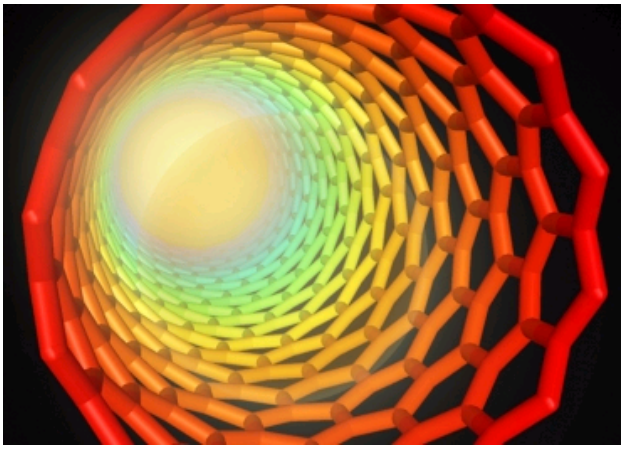
Big power from tiny wires

New discovery shows carbon nanotubes can produce powerful waves that could be harnessed for new energy systems.

David L. Chandler, MIT News Office

March 8, 2010



A carbon nanotube (shown in illustration) can produce a very rapid wave of power when it is coated by a layer of fuel and ignited, so that heat travels along the tube. Graphic: Christine Daniloff

A team of scientists at MIT have discovered a previously unknown phenomenon that can cause powerful waves of energy to shoot through minuscule wires known as carbon nanotubes. The discovery could lead to a new way of producing electricity, the researchers say.

The phenomenon, described as thermopower waves, "opens up a new area of energy research, which is rare," says Michael Strano, MIT's Charles and Hilda Roddey Associate Professor of Chemical Engineering, who was the senior author of a paper describing the new findings that appeared in *Nature Materials* on March 7. The lead author was Wonjoon Choi, a doctoral student in mechanical engineering.

Like a collection of flotsam propelled along the surface by waves traveling across the ocean, it turns out that a thermal wave — a moving pulse of heat — traveling along a microscopic wire can drive electrons along, creating an electrical current.

The key ingredient in the recipe is carbon nanotubes — submicroscopic hollow tubes made of a chicken-wire-like lattice of carbon atoms. These tubes, just a few billionths of a meter (nanometers) in diameter, are part of a family of novel carbon molecules, including buckyballs and graphene sheets, that have been the subject of intensive worldwide research over the last two decades.

A previously unknown phenomenon

In the new experiments, each of these electrically and thermally conductive nanotubes was coated with a layer of a reactive fuel that can produce heat by decomposing. This fuel was then ignited at one end of the nanotube using either a laser beam or a high-voltage spark, and the result was a fast-moving thermal wave traveling along the length of the carbon nanotube like a flame speeding along the length of a lit fuse. Heat from the fuel goes into the nanotube, where it travels thousands of times faster than in the fuel itself. As the heat feeds back to the fuel coating, a thermal wave is created that is guided along the nanotube. With a temperature of 3,000 kelvins, this ring of heat speeds along the tube 10,000 times faster than the normal spread of this chemical reaction. The heating produced by that combustion, it turns out, also pushes electrons along the tube, creating a substantial electrical current.

Combustion waves — like this pulse of heat hurtling along a wire — "have been studied mathematically for more than 100 years," Strano says, but he was the first to predict that such waves could be guided by a nanotube or nanowire and that this wave of heat could

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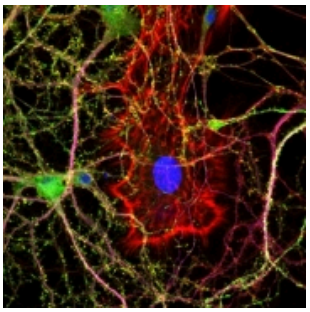

MIT neuroscientists have shown that the protein Arc is necessary for neurons like this one to adjust their responses to new sensory stimuli. (The blue circle is the neuron's nucleus, and the red strands are actin filaments.) Image: Jason Shepherd

One protein appears to control neurons' ability to react to new experiences, MIT scientists show.

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Thermopower waves

A reaction wave travels across a centimeter-long bundle of carbon nanotubes in 100 ms, consuming the energetic fuel with which they are coated. The reaction is initiated by a pulse of heat at the right side, in this case a small butane flame.

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Michael Strano

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push an electrical current along that wire.

