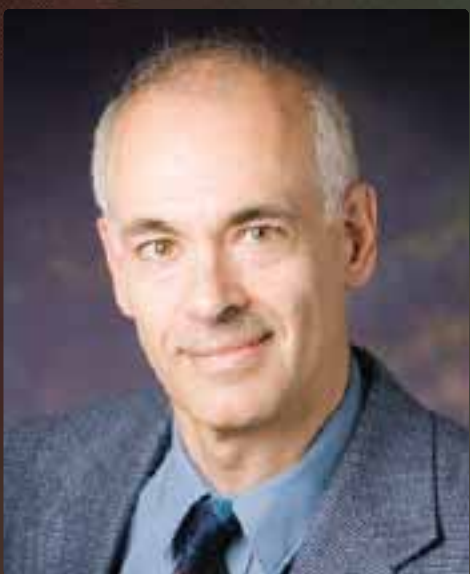
Carbon nanocreations

Scanning tunnelling microscopy pioneer and co-founder of technology company Tiptek, **Professor Joseph W Lyding** discusses his work on 2D materials and carbon nanotubes



Why did you choose to explore carbon nanotubes (CNTs) at the start of the century, and can you outline the most significant discoveries you have made since then?

It is very difficult to fabricate atomically perfect nanoscale structures. However, in the case of CNTs, nature does the job for us. That said, it is important to understand how nanotubes interact with their environment, which includes their electrical contacts and the surfaces they contact.

We set out to explore these effects, first by developing a method to deposit nanotubes onto atomically clean surfaces. We were then able to observe subtle effects; for example, what happens when you alter the alignment of a nanotube with the underlying atomic lattice of the substrate.

Can you give examples of carbon nanotube network (CNN) devices and provide an insight into what triggered your interest in finding a way to improve current conduction between nanotubes?

CNN devices are attractive in that they are quite easy to fabricate and have numerous potential applications; for example, in low-cost wearable flexible electronics. The key device is the transistor, whose speed and power efficiency critically depends on how well electrons can flow through the nanotube network.

Unfortunately, in these nanotube networks the electrons must jump from nanotube to nanotube as they pass from one end of the transistor to the other. These 'jumps' are very inefficient and slow down the performance of the transistor by a factor of 10 to 100. It simply occurred to me one day that the nanotube-nanotube junction problem could be solved via nanosoldering.

Beyond CNT research, what other areas does the Lyding Research Group explore?

We are exploring the fabrication of devices based on the 2D atomically thin materials graphene and boron nitride, as well as the layered transition metal dichalcogenides like molybdenum disulphide. There is a worldwide effort to study these and related materials to replace silicon in future integrated circuit chips.

In addition, we are investigating the atomically precise fabrication of semiconducting graphene nanoribbons by combining bottom-up chemical synthesis with top-down fabrication driven by electrons from our scanning tunnelling microscope (STM). We are also developing nanometre-scale metal wires that can be used to make connections to ultra-small structures like CNTs and graphene nanoribbons.

An offshoot of our work in microscopy has been the development of a patented tip sharpening process that now serves as the basis for a startup company, Tiptek, LLC, which was founded to commercialise this process.

What skills and expertise are represented in the Lyding Group? Who are your collaborators and what do they add to your studies?

My group has expertise in scanning probe microscopy. We construct our STM systems from the ground up as well as synthesise many of the materials, such as CNTs and graphene, which we use in our experiments. And we have expertise in fabricating these materials into electronic devices.

My collaborators include Professor Gregory Girolami (from the Chemistry Department of the University of Illinois at Urbana-Champaign – UIUC) whose group synthesises all of the molecules used in our nanosoldering experiments. We also collaborate with Professors John Rogers (UIUC Materials Science and Engineering) and Eric Pop (Stanford University Electrical Engineering). Their groups fabricate nanotube devices for the nanosoldering experiments.

To explain the subtleties of graphene-substrate interactions that we observe in our experiments, we use atomistic simulations performed by Professor Narayana Aluru (UIUC Mechanical Science and Engineering). And finally, we collaborate with Professor Salvador Barraza-Lopez (Physics Department of the University of Arkansas) who also conducts simulations to explain our atomistic-level experiments.

How do you involve undergraduate students in your nanotechnology projects? Is your aim to inspire the next generation of nanoscience thought leaders?

Undergraduates are heavily involved in our research. It is important to immerse them in open-ended problems that they do not see in their classroom curriculum. This is how I got my start in research and I found it to be enlightening and inspiring. A number of our undergraduate researchers have been authors on our papers and presented their research at major conferences.

In which areas do you see your investigations progressing in the next five to 10 years?

We are just beginning to obtain some very interesting results in our graphene nanoribbon experiments, so I expect this effort to grow in the near future. We are also exploring the effect of the nanosoldering process on mechanical strength and thermal conductivity of nanotube networks.