Development of a new speckle optical tweezer

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1. The origin of optical tweezers

The father of the optical tweezers, Arthur Ahskins, first pioneered the invention in 1986 when he used a single tightly focused laser beam to trap dielectric spheres. Afterwards, optical tweezers took off and became an indispensable tool. Its applications range from biology (for example, to grab hold of a single cell) to quantum physics (to trap single atoms).

Generally, the gradient force (Figure 1) traps transparent particles at a beam's focus. However when dealing with absorbing particles, the photophoretic force (Figure 2), which pushes particles away from the focus, becomes much greater than the gradient force [14]. Thus a different method must be used to trap absorbing particles.

2. How speckle tweezers work

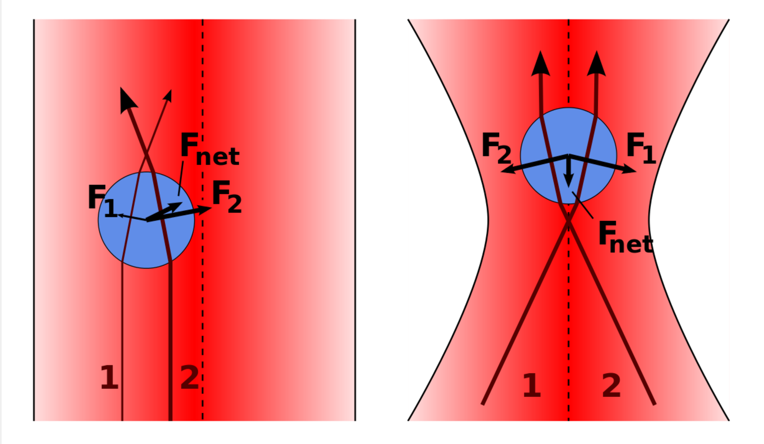

Figure 1. The change in intensity—i.e., intensity gradient—of the trapping beam results in a net force, the gradient force, on the particle towards the beam's focus where intensity is greatest [4].

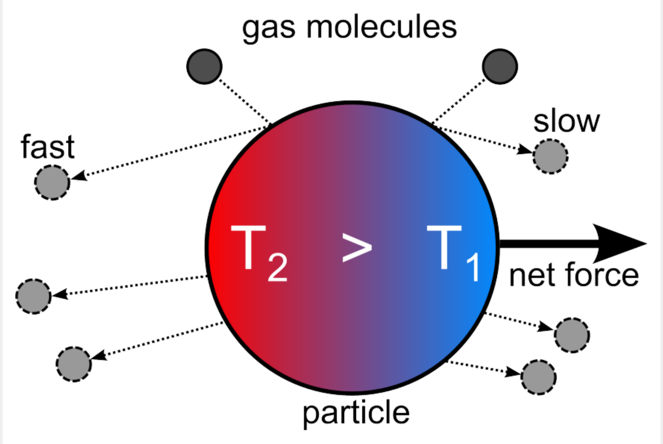

Figure 2. Photophoretic force is caused by a transfer of momentum from gas molecules that bounce off non-uniformly heated particles [14].

Speckles are a result of diffusely reflected light and are generally considered an unwanted imperfection in optics. However, *speckle tweezers* take advantage of these granular patterns (Figure 4). A combination of gradient and photophoretic forces trap transparent particles in "hot spots" and absorbing particles in "dark spots" of the speckle pattern [13].

A particle's size, refractive index, and other physical characteristics greatly influence the magnitude of the optical forces exerted on it [15]. Thus adjusting the size and intensity of the speckle influences the type of particles trapped.

