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Soft and elastic circuits for electronics anywhere, not just everywhere

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Electronic circuits become compliant and will thus enable development of improved interfaces with 3D structures, including the human body.

Two trends drive and shape the technological and commercial landscape of today's integrated-electronics industry: micro- and macroelectronics. Microelectronics refers to ultrahigh-performance transistor circuits integrated on the surface of flat and rigid silicon substrates. Such integrated circuits are embedded in nearly every piece of equipment in the household: microelectronics is everywhere. Macroelectronics refers to integrated circuits prepared on surfaces that are larger than a semiconductor wafer, such as medical x-ray-sensor arrays[1] and flat-panel displays.[2] Its technology relies on integration of thin-film ($<1\mu$m-thick) device materials patterned onto square-metre glass plates. Macroelectronic circuits often include a transistor backplane (providing power, computation and communication) and a functional frontplane (e.g., a LED matrix).[3]

Over the last ~20 years, plastic substrates have progressively replaced glass plates as macroelectronic-circuit carriers. The initial motivation for their application was driven by the reduced weight of plastic foils compared to that of thick glass panels. The flexibility of plastic foils quickly raised interest both in academia and industry. Today, flexible electronics (or macroelectronics on plastic) is a distinct research field, and the first commercial products are entering the market.[4]

Over the last decade, a new class of macroelectronics has emerged in stretchable circuits or 'electronic skins.' The latter can bend and roll, but they can also mold to any articulated and complex-shaped structure (see Figure 1). Applications are vast and range from robotic skins[5] and morphing phones[6] to therapeutic monitoring systems.[7,8] Stretchability in an integrated-electronics system is, therefore, its ability to negotiate mechanical deformations without letting them interfere with electrical functionality. This is a novel and challenging demand on electronic-device technology, which is built on brittle and stiff device materials.

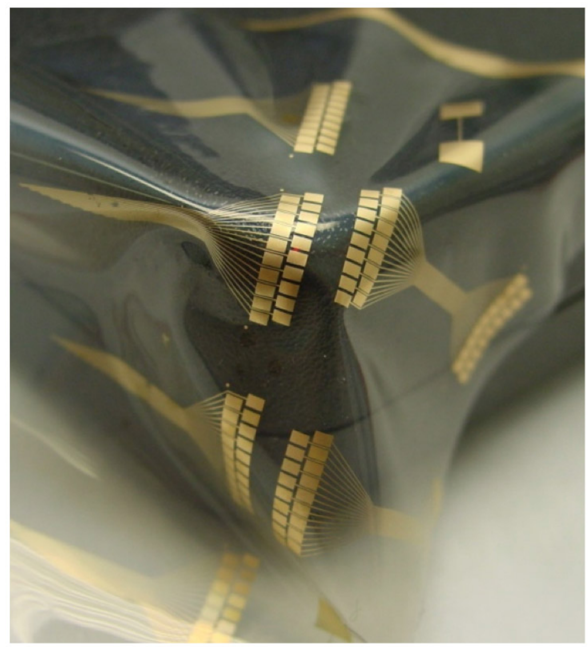

Figure 1. Gold electrodes on silicone skin wrapped around a table corner. (Photo: T. Adrega.)

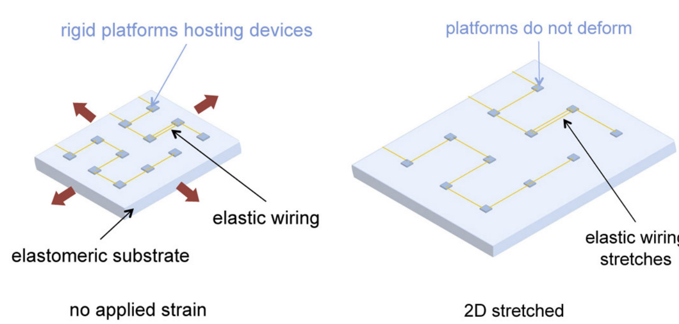

Figure 2. Mechanical architecture of stretchable electronics. (left) Relaxed and (right) 2D stretched structure. Blue pads are rigid platforms, yellow stripes stretchable wiring and red arrows directions of applied tensile strain.

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We have shown that the manufacturing of stretchable electronics relies on careful selection of device materials and related technology (most inorganic-device materials fracture at small strain, $<1\%$) and on a pixelated mechanical architecture, where rigid platforms are interconnected with stretchable wiring (see Figure 2).[9, 10] The electronic circuits are implemented onto a rubbery substrate, such as silicone or polyurethane. The platforms are designed to host fragile devices and protect them from large mechanical deformations. Stretchable wiring deforms with the substrate, guaranteeing elasticity and electrical functionality.

