Supporting Information

Porous PEDOT:PSS Smart Thermal Insulators Enabling Energy Harvesting and Detecting

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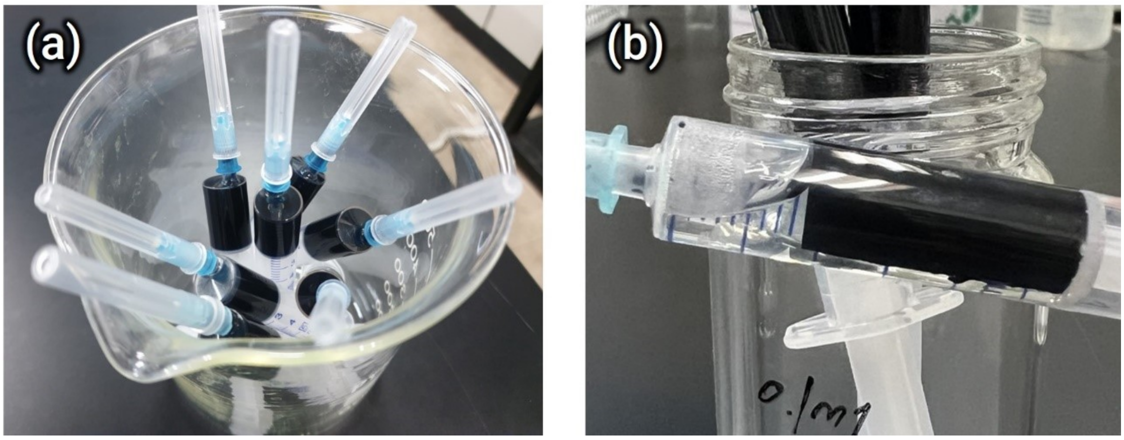

Figure S1. (A) Image of PEDOT:PSS/$MgSO_4$/EtOH mixture filled into polypropylene syringe being used as a mold for hydrogel formation. (B) Image of PEDOT:PSS hydrogel suspended inside solvent after complete cross-linking via heat treatment.

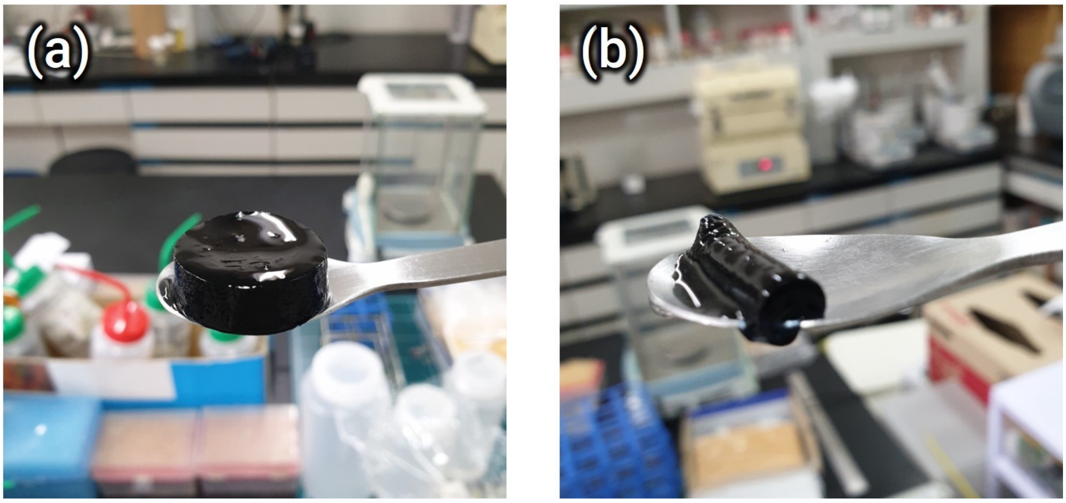

Figure S2. Image of PEDOT:PSS hydrogel retrieved after heat treatment which was formed inside (A) wide mouth cylindrical jar, and (B) 3ml polypropylene syringe.