In the group's initial experiments, Strano says, when they wired up the carbon nanotubes with their fuel coating in order to study the reaction, "lo and behold, we were really surprised by the size of the resulting voltage peak" that propagated along the wire.

After further development, the system now puts out energy, in proportion to its weight, about 100 times greater than an equivalent weight of lithium-ion battery.

The amount of power released, he says, is much greater than that predicted by thermoelectric calculations. While many semiconductor materials can produce an electric potential when heated, through something called the Seebeck effect, that effect is very weak in carbon. "There's something else happening here," he says. "We call it electron entrainment, since part of the current appears to scale with wave velocity."

The thermal wave, he explains, appears to be entraining the electrical charge carriers (either electrons or electron holes) just as an ocean wave can pick up and carry a collection of debris along the surface. This important property is responsible for the high power produced by the system, Strano says.

Exploring possible applications

Because this is such a new discovery, he says, it's hard to predict exactly what the practical applications will be. But he suggests that one possible application would be in enabling new kinds of ultra-small electronic devices — for example, devices the size of grains of rice, perhaps with sensors or treatment devices that could be injected into the body. Or it could lead to "environmental sensors that could be scattered like dust in the air," he says.

In theory, he says, such devices could maintain their power indefinitely until used, unlike batteries whose charges leak away gradually as they sit unused. And while the individual nanowires are tiny, Strano suggests that they could be made in large arrays to supply significant amounts of power for larger devices.

The researchers also plan to pursue another aspect of their theory: that by using different kinds of reactive materials for the coating, the wave front could oscillate, thus producing an alternating current. That would open up a variety of possibilities, Strano says, because alternating current is the basis for radio waves such as cell phone transmissions, but present energy-storage systems all produce direct current. "Our theory predicted these oscillations before we began to observe them in our data," he says.

Also, the present versions of the system have low efficiency, because a great deal of power is being given off as heat and light. The team plans to work on improving that efficiency.

Ray Baughman, director of the Nanotech Institute at the University of Texas at Dallas, who was not involved in this work, calls the research "stellar."

The work, Baughman says, "started with a seminal initial idea, which some might find crazy, and provided exciting experimental results, the discovery of new phenomena, deep theoretical understanding, and prospects for applications." Because it uncovered a previously unknown phenomenon, he says, it could open up "an exciting new area of investigation."

energy out heat. Given the planet increasingly getting warmer time to time, these inventions are vital to make use of heat to produce energy, not necessarily sun light. Heat of all kinds!

Wishing you the best,
Cheers
Kutti

T.Roc - **Critical Reasearch Area** 2010-03-08 09:49:18

This looks promising, and of course, we need to find alternate energy sources wherever possible.

I've thought about this before by using sound waves - any comments on that possibility?

There is a thread started at Sapo's Joint with this article linked. http://saposjoint.net/Forum/viewtopic.php?f=5&t=2156

saeed - **Hail MIT** 2010-03-08 09:49:31

Congrats on the phenomenal achievement. Here the specialty is the use of Carbon nano tube. It helps or stimulates the flow of charge carriers with the wave. I would really like to know how the atomic structure of the nano tubes play their part?
SAEED.

kgb1001001 - **Do you need to coat it with fuel to start the casc** 2010-03-08 12:29:38

Interesting article! Question - would the chemical reaction from the fuel on the outside of the tube be necessary to start the wave of electrons heading down the tube? What if there was simply a pulse of heat (say, from an explosion - think pulsed nuclear fusion) on the end of the tube to start with?

grant.upjohn - **Jet Propulsion** 2010-03-08 12:30:10

Would it be possible to bundle some of the nanotubes togeether to form a propulsion system?

As the shape/size of the nanotubes, seems to be maximising the speed of the heat propegating along the length of the nanotube to quote "10,000 times faster than the normal spread of this chemical reaction", then surely that would indicate that it would make a more suitable material to form the basis of a jet propulsion system.

I would imagine it would depend also on how long it would take to reactivate the nanotubes after the reaction, befoore you could use them again. But if it takes a while between reactions to prime the nanotubes again for more reactions, maybe the propulsion system can have multiple reaction chambers, that get primed and conbusted in sequence, giving a continuous thrust.

