How are droplets displaced by ultrasounds?

March 31 2010

Understanding the physical mechanisms that enable a droplet to be displaced by propagating an acoustic wave along the substrate on which it lies is the hurdle that has been overcome by researchers from the Institut d'Electronique de Microélectronique et Nanotechnologies (CNRS/France).

They have succeeded in detailing the structure of the ultrasounds that propagate in a droplet and which lead to its oscillation and then its displacement. These results, published in the journal *Physical Review E*, could be profitably employed to optimize biochemical analyses conducted on DNA chips, which use droplets of biological liquids.

Researchers from Lille have studied the dynamics of a small droplet resting on a substrate, along which an acoustic wave is propagated, comparable to the first waves detected by seismographs during seismic tremors. What is the effect of this mini-earthquake on the droplet? The researchers observed (see the appended film, shot with a rapid 5000 images per second camera) that the droplet is displaced in the direction of propagation of the wave at a velocity that can attain several centimeters a second. Furthermore, the shape of the droplet is modified: the droplet begins to oscillate and is periodically stretched upwards and then flattened.

Why these dynamics? The propagated acoustic waves have the unique characteristic of being displaced solely on the surface of the substrate, without penetrating into it. Consequently, they do not undergo any deviation or reflection and are thus only attenuated to a very small extent. Their amplitude, of the order of a nanometer, and their frequency, around 20 MHz(2), produce significant accelerations: the substrate undergoes local deformations of 1 to 2 nanometers repeated at a very short interval, which makes the droplet oscillate and deform and brings about its displacement in the direction of propagation of the wave.

Although this phenomenon had already been observed, the physical mechanisms behind it were not understood. The team, which includes microsystem designers, acousticians and specialists in fluid dynamics, have identified the acoustic and fluidic mechanisms leading to these surprising oscillatory dynamics by conducting a quantitative experimental study and numerical simulations, which have enabled them to elucidate the detailed structure of the acoustic wave within the droplet.

They have shown that the acoustic wave is partly radiated in the liquid and, due to the viscosity of the liquid, a phenomenon known as “acoustic streaming” is created, comparable to the phenomenon that a slight air current produces near to a powerful loudspeaker. In this way, the acoustic wave can produce a constant, directional flow. There is also another phenomenon that comes into play: if the acoustic wave is only partially attenuated by the viscosity of the liquid, it manages to reach the interface between the air and the liquid of the droplet. The conservation of the quantity of movement at this interface and the difference of acoustic indexes between water and air then induce a radiation pressure that deforms the interface. This pressure, coupled to the specific dynamics of the droplet, creates oscillations.

There are many applications for this phenomenon. Firstly, by displacing small droplets, certain parts of a surface can be dried selectively. This property could be useful when droplets are confined in certain zones of a surface that is difficult to access.

Droplets are moreover increasingly used for carrying out biochemical reactions on DNA chips. This technique makes it possible for example, with a very small quantity of biological liquid, to test a whole series of drug candidates or to carry out multiple enzymatic reactions. The interest is to significantly cut testing costs. However, due to the small size of the droplets, it is difficult to ensure correct mixing and the reactions are very slow. The use of acoustic waves makes it possible to mix the components continuously and thus increase the reaction rate. By understanding how acoustic waves act on the displacement of droplets, researchers could optimize such reactions.

More information: Droplets displacement and oscillations induced by ultrasonic surface acoustic waves: a quantitative study, P. Brunet, M. Baudoin, O. Bou Matar and F. Zoueshtiagh. Physical Review E, 19 March 2010.

Provided by CNRS