

## Supporting information

**Steady and robust CNTs-based electric heating membrane fabricated by addition of nanocellulose and hot-press encapsulation**

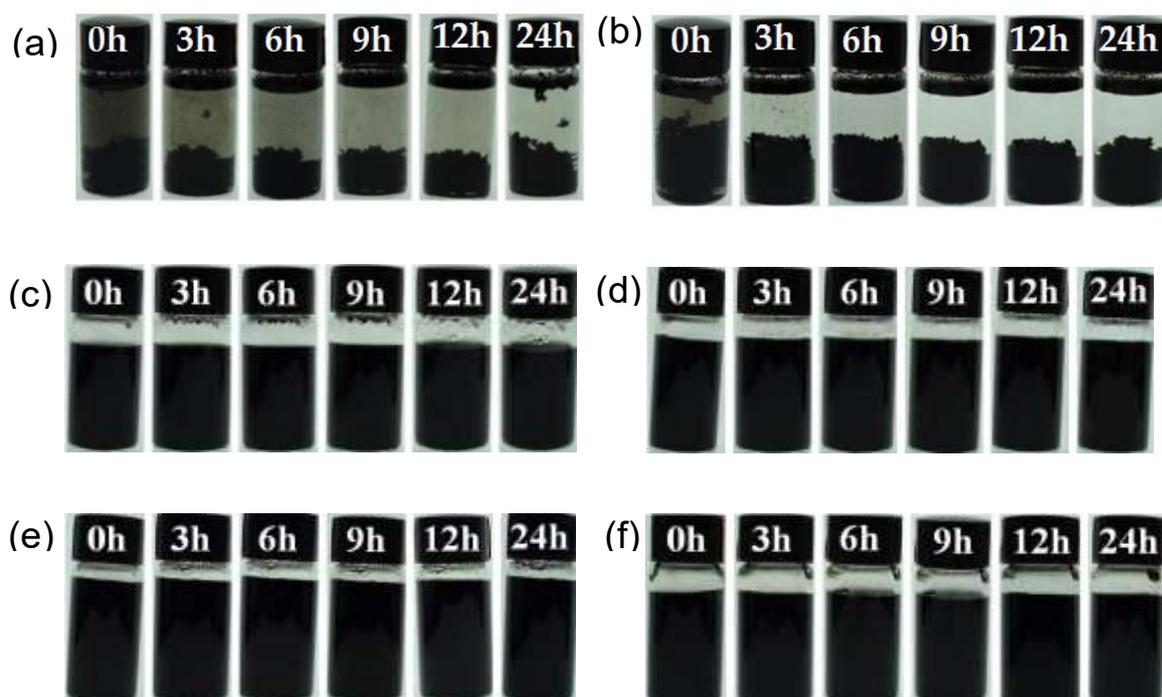
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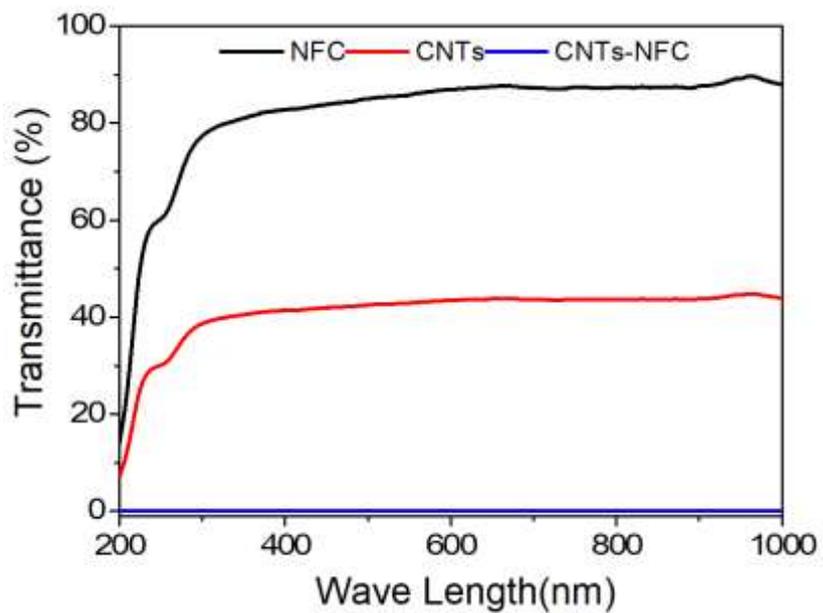
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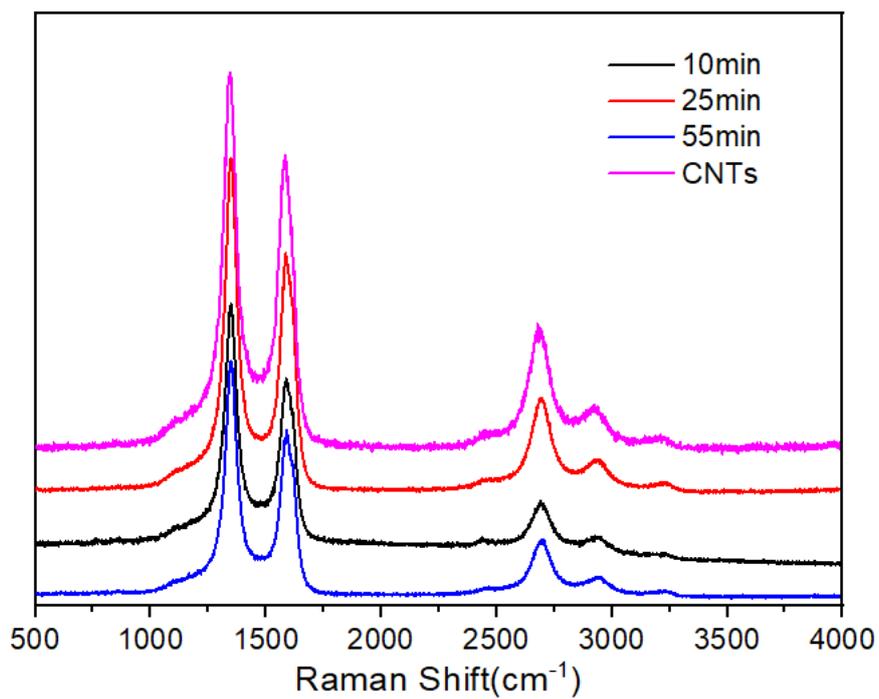
