Supplementary Information

Manufacturing

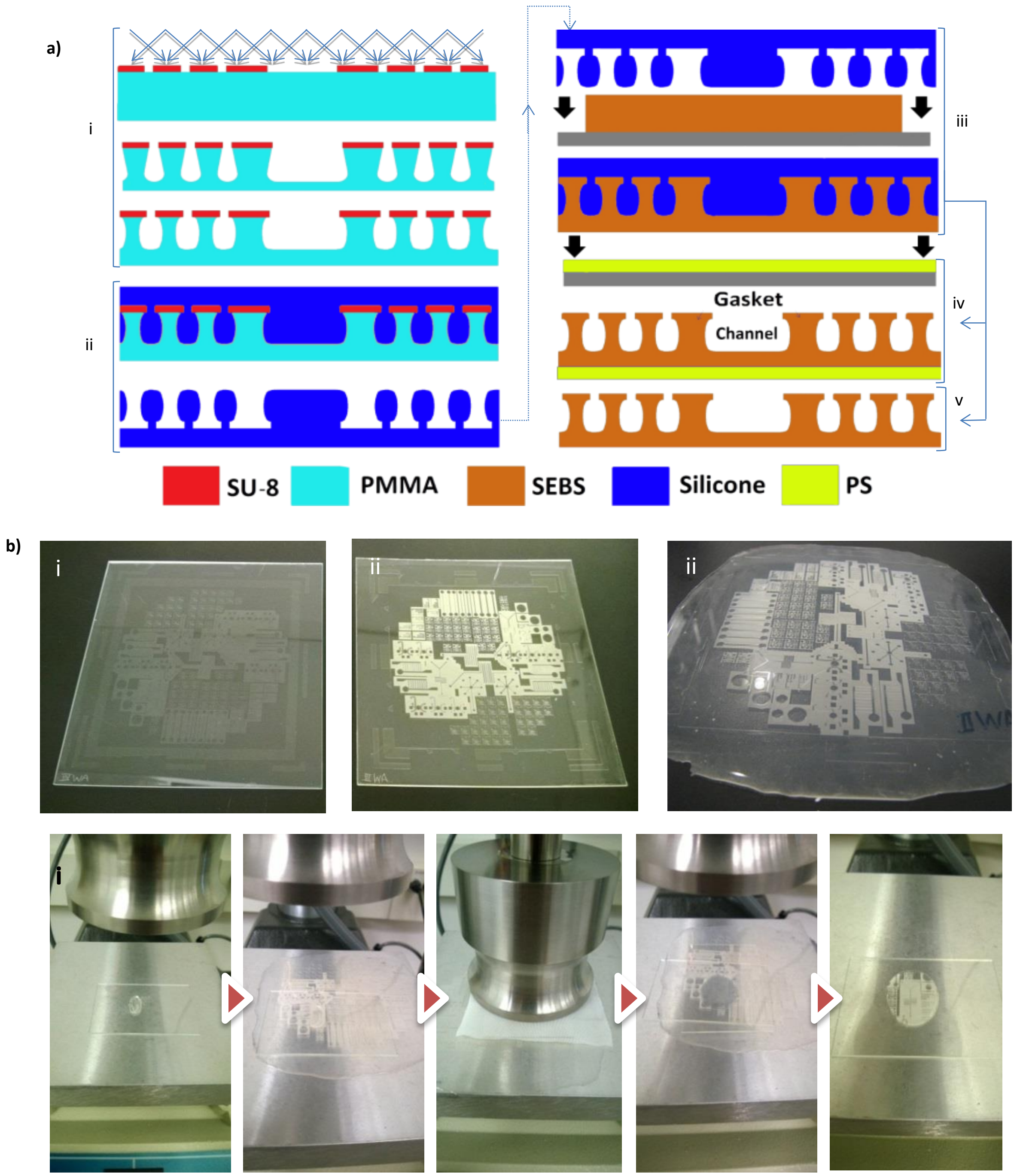

Fig. S1 (a): Process layout for fabrication of gecko-inspired-adhesive integrated microfluidic devices i) PMMA master mold development ii) silicone daughter mold casting iii) thermo compressive molding of SEBS iv) SEBS device with PS backing v) SEBS device without any backing

