

MICROMANIPULATION

Stick and place

Systems in optoelectronics, (bio)sensors and actuators rely on the integration of heterogeneous components. Such integration will be aided by a simple technique — based on soft adhesion to an elastomeric stamp — for transferring microscopic objects to a wide range of surfaces.

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Conventional microelectronic technology is widely successful, as shown by the increasing power of computers and the ubiquitous cell phone¹. The driving force in microelectronics has been to put small features on small areas with exact specifications. These devices are wonderfully complex but fabricated on planar silicon wafers one layer at a time. What about other applications such as large solar panels, displays, or electronics on flexible materials that require large areas or soft materials to be patterned^{2–4}? Here, the limits of conventional microelectronics are exceeded and new methods for fabrication are needed. Most alternative methods use self-assembly or 'pick and place' methods that require substrates to be fabricated to recognize individual components or a robot to gently move millions of microstructures from one surface to another. In an article on page 33 of this issue, M. A. Meitl and colleagues report an ingenious method to rapidly transfer large numbers of objects from one surface to another through a slab of polydimethylsiloxane (PDMS)⁵.

The method, remarkable for its simplicity, uses the soft, compliant structure of PDMS to grab and release objects. PDMS is a rubber commonly used in surface science to pattern monolayers of organic molecules on gold. It is a basic tool in 'soft lithography', and is used to make microfluidic channels^{6,7}. PDMS is useful because it is soft and bendable so that it will come into intimate contact with a flat surface, but upon release it reverts back to its original shape. PDMS sticks to a wide variety of surfaces by van der Waals (non-specific) interaction without leaving a residue behind.

Meitl and colleagues used the 'stickiness' of PDMS to grab microstructures from a surface. When a flat slab of PDMS was placed on a surface decorated with microstructures, the PDMS came into van der Waals contact with the top surface of these objects. The PDMS was ripped off the surface at high speeds and the objects remained stuck to the PDMS. To release the objects on another substrate, the patterned PDMS was placed on a new surface

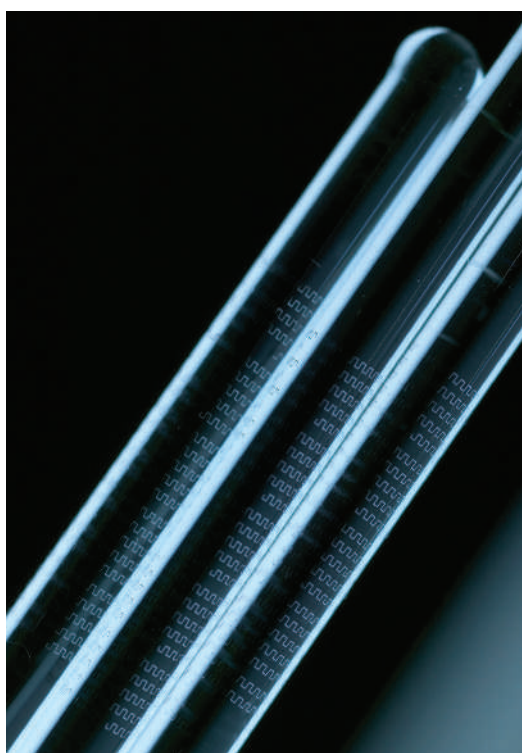


Figure 1 Fast stick, slow release. An example of unusual integration of heterogeneous materials obtained through kinetically controlled transfer printing. Microstructures of single-crystal silicon that were transferred to 3-mm-diameter glass rods⁵.

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and slowly removed. The transfer efficiency was greater than 99% for a broad range of objects and substrates (see Fig. 1, for an example).

How can PDMS both grab the objects from one surface and release them onto another? The answer lies in the rate at which PDMS is peeled from a surface. When PDMS is placed into contact with a substrate and slowly pulled from it, the separation energy, $G_{\text{substrate}}$, for the interface between the objects and the substrate is larger than the separation energy, G_{PDMS} , between the objects and PDMS. The objects remain pinned to the substrate and are not transferred with PDMS. As the rate at which PDMS is peeled from the surface is increased, the value for G_{PDMS} increases while the value of $G_{\text{substrate}}$ remains fixed. At some critical value for the peeling rate, the objects remain fixed to PDMS and are removed from the substrate. Thus, the researchers used fast peeling rates

to initially transfer objects from a surface to PDMS and slow rates to transfer these objects to a new, unpatterned surface.

