Electronic Supplementary Information (ESI)

Dielectric Elastomer Actuator with Excellent Electromechanical Performance by Slide-Ring Materials/Barium Titanate Composites†

Dan Yang[ab], Fengxing Ge[a], Ming Tian[a], Nanying Ning[a], Liqun Zhang[*a], Changming Zhao[c], Kohzo Ito[*c], Toshio Nishi[d], Huaming Wang[*e], and Yunguang Luan[e]

[a]State Key Laboratory for Organic-Inorganic Composites, Beijing University of Chemical Technology, Beijing 100029, China

[b]Beijing Key Lab of Special Elastomer Composite Materials, Beijing Institute of Petrochemical Technology, Beijing 102617, China

[c]Department of Advanced Materials Science, Graduate School of Frontier Sciences, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8561, Japan

[d]International Department, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-Ku, Tokyo 152-8550, Japan

[e]College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

†Electronic supplementary information (ESI) available.

*To whom correspondence should be addressed.

E-mail: zhanglq@mail.buct.edu.cn;

E-mail: kohzo@k.u-tokyo.ac.jp;

E-mail: hmwang@nuaa.edu.cn.

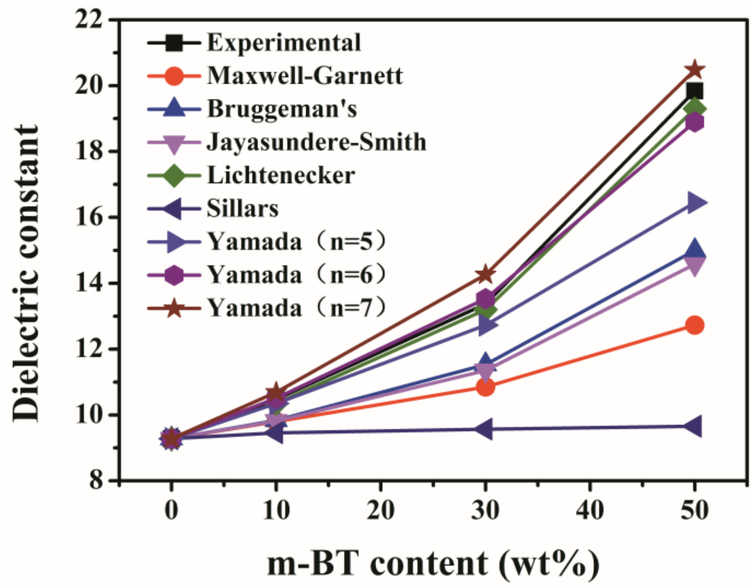

Figure S-1 Comparison of measured dielectric constant (at 1 kHz) of m-BT/SR4 composites with values predicted by various dielectric mixing rules.

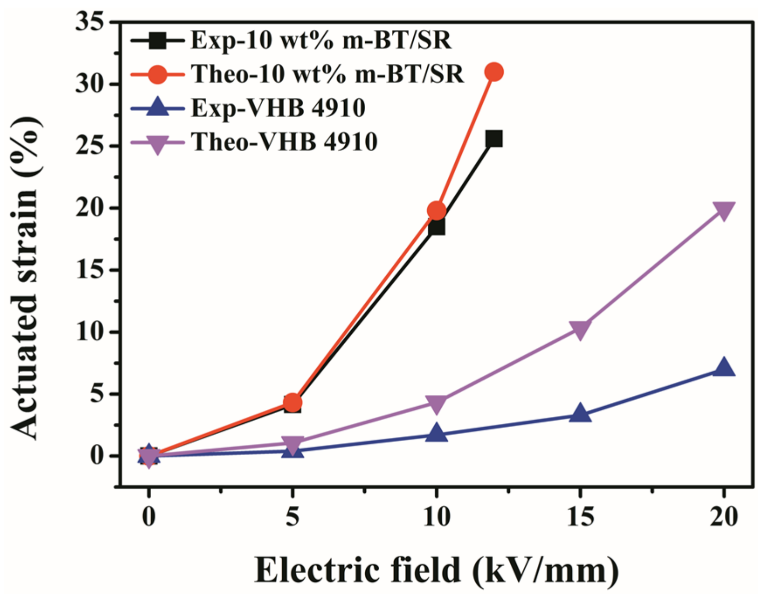

Figure S-2 Comparison of theoretical and experimental actuated strains of 10 wt% m-BT/SR4 composite and VHB 4910 (the dielectric constant of VHB 4910 used in this calculation is 4.7 and the elastic modulus of VHB 4910 used in this calculation is

0.1MPa according to our measurement).

