Scientists investigate how electric current flows in multilayer 2-D materials

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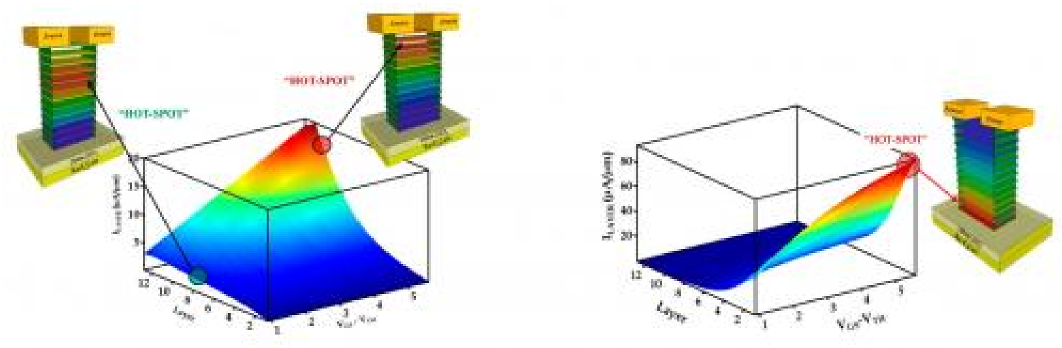

(Left) In 2-D, 13-layer MoS2, the "HOT SPOT" (the center of current distribution) is located in the upper layers at a large gate bias. (Right) In 2-D, 13-layer graphene, the "HOT SPOT" is located in the lower layers at a large gate bias. The difference arises because the location of a "HOT SPOT" is due to the material's physical properties. Credit: Das and Appenzeller. ©2013 American Chemical Society

(Phys.org) —Although scientists continue to discover the remarkable electronic properties of nanomaterials such as graphene and transition metal dichalcogenides, the way that electric current flows at this scale is not well understood. In a new study, scientists for the first time have investigated exactly how a current flows through multilayer 2-D materials, and found that current flow in these materials is very different than current flow in 3-D materials and cannot be explained with conventional models. This understanding could guide researchers in designing future nanoelectronics devices.

The researchers, Saptarshi Das and Joerg Appenzeller at Purdue University in West Lafayette, Indiana, have published their paper on current flow in 2-D layered materials in a recent issue of *Nano Letters*.

"Through our experimental approach, we have devised a new way to understand the current flow through these low-dimensional materials, and we also discovered that the conventional models for carrier transport that apply to bulk materials need to be revised for layered 2-D systems," Das told *Phys.org*.

In their study, the scientists experimentally evaluated the current flow and distribution in a transistor made of 2-D MoS_2, which was about 8 nm thick and consisted of approximately 13 layers. As the scientists explained, the current in the individual layers cannot be directly measured. So they devised an alternate method to map the current distribution in the multiple layers, which involves channel length scaling using a scanning electron microscope.

The scientists found that the current in 2-D MoS_2 is distributed among the 13 layers so that the top layers have the highest mobility and lowest resistances, while the bottom layers have the lowest mobility and highest resistance. By calculating the weighted average of the current in the individual layers, the researchers determined the location of the "HOT-SPOT" as the center of the current distribution, which in this case was at the top layers.

However, when the scientists changed the bias voltage applied to the gate, the location of the "HOT-SPOT" also changed. At high gate bias values, the resistance of each layer is low and the "HOT-SPOT" is located at the top layers. But when the gate bias is decreased, the resistance increases and the "HOT-SPOT" migrates to the lower layers. This unusual migration of the "HOT-SPOT" as a function of the applied gate bias also gives rise to an additional resistance that the researchers call "interlayer resistance," which is not found in 3-D materials and cannot be explained within the conventional model of current flow based on Schottky barrier contacts.

The scientists also experimentally evaluated the current flow and distribution in 2-D graphene consisting of about 13 layers, and observed opposite effects compared to the MoS_2. Namely, the researchers found that the current predominately flows to the bottom layers in graphene, which is where the "HOT-SPOT" is located, while the top layers have a higher resistance. The researchers explain that this difference occurs because graphene and MoS_2 have different physical properties, and the position of the "HOT-SPOT" is governed by a material's physical properties. By knowing the physical properties of a multilayer 2-D material, the position of the "HOT-SPOT" can be predicted with a 5% error margin.

Understanding the current flow and distribution in multilayer 2-D materials—along with knowing that these features differ for different materials—will likely prove very useful when designing future electronics components.

"Understanding the carrier transport in low-dimensional materials is not only appealing from a fundamental scientific standpoint, but also equally important in the context of high-performance device design," Das said. "Our experimental study combined with analytical modeling provides novel insights on the current flow in two-dimensional layered materials like MoS_2 and graphene, which will be helpful for many researchers working in this field."

Das added that his future work will focus on the implementation of new device concepts based on novel 2-D materials that utilizes their unique electrical, mechanical and optical properties.

More information: Saptarshi Das and Joerg Appenzeller. "Where Does the Current Flow in Two-Dimensional Layered Systems?" *Nano Letters*. DOI: 10.1021/nl401831u

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