Transfer printing microstructures on various surfaces using sugar

If you’ve watched sci-fi movies or read comics, the word ‘nanotech’ is one you might have encountered. We’ve seen the ‘magic’ of the technology and you would rightly consider the applications as an impossibility. But the barrier between us wrapping a postage-stamp-sized circuit around a human hair without tearing it, or tattooing a sensor directly onto a beating heart, is surprisingly mundane. The surfaces we use now are flat, and these objects are not, which leads us to the main hurdle to cross.

Every chip in your phone, every circuit in your laptop, was built on a perfectly flat silicon wafer. The machines that currently etch those microscopic patterns are extraordinarily precise. Some etchings are finer than a tenth of a hair's width. However, when asked to work with a sphere, a cylinder, or even skin, they simply cannot perform. For decades, this has been the ceiling that limits us in achieving mass production of flexible electronics.

Researchers first attempted to tackle this by building circuits on flat surfaces like intended, and then transferring them onto curved ones. The idea is simple but elegant: fabricate on flat, move to curved. But the middlemen, the carriers used to pick up and place these hair-thin structures, have always been the limiting factor. A range of methods have been tested and almost all come with their specific drawbacks. Certain methods leave harsh chemical residues on the circuits, rendering them useless, while using adhesive tapes can't conform to tight curves. Even heat-based approaches hit a roadblock as it could warp or melt the delicate devices they're trying to move. Bottom line is, each solution traded one problem for another.

Then someone approached it with a very basic idea, sugar.

In 2020, researchers showed that ordinary sugar could act as a middleman, a transfer carrier. The process is hilariously simple: pour molten sugar over the structures on the flat surface, let it harden, peel the whole film off like a sticker, place it on the target surface, and finally rinse away the sugar with water. What one is left with is no harsh solvents, no extreme temperatures, and no residue. The sugar leaves nothing behind except the transferred structure, sitting exactly where you put it.

This was already a step forward, but the sugar's real advantage as a carrier emerged two years later. Researcher Gary Zabow at the US National Institute of Standards and Technology discovered that if you gently re-heat the sugar film after placing it on a curved surface, it flows, or creeps, slow and viscous like very thick honey. And as it spreads, it drags the embedded microstructures along with it, coaxing them to conform perfectly to whatever shape it is placed on. Zabow demonstrated it on sharp edges, deep valleys, needle tips, dot like patterns and every interesting surface one could think of. He called it REFLEX: **Re**flow-driven **Flex**ible transfer.

The results were jaw-dropping, microstructures were successfully transferred onto the surface of a grain of pollen, or onto individual red blood cells, which are roughly 7 micrometres across, about one hundredth the width of a human hair. And remarkably, the pattern distortions were less than one percent, even when the new surface area changed by over 300%. Previous methods couldn't come close.

What does this unlock in the real world? Consider two examples.

Inside a hospital, the next generation of cardiac monitors won't be rigid boxes strapped to a patient's chest. They'll be ultrathin mesh sensors draped directly over the heart muscle, measuring electrical signals from every angle simultaneously. Sugar-assisted transfer is one of the very few techniques gentle to place those sensors without damaging the tissue. Similar logic applies to neural interfaces on the folded surface of the brain, or to retinal prostheses on the curved interior of the eye.

In aerospace, structural health monitoring depends on sensors spread across fuselages, wings, and engine housings which are all curved, all unusual. A sensor that can't fully conform to a curved surface leaves gaps in coverage, and one that leaves chemical residues risks interfering with the adhesive bonds holding the aircraft together. Sugar-transferred sensors solve both problems at once, and researchers have already demonstrated strain sensors on morphing wing structures and antenna arrays on curved fuselage sections.

The larger impact is that for the first time, the curved, irregular world we actually live in is becoming accessible to the precision tools of the semiconductor industry. A grain of sugar which is cheap, biodegradable, and can be washed away with water turns out to be a more effective bridge between flat factories and complex surfaces than decades of polymer engineering. Sometimes the most elegant solutions are also the sweetest.