Table S-1 Comparing actuated strain of slide-ring materials actuator with other EAP actuators

Material	Pre-strains (x, y) (%)	Actuated strain[a)] (%)	Field strength[a)] (kV mm^{-1})	Ref
VHB 4910	540, 75	215	239	[1]
VHB 4905	300, 300	200	480	[2]
Silicone ENP SEBS 161(5-30 wt%)	300, 300	180-30	32-133	[3]
Silicone ENP SEBS 217(5-30 wt%)	300, 300	245-47	22-98	[3]
VHB 4910	300, 300	158	412	[1]
VHB4910/poly(1,6-hexanediol diacrylate)	275, 275	233	300	[4]
HS3	280, 0	117	128	[1]
Silicone-based prototype	200[b)]	18.31	96	[5]
TiO_2/SEBS	100, 100	12	27.5	[6]
PMMA-PnBA-PMMA	100, 100	12	4.5	[7]
30 wt% TiO_2/silicone	100, 100	11	10	[8]
PDMS/PHT	100, 100	7.6	8	[9]
Polyurethane-based prototype	100[b)]	2.04	127	[5]
CF19-218	100, 0	63	181	[1]
HS3 silicone	68, 68	93	110	[1]
CF19-2186 silicone	45, 45	64	350	[1]
DC 3481(5% 81-R)/20 wt% CPO	40, 40	11	27	[10]
Silicone elastomer C1	30, 30	40	12.4	[11]

CF19-2186 silicone	15, 15	33	160	[1]
VHB 4910 acrylic	15, 15	40	55	[1]
HS3 silicone	14, 14	69	72	[1]
Allyl-cyano/SiR	10, 10	7	20	[12]
TiO_2/PDMS	5, 5	18	50	[13]
Dipole/PDMS	5, 5	14.8	1.3	[14]
DOP/HNBR	0, 0	22	30	[15]
MA20	0, 0	2.1[a)]	5	[16]
SEBS20	0, 0	1.4 [a)]	5	[16]
MBM104 ATPEG	0, 0	50	65	[17]
TiO_2/PDMS/DMSO	0, 0	13	30	[18]
PANI@PDVB/PDMS	0, 0	12	54	[19]
PEG/PDMS	0, 0	11.5	40	[20]
$BaTiO_3$/CB/PDMS	0, 0	7.46	30	[21]
PANI-g-PolyCuPc-g-PU	0, 0	7	23	[22]
23 wt% PANI/P(VDF-TrFE-CTFE)	0, 0	1.5[c)]	9.5	[23]
14PANI/15PolyCuPc/85PU	0, 0	9.3[c)]	20	[24]
SEBS-MA grafted PANI	0, 0	1.4	27	[25]
NBR/TiO_2/DOP	0, 0	3.04	20	[26]
18.26% vol% graphite/polyurethane	0, 0	0.037	0.75	[27]
5 wt% CNTs/PDMS	0, 0	4.4	1.5	[28]
P(VDF-TrFE)/40 wt% CuPc	0, 0	1.91	13	[29]
Silicone oil/PMN/PDMS	0, 0	7.4	40	[30]
CNT/P(VDF-TrFE-CFE)	0, 0	2.5	72	[31]

P(VDF-TrFE-CFE)	0, 0	4.5	130	[32]
LC gels	0, 0	2.1	25	[33]
Polyester elastomer	0, 0	11.9	15.6	[34]
6 vol% TiO_2/polyester elastomer	0, 0	11.8	9.8	[35]
SR4	0, 0	12	10	
10 wt% m-BT/SR4	0, 0	26	12	

a)Estimated from graphical data in cited reference, when no tabulated results were provided. b)The axial pre-strain. c)The longitudinal strain.

