IBM scientists demo rocking Brownian motors for nanoparticles

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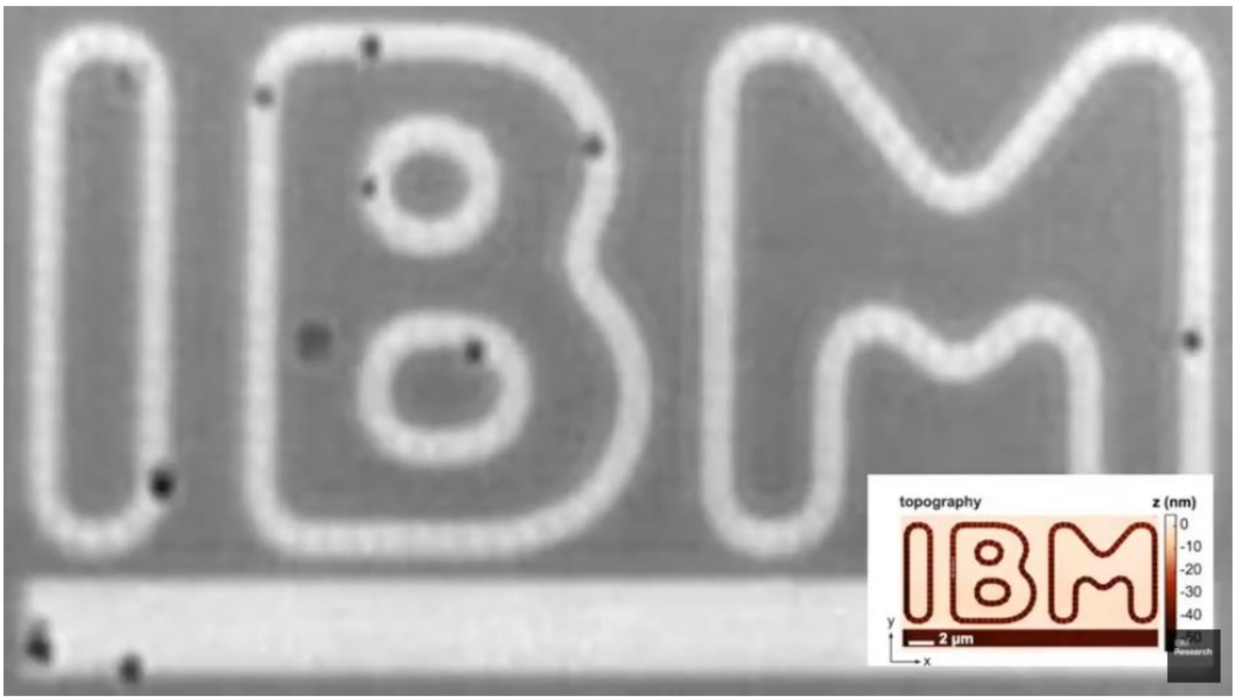

Today, our IBM Research team published the first real world demonstration of a rocking Brownian motor for nanoparticles in the peer-review journal *Science*. The motors propel nanoscale particles along predefined racetracks to enable researchers to separate nanoparticle populations with unprecedented precision. The reported findings show great potential for lab-on-a-chip applications in material science, environmental sciences or biochemistry.

No More Fairy Tales

Do you remember the Grimm version of Cinderella when she had to pick peas and lentils out of the ashes? Now imagine that instead of peas and lentils you have a suspension of nanoparticles, which are only 60 nanometer (nm) and 100 nm in size—that's 1,000 times smaller than the diameter of a human hair. Using previous methods, one could separate them with a complicated filter or machines, however these are too bulky and complex to be integrated into a handheld lab-on-a-chip.

Rocking Brownian Motor

To address this, we take inspiration from nature. In our cells molecular motors are tiny walkers that transport cargo along microtubule guiding tracks with minimal fuel consumption. They are an integral part of the muscle contraction in our body. These motors are fascinating because they overcome and even exploit the random motion that particles of the size of the walkers typically experience at this scale, called Brownian motion. This chaotic, trembling motion of the particles is caused by the water molecules, which randomly collide with particles. Fun fact, it was Albert Einstein who first gave a correct description of Brownian motion in 1905.

A Brownian motor converts this random motion into mechanical work by forcing the randomness into a straight particle movement. For this purpose scientists use the principle similar to a ratchet screwdriver, in which asymmetric teeth allow movement in one direction, but not in the other.

In addition, an oscillating external force is used, which pushes the particles against the ratchet teeth. For the particles it is much easier to pass the teeth in one direction, resulting in the directed movement of the particles. A Brownian motor does not produce directed motion, it only prevents particles from moving backwards.

Building a new device for particle separation

To start with we used a tiny, heatable silicon tip with a sharp apex to create a 3-D landscape for nanoparticles by "chiseling" away material of a polymer layer. This technique is called thermal scanning probe lithography. It was used to create the world's smallest magazine cover back in 2014.

Since we wanted to separate two different types of particles, we combined two ratchets with opposite transport directions that had differently sized teeth. We then put a water droplet containing the 60 nm and 100 nm small gold spheres on the ratchets and covered it with a thin glass, leaving a tiny gap between the tips of the teeth and the glass. Due to the electrostatic interaction between the charged surfaces and particles, the particles float in the liquid with the highest possible distance to the glass and teeth. Since a particle of greater size is less likely to explore the ratchet having the bigger teeth, the spheres moved in opposite directions and were separated. The 60 nm particles rocked to the right and the 100 nm particles to left hand side of the system within only a few seconds.

A model, which we also published in the paper, suggests that our device can separate particles ranging from 5 nm to 100 nm in size and having a radial difference of merely 1 nm. We are very confident that there are no significant hidden effects in the system since it behaves exactly as predicted by theory and we can measure all the relevant physical parameters.

Applications in various fields possible

Our device has a very small footprint, uses only 5 volts and, in contrast to existing tools, does not need any pressure or flow. This makes it ideal for lab-on-chip applications e.g. for a size analysis of particles such as DNA, proteins, quantum dots and other nanoparticles in tiny liquid volumes. It could be used in a broad range of research fields like material science, biochemistry or environmental research. One could think of structures which deliver the nano-objects of interest to sensors in order to detect ultra-small quantities, such as nanoscale pollutants in our drinking water.

The development of such a device was based on IBM's capabilities in nanostructure fabrication and its knowledge in microfluidics. In fact, it is fascinating to consider that the operation and performance of the device are determined by the precision of a single lithographic step used to fabricate the device.

More information: Michael J. Skaug et al. Nanofluidic rocking Brownian motors, *Science* (2018). DOI: 10.1126/science.aal3271

Provided by IBM