Hindawi
Journal of Sensors
Volume 2019, Article ID 1828394, 2 pages
https://doi.org/10.1155/2019/1828394

Editorial

Flexible and/or Stretchable Sensor Systems

Aftab M. Hussain,[1] **Mohamed T. Ghoneim**,[2] **Jhonathan P. Rojas**,[3] **and Hossain Fahad**[4]

[1]*International Institute of Information Technology (IIIT), Center for VLSI and Embedded Systems Technology (CVEST), Hyderabad, India*
[2]*Massachusetts Institute of Technology (MIT) Media Lab, Cambridge, MA, USA*
[3]*King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia*
[4]*University of California, Berkeley, CA, USA*

Correspondence should be addressed to Aftab M. Hussain; aftab.hussain@iiit.ac.in

Received 13 December 2018; Accepted 13 December 2018; Published 22 January 2019

With recent advancements in the field of wearable devices based on Internet of Things (IoT), the concept of flexible and stretchable electronic systems has become increasingly significant. Although decades of dimensional scaling have led to the miniaturization of the traditional complementary metal oxide semiconductor- (CMOS-) based electronic components, they still remain mechanically rigid and brittle. These rigid devices can be mounted on flexible PCB substrates to obtain a certain degree of flexibility; however, this technique cannot lead to truly body conformal electronic systems. Thus, research teams around the world have been looking at various ways of obtaining completely flexible electronic components at the device level itself. These efforts include various processes to thin down silicon chips to make them flexible or development and use of flexible and stretchable substrate materials to fabricate electronic devices.

The thinning down process for traditional silicon-based electronic chips can be performed before or after the complete transistor fabrication process [1]. These approaches are referred to as "device first" approach or "device last" approach. In case of the device last approach, thin films of single crystal silicon are transfer printed to a flexible substrate and processed further to fabricate CMOS circuitry [2, 3]. However, in this approach, many high-temperature steps have to be avoided due to the limited thermal stability of the flexible substrate, leading to a suboptimal circuit. In case of the device first approach, the circuits are made on the silicon substrate using state-of-the-art CMOS processes as usual. After completion of the process, some additional process steps are employed to thin down the silicon chip to make it flexible. These include the controlled spalling process [4, 5], the trench-protect-etch-release (TPER) process [6, 7], and the soft-etch-back (SEB) process [8, 9].

Complementing the efforts to fabricate conformal silicon chips, efforts have been made to make other components of an electronic system flexible and stretchable. These include the use of novel processes to fabricate flexible and stretchable sensor systems [10, 11], actuator systems [12, 13], communication systems [14, 15], memory modules [16, 17], and batteries [18–20]. Having flexible and stretchable versions of these systems is particularly important because body conformal end gadgets generally have applications in the IoT segment where sensing, actuation, storage, and communication are key processes. The impact of successful fabrication of conformal systems ranges from advanced healthcare and wearable diagnostics to military and aerospace applications. Indeed, several key challenges such as material selection, scalable fabrication, reliability, and cost need to be solved to ascertain ubiquitous adoption of such systems.

The call for papers for this special issue focused on publishing high-quality, high-impact, and original research articles and review articles focusing on flexible and stretchable sensor devices, sensor drive circuitry, and overall systems. In response to the call, papers were submitted from research teams across the world. These papers were reviewed for novelty and quality of research. Because of the complexity of real-life deployment of flexible and stretchable systems, special attention was given to the papers including experimental data and field data. After a rigorous peer-review process, 4 papers were accepted for publication in this special issue.

The paper by G. Prats-Boluda et al. presents a wearable textile ECG sensor electrode. Two sizes of textile concentric ring electrodes (TCREs) are fabricated and tested for monitoring cardiac activity. The electrodes are fabricated using multilayer thick film serigraphic technology. The devices are found to be low-cost and easy to implement, while having the advantages of textiles for being lightweight, stretchable, adjustable, washable, and long-lasting.

The paper by H. Nakamoto et al. presents a wearable lumbar-motion monitoring device using stretchable strain sensors. The strain sensors are fabricated using urethane elastomer and carbon nanotube membranes. Six of these strain sensors form a parallel-sensor mechanism that measures rotation angles of lumbar motion in three axes. The parallel-sensor mechanism calculates rotation angles from the lengths of the strain sensors iteratively.

The paper by M. Li et al. presents an underwater wireless sensor network (UWSN) routing algorithm based on simplified harmony search (SHS).

The paper by Y. C. Manie et al. presents a Fiber Bragg Grating (FBG) sensor using intensity and wavelength division multiplexing (IWDM), Raman amplifier, and extreme learning machine (ELM).

Conflicts of Interest

The editors declare that they have no conflicts of interest regarding the publication of this special issue.

Aftab M. Hussain
Mohamed T. Ghoneim
Jhonathan P. Rojas
Hossain Fahad

References

[1] A. M. Hussain and M. M. Hussain, "CMOS-technology-enabled flexible and stretchable electronics for internet of everything applications," *Advanced Materials*, vol. 28, no. 22, pp. 4219–4249, 2016.