References

1 R. Pelrine, R. Kornbluh, Q. Pei and J. Joseph, *Science*, 2000, **287**, 836.

2 R. Palakodeti and M. Kessler, *Mater. Lett.*, 2006, **60**, 3437.

3 R. Shankar, T. K. Ghosh and R. J. Spontak, *Adv. Mater.*, 2007, **19**, 2218.

4 S. M. Ha, W. Yuan, Q. Pei, R. Pelrine and S. Stanford, *Adv. Mater.*, 2006, **18**, 887.

5 S. Arora, T. Ghosh and J. Muth, *Sens. Actuators A*, 2007, **136**, 321.

6 H. Stoyanov, M. Kollosche, S. Risse, D. N. McCarthy and G. Kofod, *Soft Matter*, 2011, **7**, 194.

7 Y. Jang and T. Hirai, *Soft Matter*, 2011, **7**, 10818.

8 F. Carpi and D. D. Rossi, *IEEE Trans. Dielectr. Electr. Insul.*, 2005, **12**, 835.

9 F. Carpi, G. Gallone, F. Galantini and D. De Rossi, *Adv. Funct. Mater.*, 2008, **18**, 235.

10 X. Zhang, C. Löwe, M. Wissler, B. Jähne and G. Kovacs, *Adv. Eng. Mater.*, 2005, **7**, 361.

11 D. M. Opris, M. Molberg, C. Walder, Y. S. Ko, B. Fischer, and F. A. Nüesch, *Adv. Funct. Mater.*, 2011, **21**, 3531.

12 S. Risse, B. Kussmaul, H. Krüger and G. Kofod, *Adv. Funct. Mater.*, 2012, **22**, 3958.

13 H. Liu, L. Zhang, D. Yang, Y. Yu, L. Yao and M. Tian, *Soft Mater.*, 2013, **11**, 363.

14 B. Kussmaul, S. Risse, G. Kofod, R. Waché, M. Wegener, D. N. McCarthy, H. Krüger and R. Gerhard, *Adv. Funct. Mater.*, 2011, **21**, 4589.

15 D. Yang, M. Tian, Y. Dong, H. Liu, Y. Yu and L. Zhang, *Smart Mater. Struct.*, 2012, **21**, 035017.

16 B. Kim, Y. D. Park, K. Min, J. H. Lee, S. S. Hwang, S. M. Hong, B. H. Kim, S. O. Kim and C. M. Koo, *Adv. Funct. Mater.*, 2011, **21**, 3242.

17 P. H. Vargantwar, A. E. Özçam, T. K. Ghosh and R. J. Spontak, *Adv. Funct. Mater.*, 2012, **22**, 2100.

18 H. Zhao, D. R. Wang, J. W. Zha, J. Zhao and Z. M. Dang, *J. Mater. Chem. A*, 2013, **1**, 3140.

19 M. Molberg, D. Crespy, P. Rupper, F. Nüesch, J. A. E. Månson, C. Löwe and D. M. Opris, *Adv. Funct. Mater.*, 2010, **20**, 3280.

20 H. Liu, L. Zhang, D. Yang, N. Ning, Y. Yu, L. Yao, B. Yan and M. Tian, *J. Phys. D: Appl. Phys.*, 2012, **45**, 485303.

21 H. Zhao, Y. J. Xia, Z. M. Dang, J. W. Zha and G. H. Hu, *J. Appl. Polym. Sci.*, 2013, **127**, 4440.

22 C. Huang and Q. M. Zhang, *Adv. Mater.*, 2005, **17**, 1153.

23 C. Huang and Q. Zhang, *Adv. Funct. Mater.*, 2004, **14**, 501.

24 C. Huang, Q. Zhang and K. Bhattacharya, *Appl. Phys. Lett.*, 2004, **84**, 4391.

25 H. Stoyanov, M. Kollosche, D. N. McCarthy and G. Kofod, *J. Mater. Chem.*, 2010, **20**, 7558.

26 H. C. Nguyen, V. T. Doan, J. Park, J. C. Koo, Y. Lee and H. R. Choi, *Smart Mater. Struct.*, 2009, **18**, 015006.

27 C. G. Cameron, R. S. Underhill, M. Rawji and J. P. Szabo, *Proc.SPIE-Int. Soc. Opt. Eng.*, 2004, **5385**, 51.

28 L. Chen, C. Liu, C. Hu and S. Fan, *Appl. Phys. Lett.*, 2008, **92**, 263104.

29 Q. Zhang, H. Li, M. Poh, F. Xia, Z. Y. Cheng, H. Xu and C. Huang, *Nature*, 2002, **419**, 284.

30 D. Yang, L. Zhang, H. Liu, Y. Dong, Y. Yu and M. Tian, *J. Appl. Polym. Sci.*, 2012, **125**, 2196.

31 S. Zhang, N. Zhang, C. Huang, K. Ren and Q. Zhang, *Adv. Mater.*, 2005, **17**, 1897.

32 F. Xia, Z. Y. Cheng, H. Xu, H. Li, Q. Zhang, G. J. Kavarnos, R. Y. Ting, G. A. Sadek and K. D. Belfield, *Adv. Mater.*, 2002, **14**, 1574.

33 C. Huang, Q. Zhang and A. Jakli, *Adv. Funct. Mater.*, 2003, **13**, 525.

34 D. Yang, M. Tian, H. Kang, Y. Dong, H. Liu, Y. Yu and L. Zhang, *Mater. Lett.*, 2012, **76**, 229.

35 D. Yang, M. Tian, Y. Dong, H. Kang, D. Gong and L. Zhang, *J. Appl. Phys.*, 2013, **114**, 154104.