

environment, with the least possible lag between changes and their detection.

For Mauritius it was special, as this momentous coming together of IOR nations and the signing of the MoU happened quite appropriately at the centre of the Indian Ocean triangle. And by hosting this conference, this strategically located country in the Indian Ocean has shown to the world community the importance Mauritius attaches to ocean issues and also demonstrated her readiness

to play a significant and central role in the development of operational oceanography in the Indian Ocean. For the first term (2002–2004), K. Radhakrishnan (India) was elected as Chairman of IOGOOS. The other IOGOOS officers are J. Kasungu (Kenya) representing Eastern African region, H. Ganoo (Mauritius) representing the Island states, A. Forbes (South Africa) representing the Southern African region, N. Smith (Australia) representing Eastern Indian Ocean

Region, while the Indian National Centre for Ocean Information Services (INCOIS), Hyderabad would host the Secretariat.

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Pollin Prize for Mahalanabis

Dilip Mahalanabis recently received the first Pollin Prize (2002) in Pediatric research. Mahalanabis is cited for his seminal contributions to the discovery and implementation of the oral rehydration therapy (ORT) for infectious paediatric diarrhoea, in place of the usual intravenous fluid replacement. Three Americans (Norbert Hirschhorn, David R. Nalin and Nathaniel F. Pierce) shared the Prize along with him.

The Pollin Prize, an international award created by Irene and Abe Pollin and their family from Maryland (USA), recognizes outstanding research achievements in areas relating to children's health. The inaugural prize has been awarded in New York on 15 November 2002. The award consists of a cash prize of US \$ 100,000 in addition to a US \$ 100,000 fellowship grant for another staff position.

Mahalanabis holds a medical degree from the Calcutta University, and postgraduate diploma and certificate in paediatrics from London and Edinburgh (UK). Before taking up his current position as the Honorary Director of a non-governmental research organization, Society for Applied Studies, Kolkata, he has served in various capacities in Kolkata and also for the World Health Organization. He is a member of the Royal Swedish Academy of Sciences.

RESEARCH NEWS

Sensitive flow sensors with carbon nanotubes

Nirupa Sen

Sensors are basically devices which work on the ability to convert one form of energy which is not directly measurable, to another which can be measured. For example, our eyes are light sensors – converting light energy to electrical pulses that are recorded by the brain. Sensors are so much a part of our lives that we are quite oblivious about them. They are in our cars, watches, heating ovens, computer printers . . . , the list is endless.

A flow sensor is a device which can record fluid flow. What is so special about a flow sensor with nanotubes? It is part of an ongoing effort worldwide to have a representative in the microscopic nano-world of all the sensing elements in our present macroscopic world (world with large objects). As part of this ongoing quest Shankar Ghosh, Ajay Sood and N. Kumar have recently discovered a new phenomenon that takes place when a

liquid flows on carbon nanotubes, and provided a theoretical explanation for the same¹. This will allow application of this phenomenon for measuring fluid flows and at the same time make it amenable to fine tuning, to enhance efficiency.

Carbon nanotube structures are fullerene-related consisting of graphene cylinders closed at either end with caps containing pentagonal rings (Figure 1). Discovered in 1991 by the Japanese electron microscopist Sumio Iijima while studying the material deposited on the cathode during the arc-evaporation synthesis of fullerenes². The central core of the cathodic deposit found by him contained a variety of closed graphitic structures including nanoparticles and nanotubes. It was the first time a material with such a revolutionary structure was seen. A short time later, Thomas Ebbesen and Pulickel Ajayan, from Iijima's lab, showed how nanotubes could be pro-

duced in bulk quantities by varying the arc-evaporation conditions³. This simple method of preparation of these materials has paved the way to a multitude of research efforts looking into the physical and chemical properties of carbon nanotubes in laboratories worldwide. Single wall carbon nanotube bundles, with an average tube diameter of 1.5 nm used in the experiment of Sood *et al.*, were prepared by the electric-arc method in C. N. R. Rao's laboratory⁴.

What Sood and coworkers have actually found is the development of current/voltage in a bundle of single-walled carbon nanotubes when the bundle is kept in contact with flowing liquid. Development of such current/voltage was predicted by P. Král and Moshe Shapiro in 2001 who theoretically investigated the behaviour of nanotubes in a flowing liquid⁵. Generally an electric current in a material is produced when flow of free charge carri-

