Looking at the future through graphene goggles

September 8 2014, by Michael Fuhrer

There's definitely room for improvement in night-vision goggle technology – and graphene could make a huge contribution. Credit: UK Ministry of Defence/Flickr, CC BY-SA

Graphene – an atom-thick sheet of carbon – has been touted as a new wonder material: it is stronger than steel and conducts electricity better than copper.

In the journal *Nature Nanotechnology* today, my colleagues and I show how graphene can be used to build a detector of long wavelength (far infrared or terahertz) light that is as sensitive as any existing detector, but far smaller and more than a million times faster. The detector could improve night-vision goggles, chemical analysis tools and airport body scanners.

But before I go into the research, I'd like to talk about how we get from the discovery of a new wonder material such as graphene to new technologies that are useful.

As a researcher working on new materials, I am constantly asked "what is it good for?" To answer this, the first thing we researchers often try is to imagine the new material as a replacement for an existing one in an existing technology.

The problem with that approach is that any existing technology has a lot of momentum. For example, consider computer processors. The electrons in graphene move about 70 times faster than those in silicon (used in most computer processors today) under the same conditions, so graphene could arguably be used to make faster computer chips.

But it's not that simple. There are many reasons we use silicon besides the speed at which electrons travel – it readily forms a strong oxide coating and it is easy to dope, to name a couple. And changing to a radically different material would mean throwing away all the infrastructure used to make silicon chips that was developed at enormous expense over the past several decades.

So a better question—though much more difficult to answer—is to ask what a new material might enable us to do that no other material has before. The answers to that question don't always come immediately, and sometimes they come serendipitously.

Two layers are better than one

One property of graphene that interested me was that bilayer graphene (two layers stacked one on another) has a bandgap—the basic property of a semiconductor—that can be tuned by applying an electric field to the material.

I teamed up with researchers at the University of Maryland to try to measure this bandgap using infrared light, since infrared photons have energies which are similar to bilayer graphene's bandgap. When we measured the conductance of our bilayer graphene under infrared illumination, we found that it changed much more than we expected.

In fact, the change in conductance in our graphene was greater than that of the commercial silicon photodetector we were using to measure the power of our infrared beam! For some reason, our graphene was an excellent photodetector.

We knew enough about graphene to figure out what was happening. When the electrons in graphene absorb light, they heat up. In most materials, the electrons quickly lose energy to vibrations of the atoms, which we sense as heat.

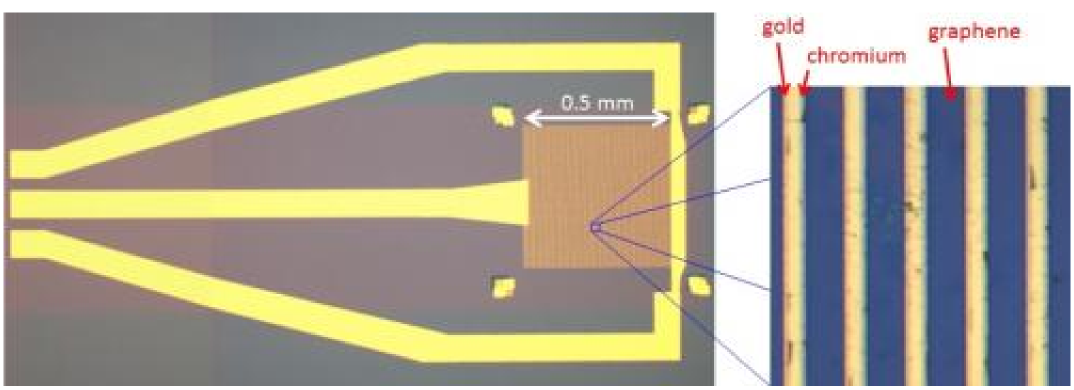
But in graphene this process of heat loss is very inefficient, which gives graphene its extraordinarily high electrical conductivity. What we realised is that bilayer graphene with a bandgap has a conductance that varies strongly with electron temperature, allowing us to read out the change in electron temperature caused by the light heating the electrons.

Such a device is called a "hot electron bolometer" and bilayer graphene makes a very good one. We published our result in the journal *Nature Nanotechnology* in 2012, and several research groups are interested in developing graphene bolometers as exquisitely sensitive cryogenic detectors for use in radio astronomy.

Unfortunately, the bolometric effect only works well at low temperature, where bilayer graphene's resistance changes strongly with temperature. But we knew from our measurements that hot electron effects should be important in graphene at room temperature.

Our team designed a device which could measure the hot electrons at room temperature, using an effect called thermoelectricity. Our first graphene photothermoelectric detectors were comparable in sensitivity to the best available room-temperature detectors of light in the far infrared, or terahertz, regime of the electromagnetic spectrum, and we saw room for orders of magnitude improvements in sensitivity with new designs.

Interestingly, our devices were more than a million times faster than those detectors, and it's these results we publish today, once again in *Nature Nanotechnology*.



A graphene photothermoelectric detector. The active area of the device is a 0.5 mm by 0.5 mm square which consists of strips of graphene contacted by partially overlapping gold and chromium electrodes. Credit: Michael Fuhrer, Author provided

Graphene shows us the light

Detection of infrared and terahertz light has numerous uses, from chemical analysis to night-vision goggles to body scanners used in airport security.

But since an ultra-fast, sensitive terahertz detector had never been considered a possibility before, it's hard to say where our devices might be applied.

Our detector could be used to speed up chemical analysis techniques such as Fourier transform infrared spectroscopy, or FTIR.

Because the graphene detector is easily microfabricated, we envision arrays of detector pixels suitable for imaging, which could lead to inexpensive infrared cameras or night-vision goggles.

Our calculations show that the hot electron photothermoelectric effect can be an efficient means of gathering energy from light. Perhaps our devices could be used to gather the infrared light escaping the Earth into the night sky, and turn it into electricity. Maybe they will be used for something that we haven't even thought of yet.

But had we never set out to investigate a new material simply for the sake of understanding how it works, we never would have discovered these new answers to the question, "what is it good for?"

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