(b). Visual depiction of the fabrication process. i) SU-8 Patterned PMMA Wafer. ii) UV Exposed, post etched PMMA wafer, iii) Silicone Daughter mold iv) Thermo-compressive molding process

The master mold is fabricated in Plaskolite's OPTIX® acrylic, using deep UV lithography (254 nm) and a pre-patterned thin SU-8 layer acts as a mask and ultimate master for overhanging caps. A negative replica mold is fabricated by casting silicone rubber against the PMMA master mold. The formation of interlocked features during the casting process warrants the use of high tear strength silicone. TC 5030 (BJB Enterprises®) has been chosen for its high tear strength (11.4kN/m for TC 5030 vs. 2.6kN/m for Sylgard 184) which ensures successful demolding of interlocked features.

A PMMA sheet was cut into 5 inch x 5 inch substrates using a CO_2 laser cutter (Universal Laser systems®). After cleaning the substrate in DI water and drying with N_2, SU-8 2002 (MicroChem®) was spin coated on it and the substrate was baked at 85°C for 10 minutes. The ideal prebake temperature for SU-8 is 95°C, but at this temperature the PMMA substrates can warp significantly, causing problems in the subsequent processes. The SU-8 is patterned using a 365nm UV light source, which defines the location of the channels, gasket shapes and the supporting fibers using the same mask. The substrates were subjected to a post exposure bake at 85°C for 20 minutes and subsequently developed in SU-8 developer. The substrates were then exposed to a 254 nm UV light source (Stratalinker 2400™, ~4 mW/cm2) for few hours, depending on the desired channel depths. To obtain uniform exposure throughout the area, the substrates were rotated on a battery operated turntable during the exposure process. For these channel variations, the majority of exposures were completed with uncollimated 254 nm light, but this can be partially collimated if desired as demonstrated by Sameoto et al[1]. The ultimate developed depth is a function of total exposure dose, gap size between features (due to the uncollimated source) and development time. Development time is chosen to achieve a cap overhang to thickness ratio of ~2:1 based on previous experience in enhancing normal adhesion strength[2]. The natural undercutting of fibers due to the uncollimated exposure also helps enhance the mushroom shaped geometry in reducing stress concentrations on cap edges.

The substrates were developed in SU-8 developer, with a final IPA rinse. The development time is chosen to get the desired cap overhang and the rate of PMMA undercut is approximately 100 nm/minute for the typical cleanroom temperatures experienced. The resulting mold is the desired positive template. The negative mold is created using silicone by casting against the PMMA master mold. Curing is completed either at room temperature for a day or after 1-2 hours at 80°C. This negative mold can used to obtain the desired devices in various structural materials.

Thin pucks of Kraton were pre-fabricated by heating the pellets up to 200°C between glass slides under a small load and stored at room temperature. These pucks are placed on glass slides pre-heated on the hot plate at 200°C. The silicone mold is placed against the puck and a regulated load is applied for 30 sec. After removal of the load, the sample is removed from the hotplate and cooled. After reaching room temperature, silicone is demolded from the Kraton and then the Kraton sample is peeled off the glass and can be bonded to any smooth surface immediately.