It would be cool to see something like this take shape, It could mean we get more fuel efficient jet engines, or even jets that can be scaled down for the use in UAVs.

sbgol - **carbon nanotube therma** 2010-03-09 04:40:27

The reaction reminds me of similiar one used in a thermal battery. In that case, the battery once triggered operates about 700 C and generates high power for a short period of time. It was used by the military as a long term passive battery that did not discharge over time and would be available for a short power burst when initiated. It would be interesting to see if this type of reaction would be suitable for this application.
Stan

shobazee - **Push electrons** 2010-03-09 04:40:36

Congrats for the promising invention..the energy produced by this novel system puts out energy, in proportion to its weight, which is about hundred times greater than an equivalent weight of a lithium-ion battery..
Cheers
Mary

sanman - **VASIMR, Tactical Lasers, EMP Bombs?** 2010-03-09 04:41:11

Could this thing be used as a bulk electrochemical material to power a VASIMR plasma thruster instead of a nuclear reactor?

Could it be used to power tactical lasers, or even EMP weapons?

Or what about as a krytron-style ignition device for multi-stage vehicles?

Spicy Scott Works - **propulsion system?** 2010-03-09 11:02:49

grant.upjohn is thinking the same way I am. Not nearly as technical as I need to be to understand this, but is there any way to give the nanotubing a rifling type effect, as used in firearms?

Would this produce a more streamlined effect of the electrons, heat, and energy traveling down the tube? Or, maybe, a tube shape that looks like a strand of DNA encased with a skin.

This all leading to a better aimed propulsion system since the particles are aimed as aposed to just traveling in a direction.

What if you surround this specially coated nanotube with nanotubes that absorb the generated heat and manipulate that in a different way?

Ramblings of an interested human....

grant.upjohn - **re: propulsion system?** 2010-03-10 05:02:41

Although they haven't given the exact dimensions, I would imagine due to the size of the nanotubes, it would probably equate to the rifling effect you mention.

Which interestingly, could make for better firearms. With a lot of guns you see the flash created from the combustion of the powder, if that powder were to be combusted in a parallel set of nanotubes, i would imagine a lot more of the energy from the combustion would be sent in the direction of the projectile, rather than heating the barrel of the gun and spattering out the sides of the chamber. Secondary to that, would be the current created from the heat traveling down the nanotubes towards the projectile, you could use that to combust the next round of munitions.

When you say surround the nanotube with something that absorbs heat. The carbon nanotubes themselves absorb the heat which is what creates what MIT have termed "electron entrainment". so the carbon nanotubes are absorbing the propogating heat causing a wave of electrons to flow through the carbon nanotubes, therefor generating current. Unless the carbon naotubes emit heat as a result of this rush of electrons, I wouldn't have thought putting a layer of anything on the outside of the nanotubes would add any additional gains, but I may be wrong. Maybe double walled carbon nanotubes, would provide that extra layer of absorbtion if there is loss. I am only surmising here.

enertico - **Brightly energetic** 2010-03-09 12:29:57

In a regular car, a vast amount of waste energy goes to the tail pipe.
Maybe with your novel device, it could be possible to use less fuel; and instead of the mechanical system, the heat would be used to generate electricity to propel the vehicle, which would become a highly efficient hybrid.

grant.upjohn - **re: Brightly energetic** 2010-03-10 05:01:57

Enertico, the point you make seems quite valid, to extract the otherwise wasted heat.

Would it also not make more sense to do away with the internal combustion engine as it currently stands and instead substitute it with the carbon nanotubes and an electric motor. As a lot of cars emit carbon monoxide, using the carbon nanotubes, might do more than just allow us to draw energy from the heat created from the combustion, it might also allow us to more completely combust the fuel, so as to produce carbon dioxide, assuming you can get enough oxygen into the process to ensure complete oxidation.

The mind boggles...

superdave - **Seriously?** 2010-03-11 04:48:53

Am I the only one who sees this in its proper light?

Wow... wasted brilliance!!

RigneyJim 2010-03-11 11:27:53

Great. Does this have anything to do with spiral energy?

skywatcher - **Wonderful research!** 2010-03-11 11:28:21

I have long felt that our electronic technological advancements hinged on, not the invention of transistors, but on the advancement of storage batteries to power the electronics. Thus far, advancements have been incremental at best, with dependence on more and more exotic materials for reduced mass and longer operational life. This invention may be the quantum leap we need to help solve many of the world's problems, from lighting in remote areas, to more compact drive systems in vehicles, and further, to advance the possibilities of space travel.

Keep up the great work!
Barrie in Canada

glong56 - **Extract H from H2O in the nanotube reaction?** 2010-03-15 05:23:03

Could the fuel coating the nanotube be hydrogen extracted from H2O in the electrical/thermal reaction? And could the reaction be perpetuated as in H2O electrolysis?