Supporting Information

Laser-engraved Carbon Nanotube Paper for High Sensitivity, Highly Stretchability and High Linearity Strain Sensors

Yangyang Xin, Jian Zhou,* Xuezhu Xu, and Gilles Lubineau*

King Abdullah University of Science and Technology (KAUST), Physical Sciences and Engineering Division, COHMAS Laboratory, Thuwal 23955-6900, Saudi Arabia; Tel:+966(12)8082983

E-mail: jian.zhou@kaust.edu.sa; gilles.lubineau@kaust.edu.sa

This PDF file includes:

1. Sample preparation and characterization

2. Mechanical sensing

Figure S1 to S8

Table S1

*To whom correspondence should be addressed

Sample preparation and characterization

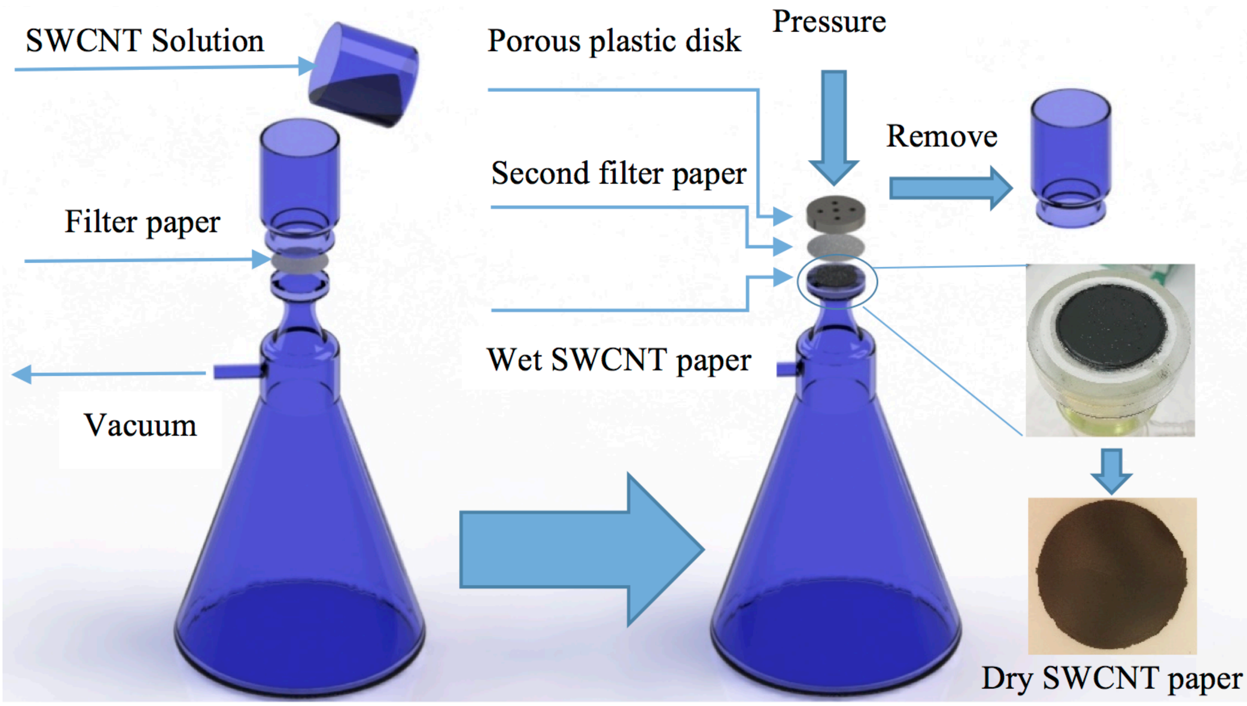

Figure. S1 Key steps in fabricating SWCNT papers.

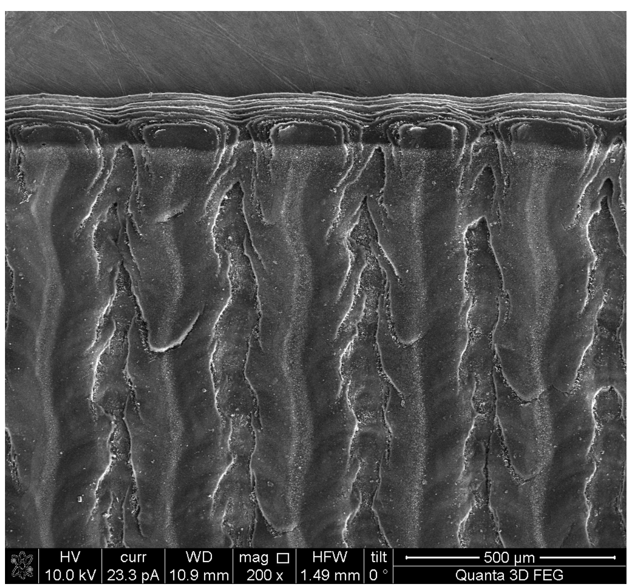

Figure. S2 SEM image of the laser-engraved SWCNT paper in a top view.

