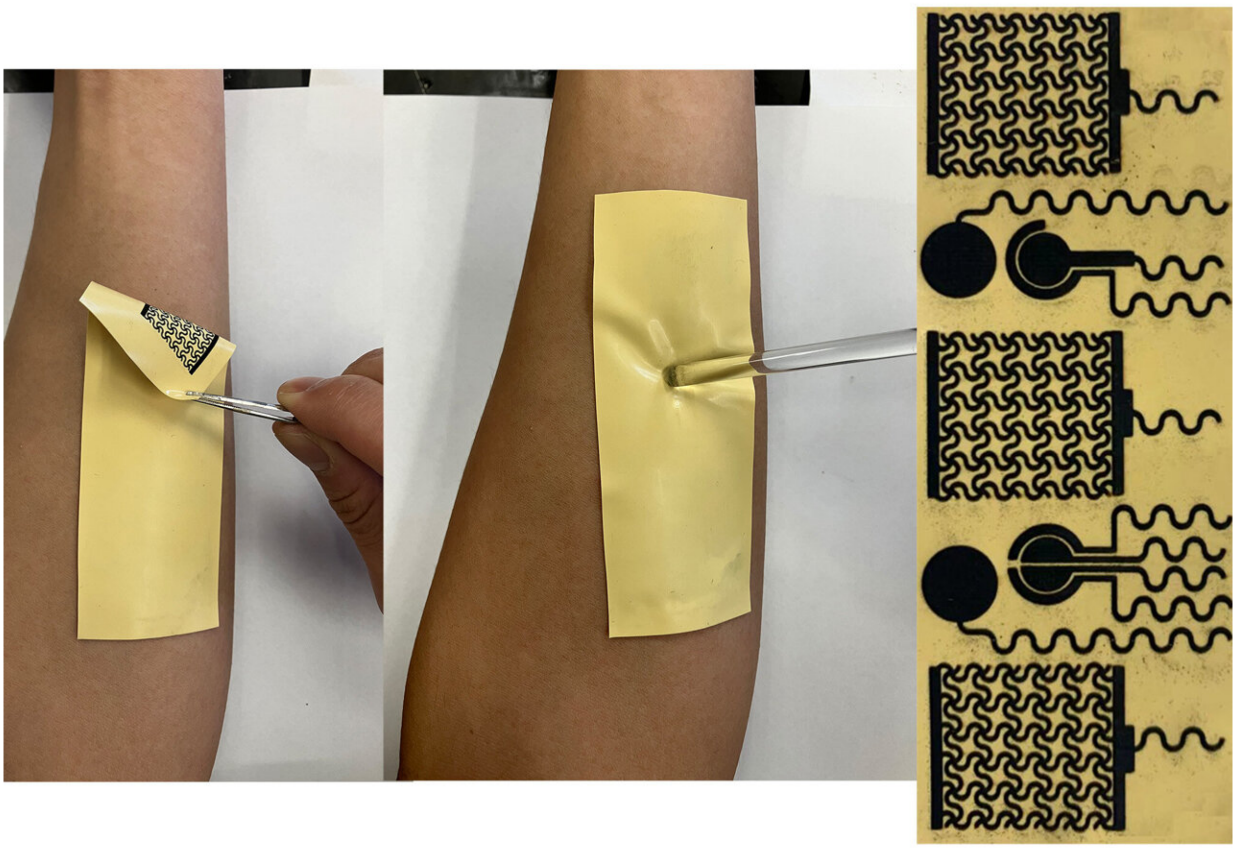
Rewritable, recyclable 'smart skin' monitors biological signals on demand

May 30 2024, by Ashley WennersHerron



Penn State researchers recently developed an adhesive sensing device that seamlessly attaches to human skin to detect and monitor the wearer's health. The writable sensors can be removed with tape, allowing new sensors to be patterned onto the device. Credit: Jia Zhu/Penn State

