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'Next-generation' optical tweezers trap tightly without overheating (w/ video)

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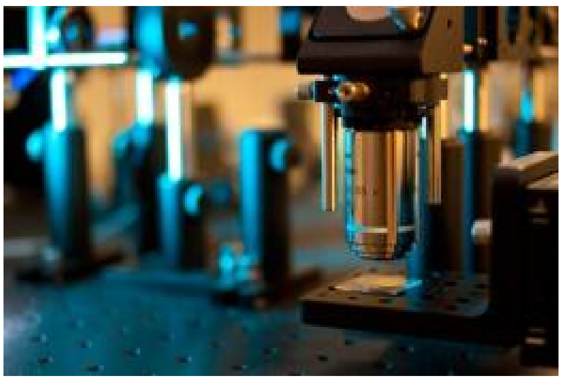


The optical table in the Crozier lab at Harvard SEAS.

(PhysOrg.com) -- Engineers at Harvard have created a device that may make it easier to isolate and study tiny particles such as viruses.

Their plasmonic nanotweezers, revealed this month in *Nature Communications*, use light from a laser to trap nanoscale particles. The new device creates strong forces more efficiently than traditional optical tweezers and eliminates a problem that caused earlier setups to overheat.

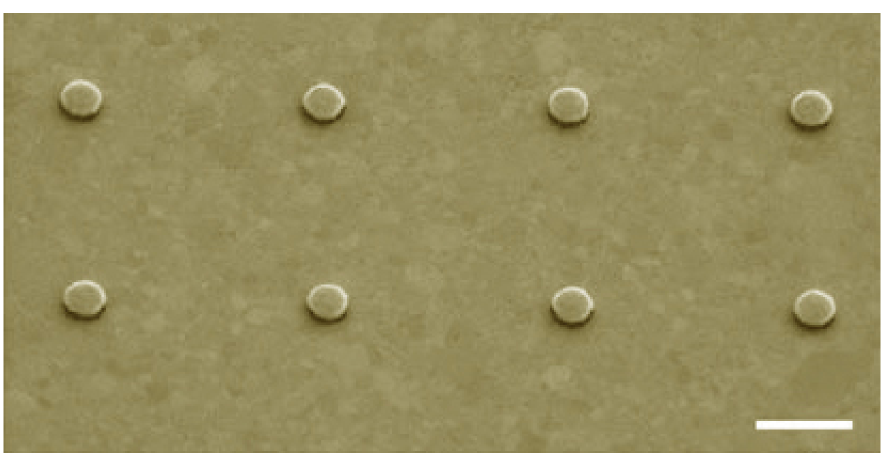
“We can get beyond the limitations of conventional optical tweezers, exerting a larger force on a nanoparticle for the same laser power,” says principal investigator Ken Crozier, Associate Professor of Electrical Engineering at the Harvard School of Engineering and Applied Sciences (SEAS).

"Until now, overheating has been a major problem with tweezers based on surface plasmons. What we've shown is that you can get beyond that limitation by building a plasmonic nanotweezer with an integrated heat sink."

Optical tweezers have been an essential tool in biophysics for several decades, often used for studying cellular components such as molecular motors. Researchers can trap and manipulate the proteins that whip a flagellum, for example, and measure the force of its swimming motion.

But optical tweezers have drawbacks and limits, so researchers like Crozier are perfecting what might be called the "next-generation" model: plasmonic nanotweezers.

To create conventional optical tweezers, which were invented at Bell Labs in the 1980s, scientists shine a laser through a microscope lens, which focuses it into a very tight spot. The light, which is made up of electromagnetic waves, creates a gradient force at that focused spot that can attract a tiny particle and hold it within the beam for a short period of time—until random motion, radiation pressure, or other forces knock it out.



