

Gas flow over carbon nanotubes and doped semiconductors sparks a voltage

Bangalore The team that last year generated voltage and current by passing liquids over carbon nanotubes¹ now claims to have produced a similar effect by using gases as well.

Physicists Ajay Sood and his graduate student Shankar Ghosh, of the Indian Institute of Science in Bangalore, report² the direct generation of measurable voltages and currents when a gas flows over a variety of solids, even at the modest speed of a few metres per second².

The researchers say that the underlying mechanism is an interesting interplay of Bernoulli's principle and the Seebeck effect. Pressure differences along the streamlines give rise to temperature differences across the sample, they say; these in turn produce the measured voltage.

The electrical signal produced depends on the square of the Mach number, M , a guide to the flow speed, and is proportional to the Seebeck coefficient of the solids. The Seebeck effect states that when a thermal gradient is applied to a solid it will be accompanied by an electric field in the opposite direction; the Seebeck coefficient is a measure of this.

The scientists have presented the results for doped silicon and germanium, single- and multi-wall carbon nanotubes and graphite. "Our results show that gas flow sensors and energy conversion devices can be constructed, based on the direct generation of electrical signals," the scientists claim.

Last year, the duo, along with their colleague N. Kumar, demonstrated that

the flow of liquids over single-wall carbon nanotubes generates a voltage in the tubes along the flow direction¹. The induced voltage had a logarithmic dependence on flow velocity; this phenomenon was specific to the one-dimensional nature of the nanotubes and was absent in graphite.

Having demonstrated this phenomenon using liquids, the scientists investigated whether similar mechanisms could generate voltages in carbon nanotubes from the flow of gases as well.

In their paper², the duo show that an equally striking effect exists for gas flow, "but for a fundamentally different reason from the mechanisms operating for the liquid flow".

Specifically, they have shown that the flow of common gases such as argon, nitrogen and oxygen over single-wall carbon nanotubes causes the direct generation of voltage. They also observed that the effect is not unique to nanotubes — they have also generated voltage in a wide variety of solids, including single- and multi-wall carbon nanotubes, doped semiconductors and metals. This has been achieved using a wide range of gas velocities: in their experiments (see Fig. 1 for the experimental set-up) they used a range of flow speeds from 1 to 140 metres per second.

The researchers also established that the voltage and current depend quadratically on the flow velocity, whereas the magnitude and sign of the voltage are dependent on the properties of the solid. The team used single crystals of n-type germanium, n-type silicon, p-type silicon, single-wall carbon nanotubes, multi-wall carbon nanotubes, graphite and polycrystalline copper to establish the ubiquity of voltage generation induced by gas flow.