Fiber design guidelines

Extensive experimental studies have been performed at our group[3-5] and theoretical models designed by others[6-9] to understand the appropriate fibre geometries that maximize adhesion strength. The normal adhesion strength isn't a simple function of contact area, but rather a combination of stress distribution in the cap (determined by loading and cap geometry), aspect ratio, supporting fiber geometry and backing layer stiffness. Mushroom shaped fibers are the clear consensus as the basic geometry to enhance normal adhesion, but in practice, the exact shape needs to be balanced with respect to manufacturability, fiber anti-collapse properties, and tolerance to shear loads. A general guideline that was used in making the adhesive designs was to aim for a cap overhang to thickness ratio of approximately 2:1 (based on experience in cap stability for this material modulus) [2]. Larger overhangs would frequently result in cap collapse or tearing during demolding or after adhesive was used, and smaller overhangs were less tolerant to shear loads but most ratios between 1:1 and 2:1 were acceptable. The supporting fiber aspect ratios were selected to be approximately 1:1 (cap diameter to total height) to minimize any possible fiber collapse upon demolding while still providing enough flexibility to make good contact with the opposing surface. This low fiber aspect ratio also makes the original acrylic mold far more durable, but if a stiffer structural material was needed for the fibers, then higher aspect ratios would provide better results. If smaller height channels are desired then smaller diameter fibers are preferably used elsewhere to keep the 1:1 aspect ratio, but the basic geometry still works even with low aspect ratio fibers and gaskets as long as the cap overhang is sufficient[4] .When well designed, very strong reversible adhesion is attained, as demonstrated in example images S2 and S3.