[2] J.-H. Ahn, H. S. Kim, E. Menard et al., "Bendable integrated circuits on plastic substrates by use of printed ribbons of single-crystalline silicon," *Applied Physics Letters*, vol. 90, no. 21, article 213501, 2007.

[3] E. Menard, K. J. Lee, D.-Y. Khang, R. G. Nuzzo, and J. A. Rogers, "A printable form of silicon for high performance thin film transistors on plastic substrates," *Applied Physics Letters*, vol. 84, no. 26, pp. 5398–5400, 2004.

[4] F. Dross, J. Robbelein, B. Vandevelde et al., "Stress-induced large-area lift-off of crystalline Si films," *Applied Physics A*, vol. 89, no. 1, pp. 149–152, 2007.

[5] Y. Kwon, C. Yang, S.-H. Yoon, H.-D. Um, J.-H. Lee, and B. Yoo, "Spalling of a thin Si layer by electrodeposit-assisted stripping," *Applied Physics Express*, vol. 6, no. 11, 2013.

[6] G. T. Sevilla, J. P. Rojas, S. Ahmed, A. Hussain, S. B. Inayat, and M. M. Hussain, "Silicon fabric for multi-functional applications," in *2013 Transducers & Eurosensors XXVII: The 17th International Conference on Solid-State Sensors, Actuators and Microsystems (TRANSDUCERS & EUROSENSORS XXVII)*, pp. 2636–2639, Barcelona, Spain, 2013.

[7] J. P. Rojas, G. A. Torres Sevilla, M. T. Ghoneim et al., "Transformational silicon electronics," *ACS Nano*, vol. 8, no. 2, pp. 1468–1474, 2014.

[8] G. A. Torres Sevilla, M. T. Ghoneim, H. Fahad, J. P. Rojas, A. M. Hussain, and M. M. Hussain, "Flexible nanoscale high-performance FinFETs," *ACS Nano*, vol. 8, no. 10, pp. 9850–9856, 2014.

[9] G. A. Torres Sevilla, A. S. Almuslem, A. Gumus, A. M. Hussain, M. E. Cruz, and M. M. Hussain, "High performance high-κ/metal gate complementary metal oxide semiconductor circuit element on flexible silicon," *Applied Physics Letters*, vol. 108, no. 9, 2016.

[10] J. M. Nassar, M. D. Cordero, A. T. Kutbee et al., "Paper skin multisensory platform for simultaneous environmental monitoring," *Advanced Materials Technologies*, vol. 1, no. 1, 2016.

[11] A. M. Hussain and M. M. Hussain, "Deterministic integration of out-of-plane sensor arrays for flexible electronic applications," *Small*, vol. 12, no. 37, pp. 5141–5145, 2016.

[12] A. M. Hussain, E. B. Lizardo, G. A. Torres Sevilla, J. M. Nassar, and M. M. Hussain, "Ultrastretchable and flexible copper interconnect-based smart patch for adaptive thermotherapy," *Advanced Healthcare Materials*, vol. 4, no. 5, pp. 665–673, 2015.

[13] H. Zhao, A. M. Hussain, M. Duduta, D. M. Vogt, R. J. Wood, and D. R. Clarke, "Compact dielectric elastomer linear actuators," *Advanced Functional Materials*, vol. 28, no. 42, 2018.

[14] A. M. Hussain, F. A. Ghaffar, S. I. Park, J. A. Rogers, A. Shamim, and M. M. Hussain, "Metal/polymer based stretchable antenna for constant frequency far-field communication in wearable electronics," *Advanced Functional Materials*, vol. 25, no. 42, pp. 6565–6575, 2015.

[15] S. Hong, S. H. Kang, Y. Kim, and C. W. Jung, "Transparent and flexible antenna for wearable glasses applications," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 7, pp. 2797–2804, 2016.

[16] M. T. Ghoneim, M. A. Zidan, M. Y. Alnassar et al., "Thin PZT-based ferroelectric capacitors on flexible silicon for nonvolatile memory applications," *Advanced Electronic Materials*, vol. 1, no. 6, 2015.

[17] M. T. Ghoneim and M. M. Hussain, "Study of harsh environment operation of flexible ferroelectric memory integrated with PZT and silicon fabric," *Applied Physics Letters*, vol. 107, no. 5, 2015.

[18] A. T. Kutbee, R. R. Bahabry, K. O. Alamoudi et al., "Flexible and biocompatible high-performance solid-state micro-battery for implantable orthodontic system," *npj Flexible Electronics*, vol. 1, p. 7, 2017.

[19] D. Singh, A. T. Kutbee, M. T. Ghoneim, A. M. Hussain, and M. M. Hussain, "Strain-induced rolled thin films for lightweight tubular thermoelectric generators," *Advanced Materials Technologies*, vol. 3, 2018.

[20] S. Xu, Y. Zhang, J. Cho et al., "Stretchable batteries with self-similar serpentine interconnects and integrated wireless recharging systems," *Nature Communications*, vol. 4, article 1543, 2013.