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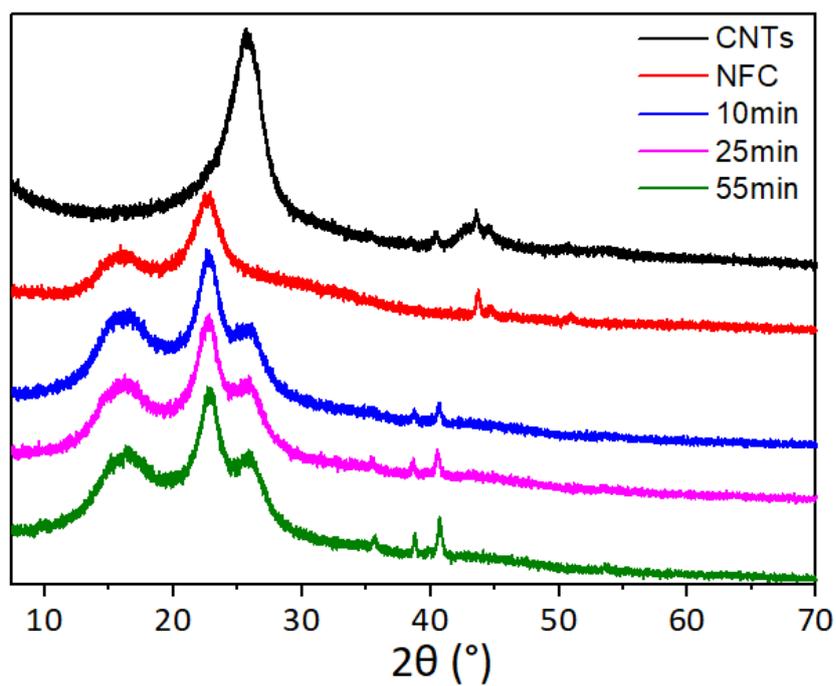
**Figure S1.** The sedimentation experiment of the CNTs suspension after ultrasound for (a) 5 min (b) 20 min and the CNTs-NFC mixture suspension after ultrasound for (c) 10 min (d) 25 min (e) 40 min (f) 55 min, with a standing time for 0 h, 3 h, 6 h, 9 h, 12 h and 24 h.