3. The makings of the new speckle tweezer

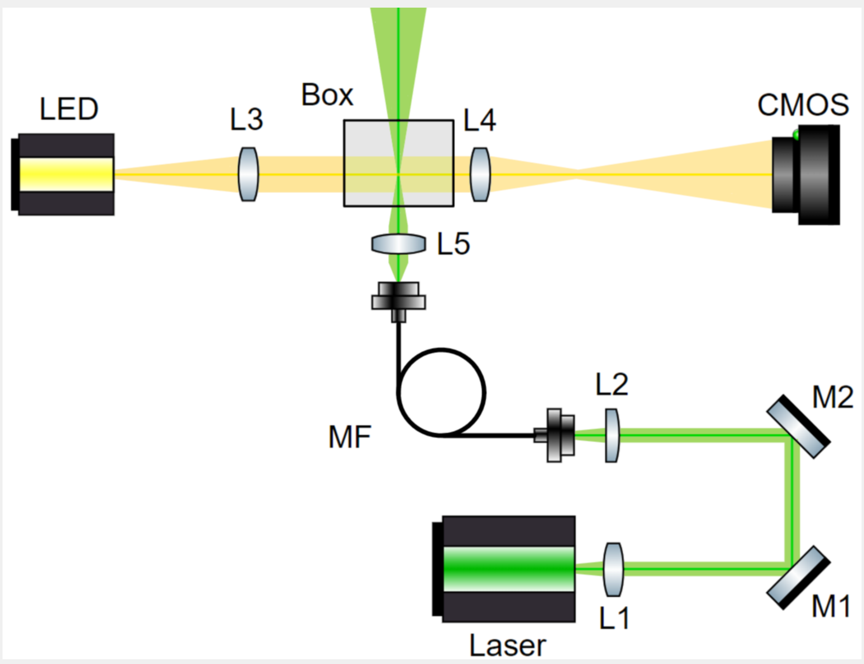

Figure 3. A 532 nm laser was directed into a multimode fiber with a 105 μm core. The light was then pointed into a microscope objective lens. The lens focused the laser into an isolated space for trapping of particles in a box. The box was illuminated by an LED and imaged with a monochrome CMOS camera.

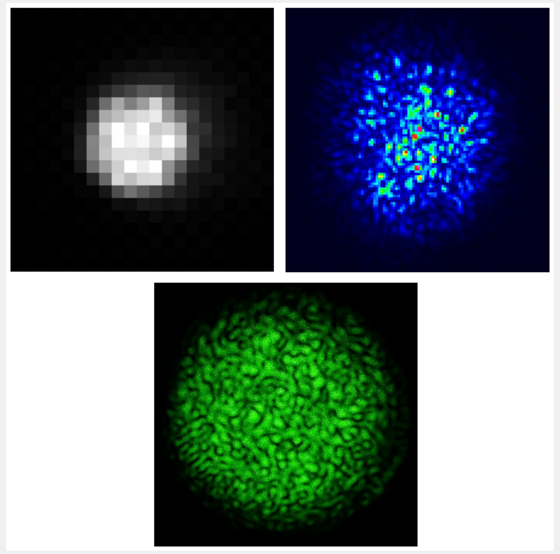

Figure 4. Generated speckle pattern imaged at the focus (CMOS Camera), near the focus (Beam Profiler), and when the beam hit a wall (iPhone).

Figure 5. Sample particles used for trapping. Left to right: yeast, lycopodium, chalk dust, felt-tip pen.