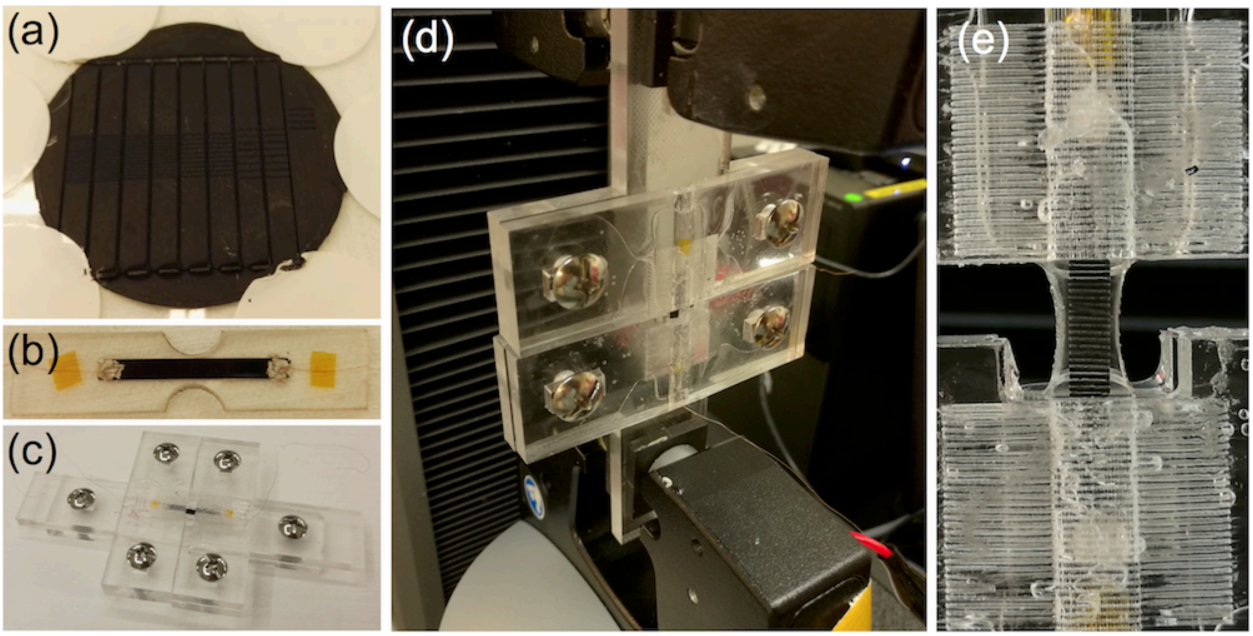

Figure. S3 (a) A laser-engraved SWCNT paper with controlled crack density. (b) A typical sample of the SWCNT paper embedded in the PDMS substrate. (c) The sample holder for the sensor. (d) The setup for electromechanical test. (e) A typical example of the strain sensor during stretching.