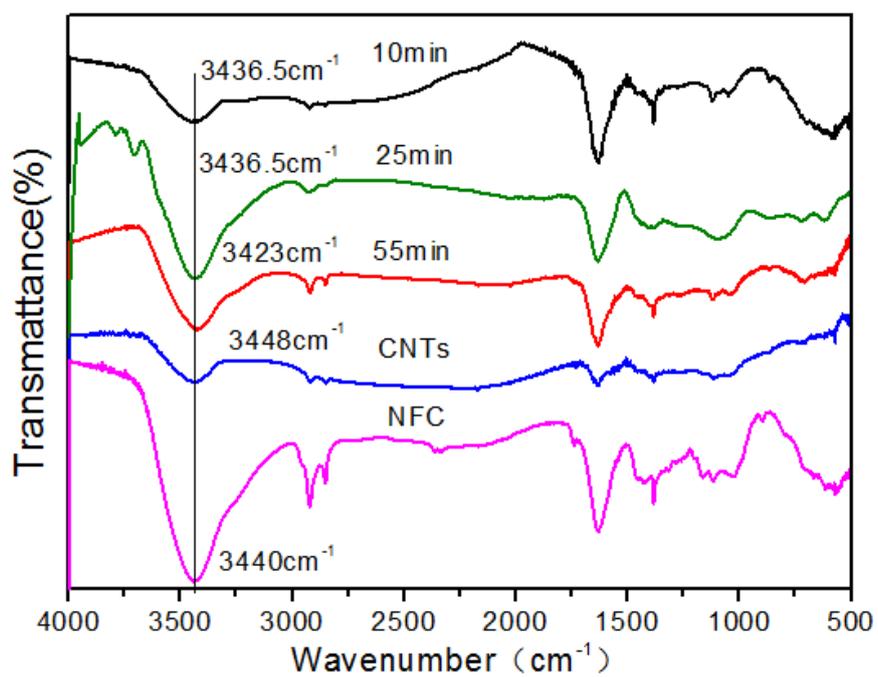
**Figure S2.** UV-vis spectroscopy on the suspensions.



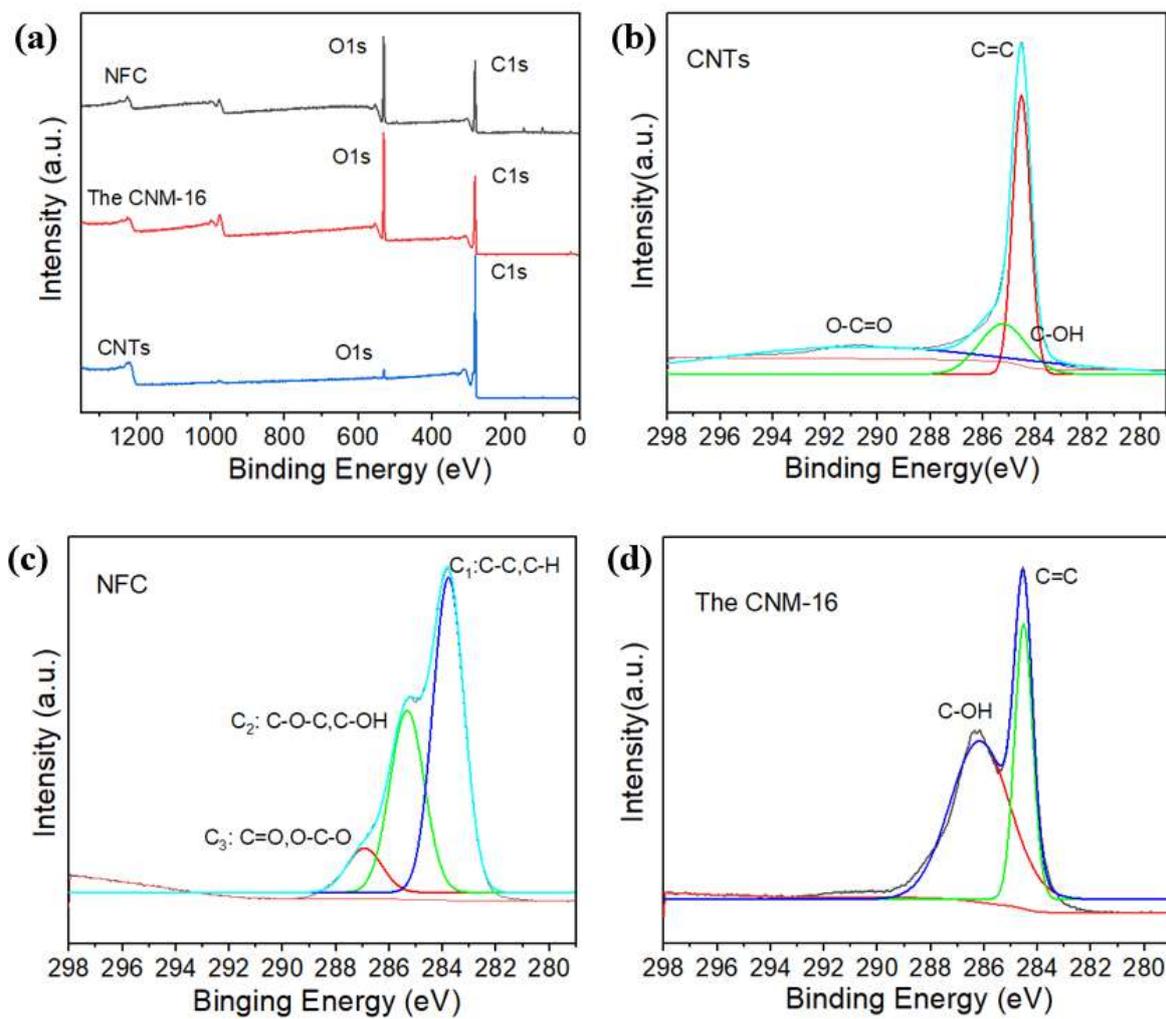
**Figure S3.** Raman spectrum of CNTs and the CNM with different dispersion times.



