Connecting with the nano world

International outreach of materials and computer scientists and electronic engineers at Durham…

Microelectromechanical systems (MEMS) are micron size devices that combine electrical circuits and mechanical parts. These small-scale engineering devices are produced using modern silicon fabrication, also known as integrated circuits technology. Over the last 10 years, they have seen an ever increasing importance in our daily life and are found in most consumer electronics such as touchscreen devices, smartphones, portable PCs and tablets, cameras, kindles and games consoles, PDAs and hi-fi systems. They also play a key role in functional sensors, medical devices, automobiles and control systems.

This significant development is underpinned by recent progress accomplished in the fabrication technology and analytical tools. The net result is the miniaturisation of sensors, functional devices and complex computers exhibiting enhanced performance to be designed on a small fraction of their size than previously possible. Durham University is one of the key players in the development of these MEMS devices, actively engaged in the design of various sensors and functional devices and is closely working with industry.

Contamination source tracking

Under the FUST project (an SME-university project funded by the European Commission, Framework Programme 7), Durham is working with industry on the development of a fully automated cultivation and liquid sample handling system for high-throughput FTIR spectroscopy and databases. The main objective of this programme is the tracking and identification of mould contamination in fruit juice production lines, which is responsible for 12.5-40% spoilage due to fungal contamination.

Integration of carbon nanotubes

The expertise at Durham has expanded significantly to include the integration of nanomaterials into MEMS devices. For instance, collaborative research between teams from Durham University (Dr Zeze) and Lancaster University (Dr Kolosov), funded by the UK Engineering and Physical Sciences Research Council (EPSRC) between 2009 and 2012, has led to the development a sub 30 nanometre spatial and thermal resolution by integrating carbon nanotubes (CNTs) in scanning thermal microscopy (SThM). This enables direct mapping of localised temperature distribution and nanoscale energy transport in materials, including conductive materials such as a single layer of graphene as well as a few nanometre thick aluminium layer in Benzocyclobutene (BCB)/Al VLSI interconnects.

Two major breakthroughs in fabrication made this possible, i.e. the development of a new edge lithographic technique (ELITH) and the integration of CNTs in SThM using a combination of cleanroom processing and focused ion beam milling techniques. The outstanding physical properties of CNTs and their high aspect ratio, in particular, allow the point of contact between the CNT-SThM tip and the material under investigation to be as small as 9-60nm. As a result, feature sizes of the same order of magnitude can be topographically and thermally resolved, though the temperature mapping may be limited by the phonons mean free path.

ELITH exploits a polymer buffer layer and etching gas pressures to extend the capabilities of controlled undercutting methods (Advanced Materials 23, 5039, 2011). For instance, etching the polymer buffer at high pressures undercut the metal mask and the pair forms a lift off structure. In turn, low pressures etching are highly directional and lead to metal-polymer mask for substrate etching. The process can be repeated multiple times to create simple to complex nanometre size structures over large surface areas.

This new nanopatterning approach is simple, high yield and rapid for creating nanowires, dots, trenches and fins, without resorting to high resolution or expensive lithographic tooling. The method is highly selective, versatile and allows 80-400nm features to be created over large areas and over any solid substrate using conventional silicon fabrication. To demonstrate ELITH's potential for applications, gold nanowire transparent electrodes exhibiting excellent optoelectronic properties (high transparency and very low sheet resistivity), comparable to that of indium tin oxide (ITO) were produced. Such techniques, if developed further, may offer an alternative to ITO, the standard material used in transparent electrodes, which is based on rare earth metals, in very short supply and not environmentally friendly to manufacture. It can also deliver large area, pre-patterned transparent, yet highly conductive, electrodes for use in a wide variety of emerging and existing applications, spanning solar cells, flat panel display backplanes, plastic and flexible electronics.

As detailed in a recent article published in Nano Letters (2012), ELITH was used to pattern nanometre size trenches onto silicon oxide to investigate thermal transport properties in graphene nanostructures by SThM. Direct imaging of nanoscale thermal transport in few-layer graphene (Fig. 1) was demonstrated, with approximately 50nm lateral resolution. Subsequent work between Durham and Lancaster indicated that the integration of CNT in SThM (Fig. 2) can lead to controlled local nanolithography (oxidation) on highly doped silicon and achieve a spatial and thermal resolution better than 30nm. Therefore, direct thermal mapping to explore nanoscale ballistic and diffusive regimes of heat transfer in materials becomes possible.

