Researchers Induce Superconductivity in an Insulator

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(PhysOrg.com) -- To continue to improve semiconductor devices, such as transistors, which form the backbone of the consumer electronics industry, researchers need to be able to control the movement and density of the electric charge within them.

Many scientists are particularly interested in finding ways to increase the maximum density of charge in semiconductor devices. Doing so could lead to a major achievement in semiconductor research: inducing superconductivity in field-effect transistors (FETs) -- tiny semiconductor-based devices essential to integrated circuits (a single computer chip can contain millions). FETs could be vastly improved, eventually leading to better products for consumers.

One key way to control charge density is by mixing in impurity atoms, a process called doping. Another way is using external electric fields. But in the latter method, problems arise with FET types that have insulating layers, such as the metal-oxide-semiconductor FET, or MOSFET (where the oxide layer is an insulator).

Recently, researchers from Tohoku University in Sendai, Japan, and the Japan Science and Technology Agency demonstrated that it is possible to make an insulator superconduct within an FET structure. In the October 12 online edition of Nature Materials, the scientists describe their unusual FET structure, which incorporates an organic current-carrying material (an electrolyte) consisting of a polymer mixed with a salt.

The basic structure is layered: a top platinum electrode, the electrolyte, and strontium titanate ($SrTiO_3$), a mineral and strong insulator. Attached to the $SrTiO_3$ surface are two gold islands that serve as electric leads and contacts. The total structure has a thickness of only a few hundred nanometers (billionths of a meter).

When a voltage is applied across the platinum layer and gold contacts using a battery, turning the structure "on," the effect is of a double-layer capacitor. The voltage splits the positive and negative ions in the electrolyte, sending negative charge to upward to the platinum surface and positive charge downward. This induces a very large negative "image" charge on the $SrTiO_3$ surface, forming a conduction path between the two gold contacts. The electrolyte acts as a dielectric, an insulating material used between two capacitor plates to allow more charge to be stored before the capacitor breaks down.

Corresponding author Masashi Kawasaki, who is affiliated with both Tohoku University and the Japanese Science and Technology Agency, told *PhysOrg.com*, "The problem with past attempts to use electric fields to induce superconductivity in an insulator is there were no dielectric materials that could sustain a high enough field to build up the necessary charge in the insulator. So instead of the standard dielectric oxide, we've used a conducting polymer."

Using this method the researchers increased the $SrTiO_3$ charge-carrier density from zero to approximately 10 trillion carriers per square centimeter. When cooled down to 0.4 K (about -460 degrees Fahrenheit), it becomes superconducting.

Kawasaki and his colleagues think their approach is a promising way to discover superconducting behavior in other unlikely materials.

"We do not need to worry about the complicated chemistry involved in mixing materials. All we need is a polymer and a battery. This way of making a superconductor may open a door to unexplored superconducting materials," said Kawasaki.

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