For argon at a flow velocity of 11 metres per second, the voltage generated is

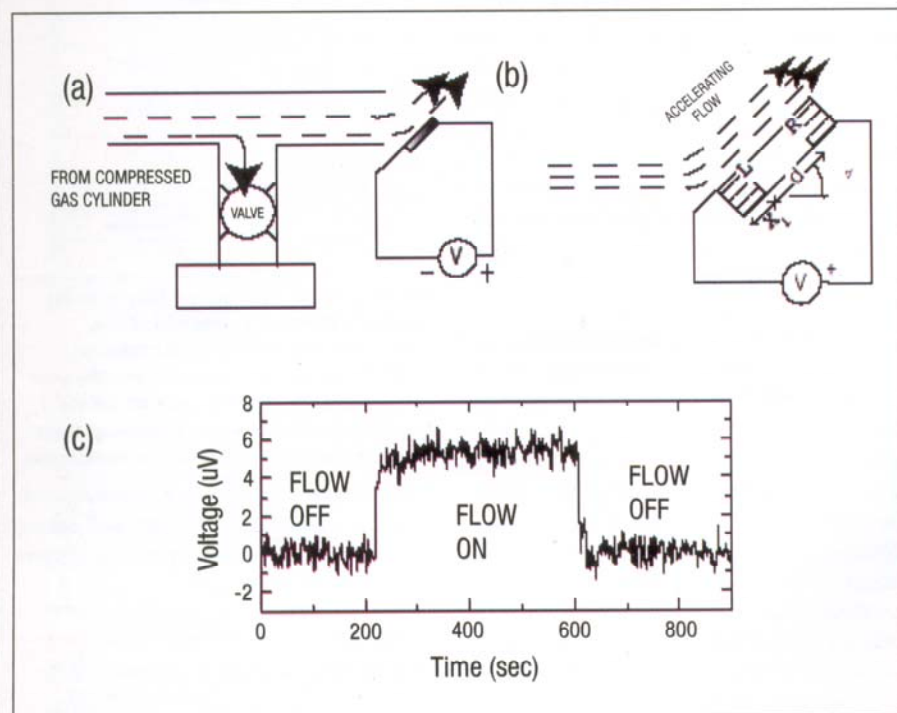
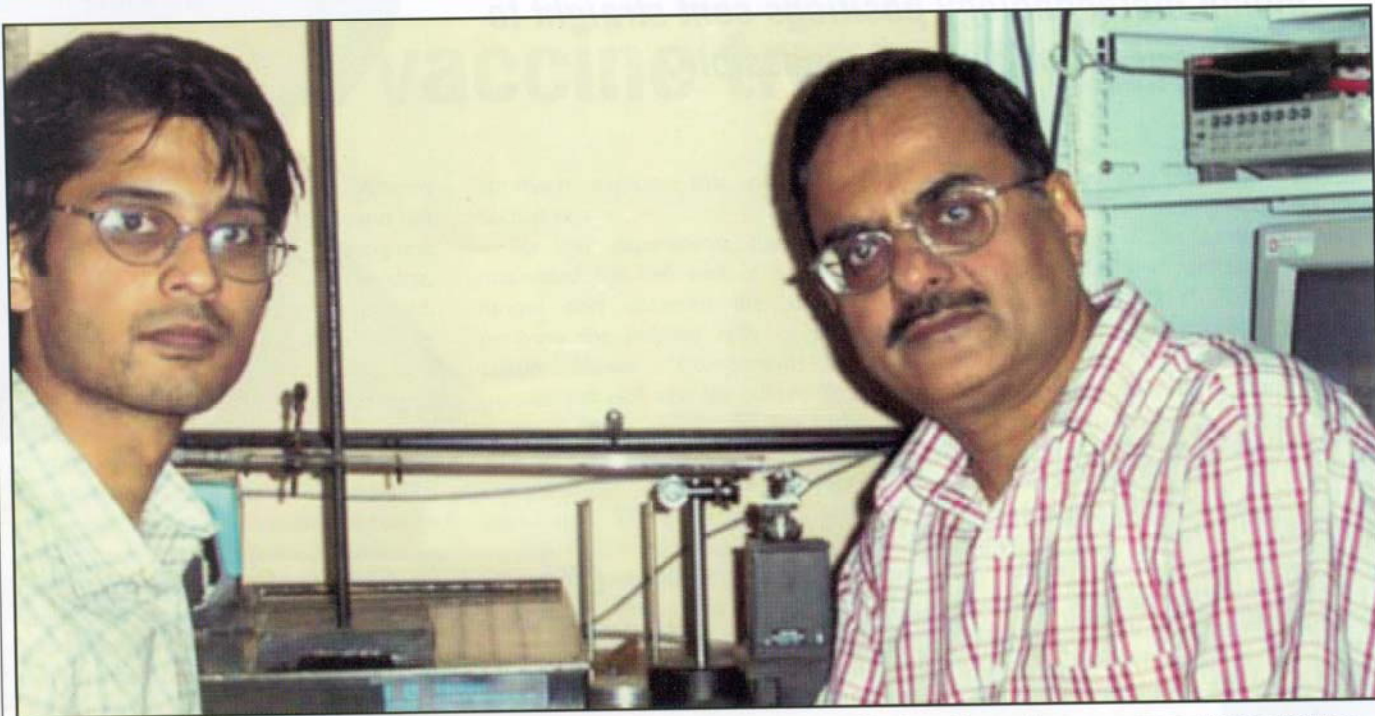


Figure 1 Go with the flow. The experimental set-up used by Sood and Ghosh¹, showing compressed gas from a cylinder (a) passing over a sample that is kept in an inclined position (b). This causes a potential difference across the sample, but only when the gas is flowing (c).



