Electrons falling flat: Germanium falls into a 2-D arrangement on zirconium diboride

December 4 2020

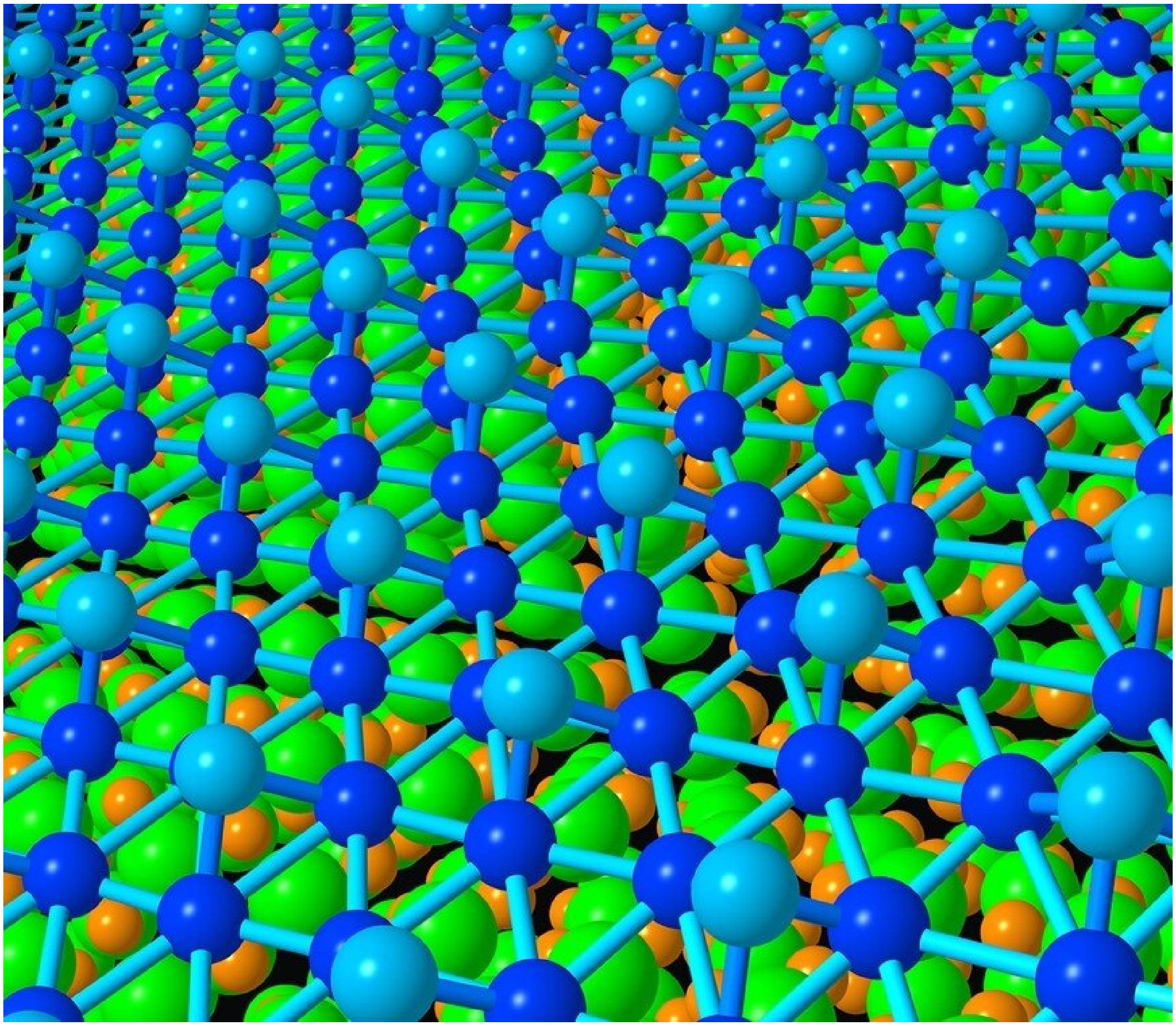

Figure 1. Ball-and-stick model for bitriangular Ge lattice on zirconium diboride Germanium atoms (light and dark blue) spontaneously crystallize into a two-dimensional (2D) “bitriangular” lattice on zirconium diboride thin films grown

on germanium single crystals (green: Zr atoms, orange: B atoms). Credit: Japan Advanced Institute of Science and Technology

Scientists have recently revealed, both theoretically and experimentally, that germanium atoms can arrange themselves into a 2-D "bi-triangular" lattice on zirconium diboride thin films grown on germanium single crystals to form a "flat band material" with an embedded "kagome" lattice. The result provides experimental support to a theoretical prediction of flat bands emerging from trivial atomic geometry and indicates the possibility of their existence in many more materials.

