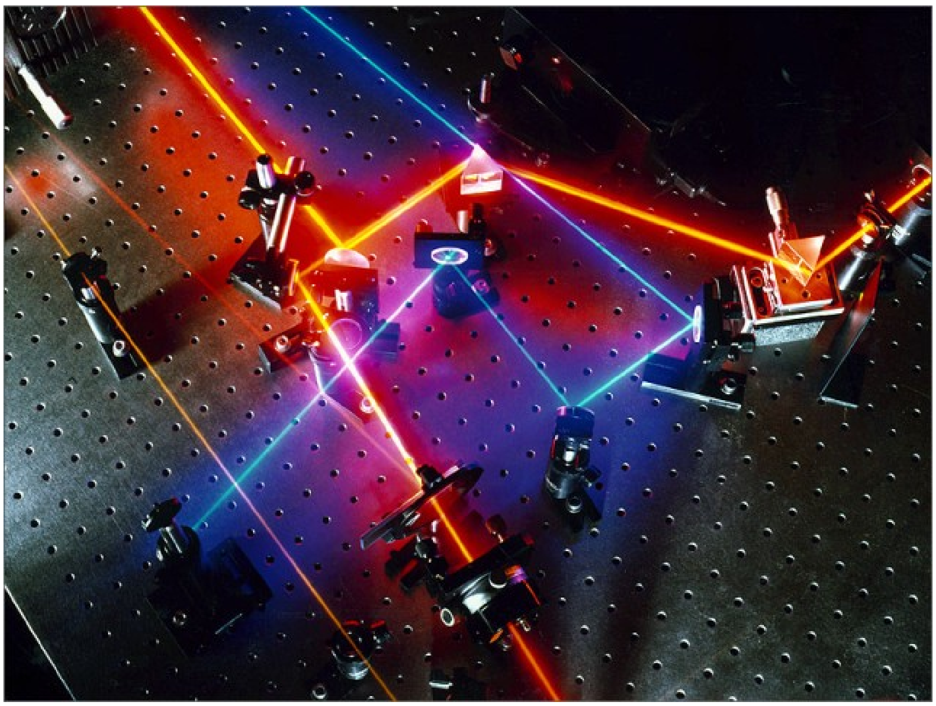
Bendy silicon is sensitive enough to register a falling virus

Tiny cantilever sensor capable of measuring femtoNewton forces.

by Chris Lee - Sept 19 2014, 5:05pm MDT

29



The lasers involved look nothing like these.

NREL

One of the side benefits of the smartphone generation is that there is lots of interest in making new and better sensors. The current generation of smartphones comes equipped with accelerometers, gyroscopes, proximity sensors, and light sensors. Thanks to these, your smartphone knows its orientation, its motion, when it's in the dark, and when you put it to your face. It's a compass, a level, a location beacon, a pedometer, and much, much, more. We're told that wearable devices are the next big thing. These devices will be packed with even more sensors.

The sensitivity of sensors often depend on their physical dimensions: big gyroscopes can detect smaller changes in location and orientation than small gyroscopes. Likewise, long cantilevers measure smaller changes in torque than short cantilevers. This is simply because a change in torque rotates the cantilever by a fixed angle—the longer the cantilever is, the larger the displacement at the end, and larger displacements are easier to detect.

But a team of Canadian researchers have found that it's possible to make a relatively compact sensor that's also exquisitely sensitive—so sensitive, in fact, that it can detect the force exerted by a virus falling on it.

Smoke and mirrors

In order to increase a sensor's sensitivity while also reducing the physical size, researchers need to

LATEST FEATURE STORY

FEATURE STORY (2 PAGES)

How EA's jet-setting founder avoided $26 million in taxes

"I bought a private jet because I thought it would make me more efficient in my work."

WATCH ARS VIDEO

come up with ways to measure ever smaller displacements and rotations. One option they're looking at involves using optical cavities.

An optical cavity is nothing more than a pair of mirrors that face each other. Once light gets inside the cavity, it reflects back and forth between the mirrors. This can only happen if the wavelength of the light matches the spacing between the mirrors and if the light has a particular spatial pattern that matches the orientation and shape of the mirrors. These features are called optical modes, and the process of getting light *into* an optical cavity is called mode matching. If one of the mirror is shifted suddenly, then the light mode will no longer match the optical cavity mode and photons will leak out through the mirrors.

To give you an idea of how important mode matching is, let's take an example of an optical cavity created by two mirrors that are 99.9 percent reflective. If I shine a one milliWatt laser at one of the mirrors, but in such a way that it doesn't match the mode, then only a microwatt will be transmitted by the first mirror, and a nanowatt transmitted by the second mirror. So, a light detector on the other side of the second mirror will see, essentially, darkness. Of course, the photons aren't lost; if I measure the power reflected by the first mirror, I get nearly one milliWatt: all the light is reflected.

However, if I match the mode of the cavity perfectly, then the amount of light builds up in cavity, although some of it is also partially transmitted at each mirror. At the front mirror, where we are shining the light into the cavity, the light coming out of the optical cavity and the light reflected from the front mirror have the same amplitude, but they destructively interfere, so, *no light is reflected by a mirror that has a reflectivity of 99.9 percent*. And, coming out the other end, I find that one milliWatt of light is transmitted. The optical cavity is, apparently, transparent.