Mechanical sensing

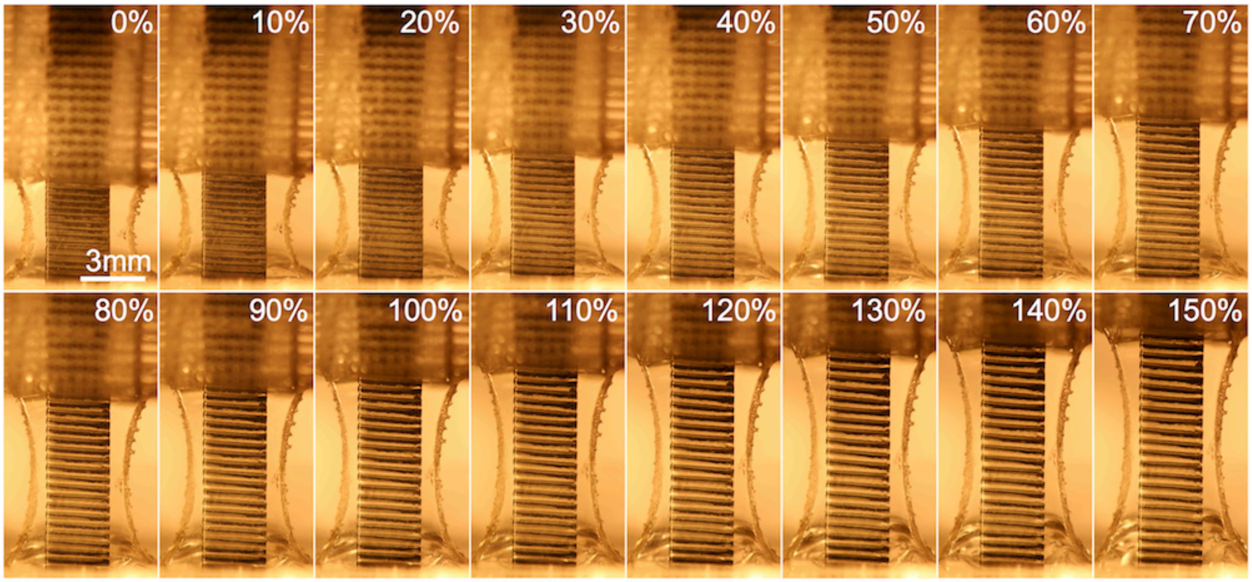

Figure. S4 Crack opening of a high crack density SWCNT paper in PDMS substrate when stretched from 0 to 150% strain.

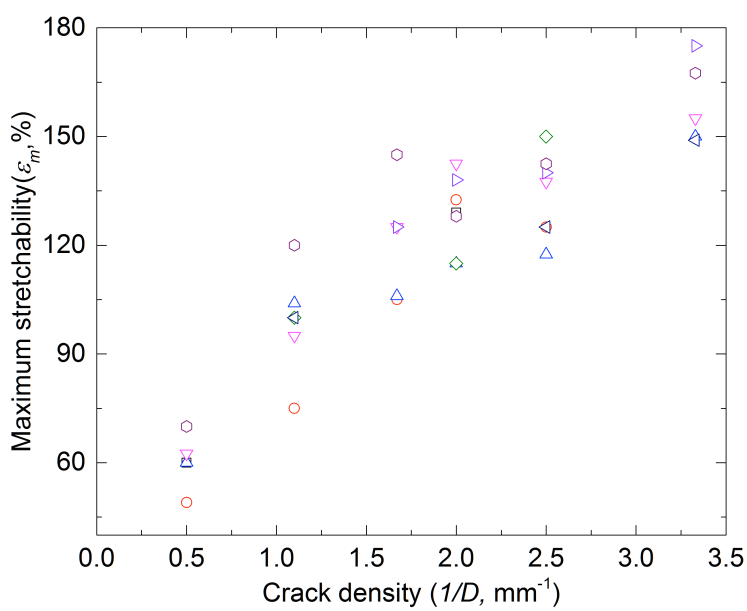

Figure. S5 Raw data of stretchability against crack density.

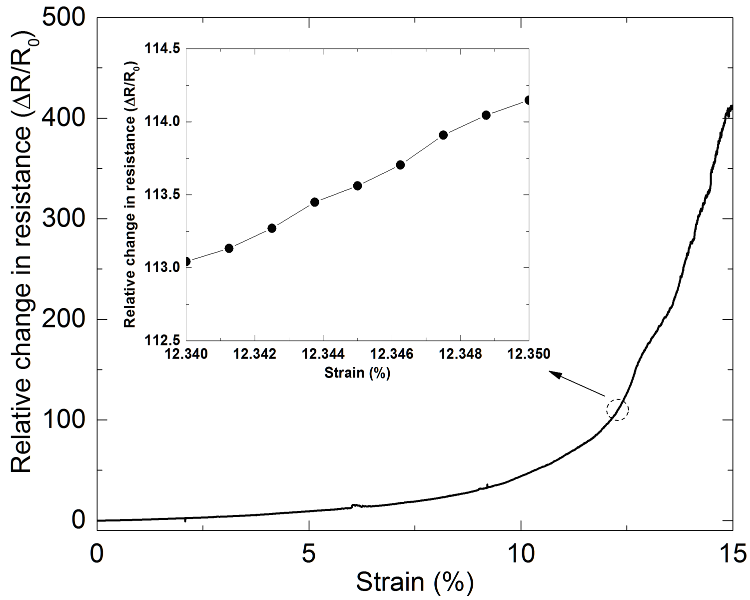

Figure. S6 Relative resistance change versus applied strain of the sensor. Inset shows the sensor is able to detect a strain as small as 0.001%. The stretching speed is 0.05 μm s^{-1}.

