Atomic-resolution images provide fresh insights into a mysterious state found in superconducting materials

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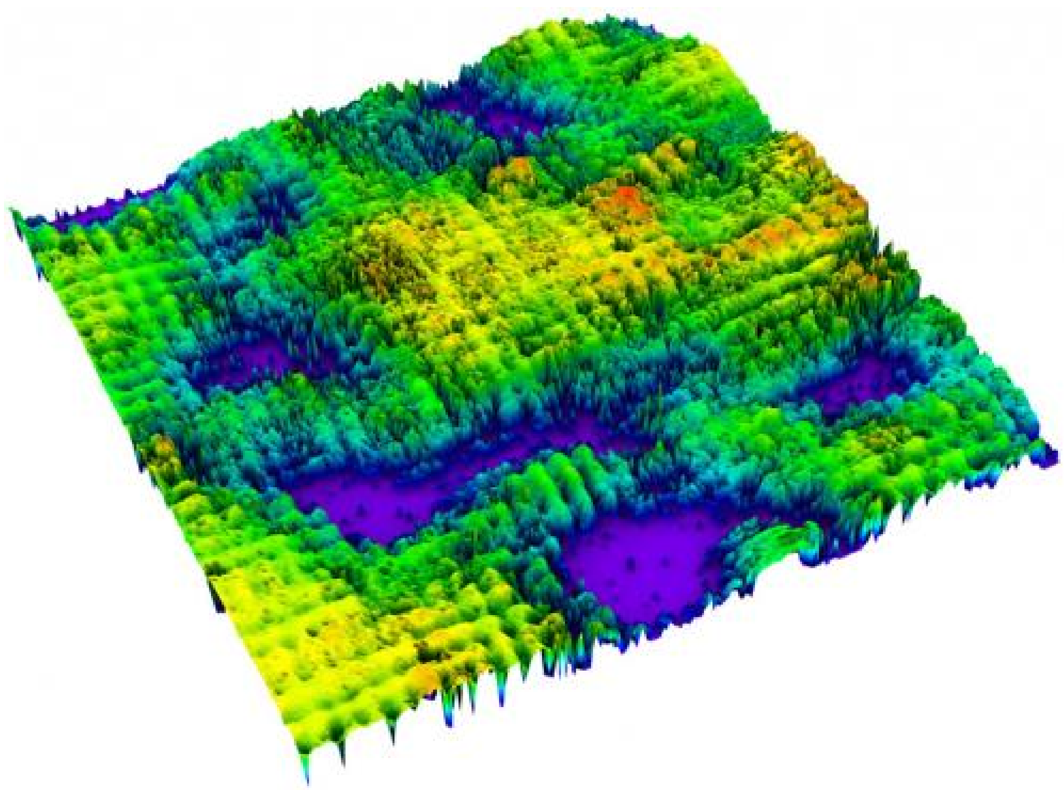

This scanning-tunneling-spectroscopy image of Ca2-xNaxCuO2Cl2 shows the merging of clusters (in green and yellow) where the so-called pseudogap state has developed. Credit: 2012 Yuhki Kohsaka, RIKEN Advanced Science Institute

Superconductivity describes the state of certain materials when they conduct electric currents without any resistance. For superconductivity to develop, these materials generally have to be cooled to temperatures below roughly –140 °C, depending on the material. The family of materials that requires the least amount of cooling is known as cuprate superconductors. These compounds are therefore technologically interesting, but scientists are still working to understand the fundamental mechanism underlying superconductivity in these materials. In fact, determining what makes cuprate superconductors tick is one of the grand challenges in condensed-matter physics.

Now, an international research team, led by Yuhki Kohsaka and Hidenori Takagi from the RIKEN Advanced Science Institute, Wako, has provided fresh perspectives on the behavior of these systems. The researchers, from Japan, the US and the UK, took atomic-resolution images of a cuprate material as it undergoes the transition from a 'normal' solid to a superconductor. A broad pool of data has been accumulated since the discovery of cuprate superconductors in 1986, but only a few studies provided microscopic details of how the superconducting state in cuprate materials emerges.

Using a unique setup, combining an exquisitely stable scanning tunneling microscope with high-quality samples, the researchers studied an enigmatic state known as the 'pseudogap state'. This state appears when the parent compound of their material, $Ca_2CuO_2Cl_2$—which is not a superconductor—is gradually doped with sodium atoms. Once the degree of doping is above a critical level, the material becomes superconducting. At intermediate levels of doping, however, the compound goes through the pseudogap state, whose role is the topic of intense debate among physicists.

Kohsaka and colleagues found evidence that the pseudogap state may be helpful for emergence of the superconducting state. At very low doping levels, they saw the formation of distinct nanometer-scale clusters that are in the pseudogap state. As they added more dopant atoms, they observed that these clusters start to connect. Intriguingly, full connection happens just as the material becomes a superconductor.

These are important new insights into the microscopic behavior of cuprate superconductors. But Kohsaka remains cautious: "We do not claim yet a local correlation between the pseudogap and superconductivity. We don't have experimental evidence strong enough to prove such a correlation. But establishing this connection will be an important direction of future study."

More information: Kohsaka, Y., Hanaguri, T., Azuma, M., Takano, M., Davis, J. C. & Takagi, H. Visualization of the emergence of the pseudogap state and the evolution to superconductivity in a lightly hole-doped Mott insulator. *Nature Physics* 8, 534–538 (2012). www.nature.com/nphys/journal/v … 7/abs/nphys2321.html

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