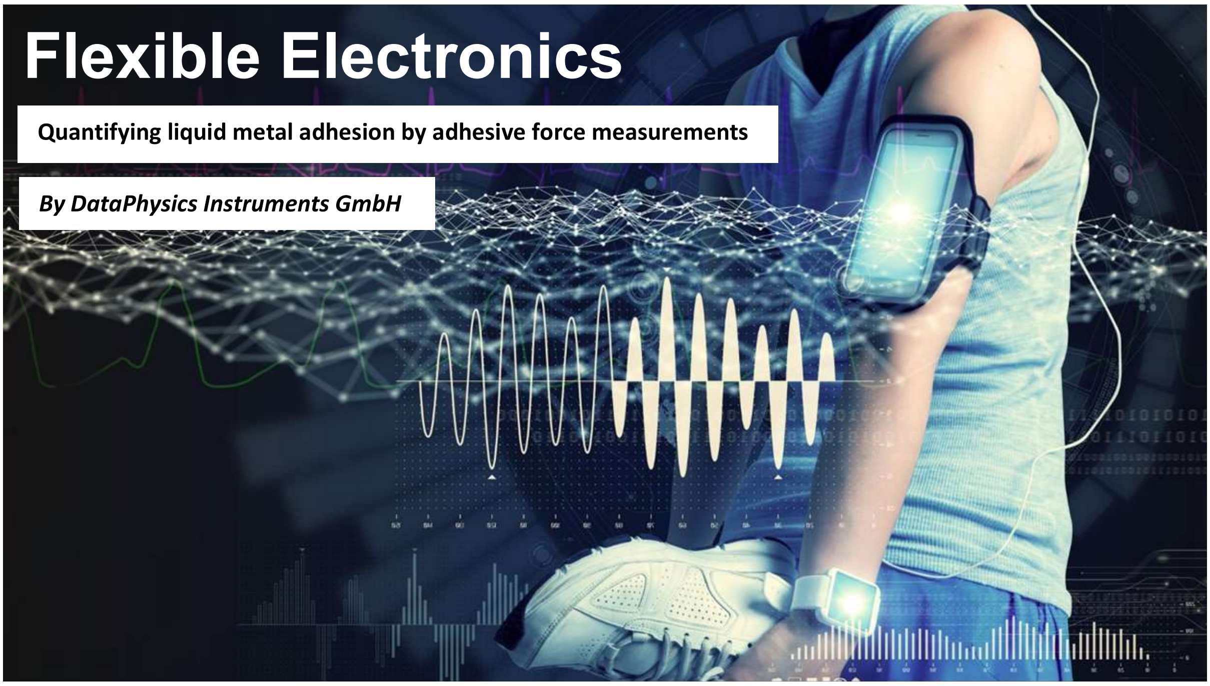
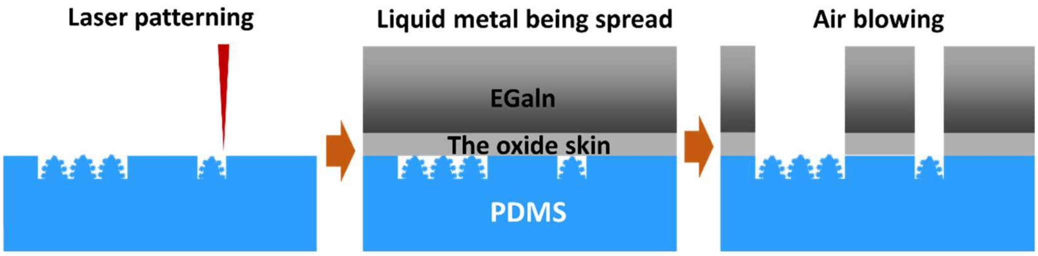
How adhesive force and contact angle measurements help to develop wearable electronic devices.

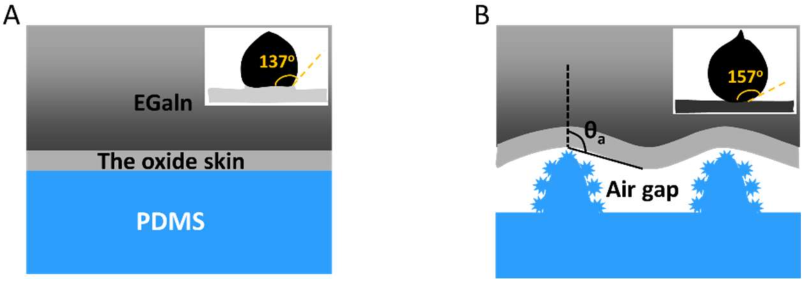


Flexible electronics attract tremendous attention for applications like biosensors, portable equipment, antennas, and wearable devices. Compared to traditional solid metals, Gallium (Ga)-based liquid metals are promising candidates for fabricating flexible electronics due to their nontoxicity, great flexibility and high conductivity. However, a thin oxide shell (Ga_2O_3) that forms on the surface of Ga-based liquid metals has an ultrahigh adhesion to the solid surface, which resulted in irremovable adhered liquid metal. This effect limited the precision of the preparation of Ga-based microelectronic devices and further hindered their practical applications. Unfortunately, even though the oxide shell can be removed by corrosive solutions (acid/alkaline), Ga_2O_3 would quickly form again after the exposure to air. Repellency of liquids can be accieved on superhydrophobic coatings, but Ga-based liquid metals are non-Newtonian liquids showing different wetting behaviors from Newtonian liquids like water. The mechanism behind how to design a liquid-metal repellent surface has not been deeply revealed yet. The reported liquid-metal repellent surfaces are often made by expensive masks and complex substrates. Furthermore, their production process is quite complicated and the materials are not durable enough for practical applications. Therefore, achieving durable liquid-metal-repellent surfaces by a simple and flexible method is still an open challenge. Recently, Zhang et al. have solved this tough problem by applying femtosecond laser direct writing (FLDW) technology leading to material surfaces with controlled wettability for the liquid metal (EGaIn) and a reduced adhesion between the liquid metal and the solid surface (**Picture 1**).



