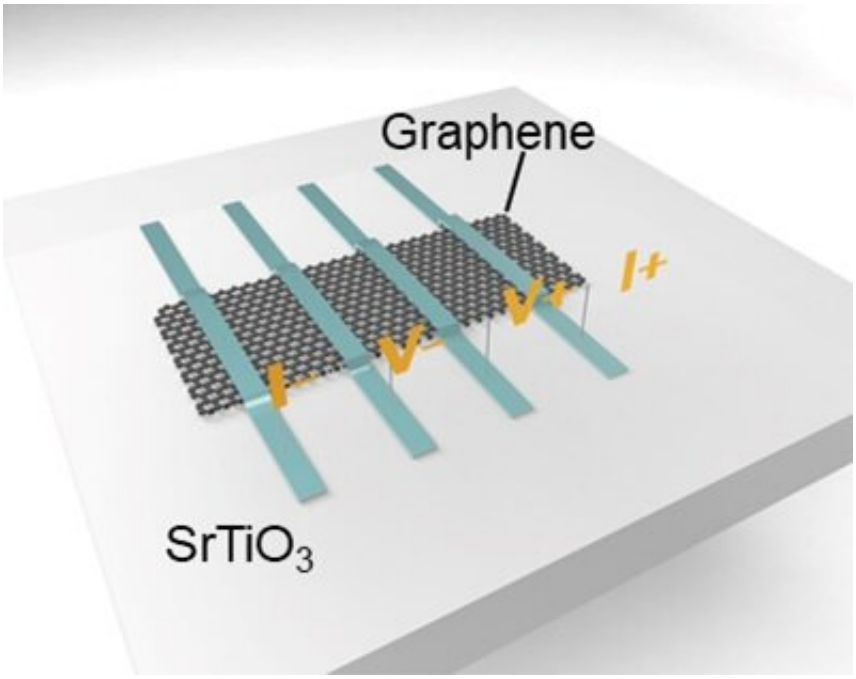
New insights into memristive devices by combining incipient ferroelectrics and graphene

November 23 2020



This illustration shows how strontium titanium oxide is combined with graphene strips. The combination opens up a new path to memristive heterostructures combining ferroelectric materials and 2D materials. Credit: Banerjee lab, University of Groningen

Scientists are working on new materials to create neuromorphic computers with a design based on the human brain. A crucial component is a memristive device, the resistance of which depends on the history of

the device—just as the response of neurons depends on previous input. Materials scientists from the University of Groningen analyzed the behavior of strontium titanium oxide, a platform material for memristor research and used the 2-D material graphene to probe it. On 11 November 2020, the results were published in the journal *ACS Applied Materials and Interfaces*.

Computers based on switches that have a value of either 0 or 1. Using a great many of these binary systems, computers can perform calculations very rapidly. However, in other respects, computers are not very efficient. Brains use less energy for recognizing faces or performing other complex tasks than a standard microprocessor. That is because the brain is made up of neurons that can have many values other than 0 and 1 and because the neurons' output depends on previous input.

Oxygen vacancies

To create memristors, switches with a memory of past events, strontium titanium oxide (STO) is often used. This material is a perovskite, whose crystal structure depends on temperature and can become an incipient ferroelectric at low temperatures. The ferroelectric behavior is lost above 105 Kelvin. The domains and domain walls that accompany these phase transitions are the subject of active research. Yet it is still not entirely clear why the material behaves the way it does. "It is in a league of its own," says Tamalika Banerjee, professor of spintronics of functional materials at the Zernike Institute for Advanced Materials, University of Groningen.

The oxygen atoms in the crystal appear to be key to its behavior. "Oxygen vacancies can move through the crystal and these defects are important," says Banerjee. "Furthermore, domain walls are present in the material and they move when a voltage is applied to it." Numerous studies have sought to find out how this happens, but looking inside this

material is complicated. However, Banerjee's team succeeded in using another material that is in a league of its own: graphene, the two-dimensional carbon sheet.

Conductivity

"The properties of graphene are defined by its purity," says Banerjee, "whereas the properties of STO arise from imperfections in the crystal structure. We found that combining them leads to new insights and possibilities." Much of this work was carried out by Banerjee's Ph.D. student Si Chen. She placed graphene strips on top of a flake of STO and measured the conductivity at different temperatures by sweeping a gate voltage between positive and negative values. "When there is an excess of either electrons or the positive holes, created by the gate voltage, graphene becomes conductive," Chen explains. "But at the point where there are very small amounts of electrons and holes, the Dirac point, conductivity is limited."

In normal circumstances, the minimum conductivity position does not change with the sweeping direction of the gate voltage. However, in the graphene strips on top of STO, there is a large separation between the minimum conductivity positions for the forward sweep and the backward sweep. The effect is very clear at 4 Kelvin, but less pronounced at 105 Kelvin or at 150 Kelvin. Analysis of the results, along with theoretical studies carried out at Uppsala University, shows that oxygen vacancies near the surface of the STO are responsible.

Memory

Banerjee: "The phase transitions below 105 Kelvin stretch the crystal structure, creating dipoles. We show that oxygen vacancies accumulate at the domain walls and that these walls offer the channel for the

movement of oxygen vacancies. These channels are responsible for memristive behavior in STO." Accumulation of oxygen vacancy channels in the crystal structure of STO explains the shift in the position of the minimum conductivity.

Chen also carried out another experiment: "We kept the STO gate voltage at -80 V and measured the resistance in the graphene for almost half an hour. In this period, we observed a change in resistance, indicating a shift from hole to electron conductivity." This effect is primarily caused by the accumulation of oxygen vacancies at the STO surface.

All in all, the experiments show that the properties of the combined STO/graphene material change through the movement of both electrons and ions, each at different time scales. Banerjee: "By harvesting one or the other, we can use the different response times to create memristive effects, which can be compared to short-term or long-term memory effects." The study creates new insights into the behavior of STO memristors. "And the combination with graphene opens up a new path to memristive heterostructures combining ferroelectric materials and 2-D materials."

More information: Si Chen et al, Unveiling Temperature-Induced Structural Domains and Movement of Oxygen Vacancies in SrTiO3 with Graphene, *ACS Applied Materials & Interfaces* (2020). DOI: 10.1021/acsami.0c15458

Provided by University of Groningen

Citation: New insights into memristive devices by combining incipient ferroelectrics and graphene (2020, November 23) retrieved 23 May 2024 from

https://phys.org/news/2020-11-insights-memristive-devices-combining-incipient.html

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.