MAMO 13.05.14.

Posted: Apr 30, 2014

Better control over topological insulator could revolutionize computer, telecommunications industries

(*Nanowerk News*) In April 2014, a project in which Pedro L. Galindo, University Professor and member of the Computer Engineering Department of the University of Cadiz (UCA), has participated in has been featured on the cover of the magazine *Nature Physics* ("Tuning Dirac states by strain in the topological insulator Bi2Se3").

In this project, the discovery made by the co-authors of the project is explained: how to modify in a controlled way the behaviour of a family of revolutionary materials known as topological insulators. These materials are destined to become the forerunners of a new generation of microprocessors with high performance and low energy consumption which will revolutionize the computer, mobile phone, telecommunication and car industries, etc. Remember that nowadays, any industrial, domestic or energy consuming device has a microprocessor incorporated.

In 2007, a new family of materials was discovered in experiments: topological insulators. Since then, a large number of researchers have centred their work on them. These peculiar materials behave in a strange way as they are insulators on the inside but behave like conductive metals on the surface. That is to say, the material behaves like a relatively thick layer of plastic that separates two extremely thin layers of conductive material, with the difference that the whole thing is made of one and the same material: it simply behaves in this way. When this material is only a few atoms thick its surface can conduct electricity with an efficiency of almost 100%.

Under the title "Tuning Dirac states by strain in the topological insulator Bi2Se3", the project has been carried out over the last few years in collaboration with researchers from the University of Wisconsin (USA) and the University of York (UK). Through this project, it has been demonstrated both theoretically (with DFT simulations) and experimentally (using advanced techniques for determining the distortion from electronic microscope images), that the behaviour of a topological insulating material (Bi2Se3) is proportionally correlated to its distortion.

This fact opens the doors to the possibility of using distortion to develop devices whose behaviour can be modified in a controlled way. In this way, for example, the piezoelectric effect could be used and by applying electricity to a crystal, distort it and thereby control the topological insulator dynamically.

Dr. Pedro L. Galindo's work is the fruit of many years of work at the heart of his research group and focusses on calculating the structural distortion in high resolution images from electronic microscopes. His software for calculating distortion is called Peak Pairs Analysis (PPA), the

fundaments of which were published in the magazine Ultramicroscopy, and which has been distributed by the Japanese company HREM Research Inc. (world leaders in software applied to electronic microscopes) since 2009 from their headquarters in Tokyo, via a Temporary Licence Agreement from the UCA. The income from the royalties of this software are the largest source of the UCA's income from this concept. Over the last few years, the software has been purchased by businesses, research centres and universities of important standing such as SAMSUNG, TOSHIBA, FEI, JEOL, U.S. Air Force, Sandia Labs., Oak Ridge Natl. Lab, Los Alamos Labs., Max-Planck Institute, TU Wien, KBSI Korea, ITRI Taiwan, Osaka Univ., and Beijing Univ. of Technology, among others.

For the development and improvement of this aforementioned software, the UCA's supercomputer has been used (http://supercomputacion.uca.es), a machine which was financed by European Regional Development Funds (ERDF) in two stages, for a total of nearly a million Euros, and the application, design and implantation of which was led by Pedro L. Galindo and carried out in collaboration with other research groups at the UCA (Dr. Rafael García Roja) and personnel from the central computer service (Abelardo Belaústegui and Gerardo Aburruzaga). This machine, one of the most powerful in Andalusia, is currently in the service of the UCA's research community.

It is important to emphasize that this project, published in Nature Physics, has as its final objective the manufacturing of real devices of exceptional characteristics. For example, topological insulating materials could be used to wire the components of a microprocessor, allowing the electrons to flow at speeds near to light speed, with a practically non-existent energy consumption, thereby reducing the generation of heat which would allow the calculation speed to be increased enormously.