4. And we have liftoff!

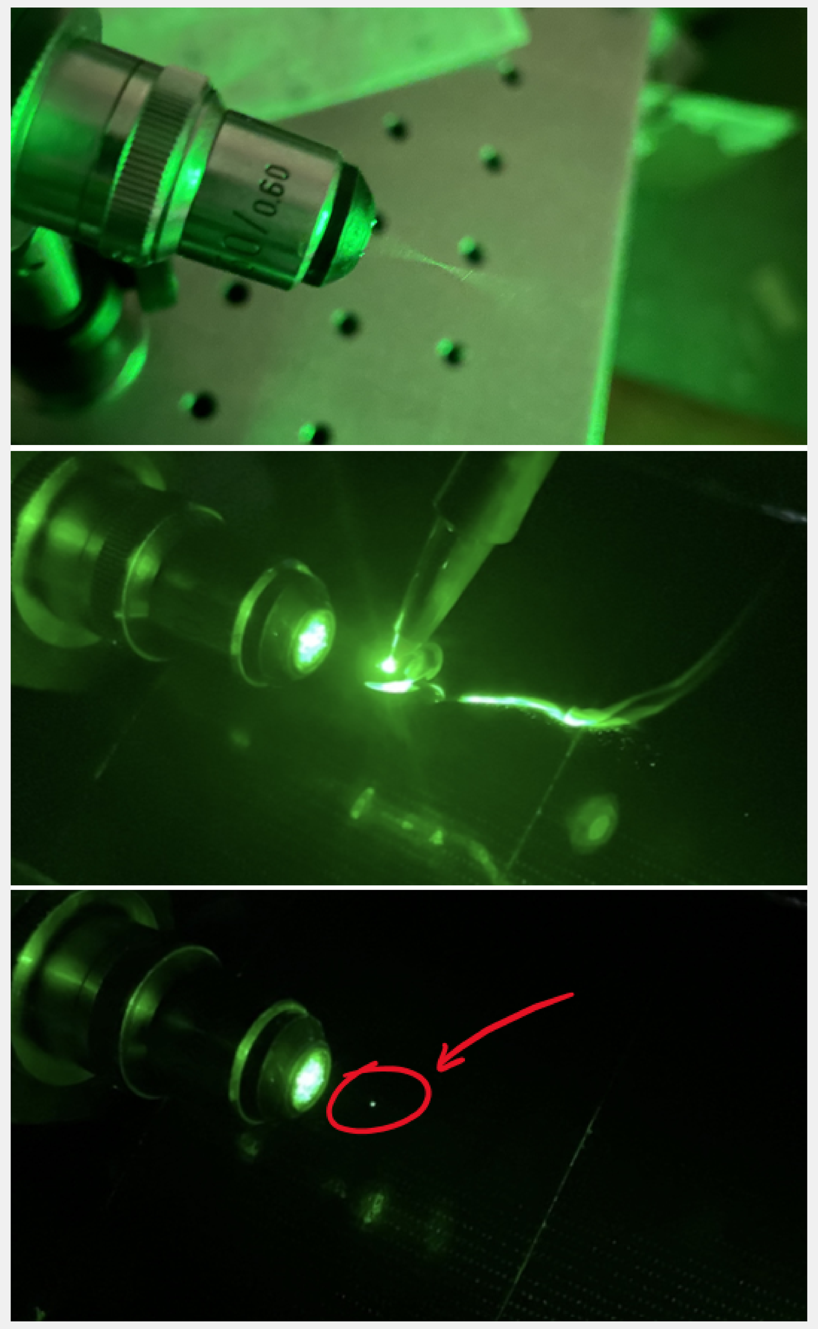

Figure 6. A Paper Mate felt-tip pen was placed at the focus of the laser beam. The ink heated up and produced smoke. As the burned particles crossed the beam, some got trapped in its focus.

The laser (DPGL-2150, $\lambda = 532$ nm) was a TEM_{00} beam, so its intensity profile is nearly Gaussian.

The multimode fiber's core was 105 μm in diameter. A 50x magnification microscope objective tightly focused the laser beam's width to less than the core.

Thus the Gaussian RMS width or standard deviation of the beam's intensity profile (σ) should be on an order of magnitude of 20 μm.

The full width at half-maximum (FWHM), the width of the beam where it's half the maximum intensity, is given by:

$$FWHM = 2\sqrt{2 \ln 2}\sigma \approx 47.1\ \mu m.$$

Using a line profile on the image of the beam's focus taken with a CMOS Camera (Figure 4), the FWHM was measured to be 318 pixels.

A clearer image taken with a Beam Profiler (Figure 4) was used to approximate the focus's structure and find the width of the "dark spots." The gaps between the hot spots were about 20 pixels.

So, the width of the "dark spots" in the speckle field, and hence the size of the trapped ink particles, is on the order of $47.1\ \mu m \cdot 20/318 \approx 2.96\ \mu m$.

5. Long story short...

- A speckle field was created by coupling a laser into and out of a multimode fiber. A microscope objective focused the laser to a point where particles were trapped by photophoretic forces.
- Yeast, lycopodium, and chalk dust were not trapped (most likely because they were too large), but particles (diameter $\sim 2.96\ \mu m$) forced out of a pen by steam from laser-heated ink were trapped.
- Particles from the pen were not uniform in size, and it seems only certain particles were trapped. This is possible evidence of selective trapping.

Figure 7. Physical setup in the Laser Teaching Center.

6. What's next?

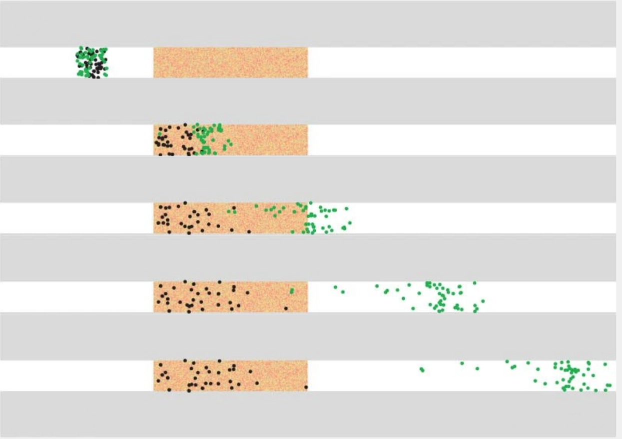

Figure 8. Speckle sieve in action.

- Improve imaging of the trapping area and the particle(s).
- Use speckle tweezers as a *speckle sieve*, trapping particles with similar characteristics while allowing others to pass through (Figure 8) [15].
- Trap multiple particles (or verify if multiple are already trapped) and trap larger particles (e.g. lycopodium) by modifying speckle pattern.
- Determine the predominant forces acting on the ink particles in this work due to the complicated nature of photophoretic optical traps.
- **Goal:** Develop system to assist with targeted, non-contact collection of space dust and *in situ* analysis of trapped particles using methods such as Raman spectroscopy [12].

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References

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