**Figure S4.** XRD spectrum of CNTs, NFC and the CNM with different dispersion times.



**Figure S5.** FT-IR spectrum of CNTs, NFC, and the CNM with different dispersion times.



**Figure S6.** XPS spectra of CNTs, NFC and the CNM-16.

**Table S1.**  $\zeta$ -potential of NFC, CNTs and CNTs-NFC mixture suspension.

Sample	Average $\zeta$ -potential (mV)	Standard deviation
NFC suspension	-42.85	$\pm 1.49$
CNTs suspension	-1.62	$\pm 0.87$
CNTs-NFC mixture suspension	-42.47	$\pm 1.28$

**Table S2.** Fitting parameters of Raman spectrum of CNTs and the CNM with different dispersion times.

Samples	D band		2D band		G band		$I_D/I_G$ Area	$I_{2D}/I_G$ Area
	Raman shift/cm <sup>-1</sup>	FWHM/c m <sup>-1</sup>	Raman shift/cm <sup>-1</sup>	FWHM/ cm <sup>-1</sup>	Raman shift/cm <sup>-1</sup>	FWHM/ cm <sup>-1</sup>		
CNM-10'	1357.55	103.35	2691.05	131.03	1587.37	105.97	4.00	3.08
CNM-25'	1345.37	87.07	2694.08	124.71	1589.69	88.79	2.55	1.95
CNM-55'	1348.82	88.08	2695.11	121.05	1590.37	90.04	3.11	2.38
CNTs	1343.70	97.75	2686.53	133.24	1581.63	95.46	1.24	2.31

**Table S3.** Elemental composition of CNTs, NFC, and the CNM-16 determined by XPS analysis.

Samples	Carbon (at%)	Oxygen (at%)	C/O (ratio)
CNTs	97.69	2.31	42.29
NFC	71.31	28.69	2.49
CNM-16	69.80	30.20	2.31