Source: *Universidad de Cádiz*

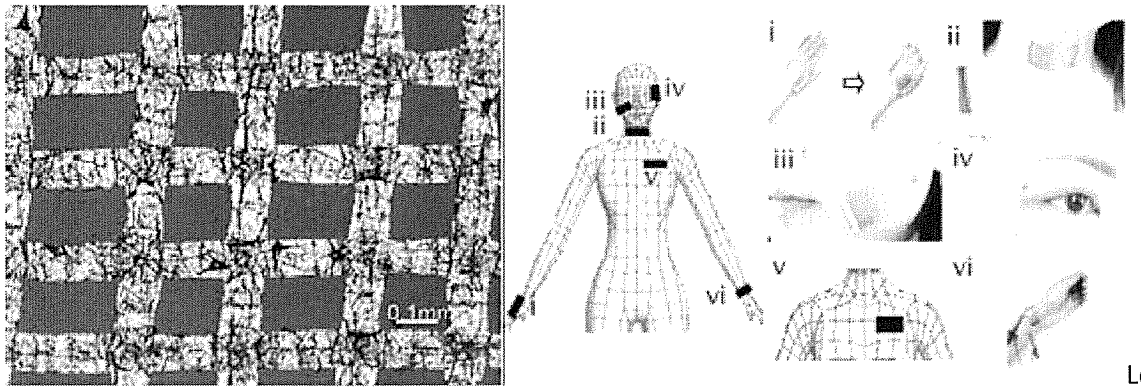
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Posted: Apr 30, 2014

Wearable graphene strain sensors monitor human vital signs

(*Nanowerk Spotlight*) Monolayer graphene exhibits exceptional electronic and mechanical properties, making it, among other applications, a very promising material for nanoelectromechanical devices. Last year, for instance, researchers demonstrated that the piezoresistive effect in graphene in a nanoelectromechanical membrane configuration can provide direct electrical readout of pressure to strain transduction. Graphene's piezoresistive effect,

combined with its other properties such as ultra-translucency, superior mechanical flexibility and stability, high restorability, and carrier mobility, enables the use of graphene in high-sensitivity strain sensors. Potential application areas for these sensors could be found in flexible display technology, robotics, smart clothing, electronic skin, *in vitro* diagnostics, implantable devices, and human physiological motion detection – which has been considered as an effective approach to evaluate human health. To demonstrate this application, researchers at Tsinghua University and Nanchang University in China have now reported on a method to monitor human motions. Their paper appeared in the April 14, 2014 online edition of *Advanced Function Materials* ("Wearable and Highly Sensitive Graphene Strain Sensors for Human Motion Monitoring"). "We prepared a simple-structured and low-cost graphene woven fabrics (GWFs) strain sensor, which can readily distinguish various strain levels of human motion signals," Hongwei Zhu, a professor at Tsinghua University, tells Nanowerk. "As we applied stress on the strain sensor, high-density cracks generated in the network, leading to the decrease of current pathways decrease and the increase of resistance."



Left: Optical photograph of a GWFs-PDMS-tape composite film. Right: Photo images of GWFs-PDMS-tape at various positions. (Image: Prof. Zhu, Tsinghua University) The team obtained their GWFs by using chemical vapor deposition (CVD) to grow graphene on the surface of crisscross copper meshes – similar with the graphene growth on the copper foil substrate. Subsequently, the copper mesh was etched away and the remaining graphene fabric transferred to a pretreated film composited with medical tape and PDMS glue, which is a flexible, biocompatible, shape controllable material, upside as the substrate. Completing the strain sensor was the connection of silver wires to the graphene mesh. When used as a human motion sensor, the signals of GWFs resistance change depend on deformation strain which is formed by the motions. The stronger the motion is, the larger the strain is, and the easier the motion signals can be recorded. "Our GWF strain sensor can readily distinguish various strain levels of human motion signals," says Zhu. "Thanks its special crisscross configuration compared to conventional graphene films, GWFs possesses an extremely high gauge factor, which we calculated to be ~103 under 2-6% strains, 106 under higher strains (>7%), and ~35 under small strain of 0.2%. This indicates that the sensor could be stretched by a tiny deformation of 0.2% with obvious resistance change, enough to be recorded." In other words, as Zhu notes, the signals of any weak motions, including vital signs such as pulse and breathing, phonation, expression changes, or blink of an eye, can be detected (as illustrated in the figure above). The sensor could also endure a large deformation of 30% with the completely reversible electrical property. "Owing to its distinctive features of high sensitivity and reversible extensibility, our graphene-based piezoresistive sensors have wide potential applications in fields of flexible displays, robotics, fatigue detection, body monitoring, *in vitro* diagnostics, and advanced therapies," Zhu concludes. *By Michael Berger.*
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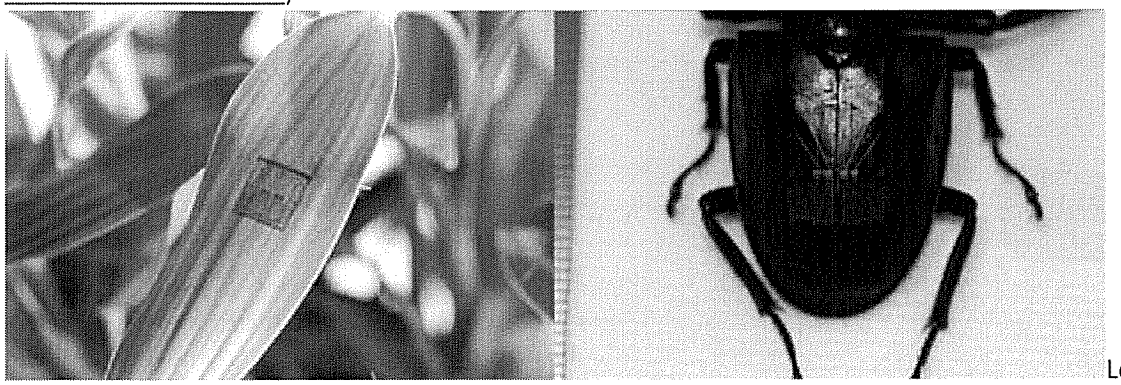
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Posted: May 02, 2014