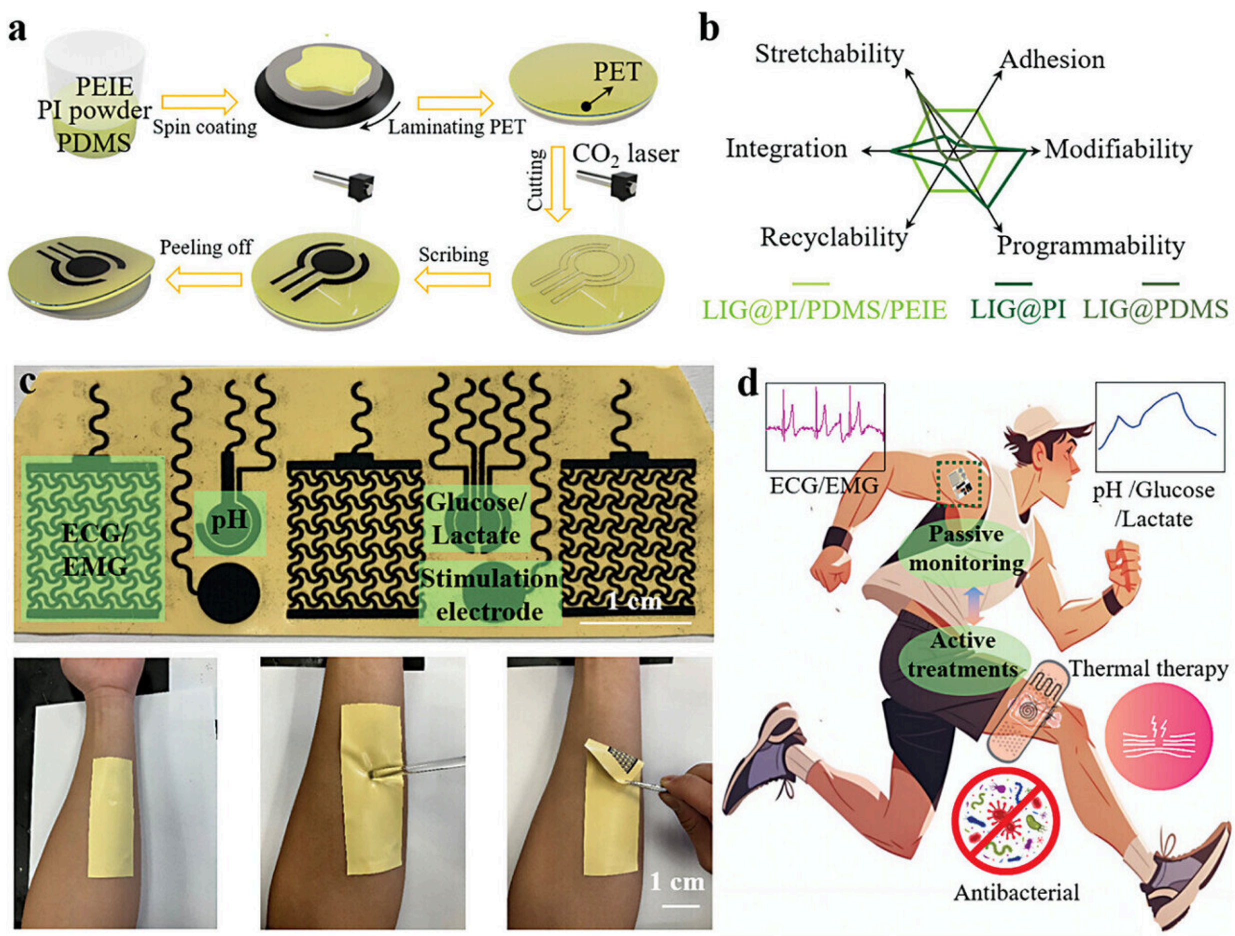
Skin can send certain health-related signals, such as dry skin feeling tighter to indicate the need for moisture. But what if skin could be smarter, capable of monitoring and sharing specific health information, such as the concentration of glucose in sweat or heart rate? That was the question driving a team led by Penn State researchers that recently developed an adhesive sensing device that seamlessly attaches to human skin to detect and monitor the wearer's health.

