How shaping light can change particle behavior

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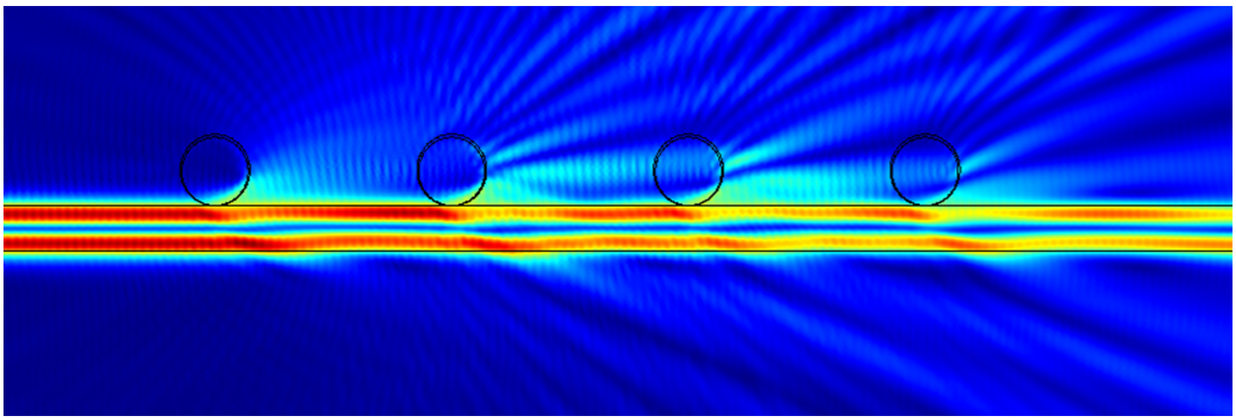

Laser light coupled into the microfiber. Credit: OIST

Light can take many different forms. Even in our day-to-day life, sunlight is vastly different from fluorescent light. In physics, when studying interactions between light and tiny particles, the shape of the light can make a big difference. Scientists from Okinawa Institute of Science and Technology Graduate University (OIST) and collaborators at the University of Innsbruck in Austria found that the interactions between particles trapped in light distributed along an optical microfiber, as well as the speed of particle movement were different based on the light's characteristics. The results were recently published in *Scientific Reports*.

Distributing light across an optical microfiber is used as a way to manipulate tiny particles for a variety of possible applications not only in the world of physics, but also biology. There are two main ways to work with light and optical microfibers: in the fundamental mode and the higher order mode. The fundamental mode is the basic light shape where the energy is strongest in the middle of the beam of light and fades at the edges. If the light is any other shape, it can be classified as a higher order mode, which can be created by shining the light through a certain type of crystal.

The OIST team had previously found that the use of higher order modes trapped and moved single particles more rapidly than the fundamental mode. This time, they looked more closely at the differences between particle interactions and speed changes when dealing with more than one particle, in the fundamental or the higher order mode. When there are multiple particles trapped in the light surrounding an optical microfiber, they align in a specific order, which is called the optical binding effect.

To explore these particle interactions, the researchers trapped up to five particles using optical tweezers. They then moved the particles towards the optical microfiber and released them into the light field around the microfiber. The team measured the speed at which the particles were traveling along the microfiber.

Maimaiti Aili, OIST Special Research Student. Credit: OIST

"We did measurements for both fundamental and higher order modes," Aili Maimaiti, OIST Special Research Student and first author said. "We found that higher order modes had a different effect on the particles. In higher order modes, the collective particle speed slows down when more particles are added, while the opposite is true for the fundamental mode."

They also calculated the distance between multiple particles as they moved. They did this calculation each time they added a particle up to the maximum of five particles. The team found that the particles farther from the light source have a smaller space in between them - or interparticle distance - but as you move closer to the light source, the space is larger. When they looked at the differences between fundamental and higher order modes, they found that the interparticle distance was smaller in higher order modes.

"This is proof that the binding effect is different under the higher order mode," Maimaiti said.

The researchers developed a theoretical model that supported the experimental findings. The model explained that the particles act as mirrors that reflect and transmit the light in which they are trapped and this causes their interaction.

They highlighted the importance of understanding these interactions between particles trapped in light. Physical phenomena, such as particle behavior in higher order modes not only allows for better control of the particle positions, but additionally could be useful in studying quantum effects with chains of atoms in 1D crystal-like structures.

More information: Aili Maimaiti et al, Nonlinear force dependence on optically bound micro-particle arrays in the evanescent fields of fundamental and higher order microfibre modes, *Scientific Reports* (2016). DOI: 10.1038/srep30131

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