Integrating nanoelectronic devices onto live plants and insects

(*Nanowerk Spotlight*) Conventional electronic devices are composed of stiff and brittle silicon materials which tend to be mechanically incompatible with nonplanar or flexible substrates; yet the future of electronics will be flexible and transparent. There are basically two ways of achieving this: develop low-cost generic batch process using a state-of-the-art CMOS process to transform conventional silicon electronics into flexible and transparent electronics while retaining its high-performance, ultra-large-scale-integration density and cost (read more: "Flexible and semitransparent silicon electronics"). Or develop new substrates and techniques such as inkjet-printing of graphene or other semiconductor inks on flexible substrates (also see: "Flexible, carbon-based nanotechnology thin-film transistors"). Taking the approach of flexible electronics one step further, researchers in Korea now have integrated all-carbon based electronic devices to live plants and insects. They report their findings in the April 17, 2014 online edition of *Nano Letters* ("In-situ Synthesis of Carbon Nanotube–Graphite Electronic Devices and Their Integrations onto Surfaces of Live Plants and Insects").



Left: SWCNTs-graphite arrays transferred onto surface of a live leaf and (right) onto a live beetle. (Images: Dr. Lee, UNIST) "Technologies to interface electronic circuits, especially sensor networks that have capabilities of transferring information and power wirelessly, with living flora and fauna can monitor the conditions of the environment, including the detection of chemical weapons, pollution, and infections, etc.," Kyongsoo Lee, a postdoctoral fellow in Prof. Jang-ung Park's Flexible Nanoelectronics and Biotechnology Lab at Ulsan National Institute of Science and Technology (UNIST), tells Nanowerk. "In addition, the attached devices can function consistently as sensors even after the *in vivo* activities of animals and plants have stopped." Lee, first author of the paper, and a team of fellow researchers from UNIST, developed an unconventional approach for the *in situ* synthesis of monolithically integrated electronic devices based on single-walled carbon nanotube (SWCNT) channels and graphitic electrodes. The highly flexible transistors were formed directly by the *in situ* synthesis using patterned metal catalyst films and subsequently could be transferred to both planar and nonplanar substrates, including papers, clothes, and fingernails. Carbon nanotubes have high sensitivity to a large number of different gases and vapors which are important in areas as diverse as environmental monitoring, process monitoring in industry, agriculture, personal safety, medicine, or security screening. Gas sensors often operate by detecting the subtle changes that deposited gas molecules make in the way electricity moves through a surface layer. One advantage that CNTs offer for gas sensors is their fast response time and the fact that they react with gases at lower temperatures, sometimes even as low as room temperature. "On the basis of these

capabilities, we demonstrated a sensor platform which can be interfaced with inherent life forms in nature for monitoring environmental conditions wirelessly," says Lee. "To demonstrate our sensor technology, we conducted experiments with real-time gas sensor arrays on a leaf of a live plant (*Dracaena sanderiana cv. Virens*) and on the epidermis of a live insect (*Lucanus maculifemoratus dybowskyi parry*) for the detection of stimulants of sarin nerve agent (DMMP)." He adds that this all-carbon electronic device demonstrated superb mechanical flexibility and good adhesion to the nonplanar surfaces of biomaterials. The researchers are confident that their device technology may also find uses in a variety of other applications such as artificial skin that inculdes sensors and displays for collecting information, threat detection (toxins or pollutants), or as a component of wearable displays. The team are already planning to develop artificial skin for eletronics with unconventional geometries. Lee points out that remaining technical challenges arise from requirements for commercial applications, such as the need for long-distance detection, which can be improved by circuit design and using different nanomaterials. *By Michael Berger. Copyright © Nanowerk*

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