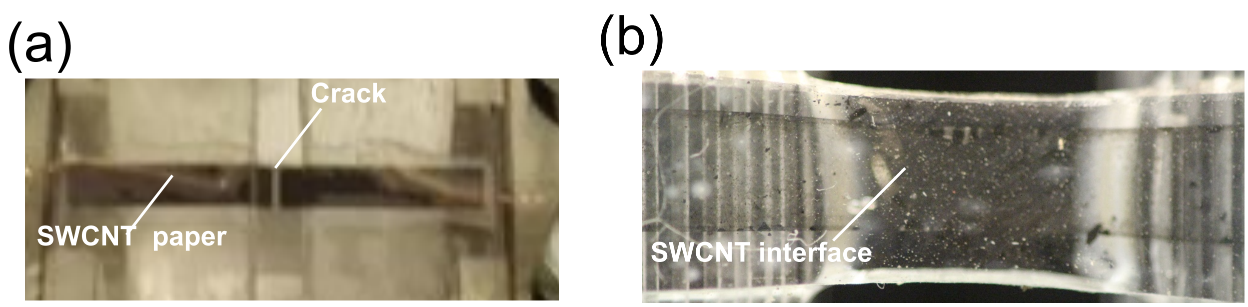

Figure. S7 Optical images of a pure SWCNT paper (a) and SWCNT interface on PDMS (b) under loading, respectively.

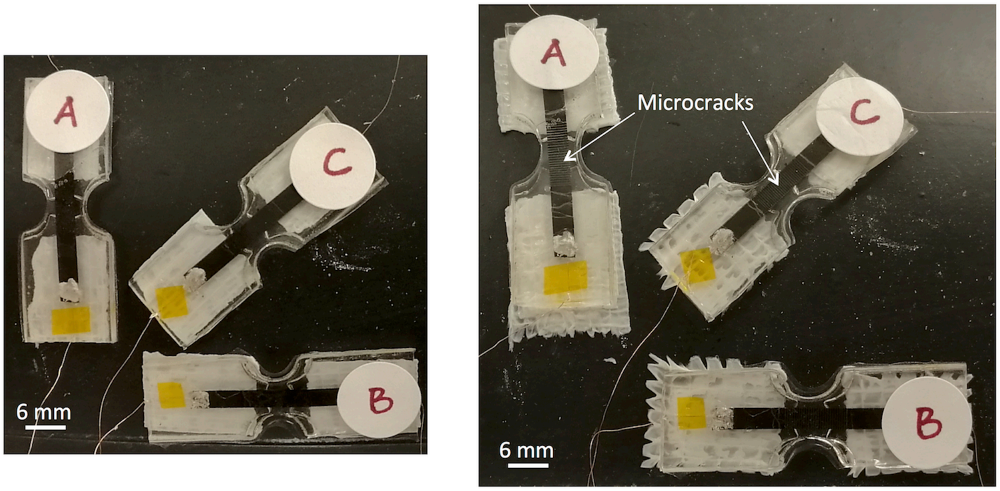

Figure. S8 Optical images of a tire attached with 3 sensors before and after inflation, respectively.

Table. 1 Summary of strain sensing properties based on nanomaterial-enabled stretchable conductors.

