MICROMANIPULATION

Optoelectronic tweezers

A low-power light image projected on a photoconductive layer can initiate non-uniform electric fields over a large area, and allow the manipulation and sorting of particles without wires and electrodes and in the absence of flow.

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Light and oscillating electric fields can grab and move objects at the microscale in a non-contact manner: this has allowed immense strides in molecular and cell biology and new fundamental physical insights. The latest advance reported in *Nature*[1] shows how reconfigurable light patterns made with an incoherent and not very powerful light source (even a light bulb will do!) projected onto a specialized surface may induce controlled motion of objects. This opens up exciting new prospects for high-throughput biological cell analysis and studies of particle dynamics at the thermodynamic limit, thanks to extended, optically defined potential-energy landscapes.

Around 400 years ago, Kepler, who is mainly known for the laws of planetary motion, had a fascination with comets and why their tails pointed away from the Sun. He attributed this to radiation pressure from the Sun and even wrote about the possibility of solar sails travelling from the Earth to the Moon! Today we know that Kepler's visionary thoughts about moving matter with light are ensconced in our understanding of light–matter interactions, and these are the essential concepts exploited in conventional optical micromanipulation. Light can move, trap and guide matter as it possesses momentum $p = h/\lambda$ where λ is the wavelength and h Planck's constant. At the microscopic level, this effect arises when a transparent object changes (refracts or reflects) the direction of an incident light field. At the same time this causes a force on the microscopic object that holds it in the brightest part of the beam. This effect has been exploited in several non-contact methods to move objects, the most prolific of which has been optical tweezers[2]. Although attempts at building solar sails are still in their infancy[3], their microscale equivalents exist, and they move around objects like cells or microparticles.

These insights have revolutionized our understanding of molecular motors[4], and have had a major impact in fundamental colloidal and physical science[5]. Along with these developments, scientists also found that it was possible to manipulate objects using electric-field gradients. This method, called dielectrophoresis, works in a rather intriguing way: placing an object in an electric field results in a force if the object is charged (the well-known Coulomb interaction). However, if the field is non-uniform we can even exert forces on a neutral object due to the action of the applied field on induced dipoles within the object and the surrounding medium. The resulting motion can either be away from or towards the regions of high field intensity. A major drawback, though, has been that dielectrophoresis typically needs hardwired electrical connections to initiate action. Dielectrophoresis is akin to an electrical analogue of optical tweezers in principle.

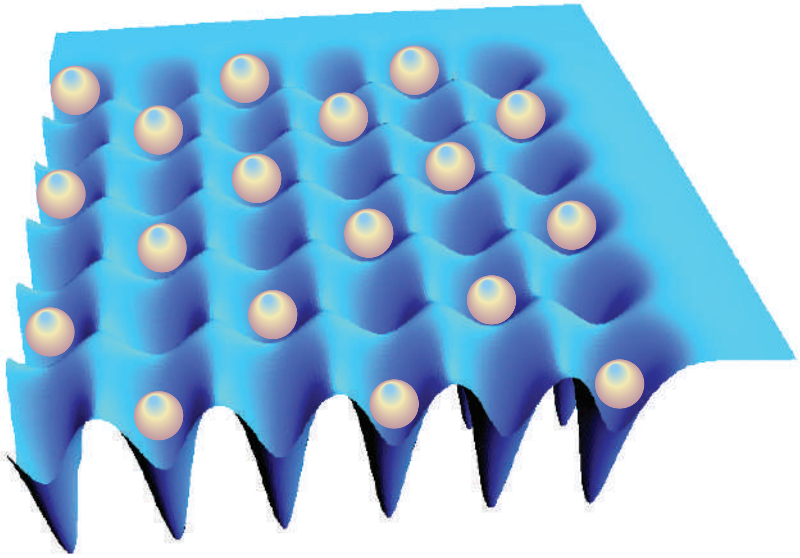

Figure 1 A potential-energy landscape created by light. Particles may reside in each lattice site. The work of Chiou *et al.*[1] allows such extended landscapes to be greatly enlarged, and have shown landscapes of up to 15,000 particles. (Picture courtesy of G. Spalding).

The new report offers a potentially revolutionary method of moving objects that retains much of the flexibility of optical tweezers and combines the reconfigurability of light patterns with the power of dielectrophoresis. Chiou and colleagues[1] illuminate a special photoconductive layer with a light pattern. The photoconductive layer is connected with a parallel conductive layer and the two are biased with an alternating voltage signal. Together they form a sample chamber that holds the particles or cells. The light image, projected by a special light modulator, induces virtual electrodes due to the gain of the photoconducting material. This yields non-uniform electric fields and effectively allows dielectrophoresis to occur without wires. This advance addresses some key shortcomings in the field using an ingenious idea: a light source of very low power illuminating a suitable photoconductive layer can initiate a suitable oscillating field anywhere over a large area.

The beauty of the method is that there is no need for any lithography or nanostructures. The photoconductive gain means that just microwatts of light can exert sufficiently large forces to move cells. The work presented may address key challenges in the emergent area of microfluidics and micrototal analysis systems. In this arena, scientists wish to manipulate, discriminate and interrogate samples, including biological samples: this could lead to new screening methods for the future. Chiou and colleagues show the potential of their technique in the separation of live cells from dead ones, based on their differing dielectric properties. They also show very large arrays of traps — an optical potential-energy landscape containing 15,000 sites may be created (Fig. 1). The resolution achieved is higher than other related electrophoretic methods. This is important because it has the potential to turn dielectrophoresis into a suitable method for addressing individual cells or particles.

The pertinent point is the reconfigurability: the absence of wires means freedom to illuminate a large area and change the landscape in which microscopic objects can be arranged at will. This work is likely to lead to a whole host of new studies in years to come. Scientists are very excited about separating or sorting dielectric objects and biological cells in a passive high-throughput manner[6]. This method may allow for sorting of objects over a much larger region than has previously been realized. Biologists wish to perform parallel studies on cell substrates and scientists have long known that colloids on an optical landscape offer excellent test-beds for studying defect dynamics, grain boundaries and competition, which can give insights right down to the atomic scale. The new optoelectronic tweezers are likely to facilitate new and exciting investigations in these or even totally new directions.

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