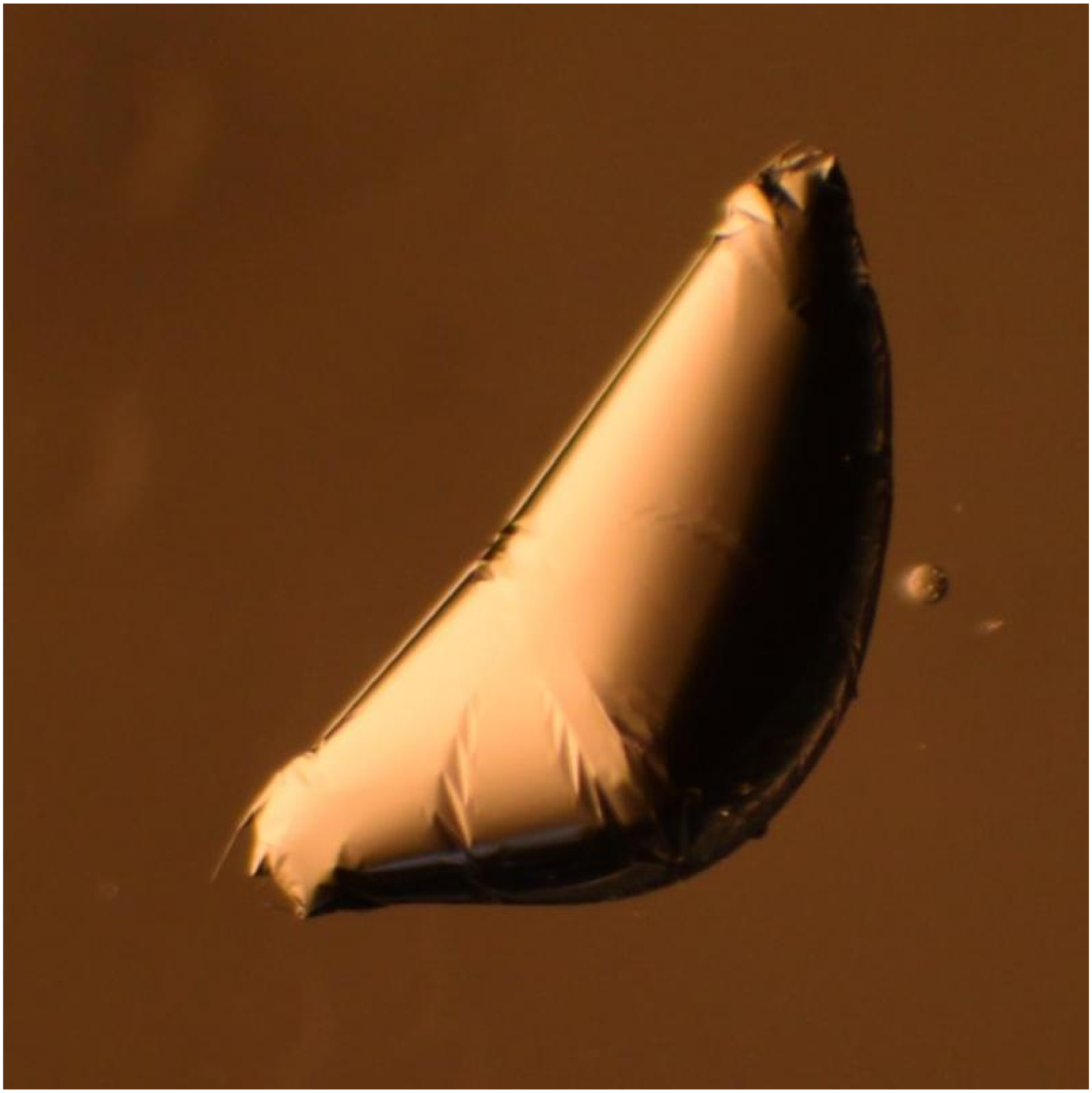
Using ultrathin sheets to discover new class of wrapped shapes