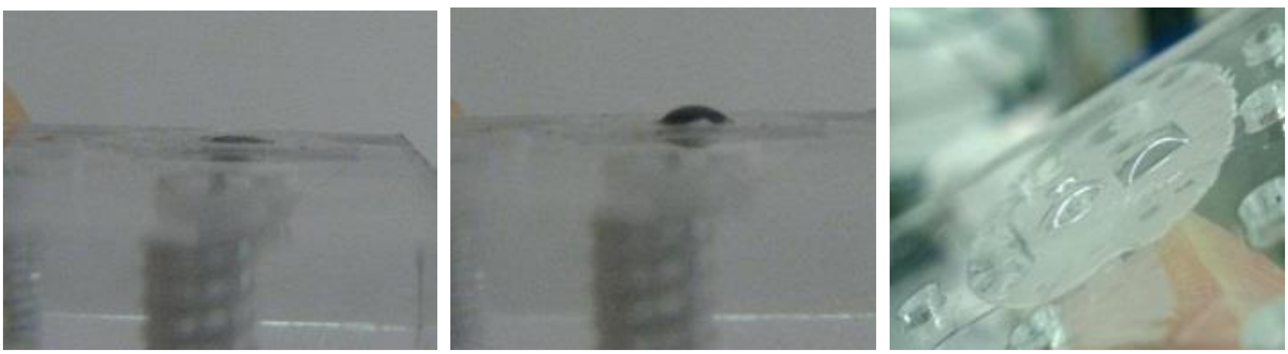

Fig.S2: Pressure induced inflation of the blister without a rigid backing

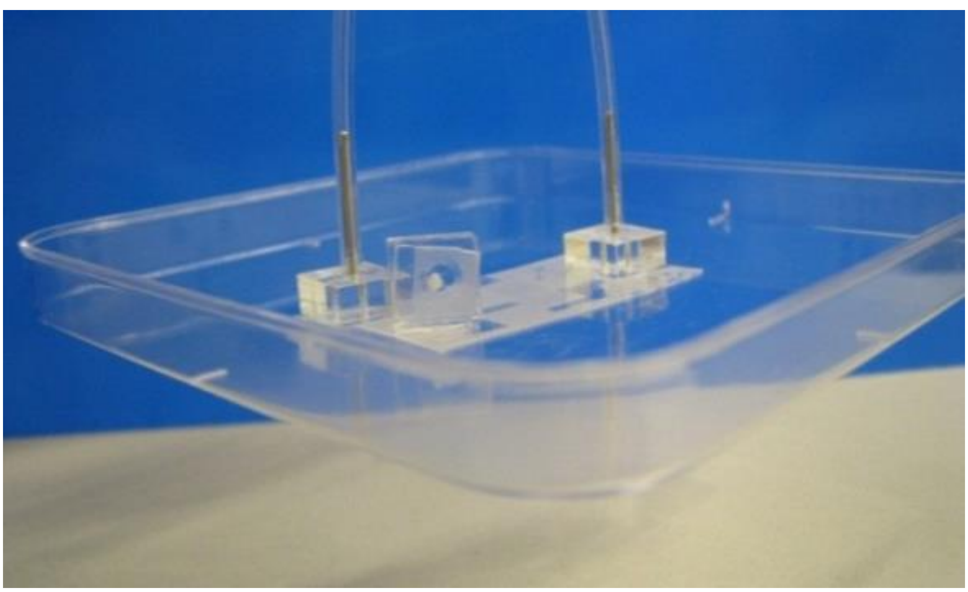

Fig. S3: A micromixer design on polystyrene petri-dish suspended by stick and play world to chip interconnects

Failure Modes

The primary means of premature bonding failure are nearly always either manufacturing defects in fully filling in the gasket structure, or insufficient cleanliness of the substrates. This could almost always be detected prior to filling with liquid with a quick visual inspection under a microscope of the gasket perimeter. Because van der Waals adhesion is only effective in a range of a few nm, high quality surfaces are important. Additionally, for substrates and channels that are very hydrophilic, small gaps in the gasket where fluid can fill in by capillary action will be a source of spontaneous leakage. An internal defect in a cap or a gasket is far less severe than one that crosses the boundary from gasket to the channel. Figure S4 shows a leakage from a channel caused by debris on a gasket near a reservoir made from hydrophilic polyurethane. The dyed water fills in the fiber via capillary action in this location. In the same design, where there was no defect, liquid remains fully contained by the gasket structures

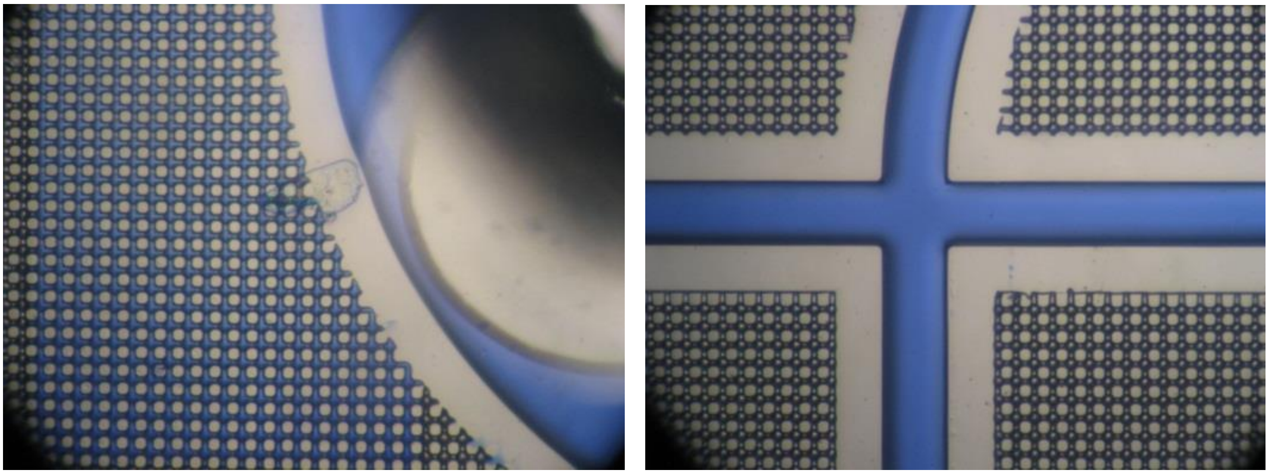

Fig. S4: A piece of debris causing leakage via capillary action in hydrophilic polyurethane gecko gasket. No leakage of liquid is seen on a clean surface.

References

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