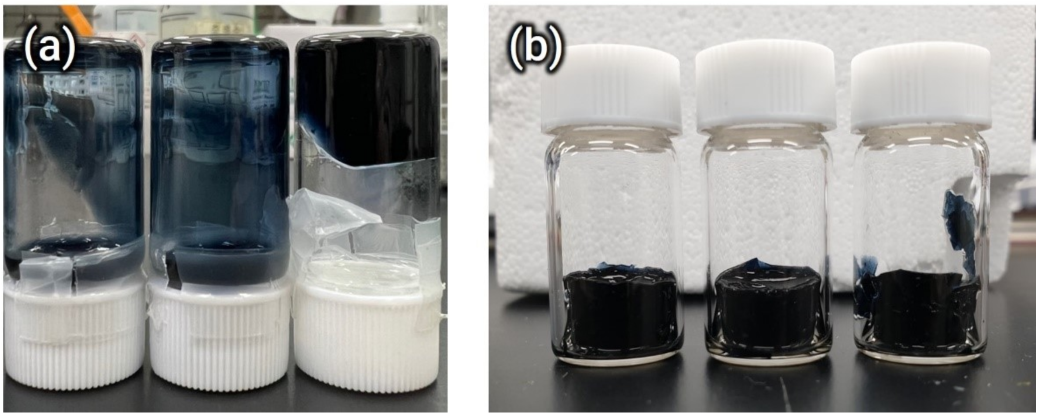

Figure S3. Image of PEDOT:PSS solution after heat treatment. (A) Samples in which 10wt%, 20wt%, 30wt% EtOH was added (respectively, from left to right), without $MgSO_4$ addition. (B) Sample in which 10wt%, 20wt%, 30wt% EtOH was added (respectively, from left to right), where $MgSO_4$ was added as cross-linking agent.

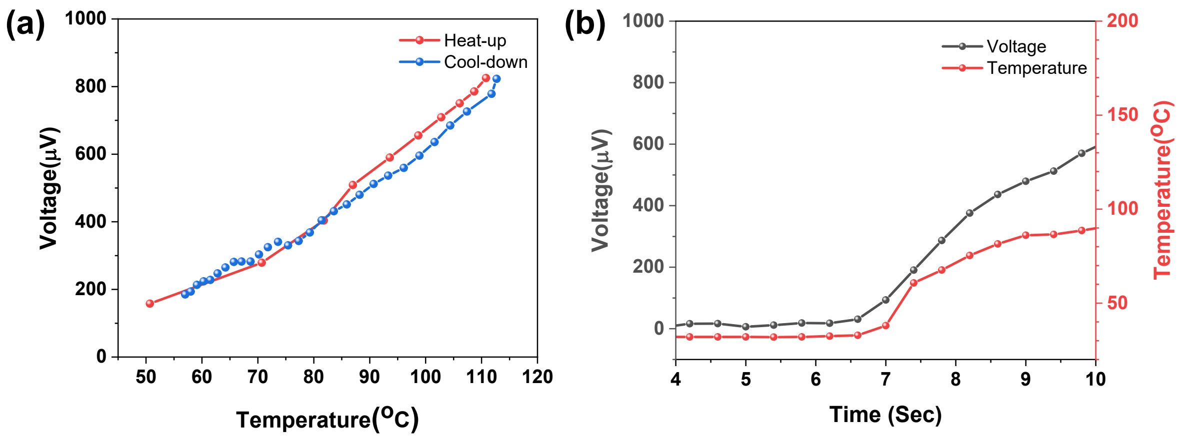

Figure S4. (A) Voltage-temperature plot of a typical response cycle by heating and subsequent cooling of porous PEDOT:PSS. (B) Magnified voltage-time plot showing response time of porous PEDOT:PSS for temperature detection.