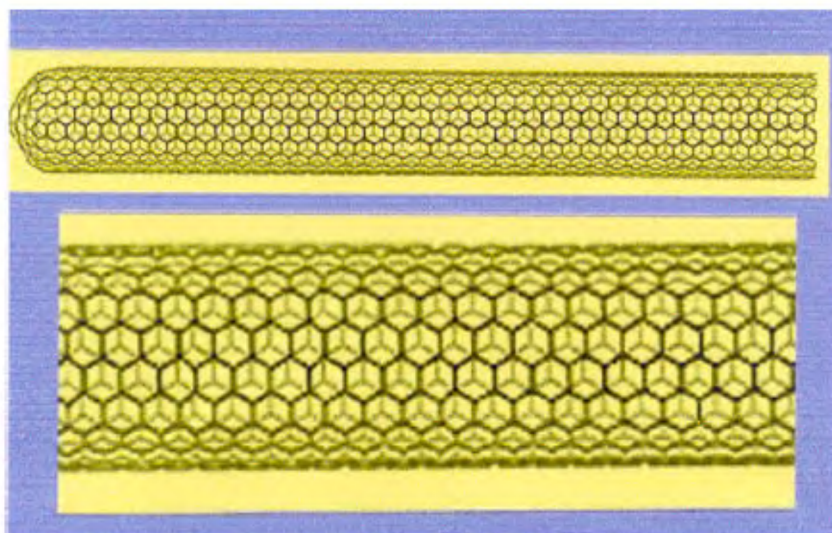


Figure 1. Carbon nanotubes (upper plate). Enlarged view showing details (lower plate).

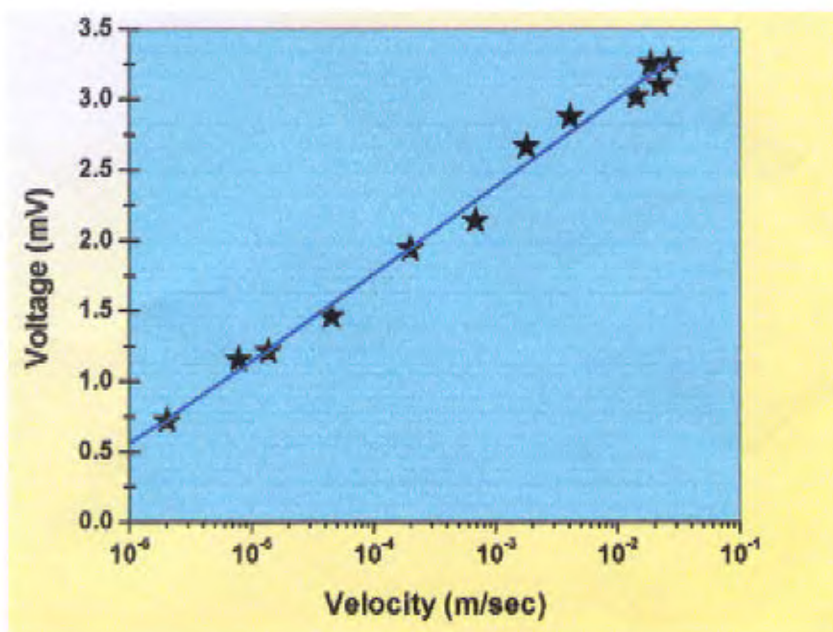


Figure 2. Variation of voltage developed as a function of velocity of water. Solid line is a fit to logarithmic functional form.

ers is induced in the material. According to Král and Shapiro, the generation of an electric current in a nanotube is essentially due to transfer of momentum from the flowing liquid molecules so as to have a dragging effect on the free charge carriers in the nanotube. The outcome, according to these workers, is a linear dependence of the induced electric current on the flow velocity.

In sharp contrast, Sood and coworkers have found that the behaviour is highly

sublinear where the induced voltage fits a logarithmic velocity dependence over nearly six decades of velocity (Figure 2). The magnitude of the voltage/current also depends on the ionic conductivity and the polar nature of the liquid. As ions and polar molecules have fluctuating Coulomb fields, Sood *et al.* have assigned the observed behaviour to scattering of free carriers by these fluctuating fields. The exact model is termed as 'the pulsating asymmetrical ratchet model'. The terms

describe the phenomenon itself, whereby ions flowing past a certain point in the nanotube produce Coulomb pulses while the asymmetry is provided by the velocity gradient at the liquid–solid interface.

Sood *et al.* found that even at a very low flow velocity of 5×10^{-4} m/s, a voltage of 0.65 mV is generated and for a flow velocity of the order of 10^{-5} m/s saturation was observed. The experimental data points fitted to an empirical equation $V = \alpha \log(\mu\beta + 1)$ showing the sensitivity of the generated voltage to the flow velocity. This aspect of the discovery qualifies this to be a flow sensor. Further, it can be used as energy conversion device, i.e. nanotubes can generate voltages in flowing liquid environment.

The prospects for carbon nanotube research are exciting, as their shapes, ranging from single-layer, ropes, horn, etc. demonstrate immense potential. The fact that carbon nanotubes can be filled at will, with even biological molecules, opens a plethora of possibilities. Nanohorns are now part of a new generation fuel cells for hydrogen storage, etc. and carbon nanotubes could even substitute silicon as future chips. The structure of nanotubes, and their individual properties, whether conducting or insulating, determine their role as dream candidates in the realm of nanoelectronics. Their strength gives their usefulness an added dimension. Despite the large volume of research in carbon nanotubes and its applications, there is a long way before we can eye products in the market. Yet, the thrilling progress on the research front in this area clamours for attention.

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