This happens because an optical cavity *stores* light. The power within the optical cavity builds up to 1,000 times the power of the laser: one Watt is stored in the optical cavity in our example. So, the 0.1 percent of the light that leaks back out gives us our milliWatt back.

How can this be used in a sensor? If one of the mirror shifts even slightly then suddenly, the transmitted power will drop and the reflected power will rise. This makes for a very sensitive detector of motion. Indeed, in with this technique, the more reflective the two mirrors are, the more sensitive it is. The flip side is that it responds more slowly as well.

I think they will have to work quite hard, however, to beat the achievements of a group of Canadian physicists. They have created a cantilever torque sensor with a sensitivity of around 1.2×10^{-20} Nm/√Hz. To put that in perspective, for human movement, which typically have a millisecond timescale, this sensor would be able to detect torques as small as 10^{-19} Nm. Okay, maybe that doesn't help, because torque can be hard to envision. That torque is the equivalent of applying a 50fN force to the end of the cantilever. Or, to make the comparison even less imaginable, this is around about the force imparted by a virus landing on the end of the cantilever.

Making a light torque sensor

To obtain such an insanely sensitive sensor, the researchers used a set of very cool tricks. But first, let's deal with the ordinary. A torque sensor is basically a cantilever. A pair of long, narrow cantilevers were machined from silicon in such a way that the free ends of the cantilevers faced each other. Then, the researchers drilled holes in the cantilevers. This has two effects: first, it reduces the mass of the cantilevers, which allows them to bend more in response to a small applied force. But, more importantly, the holes create an optical cavity.

Each hole in the silicon acts as a poor mirror, but there are about 15 holes in each cantilever, all spaced such that they behave as a single, high-quality mirror. Think of it like this: if I have a pair of mirrors that are just 15 percent reflective, then they will make a very poor optical cavity—the cavity won't store much light. But, I can take a second pair of identical mirrors and place them within the cavity, such that the optical mode is the same. These now act together to create a cavity that is much better than the one with just two mirrors. I can repeat the process as often as I like to create arbitrarily better and better optical cavities.

For the cantilever, each silicon-air interface is about 50 percent reflective. But, with 15 holes, a single photon will make, on average, about 100,000 round trips in the optical cavity before exiting. So, in effect, each "mirror" is about 99.998 percent reflective. This makes the optical cavity very, very sensitive to movement from the cantilevers. Apply a torque, the cantilever bends very slightly, the mode of the cavity changes, and all the light leaks out. A very effective little machine.

Seems complicated, why do it this way?

One of the reasons why the researchers chose to do it this way is that every measurement acts on the thing being measured, in a process called back action. For instance, if we measured the movement of the cantilever via a change in electrical resistance, then the electric field associated with the coils and such-like used to make that measurement will also stiffen the cantilever, reducing its sensitivity.

The same is true of optical method described above. However, in this case, the back action occurs at optical frequencies. If we try to measure torques that vary at a frequency similar to the light frequency, then the back action of the light will kill the measurement. However, most measurements of interest are at much lower frequencies, making this method largely immune to back action. This is not so true of other measurement techniques.

Another good reason is simply that the method becomes more sensitive by increasing the quality of the optical cavity. In other words, the physical length of the cantilever doesn't need to be extended. The biggest limitation is that of mirror fabrication—at the moment, the biggest loss is light being removed from the cavity via scattering off of fabrication imperfections. So, rather than changing the dimensions of the sensor, we just need to work on our manufacturing techniques. Again, this is not true for more traditional measurement techniques.

A reality check

The key question is whether this will ever turn up in a device near you. I am ambivalent about the chances. The reason for my ambivalence is the laser. I love lasers, but i know that even diode lasers are not that small. They certainly can't be created in the same fabrication process as the cantilevers, so you end up needing to bond them onto the sensor very precisely later on. And they can be a bit power hungry. These are the key problems that would need to be overcome.

Which is not to say that doing all that isn't possible now. It just isn't possible to do it cheaply enough to find its way into a consumer device yet. There has been some progress with some of this lately, but not progress of a sort that is compatible with the cantilevers as they were fabricated here.

Physical Review X, 2014, DOI: 10.1103/PhysRevX.4.021052

Chris Lee / Chris writes for Ars Technica's science section. A physicist by day and science writer by night, he specializes in quantum physics and optics. He lives and works in Eindhoven, the Netherlands.
@exMamaku on Twitter

← OLDER STORY NEWER STORY →

YOU MAY ALSO LIKE


New qubit design provides parity bit for Schrödinger cat states


Time dilation measured at 40 percent of the speed of light—in the lab

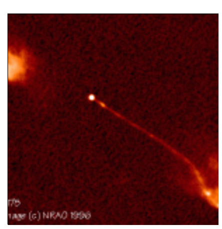

I'm not crazy (but I did buy a $450 HOTAS Warthog joystick)

Sponsored: The Future Campus and Asynchronous Learning


iPhone 6 and 6 Plus: In deep with Apple's thinnest phones


When is a single photon not a single photon?


Small object, supermassive black hole


Massive survey makes sense of the diversity of quasars