The details of the smart skin, including how it can be efficiently reprogrammed to detect various signals and even recycled, were published in Advanced Materials. The paper was included in the "Rising Stars" series, which is coordinated by multiple journals to highlight work by early career researchers around the world.

"Despite significant efforts on wearable sensors for health monitoring, there haven't been multifunctional skin-interfaced electronics with intrinsic adhesion on a single material platform prepared by low-cost, efficient fabrication methods," said co-corresponding author Huanyu "Larry" Cheng, the James L. Henderson, Jr. Memorial Associate Professor of Engineering Science and Mechanics in the Penn State College of Engineering.

"This work, however, introduces a skin-attachable, reprogrammable, multifunctional, adhesive device patch fabricated by simple and low-cost laser scribing."

Cheng explained that conventional fabrication techniques for flexible electronics can be complicated and costly, especially as sensors built on flexible substrates, or foundational layers, are not necessarily flexible themselves. The sensor's rigidity can limit the flexibility of the entire device.



LIG@PI/PDMS/PEIE-based multifunctional, recyclable, and adhesive device patch. Credit: *Advanced Materials* (2024). DOI: 10.1002/adma.202400236

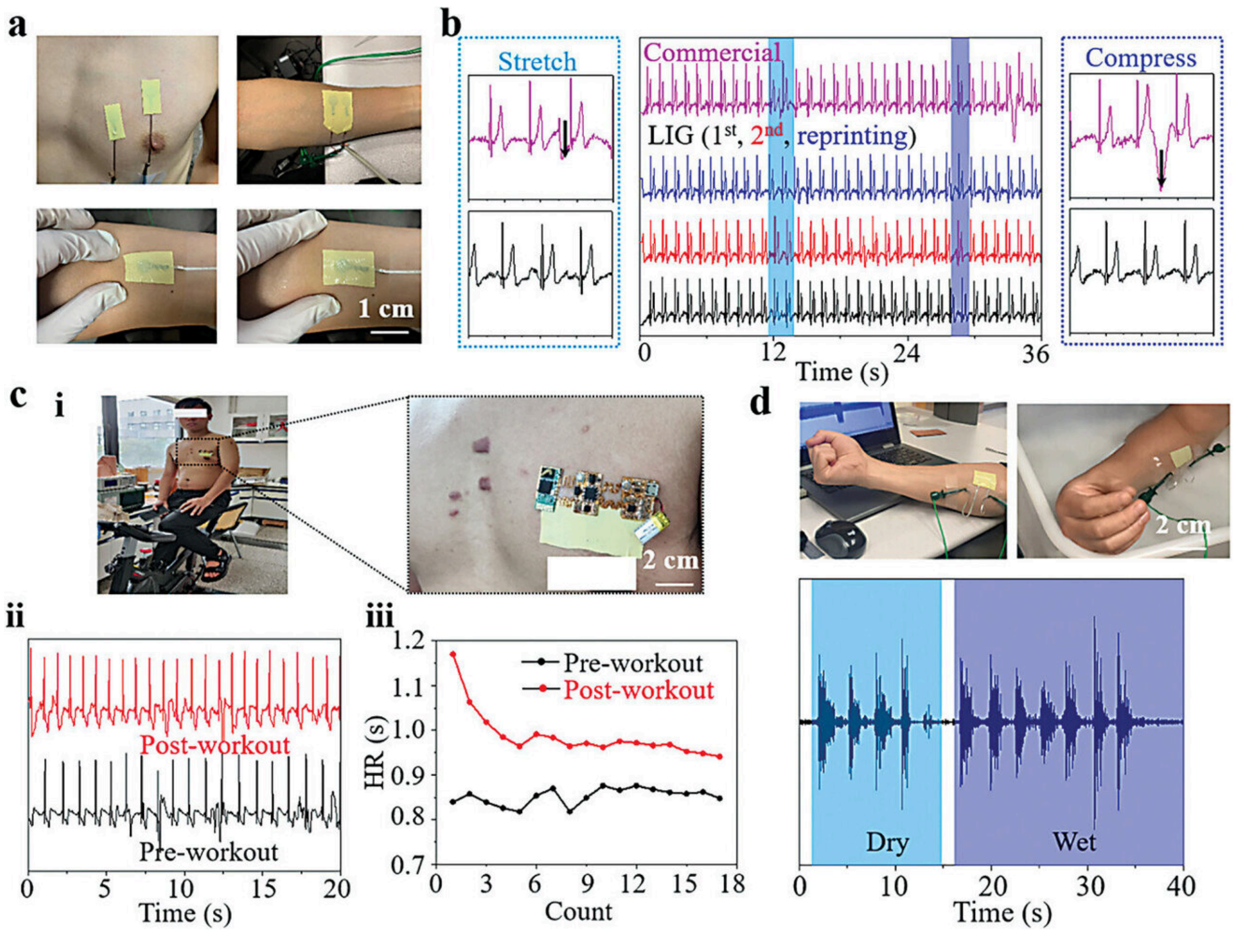
Cheng's team previously developed biomarker sensors using laser-induced graphene (LIG), which involves using a laser to pattern 3D networks on a porous, flexible substrate. The interactions between the laser and the materials contained in the substrate produce conductive graphene.

