Physicists discover 'super crystals' in a semiconductor

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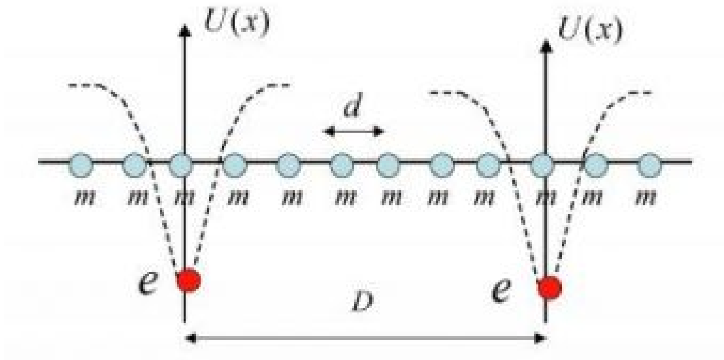

In this schematic drawing of a super-crystalline phase, the blue balls represent the periodically arranged organic molecules and the dashed lines represent a periodic superlattice of soliton walls. The superlattice D is from hundreds to thousands times larger than the period of the crystal, d. The soliton walls serve as traps for electrons, represented by red balls. The soliton wall superlattice and electron standing waves, localized on the walls, give super crystals their unique conducting properties. Credit: Courtesy of Andrei Lebed and Si Wu

University of Arizona physicists have discovered that "super crystals" -- crystals which are hundreds to thousands times larger than conventional crystals -- exist in certain organic semiconducting solids.

Pure super-crystalline organic semiconductors will conduct electricity much differently than conventional solids. Super-crystalline semiconductors, for example, could create splashes of current on electrical contacts, even in a uniform electric field, say UA physicist Andrei Lebed and graduate student Si Wu.

Most people understand how liquids freeze as solid crystals when temperatures become cold enough, like water droplets crystallizing into snowflakes or molten glass hardening into solid glass. Snowflakes are homogenous solids formed by a repeating, three-dimensional pattern of molecules that have fixed distances between the repeating molecular units. Solid glass approaches a perfect crystalline pattern, too, after a few hundred years, Lebed said.

Latter 20th-century physicists realized that at low enough temperatures, most liquids that exist in nature become energetically unstable as they solidify. Scientists discovered solids that don't have the commonly known, regular crystalline and glass phases - things like liquid crystals, quasi-crystals and charge-density waves. Charge-density waves are systems that display interesting physics, such as metals becoming insulators.

Understanding the physical nature of a solid phase is one of the most important problems in condensed matter physics, both from a fundamental point of view and from an applications point of view, Lebed and Wu said.

Leading American and Soviet physicists first predicted more than 25 years ago that some organic metals should be made up of "super crystals," Lebed said. Nobel laureate Robert Schrieffer, physicist Lev Gor'kov, who is a pioneer in superconductivity, and other members of the National Academy of Sciences were among the first to predict super crystals.

In super crystals, not only do the patterns of atoms or molecules repeat, there is also a periodically repeating super-structure of plane traps for electrons, Lebed said. "The distance between these plane traps, which are called soliton walls, are typically hundreds to thousands times greater than the distances between the organic molecules." (See the accompanying graphic, above, that illustrates this concept.)

U.S., Soviet and Japanese scientists, including Lebed, collaborated in research to discover the soliton wall superlattices, or super crystals, in organic metals. "Unfortunately, so far no one has discovered super crystals in organic metals," Lebed said.

Lebed and Wu are among the solid state theorists who collaborate with experimentalists in studying other materials that might possibly be super-crystalline.

"Our hopes for a discovery of a long awaited super-crystalline phase were raised after we started to analyze experimental data of James Brooks' group," Lebed said.

Brooks directs condensed matter experiments at the National High Magnetic Field Laboratory in Tallahassee, Fla. Three years ago, physicists there discovered a mysterious solid-state phase in a semiconductor made up of very complicated organic molecules, molecules of perylene (Per) and maleonitriledithiolate (mnt), in high magnetic fields.

"When Wu and I, who are theorists, analyzed the experimental data, what we found was a complete surprise to us," Lebed said. "Our theoretical calculations showed that the only way to explain the appearance of a mysterious high magnetic field state was to suggest that it appears inside a super-crystalline phase."

Lebed and Wu published their study in the July 13 issue of *Physical Review Letters*.

Future experiments are needed to confirm the theoretical discovery, Lebed added.

If experiments do confirm Lebed's and Wu's results, the novel, exotic solid phase in organic semiconductors promises important technological applications. Such semiconductors will conduct electricity in novels ways. Another striking feature of the super-crystalline semiconductor is that its period and electronic properties might be tuned by changing the strength of the external magnetic field, Lebed said.

Source: University of Arizona