Materials	Initial electrical properties (R_0)	$\Delta R/R_0$	Maximum strain	Gauge factor	Ref.
CNT yarn	$R_0 = 3.4K\Omega$	0.016	3.5%	0.45	1
Random SWCNT film on PDMS	$\sigma = 2200Scm^{-1}$	5	150%	3.4	2
Random MWCNT film in Ecoflex	$\sigma = Scm^{-1}$	2.5	100 %	1	?
Thickness gradient SWCNT film on PDMS	$\sigma = 2200Scm^{-1}$	3.2	2 %	161	3
Aligned SWCNT film on PDMS	-	3.28	40%	0.82	4
Aligned SWCNT film on PDMS	-	0.12	200%	0.06	4
3D SWCNT network in PDMS	$\sigma = Scm^{-1}$	0.35	1%	35	5
(PU-PEDOT/PSS)/SWCNT/(PU-PEDOT:PSS) on a PDMS	$\sigma = Scm^{-1}$	62	100%	62	6
Aligned mico/nano carbon particles in PDMS	$R_s = 60\Omega\square^{-1}$	20000	100%	20000	7
CNT fiber on prestrained Ecoflex substrate	$\sigma = 0.257Scm^{-1}$	358	960%	64	8
AgNW film in PDMS	$R_0 = 7.5-246\Omega$	9.8	70%	14	9
AgNW arrays in pre-strained PDMS	$R_0 = 5.3\Omega$	7	35%	20	10
Graphene on PE fiber in PDMS	$\sigma = 0.012-0.136Scm^{-1}$	1.8	50%	3.7	11
Graphene foam on PDMS	$R = 1000\Omega$	30	70%	29	12
Graphene on PET	$R = 15K\Omega$	0.8	2%	15	12
Nanoscale crack based metal/Polyurethane acrylate	-	35	2%	6	13
Metal foil strain gauge		-	-	2-5	ref
Single crystal silicon Strain gauge		-	-	200	ref
SWCNT wire in PDMS	$R = 40-4000\Omega cm^{-1}$	3.0×10^4	15%	1×10^5	ref
SWCNT paper in PDMS	$R = 1.7-9.3\Omega cm^{-1}$	1.0×10^6	50%	1×10^7	ref
Laser-engraved SWCNT paper in PDMS	$R = 5\Omega cm^{-1}$	4.2×10^4	153%	5.1×10^4	This study

References

(1) Zhao, H. B.; Zhang, Y. Y.; Bradford, P. D.; Zhou, Q. A.; Jia, Q. X.; Yuan, F. G.; Zhu, Y. T. *Nanotechnology* **2010**, *21*, 305502.

(2) Lipomi, D. J.; Vosgueritchian, M.; Tee, B. C. K.; Hellstrom, S. L.; Lee, J. A.; Fox, C. H.; Bao, Z. N. *Nat. Nanotechnol.* **2011**, *6*, 788–792.

(3) Liu, Z. Y.; Qi, D. P.; Guo, P. Z.; Liu, Y.; Zhu, B. W.; Yang, H.; Liu, Y. Q.; Li, B.; Zhang, C. G.; Yu, J. C.; Liedberg, B.; Chen, X. D. *Adv. Mater.* **2015**, *27*, 6230–6237.

(4) Yamada, T.; Hayamizu, Y.; Yamamoto, Y.; Yomogida, Y.; Izadi-Najafabadi, A.; Futaba, D. N.; Hata, K. *Nat. Nanotechnol.* **2011**, *6*, 296–301.

(5) Seo, J.; Lee, T. J.; Lim, C.; Lee, S.; Rui, C.; Ann, D.; Lee, S. B.; Lee, H. *Small* **2015**, *11*, 2990–2994.

(6) Roh, E.; Hwang, B. U.; Kim, D.; Kim, B. Y.; Lee, N. E. *ACS. Nano.* **2015**, *9*, 6252–6261.

(7) Rahimi, R.; Ochoa, M.; Yu, W. Y.; Ziaie, B. *ACS. Appl. Mater. Interfaces.* **2015**, *7*, 4463–4470.

(8) Ryu, S.; Chou, J. B.; Lee, K.; Lee, D.; Hong, S. H.; Zhao, R.; Lee, H.; Kim, S. G. *Adv. Mater.* **2015**, *27*, 3250–3255.

(9) Amjadi, M.; Pichitpajongkit, A.; Lee, S.; Ryu, S.; Park, I. *ACS. Nano.* **2014**, *8*, 5154–5163.

(10) Kim, K. K.; Hong, S.; Cho, H. M.; Lee, J.; Suh, Y. D.; Ham, J.; Ko, S. H. *Nano. Lett.* **2015**, *15*, 5240–5247.

(11) Cheng, Y.; R., W.; J., S.; Gao, L. *Adv. Mater.* **2015**, *27*, 7365–7371.

(12) Jeong, Y. R.; Park, H.; Jin, S. W.; Hong, S. Y.; Lee, S. S.; Ha, J. S. *Adv. Funct. Mater.* **2015**, *25*, 4228–4236.

(13) Kang, S.; Jones, A. R.; Moore, J. S.; White, S. R.; Sottos, N. R. *Adv. Funct. Mater.* **2014**, *24*, 2947–2956.