Table S1. Component analysis of PEDOT:PSS/0.5M $MgSO_4$/EtOH viscous mixture

Component	Solution Volume [mL]	Solid component	Solid content [g]	Solid density [g cm^{-3}]	Solid Volume [mL]
PEDOT:PSS solution	1	PEDOT:PSS	0.013	1.06[a]	0.01378
0.5M $MgSO_4$	0.0648	$MgSO_4$	1×10^{-4}	2.66[b]	2.66×10^{-4}
EtOH	0.1408	-	-	-	-
Total	1.2056	PEDOT:PSS/$MgSO_4$	0.0131	-	0.01405

[a]Provided by the manufacturer; [b]Density of $MgSO_4$ acquired from literature. [1]

Table S2. Porosity calculation of PU foam, porous PEDOT:PSS and upper limit estimation

Sample	Bulk weight [g]	Bulk volume [cm^3]	Solid density [$g\ cm^{-3}$]	Bulk density [$g\ cm^{-3}$]	Solid Volume [cm^3]	Porosity
PU foam	0.0895	1.98	1.05[b]	0.0452	-	0.9570
porous PEDOT:PSS	0.0492	0.9604	1.06[c]	0.051226	-	0.9517
porous PEDOT:PSS with no shrinkage	-	1.2056[a] ($V_{bulk} \approx V_{tot}$)	-	-	0.01405[a]	0.9883 (Estimated upper limit)

[a]Values acquired from Table S1; [b]Density of polyurethane acquired from literature[2]; [c]Provided by the manufacturer.

Table S3. Recent studies of porous TE carbon materials in comparison with this work

P-type TE	N-type TE	Thermal conductivity [W m^{-1} K^{-1}]	TE power density [nW cm^{-2}]	Thermal gradient[b] [K]	Ref.
PEDOT:PSS/ZnO composite	N/A	0.053	0.86	Forced gradient ΔT = 50 K	[3]
SEBS-PEDOT:PSS-melamine foam	N/A	~ 0.066	16.1	Forced gradient ΔT = 20 K	[4]
PEDOT-TOS/SWCNT aerogel	N/A	~ 0.145 (~0.09)[a]	3073 (312)[a]	Forced gradient ΔT = 50 K (ΔT = 20 K)	[5]
CNT foam	CNT foam	0.17	390.6	Stabilized gradient with fan cooling ΔT = 13.9 K	[6]
CNT/PDMS foam	CNT/PDMS foam	0.13	494.8	Stabilized gradient with fan cooling ΔT = 18.1 K	[7]
Mesoporous fibrillar PEDOT:PSS	N/A	0.065	251.0[c]	Forced gradient ΔT = 15.16 K	[8]
PEDOT:PSS aerogel	N/A	0.0526	90.2	Stabilized gradient ΔT = 15.16 K	This work

[a]Determined based on provided power plots at ΔT = 20 K; [b]Forced gradient refers to a setup in which thermal source is directly applied on both sides, stabilized gradient refers to a setup in which thermal source is applied only to one side and thermal equilibrium was reached.; [c]Determined based on provided power plots at ΔT = 15.16 K

Supporting references

1. S. S. Chadwick, *Ref. Serv. Rev.*, 1988, **16**, 31-34.
2. D. W. Van Krevelen and K. Te Nijenhuis, *Properties of polymers: their correlation with chemical structure; their numerical estimation and prediction from additive group contributions*, Elsevier, 2009.
3. W. Lee, S. Lee, H. Kim and Y. Kim, *Chem. Eng. J.*, 2021, **415**, 128935.
4. J. Oh, J.-H. Kim, K. T. Park, K. Jo, J.-C. Lee, H. Kim and J. G. Son, *Nanoscale*, 2018, **10**, 18370-18377.
5. X. Wang, L. Liang, H. Lv, Y. Zhang and G. Chen, *Nano Energy*, 2021, **90**, 106577.
6. M.-H. Lee, Y. H. Kang, J. Kim, Y. K. Lee and S. Y. Cho, *Adv. Energy Mater.*, 2019, **9**, 1900914.
7. Y. H. Kang, E. J. Bae, M.-H. Lee, M. Han, B. J. Kim and S. Y. Cho, *Small*, 2022, **18**, 2106108.
8. Q. Weinbach, S. V. Thakkar, A. Carvalho, G. Chaplais, J. Combet, D. Constantin, N. Stein, D. Collin and L. Biniek, *Front. Electron. Mater.*, 2022, **2**.