Picture 1: *Fabrication process for liquid-metal patterns by selective FLDW. The PDMS pattern is made by selctive laser treatment, dripping liquid metal onto the surface and air blowing.*

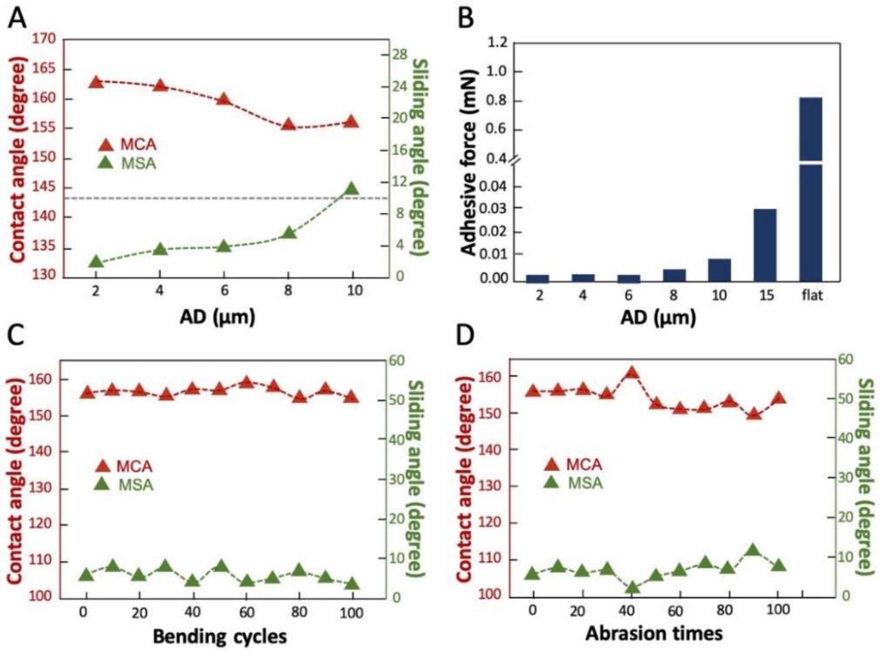
Compared to common Newtonian liquids, Ga-besed liquid-metal show a a lowered wettability on rough surfaces. The microstructures that were generated by laser on a polydimethylsiloxane (PDMS) surface include structure motives such as micro-protrusions and numerous submicro/nanoparticles which had a huge impact on the wetting properties and adhesive forces of the treated PDMS surface (**Picture 2**). In the case of a flat PDMS surface, the liquid-metal firmly adhered to the untreated PDMS surface due to the large contact area between the Ga_2O_3 oxide shell and the PDMS surface and the hydrogen bond interaction between the oxide shell and PDMS molecules.



Picture 2: *The wetting state of EGaIn droplet on untreated flat PDMS surfaces (A) and laser-induced rough PDMS surfaces (B).*

After the laser treatment, the metal contact angles (MCA) of surface increased from 137° to 157°, indicating an excellent repellence of the treated surface. The oxide shell first touched the microprotrusions and nanoparticles on the surface leading to a Cassie contact state. Also more hydrophilic surfaces that were treated with a laser to generate microstructures showed a good liquid-metal repellence, revealing that microstructures play a key role in acheving liquid-metal repellence rather than a modification of the surface chemistry.

In addition, **picture 3A** shows average distance (AD) of the laser pulse points affecte the amount of microstructures and nanostructures, thus affecting the liquid metal wetting behavior. With increasing AD distance, the MCA slightly decreased while the metal sliding angles (MSA) slightly increased. Moreover, they evaluated the adhesive forces between a liquid-metal droplet and laser-treated PDMS surface as a function of AD (**Picture 3B**). The data display a similar trend to that of the MSA (**Picture 3A**), and when the AD was less than 8 µm, the adhesive force was exstramly low.



Picture 3: *MCA/MSA and adhesive force measurements on laser-treated PDMS surface with different AD (A) (B); the bending test (C) and abrasion test (D).*

Notably, the adhesive force between the liquid metal and the treated PDMS surface was reduced by at least 266 times compared to the flat PDMS surface. Accordingly, they could obtain a liquid-metal repellent surface with ultralow adhesion when AD was less than 8 µm. Furthermore, the durability of liquid-metal-repellent surface was measured by bending the surface for different cycles or submitting the material to a sandpaper abrasion test. **Picture 2C-D** show that the MCA and the MSA had no apparent change even after 100 cycles or abrasion.

Overall, the authors developed a novel strategy to prepare liquid-metal-repellent surfaces by a femtosecond laser. The generated microstructure on the treated surface ensured liquid-metal repellence even after bending, rubbing, or immersion in different organic solutions. This work sheds light on designing soft electronics by just controlling the physical morphology of the laser-patterned liquid-metal-repellent surfaces which can be quantified by wettability and adhesive force measurements.

The adhesives forces in this work were measured by a dynamic contact angle measuring devices and tensiometer DCAT (DataPhysics Instruments GmbH, Germany).

For more information, please refer to the following article:

Femtosecond laser preparing patternable liquid-metal-repellent surface for flexible electronics; Jingzhou Zhang, Keyue Zhang, Jiale Yong, Qing Yang, Yongning He, Chengjun Zhang, Xun Hou, Feng Chen; *Journal of Colloid and Interface Science* **2020**, 578, 146-154; DOI: 10.1016/j.jcis.2020.05.055