr), and titanium (Ti).

"We have observed that this HEA remains in a state of zero electrical resistance all the way from one-bar of pressure to the pressure of the Earth's outer core, without structural changes," said one of the study's senior researchers, Professor Liling Sun of the Institute of Physics in Beijing, to *Phys.org*.

Robert Cava, the Russell Wellman Moore Professor of Chemistry at Princeton, another senior author, added, "This is a remarkable thing – we know of no other similar material – and it makes this HEA a promising candidate for new applications of superconductors under extreme conditions."

Pressure is one of the external variables that can uncover unexpected characteristics in a material. In superconductors, for example, the application of pressure has changed critical temperatures (the temp below which a material will superconduct) and induced superconductivity in materials that otherwise wouldn't exhibit the phenomenon.

Here, the group applied pressure to the HEA using a diamond anvil cell, a device that uses the polished faces of two diamonds – one of the hardest materials on Earth – to squeeze a sample placed between them. To generate sufficiently high pressure to perform the measurements on the HEA, the size of each diamond's culet – the "point" at the bottom of the gem – was 40 microns (millionths of a meter), which is about half the diameter of a human hair.

To track the possible structural changes while the sample was in the diamond anvil cell, the group used synchrotron-based x-ray diffraction (XRD) at the Shanghai Synchrotron Radiation Facility. XRD allows researchers to gain structural information on a crystalline sample based on the pattern the x-rays make after they diffract away from the atoms in the sample. They combined these techniques with complementary measurements of resistivity and magnetoresistance to characterize the superconductivity.

The results show that the HEA retains its basic crystal structure, despite the sample's volume being compressed considerably (by one measurement, when the pressure was about 96 GPa, the volume had been reduced by about 28 percent).

Sun, Cava, and their colleagues attribute the material's unique behavior and stability to its strong crystal structure, combined with the seemingly robust nature of its electronic structure when subjected to a very large amount of lattice compression.

More information: J. Guo et al, "Robust zero resistance in a superconducting high-entropy alloy at pressures up to 190 GPa." *Proc Natl Acad Sci*, 114 (2018), DOI: 10.1073/pnas.1716981114