This research offers a real potential to develop a non-destructive, true nanometre resolution CNT-SThM capable of recording simultaneously the response of materials undergoing energy excitation (thermal transport properties at the nanoscale). Hence, it could open the gate to new applications across a wide range of industries from electronics to biomedicine, crossing traditional interdisciplinary boundaries. For example, it will be possible to monitor the performance of nanoscale electronic circuitry, essential to produce cheaper, faster and reliable devices, and also to assist the accurate screening of biological samples and even to monitor drug delivery to bio-cells. Potential applications also include nanoscale failure analysis in micro and nano-circuitry, monitoring of real-time effect of drug on neurons and segregation of immiscible polymers.

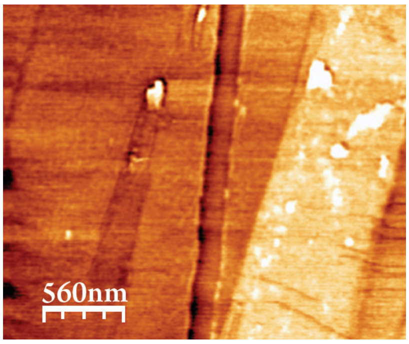

Fig.1 Scanning thermal mapping of a few graphene layers suspended over 180nm trenches prepared by ELITH

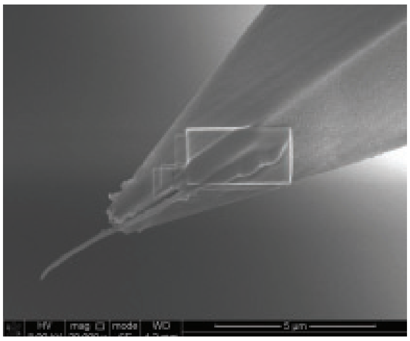

Fig.2 Carbon nanotube mounted SThM probe tip

Much of the current activity focuses on using microfabrication techniques to interface with the nanoscale materials where dimensions and tolerances in the range 0.1nm to 100nm play a critical role. This has helped Durham to secure a sizeable funding from the EC, under the FP7, through various network of excellence involving several European academic and industrial partners. Two of the project connecting the nanoscale to macroscopic world using MEMS interface are briefly outlined.

Computational carbon

A future and emerging technologies project (NASCENCE) combines the skills of Materials and Computer Scientists and Electronic Engineers at Durham with those of colleagues at the University of York, the University of Twente and the Norwegian University for Science and Technology. An initial aim is to model and understand the behaviour of molecular networks. However, a long-term goal is to build an electronic processor exploiting these architectures without reproducing individual component function, a computer without transistors.

One dimensional nanostructures

Durham is now leading a major EU-FP7 Marie Curie Action training programme 'NanoEmbrace' assembling eight industry partners and 10 internationally renowned institutions in materials science, engineering, chemistry, condensed matter physics and nanoscale device fabrication across Europe (the UK, France, Switzerland, Sweden, Italy, Russia, Finland and Austria). The project aims to gain superior control and understanding of one dimensional nanostructures and to facilitate their transfer from laboratory to industry. As such, understanding the mechanisms that govern their growth (which cannot all be described by existing models) as well as connecting them materials to the macroscopic world by integration of micro and nanofabrication are crucial aspects of this programme.

Despite the tremendous progress accomplished in MEMS technology over the past decade, which has seen their explosion in many daily consumer electronic devices, the technology is still at a seminal stage. Timely funding will lead to unprecedented discoveries and wide range of applications and help the UK to play a prominent role in this emerging multibillion science and technology paradigms.

Durham University

Dr Dagou Zeze
Senior Lecturer in Nanotechnology and Microsystems
School of Engineering and Computer Sciences
Durham University
Tel: +44 (0)1913 342531
d.a.zeze@durham.ac.uk
www.durham.ac.uk