ADVANCED FUNCTIONAL MATERIALS

Supporting Information

for *Adv. Funct. Mater.,* DOI: 10.1002/adfm.202004655

A Versatile Sacrificial Layer for Transfer Printing of Wide Bandgap Materials for Implantable and Stretchable Bioelectronics

Tuan-Anh Pham, Tuan-Khoa Nguyen, Raja Kumar Vadivelu, Toan Dinh, Afzaal Qamar, Sharda Yadav, Yusuke Yamauchi, John A. Rogers,* Nam-Trung Nguyen,* and Hoang-Phuong Phan**

Supporting Information

A Versatile Sacrificial Layer for Transfer Printing of Wide Bandgap Materials for Implantable and Stretchable Bioelectronics

Tuan-Anh Pham,[1*] Tuan-Khoa Nguyen,[1] Raja Kumar Vadivelu,[2] Toan Dinh,[1,3] Afzaal Qamar,[4] Sharda Yadav,[1] Yusuke Yamauchi,[5] John A. Rogers,[6*] Nam-Trung Nguyen,[1*] Hoang-Phuong Phan[1*]

[1] Queensland Micro and Nanotechnology Centre, Griffith University, QLD Australia
[2] Department of Chemical System Engineering, The University of Tokyo, Japan
[3] Department of Mechanical Engineering, University of Southern Queensland, QLD, Australia
[4] Electrical Engineering Department, University of Michigan, Ann Abor, MI, USA
[5] Australian Institute for Bioengineering and Nanotechnology, The University of Queensland, QLD, Australia
[6] Center for Bio-Integrated Electronics, Department of Materials Science and Engineering, Biomedical Engineering, Chemistry, Mechanical Engineering, Electrical Engineering and, Computer Science, and Neurological Surgery, Simpson Querrey Institute for Nano/biotechnology, McCormick School of Engineering and Feinberg School of Medicine, Northwestern University, Evanston, IL, USA.

E-mail: h.phan@griffith.edu.au
nam-trung.nguyen@griffith.edu.au
jrogers@northwestern.edu
tuananh.pham2@griffithuni.edu.au

1. Detailed fabrication process of SiC-based stretchable bioelectronics

+ The development of free-standing nanomembrane SiC microstructures were carried out following the steps below:

1) Starting wafer: 6-inch SiC/Si/SiC wafers with a SiC thickness of 230 nm. The SiC films were deposited on both sides of polished Si wafers. The top SiC layer was used as the functional layer, while the bottom SiC was utilized as the hard mask for Si wet-etching in KOH.

2) Spin-coat AZ 5214 photoresist at 4,000 rpm on the bottom SiC layer (thickness: 1.2 µm) Soft-bake at 100 ℃ for 1 minute.

3) Expose photoresist and develop for 30 seconds in AZ 726 MIF and rinse with DI water. Hardbake photoresist at 120 ℃ for 2 minutes for subsequent SiC dry-etching.

4) Dry etch the bottom SiC layer using SF_6 + O_2 inductive coupled plasma (ICP) to open square windows. The etching rate of SiC is approximately 100 nm/min. Strip photoresist using O_2 plasma for 25 minutes.

5) Wet-etch Si in KOH (30% wt) at 80 ℃ for approximately 10 hours until the free standing SiC membranes are formed. Due to its chemical inertness, SiC on the top and bottom layer function as an excellent hard mask for Si wet etching. The etching process is terminated once the transparent SiC nanomembranes are observed.

6) Decontaminate the KOH-etched samples using RCA cleaning.

+ The transfer printing process to integrate SiC microstructures onto PDMS slab following the steps below:

7) Deposit 100-nm Al on the SiC top layer (i.e. free-standing square membranes) using sputtering (or alternatively a 1.2 µm-thick AZ5214 photoresist can be used as the hard mark for SiC etching for the formation of this layer follow step 1 described above)

8) Attach the Al/SiC/Si wafer onto a 6-inch Si carrier-wafer using a water solvable wax.

9) Spin-coat AZ5214 photoresist at 4,000 rpm onto the free-standing Al/SiC membranes followed by soft-bake of photoresist at 100 ℃ for 1 minute. Remove the Al/SiC/Si wafer from the carrier wafer.

10) Expose photoresist and develop for 30 seconds in AZ 726 MIF and rinse with DI water.

11) Etch Al with wet-etchant (H_3PO_4 : HNO_3 : CH_3COOH) to form hard-mark for SiC dry etching.

12) Remove photoresist using photoresist stripper.

13) Deposit 300-nm Al on the backside of the sample to form a sacrificial layer using sputtering.

13) Dry etch SiC using ICP with etching rate of 100 nm/min for 2.5 minutes, which form nanothin SiC microstructures, such as SiC-spring, spiral, serpentine or propeller-like structures (The AZ5214 layer which was used as the hard mask can be removed using O_2 plasma cleaning for 25 minutes).

14) Prepare PDMS slab (1:10). Lightly press PDMS onto flexible SiC microstructures (PDMS should form a conformal contact with the Si surface).

15) Remove Al mask and Al sacrificial layer at the both side of the SiC microstructures using Al wet-etchant for 20 seconds and decontaminate the samples in DI water for 10 minutes.

16) Gently remove PDMS from the Si chip to detach the SiC nanostructures from the mother substrate.