**Table S4.** Sheet resistance of surface seven-points of the CNM with different dispersion times.

Samples	Sheet resistance $R_{\square}$ ( $\Omega$ /sq)							Average value for single CNM	Standard deviation for single CNM	Average value'	Standard deviation'
	One	Two	Three	Four	Five	Six	Seven				
CNM-10'	22.50	22.50	25.50	21.00	20.02	26.40	20.31	22.60	2.31	21.25	2.65
	22.80	23.70	24.10	22.10	17.85	23.30	18.61	21.78	2.33		
	20.74	18.62	23.70	18.14	16.97	19.76	17.55	19.35	2.14		
CNM-25'	21.70	19.40	20.50	20.88	21.10	21.20	19.13	20.56	0.89	19.75	1.41
	19.60	18.83	23.90	19.70	18.43	19.82	18.06	19.76	1.80		
	18.96	18.27	18.96	18.05	20.60	18.36	19.22	18.92	0.79		
CNM-55'	24.80	24.70	26.80	28.10	25.40	29.60	24.40	26.26	1.84	23.35	2.96
	20.63	19.88	24.90	19.35	18.84	21.10	18.68	20.48	1.98		
	26.10	21.40	25.10	22.70	22.30	22.90	22.60	23.30	1.54		

**Table S5.** Resistance and its variation during energization of EHM prepared with different dispersion times, different grammages and EM-16.

Samples	Power density (W/m <sup>2</sup> )	Resistance ( $\Omega$ )			Resistance variation after cooling (%)	Resistance variation at the moment of power off (%)
		Before electrification	The moment of power off	After cooling		
EHM-1	500	351.81	348.97	348.05	1.07	0.81
	1000	348.05	347.04	343.33	1.36	0.29
	1500	343.33	341.96	342.86	0.14	0.40
	2000	342.86	336.17	333.09	2.85	1.95
	2500	333.09	338.06	342.83	2.92	1.49
	3000	342.83	337.70	340.21	0.76	1.50
EHM-7	500	210.38	202.59	206.50	1.84	3.70
	1000	206.50	199.84	199.73	3.28	3.23
	1500	199.73	191.95	194.47	2.63	3.90
	2000	194.47	191.44	193.05	0.69	1.56
	2500	193.05	189.07	170.21	11.83	2.06
	3000	170.21	159.95	163.41	4.00	6.03
EHM-10	500	92.07	87.54	89.40	2.90	4.92
	1000	89.40	82.53	85.42	4.45	7.68
	1500	85.42	81.61	79.09	7.41	4.46
	2000	79.09	78.50	78.05	1.31	0.75
	2500	78.05	77.97	84.57	8.35	0.10
	3000	84.57	77.87	79.69	5.77	7.92
EHM-16	500	40.23	39.32	37.26	7.38	2.26
	1000	37.26	36.41	36.50	2.04	2.28
	1500	36.50	35.18	35.21	3.53	3.62
	2000	35.21	34.65	34.79	1.19	1.59
	2500	34.79	33.68	35.51	2.07	3.19
	3000	35.51	34.89	35.12	1.10	1.75
EHM-10'	500	52.54	49.08	52.55	0.02	6.59
	1000	52.55	50.09	52.30	0.48	4.68
	1500	52.30	47.41	49.80	4.78	9.35
	2000	49.80	45.93	48.48	2.65	7.77
	2500	48.48	44.72	48.45	0.06	7.76
	3000	48.45	44.45	45.79	5.49	8.26
EHM-25'	500	40.23	39.32	37.26	7.38	2.26
	1000	37.26	36.41	36.50	2.04	2.28
	1500	36.50	35.18	35.21	3.53	3.62
	2000	35.21	34.65	34.79	1.19	1.59
	2500	34.79	33.68	35.51	2.07	3.19
	3000	35.51	34.89	35.12	1.10	1.75
EHM-55'	500	39.28	36.26	37.19	5.32	7.69
	1000	37.19	33.76	36.02	3.15	9.22
	1500	36.02	32.32	35.23	2.19	10.27
	2000	35.23	31.43	34.71	1.48	10.79
	2500	34.71	31.02	34.87	0.46	10.63
	3000	34.87	31.02	33.62	3.58	11.04
EM-16	500	63.68	48.40	46.04	27.70	24.00
	1000	46.04	45.22	44.36	3.65	1.78
	1500	44.36	43.73	35.33	20.36	1.42
	2000	35.33	34.75	34.13	3.40	1.64
	2500	34.13	33.80	33.38	2.20	0.97
	3000	33.38	33.52	33.41	0.09	0.42

**Table S6.** Resistance between two electrodes of EHM before and after encapsulation.

Samples	The resistance before encapsulation( $\Omega$ )	The resistance after encapsulation( $\Omega$ )
1#	31.6	35.5
2#	24.1	31.3
3#	31.2	39.7
4#	24.5	26.5