"However, the LIG-based sensors and devices on flexible substrates are not intrinsically stretchable and can't conform to interface with human skin for bio-sensing," Cheng said, noting that human skin is changeable in shape, temperature and moisture levels, especially during physical exertion when monitoring heart rate, nerve performance or sweat glucose levels might be necessary. "Although LIG can be transferred to stretchable elastomers, the process can greatly reduce its quality."

As a result, Cheng said, it's more difficult to program a sensor device to monitor specific biological or electrophysical signals. Even when the device can be appropriately programmed, its sensing performance is often degraded.

"To address these challenges, it is highly desirable to prepare porous 3D LIG directly on the stretchable substrate," said co-author Jia Zhu, who graduated with a doctorate in engineering science and mechanics from Penn State in 2020 and is now an associate professor at the University of Electronic Science and Technology of China.

The researchers achieved this goal by making an adhesive composite with molecules called polyimide powders that add strength and heat resistance and amine-based ethoxylated polyethylenimine—a type of polymer that can modify conductive materials—dispersed in a silicone elastomer, or rubber. The stretchable composite not only accommodates direct 3D LIG preparation, but also its adhesive nature means it can conform and stick to non-uniform, changeable shapes—like humans.



Biopotential measurements by the LIG@PI/PDMS/PEIE-based adhesive patch. Credit: *Advanced Materials* (2024). DOI: 10.1002/adma.202400236

The researchers experimentally confirmed that the device can monitor the pH value, glucose and lactate concentrations in sweat as well as can be detected via finger prick blood draws. It can also be reprogrammed to monitor heart rate, nerve performance and sweat glucose concentrations in real time.

Reprogramming is as simple as applying clear tape over the LIG networks and peeling them off. The substrate can then be re-lasered to new specifications, up to four times before it becomes too thin. Once it becomes too thin, the entire device can be recycled.

Critically, according to Cheng, the device remains adhesive and capable of monitoring even when the skin is made slick with sweat or water. Currently powered by batteries or near-field communication nodules, like a wireless charger, the device could potentially harvest energy and communicate over radio frequencies, which researchers said would result in a standalone, stretchable adhesive platform capable of sensing desired biomarkers and monitoring electrophysical signals.

The team said they plan to work toward this goal, in collaboration with physicians, to eventually apply the platform to manage various diseases such as diabetes and monitor acute issues like infections or wounds.

"We would like to create the next generation of smart skin with integrated sensors for health monitoring—along with evaluating how various treatments impact health—and drug delivery modules for in-time treatment," Cheng said.

More information: Jia Zhu et al, Direct Laser Processing and Functionalizing PI/PDMS Composites for an On-Demand, Programmable, Recyclable Device Platform, *Advanced Materials* (2024). DOI: 10.1002/adma.202400236

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