A false-color SEM image of the gold nano-pillars. Underneath the flat gold surface is a layer of copper, and both metals have been evaporated onto a sheet of silicon. The top surface, with the pillars, is created through a process called template stripping, which makes it very smooth. The scale bar is one micrometer. Image courtesy of Ken Crozier.

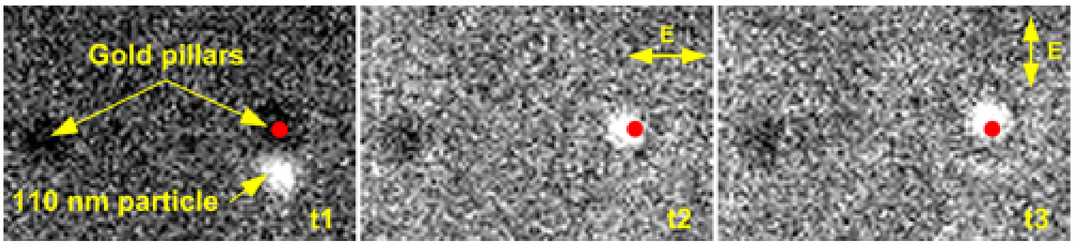
The trouble with these optical tweezers is that a lens cannot focus the beam any smaller than half the wavelength of the light. If the targeted particle is much smaller than the focal spot, the trapping will be imprecise.

At the same time, the focal size limit places an upper limit on the gradient force that can be generated. A stronger force is necessary for trapping nanoscale particles, relative to larger, microscopic particles, so conventional optical tweezers must use a very high-powered laser to trap the tiniest targets.

To overcome these problems, researchers in applied physics discovered a few years ago that they could enhance the trapping field by focusing the laser onto an array of nanoscale gold disks. The light excites the electrons at the surface of the metal, creating rapid waves of electromagnetic charge called plasma oscillations, resulting in “hot spots” of enhanced fields around the edges of the disk.

In other researchers' designs, the tiny gold disks were arrayed on a sheet of glass, and the whole setup was submerged in water with the target particles. In tests with those devices, one problem was that the brightest hotspots were at the base of the pillars, partially inside the glass, where the particles could never be trapped. A bigger problem, as Crozier's team discovered, was that unless they kept the laser power very low, the water boiled.

The Harvard team has solved both problems by replacing the glass with a piece of silicon coated in copper and then gold, with raised gold pillars. These materials are much more thermally conductive than glass, so they act as a heat sink.



Particle trapping and rotation in action. Image courtesy of Ken Crozier.

"The gold, copper, and silicon under the pillars act just like the heat sink attached to the chip in your PC, drawing the heat away," says lead author Kai Wang (Ph.D. '11), who completed the work at SEAS and is now a postdoctoral fellow at the Howard Hughes Medical Institute.

The new device reduces the water heating by about 100-fold and produces hotspots at the top edges of the pillars, where Crozier's team was able to trap polystyrene balls as small as 110 nanometers.

In an unusual twist, the team discovered that they were able to rotate the trapped particles around the pillars by rotating the linear polarizer on the optical table where they conducted the experiments. Going further, they replaced the linear polarizer with a circular one and found that the particle automatically and continuously traveled around the pillar.

As the electromagnetic field circled the pillar, it created an optical force that pushed the particle. Interestingly, despite the fact that the electromagnetic field traveled at about 1014 rotations per second, the balance between the optical force and the fluid drag resulted in a particle velocity of about 5 rotations per second, effectively a terminal velocity.

"This phenomenon seems to be entirely novel," says Crozier. "People have trapped particles before, but they've never done anything like that."

As tools for trapping and manipulating nanoparticles become more advanced, the potential applications in biophysics are extensive. One remaining challenge, however, is the researchers' ability to detect and quantify the motion of such tiny particles.

"It's going to be harder and harder to precisely track the center of the particle when we do these manipulations," says Crozier. "Progress in the realm of sensing tools will need to keep up."

Provided by Harvard School of Engineering and Applied Sciences