2. Detailed information of FEA simulation

To demonstrate the stretchability of SiC on a soft substrate, we employed a SiC spring structures stamped onto a 125 μm thick PDMS substrate. The elongation of the SiC/PDMS was obtaiend using a pressure test, as described in the main paper. To obtain the desised elovation, we used an FEA model to simulate the deformation and expansion of the PDMS membranes as well as the SiC membranes to define the required air pressure. In this model, the Young's modulus of the SiC thin film and the PDMS layer are set at at 350 GPa and 3 MPa, which were derived from [1] and [2], respectively. In this model, pressure was applied from bottom of the PDMS diaphragm, deforming the continuous U-shaped SiC structure on top. As can be seen from Fig. 4(c), the critical stress is located at the inner curves of the structure.

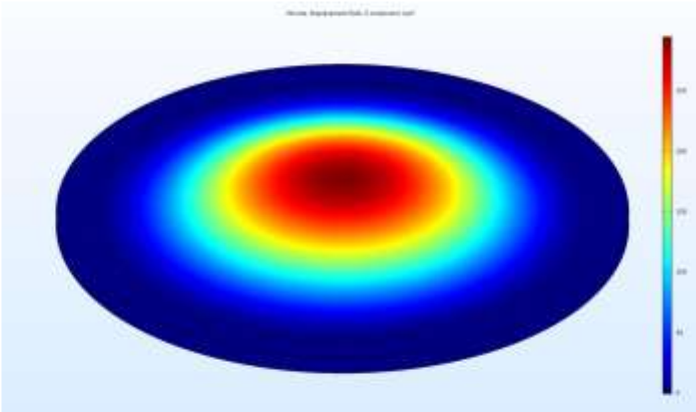

Figure S1. Simulated results showing the defection, *h*, of the SiC spring/PDMS membrane under applied pressure of 6 mbar.

3. Additional SEM images

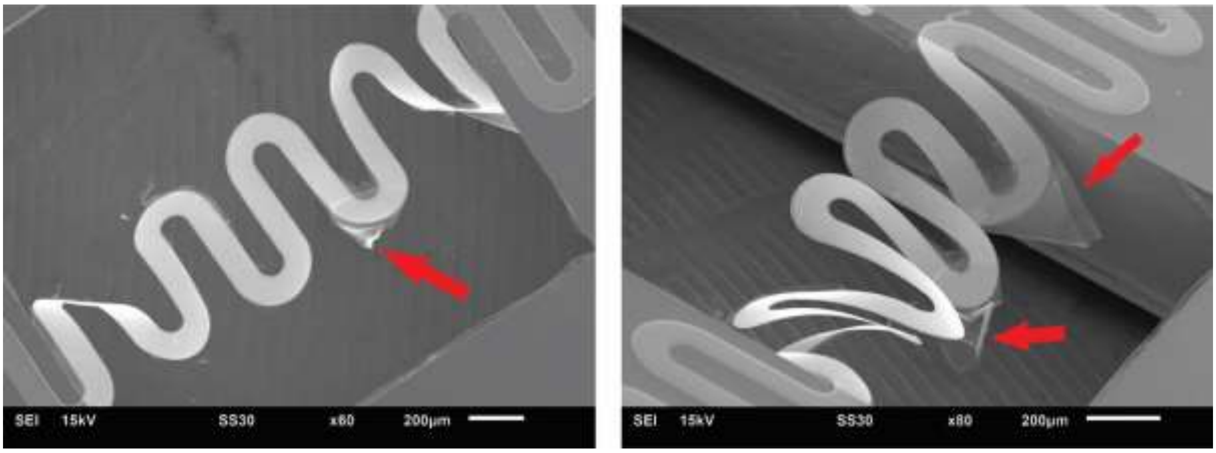

Figure S2. SEM images of the SiC spring structure without the supporting Al layer taken at different angles, clearly showing the wrinkling and the presence of residual SiC membranes of the SiC micro-spring structures remained after ICP etching process.

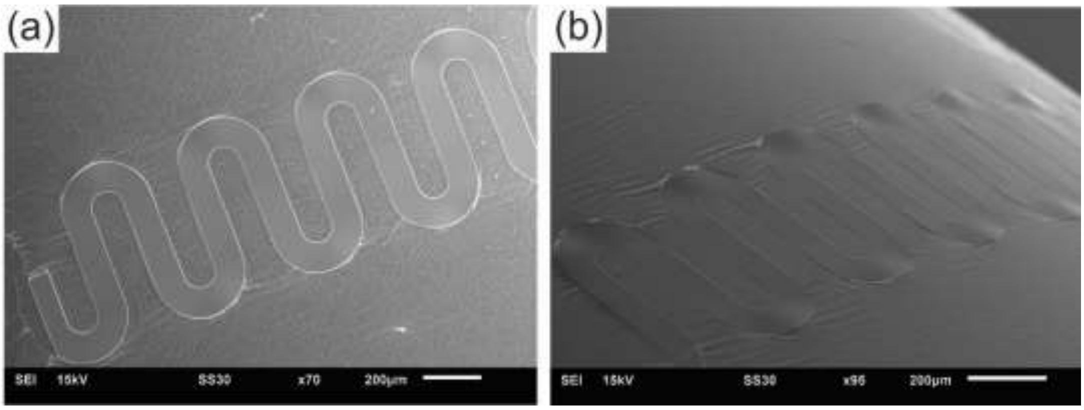

Figure S3. SEM images of SiC spring-shape successfully stamped onto a PDMS (left) and then bent around a curve surface (right) of SiC micro-spring structure showing no cracks or tears for the SiC structures.

References

[1] E. Berthier, E. W. K. Young, D. Beebe, *Lab Chip*, **2012**, *12*, 1224.

[2] K. M. Jackson, J. Dunning, C. A. Zorman, M. Mehregany and W. N. Sharpe, *J. Microelectromech S*. **2005,** 14, 664.