nanozone news

30 September 2004

Levitating laboratories

A chip-sized structure uses magnetic forces to levitate microscale droplets, turning them into miniature 'beakers' for conducting chemistry down to the single-molecule level.

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Droplets and particles of micro- and nanoscale size can be moved around on a chip-based device created by researchers in Texas. The particles don't make physical contact with the device walls, but are levitated freely in air by magnetic forces.

Igor Lyuksyutov and colleagues at Texas A&M University in College Station have used their 'micromanipulation chip' (MMC) to bring liquid droplets together and merge them, to form micrometre-scale salt crystals from levitated solutions, and to manipulate objects ranging from polymer microspheres to carbon nanotube powders and red blood cells[1].

The droplets can have volumes as small as a few femtolitres (10^{-15} l), which might in principle be prepared with solute concentrations low enough that they contain only single molecules. The controlled merging of such 'microbeakers' could thus be used to study interactions or reactions at the single-molecule level.

The MMC also offers exquisite control over particle potential energies and the forces that move them: the energy can be specified with a precision down to the level of about 0.2×10^{-21} J (0.2 zeptojoules), and the forces can be adjusted within the femtonewton range. This could allow studies of fundamental physical phenomena such as brownian motion and particle collisions.

Objects are levitated in the MMC by magnetic forces. If these are strong

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enough, they can levitate even conventionally 'non-magnetic' materials owing to the diamagnetism induced by the applied field. The levitated particles acquire a magnetic moment oriented in the opposite direction to that of the field. Diamagnetism has been exploited previously to levitate all manner of macroscopic bodies, including live frogs.

Lyuksyutov and colleagues create a levitation force by mounting two permanent magnets (neodymium–iron–boron), 1 cm square by 0.1 to 2 mm thick, on a steel substrate, with a narrow gap of tens to hundreds of micrometres between them. This gap constitutes the channel along which microscopic particles are moved.

The motion is induced by laying down electrodes at intervals along the channel. Current pulses applied to these electrodes produce magnetic fields which push the levitating particles from one potential well to another between successive electrodes. Alternatively, an a.c. electric field on the electrodes can pull the particle along by dielectrophoresis. In this way, the particles can be positioned with an accuracy of about 300 nm. They will remain levitating inside the MMC essentially indefinitely.

In one experiment, the researchers used the manipulation forces to merge a droplet of water with a droplet of glycerine, both around 23 μm in diameter. In another, they grew a sodium chloride crystal about 20 × 20 × 12 μm in size from a levitated droplet of salt solution, and then showed that they could rotate the crystal by applying an a.c. field between the two permanent magnets.

The smallest objects Lyuksyutov and colleagues have manipulated so far are droplets 1 μm across. But this limit is currently set only by the relatively crude method used for creating the droplets: they are sprayed from a perfume bottle. The device was created with the initial aim of manipulating nanoparticles, and Lyuksyutov is confident that his team could in principle work with droplets as small as 100 nm across.

For smaller objects than this, thermal brownian motion could begin to pose a problem. But that could be addressed by using a paramagnetic solution rather than air as the medium surrounding the levitating particles. Lyuksyutov says that this could permit trapping and moving of 10-nm objects, and indeed his group has already captured fluorescent beads 50 nm in diameter, immersed in such a medium.

Alternatively one could reduce thermal motion by operating the device at lower temperatures — at liquid-helium temperature (4 K), 8-nm particles could be manipulated in air. Or one could make the entire device smaller, which increases the strength of the magnetic trapping field. The current MMC was made largely by hand. Using state-of-the-art lithography could shrink it by at least two orders of magnitude.

References

1. Lyuksyutov I. F., Naugle D. G. & Rathnayaka K. D. D. On-chip manipulation of levitated femtodroplets. *Appl. Phys. Lett.* **85,** 1817–1819 (2004)
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