

Jumping droplets control heat flow

SURFACE SCIENCE

Might microscopic droplets of water that bounce from one surface to another hold the answer to building energy-efficient products as large as solar panels and as small as computer chips? That is the hope of engineers at Duke University who have developed a new type of thermal diode that can regulate the flow of heat by bleeding it away or retaining it.

A thermal diode allows heat to flow in only one direction, analogous to the way in which a conventional electronic diode lets electrical current flow only one way. However, solid-state thermal diodes are not as effective as those that exploit phase change involving vaporization or condensation to transport heat. Currently available phase-change thermal diodes transfer heat in one direction 100 times more effectively than the reverse, but usually rely on gravity to drip the condensate down. This essentially precludes their use in portable electronics devices where the appropriate orientation cannot be guaranteed, preventing the recycling of the working fluid by dripping. Such gravitational thermal diodes, or thermosyphons, are exploited in Alaskan oil pipelines to prevent the heat in the pipes from melting the permafrost.



Thermal diode. Courtesy of Chuan-Hua Chen.

The Duke engineers have turned to superhydrophobic and superhydrophilic materials to circumvent this issue of gravitational dependence. They realized that tiny water droplets condensing in a thermal diode with asymmetric wettability would be self-propelled from a water-repellent to a highly absorbent surface, but that the reverse process could not occur [Boreyko and Chen, *Appl Phys Lett* (2011) 99, 234105]. "The thermal rectification is enabled by spontaneously jumping dropwise condensate,

between parallel plates, which only occurs when the superhydrophobic surface is colder than the superhydrophilic surface," the team explains. The self-propelled jumping phenomenon was previously videotaped by the team [Boreyko and Chen, *Phys Fluid* (2010) 22, 091110].

"When the water-repellant surface is colder than the water-absorbent surface, the heat transport is very effective, much like sweat taking away body heat. When the water-repellant surface is hotter, the heat flow is blocked and the diode behaves like a double-paned window," Chuan-Hua Chen explains. It is the tiny size of the jumping droplets in Chen's thermal diodes that renders gravity negligible, enabling it to function in any orientation.

A major advantage of the jumping-drop thermal diode is its scalability thanks to the parallel-plate construction, which is enabled by the condensate droplets jumping perpendicular to the superhydrophobic surface. The scalability makes the design useful for thermal rectification in a broad range of systems, from thumb-sized computer chips to roof-supported solar panels.

David Bradley

Graphene and quantum dots go green

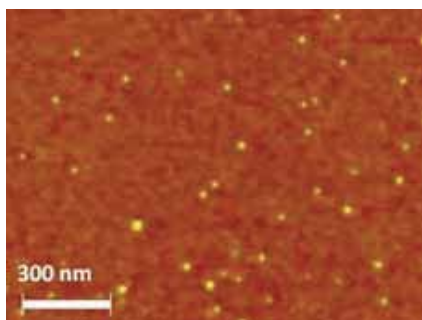
NANOTECHNOLOGY

A University of Ulster laboratory has found a simple, low cost, and environmentally friendly way to turn common graphite flakes into bulk amounts of either high quality graphene nanosheets or quantum dots.

The University of Ulster (UU) lab led by Pagona Papakonstantinou, Professor of Advanced Materials at UU, (in collaboration with colleagues in China, UK, and Ireland) discovered a simple process, which is quicker and more environmentally friendly than current established techniques. The results have been published online [Shang *et al.*, *Chem Commun* (2012) 48, 1877].

Past attempts to create high quality graphene quantum dots have involved sophisticated equipment or expensive raw materials, which have resulted in low yields. On the other hand, up to now, solution processes to produce graphene nanosheets and quantum dots in high yields have involved the use of strong acids or prolonged sonication, which introduce defects to the graphene nanocrystal.

The UU researchers came up with a simple method of producing high quality graphene nanosheets and dots. They ground cheap graphite flakes with a small quantity of ionic liquid to produce a gel and subsequently cleaned the ionic liquid. Grinding in ionic liquid helps to



AFM image of graphene quantum dots.

simultaneously fragment and exfoliate graphite flakes into graphene nanosheets. Their size can be tailored by varying grinding times.

The most important attribute of the graphene nanosheets and quantum dots compared to those reported in the literature is that they are free from any solvent contamination and possess a low concentration of oxygen, which is inherited from the original graphite powder. X-ray photoelectron spectra illustrated that the graphene products possess the same amount of oxygen

as that found in the graphite flakes. Supported by other microstructural investigations, this suggests that the center of graphene nanosheets and quantum dots is free of defects, and therefore it should be possible to maintain very high mobilities suitable for nanoelectronic devices.

Prof Papakonstantinou told *Materials Today*, "Our procedure is mild and relies on pure shear forces to detach the graphene layers from the graphite flakes. Moreover our method has the potential to be applied to other layered materials such as MoS₂ or BN in addition to graphite."

Dr Nai-Gui Shang, a researcher at UU, commented, "Grinding has been a traditional Chinese way of making ink for calligraphy and painting for over two thousand years, where the ink is produced by grinding the ink stick in an ink slab, mixed with a small amount of water. We thought why not try it with graphite flakes? Here, ionic liquid used as a novel, green grinding agent, plays a critical role in both the quality and high yield of the graphene nanostructures. We believe that graphene nanostructures produced in this way can be applied successfully to inkjet printing of nanoelectronics".

Jonathan Agbenyega