August 31 2015



UMass Amherst materials researchers recently proposed and validated a model of wrapped shapes used to encapsulate one fluid droplet within another. Shown is a 39 nm sheet, radius 1.52 mm, and water drop in silicone oil floating on fluorinated oil. Credit: UMass Amherst/Joseph Paulsen

Materials scientists seeking to encapsulate droplets of one fluid within another often use molecules like soap or micro- or nano-particles to do it. One distinct way of wrapping a droplet is to use a thin sheet that calls on capillary action to naturally wrap a droplet in a blanket of film, but because it takes some force to bend a sheet around a drop, there were thought to be limits on what can be accomplished by this process.

Now, experimental and theoretical physicists and a polymer scientist at the University of Massachusetts Amherst have teamed up to use much thinner sheets than before to achieve this wrapping process. "Thinner, highly-bendable sheets lift these constraints and allow for a new class of wrapped shapes," says experimental physicist Narayanan Menon.

Such wrapping techniques could be used to contain toxic or corrosive liquids, to physically isolate a delicate liquid cargo or to shrink-wrap drops, he points out. Details appear today in an early online edition of *Nature Materials*.

The team is made up of experimental physicists Menon and postdoctoral researcher Joseph Paulsen, theoretical physicists Vincent Démery, Benjamin Davidovitch and Christian Santangelo, and polymer scientist Thomas Russell.

Paulsen devised a process in which a circular flat sheet is placed on a drop, which is completely wrapped by the sheet as the droplet's volume is gradually decreased by withdrawing fluid with a thin straw. Small-scale wrinkles and crumples allow the sheet to curve around the droplet as it wraps.

Surprisingly, using a very thin skin to wrap a drop leads to non-spherical shapes, whereas one might have imagined that the sheet would simply conform to the spherical shape of the drop. "These non-spherical shapes are reminiscent of foods in which a filling is wrapped inside a sheet of pastry or dough, such as a samosa, an empanada or a dumpling," says Menon.

The theorists developed a general model that explains "all the observed partially and fully wrapped shapes purely geometrically, independent of material parameters, in a regime of thickness that often occurs in nature and is easily achieved in technological settings."

They point out that "Wrinkles, fold and crumples are challenging to understand on their own, let alone when they interact in a highly-curved geometry. However, we show that the essence of the wrapping process can be understood without describing any small-scale features," the authors point out. Paulsen adds, "We've shown that for very thin sheets, you can ignore the complicated small-scale features and still predict the overall three-dimensional shape of the wrapping."

This advance, funded by the Keck Foundation, brings three major technical advantages. First, when ultrathin sheets are used as wrappers, they spontaneously select a method of wrapping that wastes the least amount material in wrapping up a given volume of fluid. "This corresponds to satisfying the goal of everyone who has wrapped a gift using the least amount of wrapping paper possible," he says.

Second, energies at the droplet-wrapper interface and mechanical properties of the sheet are irrelevant in the new model, which allows greater functionality, the authors point out. Greater functionality in this case means that if you want to use a sheet with different properties, say different color, chemistry or something with holes on it, this process is not disrupted, the physicist explains.

Finally, complete coverage of the fluid can be achieved without special sheet designs, the researchers say. Menon adds, "Special sheet designs are possible, but if you are trying to do this on a large scale, then it is tedious to make sheets that are cut in some complicated way so they can fold up easily. Thin enough sheets automatically wrinkle and fold in such a way that you don't need to cut them up."

Paulsen says, "We expect our findings to be useful in applications where a liquid cargo needs to be protected in a solid barrier. Our main focus was on shape, but we expect these wrapped droplets to have interesting mechanical properties as well."

More information: Optimal wrapping of liquid droplets with ultrathin sheets, DOI: 10.1038/nmat4397

Provided by University of Massachusetts Amherst