The human mind is naturally drawn to objects that possess symmetry; in fact, the notion of beauty is often conflated with symmetry. In nature, nothing epitomizes symmetry more than crystals. Since their discovery, crystals have attracted a great deal of attention not only by their unique "symmetrical" aesthetic appeal but also by their unique properties. One of these properties is the behavior of electrons inside a crystal. From a physical point of view, an electron within a crystal can be fully characterized by its energy and a quantity called "crystal momentum," which relates to how fast the electron moves in a crystal. The relationship between the energy and crystal momentum of electrons is what scientists refer to as "band structure," which, put simply, is the allowed energy levels for the electrons within the crystal.

Recently, materials scientists have turned their attention towards what are called "flat band materials"—a class of materials possessing a band structure in which the energy does not vary with the crystal momentum and hence resembles a flat line when plotted as a function of crystal momentum—owing to their ability to give rise to exotic states of matter, such as ferromagnetism (iron-like spontaneous magnetism) and superconductivity (zero resistance to electricity flow). Generally, these "flat bands" are observed in special 2-D structures that go by names like "checkerboard lattice," "dice lattice," "kagome lattice," etc. and are typically observed either within the crystal or at the surface of layered materials. A pertinent question thus presents itself—is it possible to embed such lattices into completely new 2-D structures? Efforts to design 2-D materials have focused on answering this question, and a recent finding suggests that the answer is a "yes."

Now, in a study published in *Physical Review B* as a Rapid Communication, an international team of scientists from the Japan Advanced Institute of Science and Technology (JAIST), the University of Tokyo, the Japan Atomic Energy Agency, and Institute for Molecular Science in Japan and Tamkang University in Taiwan, led by Dr. Antoine Fleurence and Prof. Yukiko Yamada-Takamura, has reported a possible new flat band material obtained from germanium (Ge) atoms arranging themselves into a 2-D bi-triangular lattice on zirconium diboride thin films grown on germanium single crystals. While the team had already grown this 2-D material years ago, they were only recently able to unveil its structure.

Last year, a part of the team published a theoretical paper in the same journal underlining the conditions under which a 2-D bi-triangular lattice can form a flat band. They found that this is related to a "kagome" (meaning weaved basket pattern in Japanese) lattice—a term originally coined by Japanese physicists in the '50s to study magnetism. "I was really excited when I found out that the electronic structure of kagome lattice can be embedded into a very different-looking 2-D structure," recalls Prof. Chi-Cheng Lee, a physicist at Tamkang University, Taiwan, involved in the study, who predicted the presence of flat bands in the "bitriangular" lattice.

The prediction was finally confirmed after the team, in their current study, characterized the prepared 2-D material using various techniques such as scanning tunneling microscopy, positron diffraction, and core-level and angle-resolved photoelectron emission; and backed up the experimental data with theoretical calculations to reveal the underlying bi-triangular lattice.

"The result is really exciting as it shows that flat bands can emerge even from trivial structures and can possibly be realized in many more materials. Our next step is to see what happens at low temperature, and how it is related to the flat bands of the Ge bi-triangular lattice," says Dr. Fleurence, who is also the first author of this paper.

Indeed, who would've thought that a typical, run-of-the-mill semiconductor like germanium could offer such exotic and unprecedented possibilities? The 2-D world might have more surprises up its sleeve than we imagine.

More information: A. Fleurence et al. Emergence of nearly flat bands through a kagome lattice embedded in an epitaxial two-dimensional Ge layer with a bitriangular structure, *Physical Review B* (2020). DOI: 10.1103/PhysRevB.102.201102

Provided by Japan Advanced Institute of Science and Technology