One approach to fabricate electronic circuits on a stretchable substrate is to deposit and pattern inorganic and/or organic thin films directly onto the silicone membrane using ultralow-temperature ($<100°C$) processing. Stretchable wiring has been demonstrated with thin gold film on silicone. We showed that evaporated metal film on silicone can withstand uni-axial stretch to 100% strain and repeated cycling to strains of tens of percent (either uni-axially or radially).[11, 12] A stretchable, touch-sensitive sensor array can be produced using elastomers and elastic gold electrodes. The electronic skin can fit a spherical ending of a robotic arm or the wrist of a user, and can withstand the associated repeated twisting and flexing. The matrix has 3×3 elements, can detect and localize touch, and can record applied pressure and strain.[13, 14] In addition, the multisensory array functions reliably when held stretched by 20% strain and subsequently relaxed. Organic-transistor circuits and amorphous silicon transistors have also been successfully implemented on soft substrates. We have demonstrated that both types of transistors on ultracompliant substrate perform similarly to their counterparts on (flexible) plastic foil.[15, 16]

The technology developed for stretchable circuitry will enable use of electronics on arbitrary 3D free forms and environments. It will also allow for robust circuit operation in high-strain environments. Thus, ‘electronics’ will become a truly integral part of everyday life.

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References

1. B. Street, **Technology and Applications of Amorphous Silicon**, Springer, New York, 2000.
2. R. H. Reuss, B. R. Chalamala, A. Moussessian, M. G. Kane, A. Kumar, D. C. Zhang, J. A. Rogers, M. Hatalis, D. Temple, G. Moddel, B. J. Eliasson, M. J. Estes, J. Kunz, E. Handy, E. S. Harmon, D. B. Salzman, J. M. Woodall, M. A. Alam, J. Murthi, S. C. Jacobson, M. Olivier, D. Markus, P. M. Cambell, and E. Snow, *Macroelectronics: perspectives on technology and applications*, **Proc. IEEE 93** (7), pp. 1239–1256, 2005. doi:10.1109/JPROC.2005.851237
3. R. A. Street, *Thin-film transistors*, **Adv. Mater. 21** (20), pp. 2007–2022, 2009. doi:10.1002/adma.200803211
4. http://www.plasticlogic.com/ereader/index.php QUE ProReader. Accessed 15 July 2010.
5. T. Someya, T. Sekitani, S. Iba, Y. Kato, H. Kawaguchi, and T. Sakurai, *A large-area, flexible pressure sensor matrix with organic field-effect transistors for artificial skin applications*, **Proc. Nat'l Acad. Sci. USA 101** (27), pp. 9966–9970, 2004. doi:10.1073/pnas.0401918101
6. http://www.nokia.com/about-nokia/research/demos/the-morph-concept Morph concept technology. Accessed 15 July 2010.
7. Z. Yu, O. Graudejus, C. Tsay, S. P. Lacour, S. Wagner, and B. Morrison, *Monitoring hippocampus electrical activity in vitro on an elastically deformable microelectrode array*, **J. Neurotrauma 26** (7), pp. 1135–1145, 2009. doi:10.1089/neu.2008.0810
8. D.-H. Kim, J. Viventi, J. J. Amsden, J. Xiao, L. Vigeland, Y.-S. Kim, J. A. Blanco, B. Panilaitis, E. S. Frechette, D. Contreras, D. L. Kaplan, F. G. Omenetto, Y. Huang, K. -C. Hwang, M. R. Zakin, B. Litt, and J. A. Rogers, *Dissolvable films of silk fibroin for ultrathin conformal bio-integrated electronics*, **Nat. Mater. 9**, pp. 511–517, 2010. doi:10.1038/nmat2745
9. S. Wagner, S. P. Lacour, J. Jones, P.-H. Hsu, J. C. Sturm, T. Li, and Z. Suo, *Electronic skin: architecture and components*, **Proc. 13th Int'l Winterschool New Dev. Sol. State Phys., Low-dim. Syst.**, 2004. Unpublished.
10. S. P. Lacour, J. E. Jones, S. Wagner, T. Li, and Z. Suo, *Stretchable interconnects for elastic electronic surfaces*, **Proc. IEEE 93** (8), pp. 1459–1467, 2005. doi:10.1109/JPROC.2005.851502
11. I. Graz, D. Cotton, and S. P. Lacour, *Extended cyclic uniaxial loading of stretchable gold thin-films on elastomeric substrates*, **Appl. Phys. Lett. 94**, p. 071902, 2009. doi:10.1063/1.3076103
12. T. Adrega and S. P. Lacour, *Stretchable gold conductors embedded in PDMS and patterned by photolithography: fabrication and electromechanical characterization*, **J. Micromech. Microeng. 20**, p. 055025, 2010. doi:10.1088/0960-1317/20/5/055025
13. D. Cotton, I. Graz, and S. P. Lacour, *A multifunctional capacitive sensor for stretchable electronic skins*, **IEEE Sens. J. 9**, pp. 2008–2009, 2009. doi:10.1109/JSEN.2009.2030709
14. D. Cotton, I. Graz, and S. P. Lacour, *Stretchable touch sensitive keypad*, **Proc. Chem. 1**, pp. 152–155, 2009. doi:10.1016/j.proche.2009.07.038
15. S. P. Lacour and S. Wagner, *Thin film transistor circuits integrated onto elastomeric substrates for elastically stretchable electronics*, **IEEE Int'l Electron Dev. Mtg**, pp. 101–104, 2005. doi:10.1109/IEDM.2005.1609278
16. I. Graz and S. P. Lacour, *Flexible pentacene organic thin film transistor circuits fabricated directly onto elastic silicone membranes*, **Appl. Phys. Lett. 95**, p. 243305, 2009. doi:10.1063/1.3265737