This method is simple and general. The authors transferred 24,000 silicon microstructures to a GaAs wafer with a yield of >99.5% in a short period of time without the need for a clean room. They also demonstrated that layered structures could be fabricated by multiple transfers to build a three-dimensional structure one layer at a time. This method was applied to millimetre-sized objects, submicrometre-sized objects, microspheres, grains of pollen, and thin films. In the last example, the researchers transferred 100-nm-thick mica ribbons and graphite sheets 3 to 12 nm thick to demonstrate that this method can be applied to objects with at least one nanometre-sized dimension.

Many of the advantages of microelectronic technology for fabricating objects cheaply, cleanly, and in precise locations can be combined with this new transfer-printing process to transfer objects to flexible or curved substrates for a range of applications in the next generation of portable, flexible electronics. This method is a terrific addition to the toolbox of researchers and manufacturers who can readily fabricate microstructures on one substrate, but need them to be placed on a second substrate. It is easily envisioned that this method will be used with the 'pick and place' technique to rapidly achieve a 100% efficiency of transfer, where the 'pick and place' method will fill in the rare gaps of transferred microstructures. This method will make an important impact in fabricating smart, hybrid materials on flexible substrates or substrates with irregular shapes. For example, the authors printed p-n junctions and photodiodes directly on highly curved surfaces.

One of the limitations for the use of flexible materials in electronics has been the difficulty of fabricating simple, micrometre-sized devices on their surfaces. The 'stick and place' method of Meitl *et al.* can quickly overcome this limitation. As it works wonderfully on the micrometre scale, it is interesting to ask how this method will work with nanomaterials, where two or three dimensions are less than 100 nm. There are already numerous ways to fabricate nanomaterials, and if the 'stick and place' method is successful it would further enable the patterning of nanomaterials and their integration with electronic devices.

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MATERIAL WITNESS

Everything must change



No one finds it easy to come to terms with death, and for the materials scientist the death of their materials is still traumatic.

They may feel let down, as the bereaved often do; they say that the material 'failed'. And so they battle against entropy, struggling to achieve permanence in a world where impermanence is one of the fundamental laws.

For artists and designers, however, their relationship with impermanence isn't what it used to be. Some embrace change and decay, as artist Joanna Greenhill explained at a recent discussion meeting at London's Tate Modern gallery (*Fugitive Materials* 29 November 2005) on 'the art and science of impermanence'. Although painters, clothiers and sculptors once fretted over whether their pigments and dyes would fade or their metals corrode, now artists use materials that cannot possibly last long: milk, mud, snow and ice.

Artist Cornelia Parker goes further: she confessed that many of her works involve "killing off the object", which she then 'resurrects' in another form. She explodes sheds, steamrollers silverware, throws teapots off cliffs — and then arranges the remains in a way that speaks of this process of change.

And as designer Chris Lefteri showed, the issue of decay in many commercial products has been side-stepped by the shrinking of product lifetimes due to the dictates of fashion and technological progress. Today, products are discarded not when they are worn out but when they are obsolete. As a result, perfectly functioning items are sent to the landfill, unless they can somehow be recycled. "We have reached a point", Lefteri said, "where the unmaking of products is as important as the making of them."

One answer is of course to make the products biodegradable, and there are now some ingenious solutions to that — such as a water-soluble plastic for food packaging, or artificial snow for movie sets made from starch. Lefteri pointed to how the cell phone company Nokia is using shape-memory alloys for the screws holding its phones together, which automatically unscrew when placed in hot water. This makes disassembly and recycling of materials much easier.

But to a designer like Lefteri, environmental consideration isn't the only factor raised by short product life cycles. We seem prone to forming an emotional attachment to even the most mundane objects if we possess them for long enough. It's understandable perhaps that we might grow to love our car, but we even feel fond of our favourite coffee mug. If ownership becomes so fleeting, how must the designer respond? Does design itself then risk becoming redundant?

All this is a long way from the traditional concern of the materials scientist to fight decay: to foil cracks, to prevent corrosion and fatigue and wear, like modern Canutes hoping to hold back the tide of change. As materials scientist Mark Miodownik pointed out, this isn't how nature copes with impermanence. Instead, it constantly renovates and replaces by reproduction. But that's difficult.

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