Current research: Shankar Ghosh (left) and Ajay Sood in the lab where they generated voltage by passing gases over carbon nanotubes.

-16.4 μV for n-type germanium, compared with 5.9 μV for the sample of single-wall carbon nanotube bundles (Fig. 2). "The magnitude of the voltage and current can be easily scaled up by using a serial and parallel combination of sensing elements," the scientists say. Another attractive idea is to take advantage of the inverse Seebeck coefficients of n- and p-type silicon or germanium: n- and p-type strips can be alternated and electrically bonded in series to add the individual Seebeck voltages when the sample is exposed to the gas flow.

Sood and Ghosh emphasize that the effect they observed is not restricted to the few materials they studied. The guiding principle for the choice of solid is its high Seebeck coefficient, which suggests that it will occur with other solids, such as selenium, tellurium, gallium arsenide, oxides and electrically conducting polymers, says Sood.

"Our experiments clearly show that a sensor to measure the flow velocity of the gases can be made based on the electrical signal generated," Sood told *NewsIndia*. Such sensors, based on the direct generation of flow-induced voltage or current in the sensor material, would not have the drawbacks of currently used gas flow sensors, which are based on thermal anemometry. These record gas flow by measuring changes in heat transfer from a small, electrically heated wire exposed to

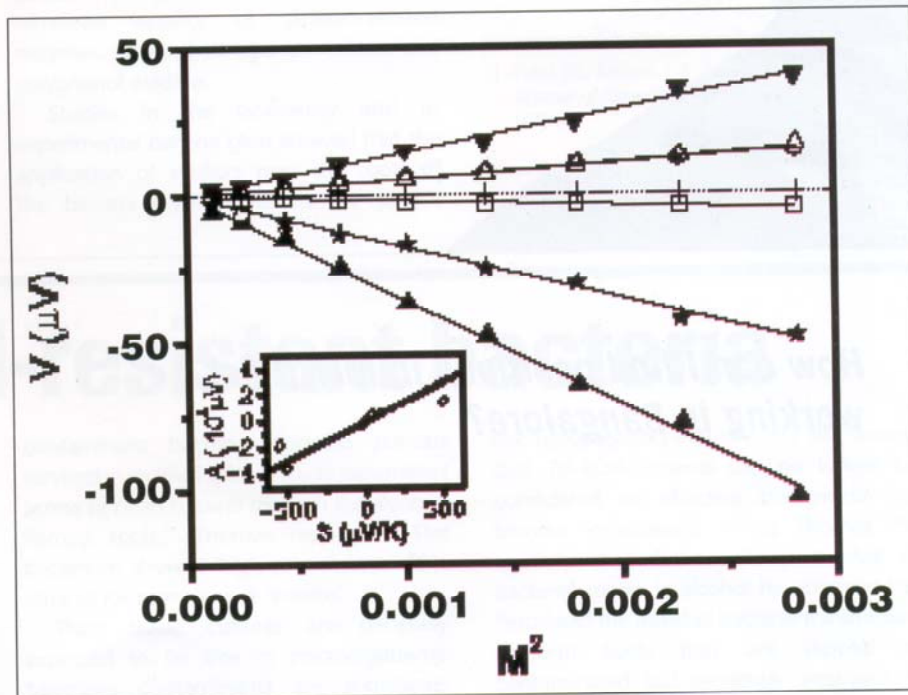


Figure 2 Making a difference. The voltage produced (V) increases with the speed of the gas; the magnitude and sign of the voltage depend on the properties of the solid sample. M is the Mach number, an indication of flow speed.

the fluid, and are prone to errors caused by any small changes in the temperature, pressure or composition of the gas.

Sood and Ghosh claim that their results also suggest that gas flow energy can be converted directly into the electrical signal without any moving parts. As a result, their work may have potential

applications in electricity generation.

1. Ghosh, S., Sood, A. K. & Kumar, N. *Science* **292**, 706 (2003).
2. Sood, A. K. & Ghosh, S. *Physical Review Letters* **93**, 86601 (2004).

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