Electronic Supplementary Material (ESI) for Nanoscale.

Electronic Supplementary Information

Patchable, flexible heat-sensing hybrid ionic gate nanochannel modified with wax-composite

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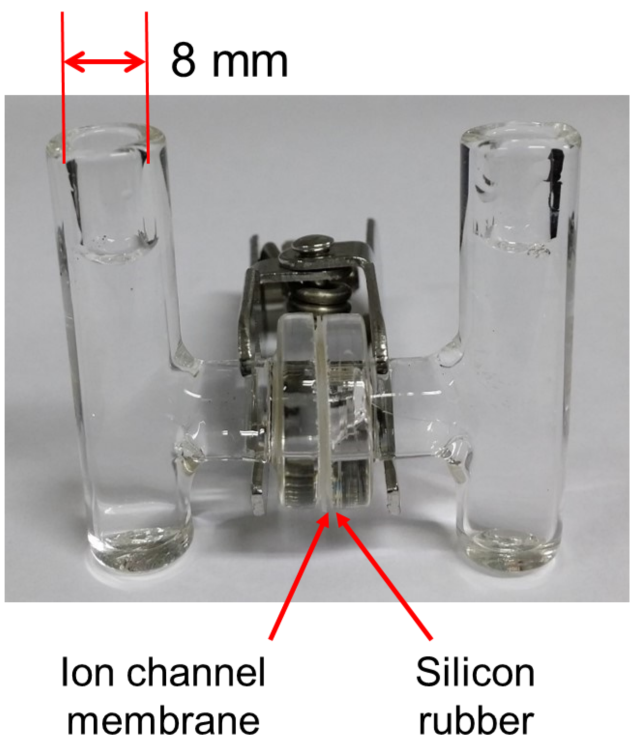

Fig. S1. An experimental cell for the measurement of ionic current.

Long-chain hydrocarbons with C–H stretching vibrations of saturated hydrocarbons of wax are seen at 2918 and 2850 cm^{-1}, carbonyl (C=O) stretching vibration from free carboxylic acid and from esters in region of 1740 cm^{-1}, $–CH_3$ and C–H deformations at about 1460 $cm^{-1}$and 1390 cm^{-1}. Rocking and wagging of $–CH_2–$ gives a clear peak at 720 cm^{-1}.[1] The peaks at 2,850, 2,920, and 1,465 cm^{-1} for stretching of $–CH_3$ and $–CH_2$ remain in mid ethylene–butylene (EB) block of SEBS are not observed or overlapped indicating that wax preferentially enter and swell EB segments.[2,3] Also, the doublet at 2924 and 2854 cm^{-1} can be overlapped to asymmetric C–H stretching of methyl and methylene groups in SEBS.

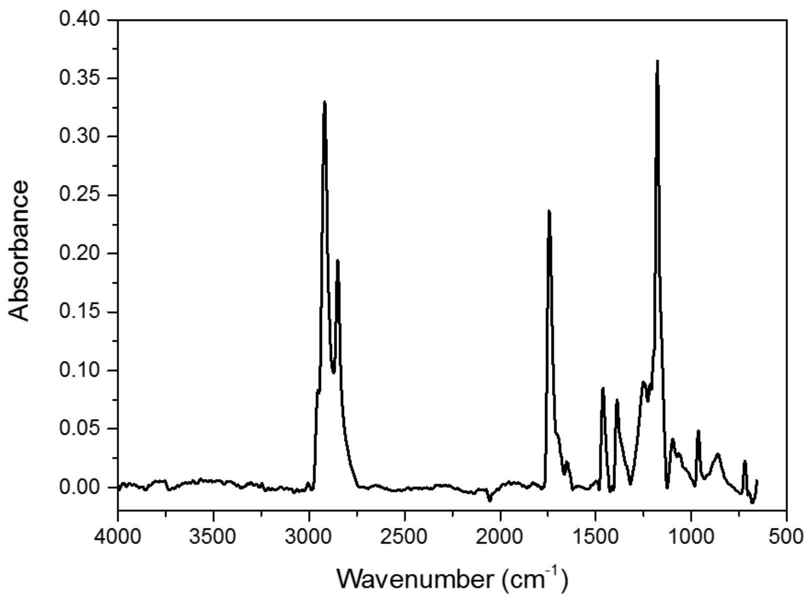

Fig. S2. Polarized infrared external reflectance spectra of wax-SEBS composite layers.

References

[1] A. B. Paterakis, *J. the Am. Inst. for Conser*. **2003**, *42*, 313.

[2] A. Ganguly, A. K. Bhowmick, *Nanoscale Res. Lett*. **2008**, *3*, 36.

[3] S. Song, J. Feng, P. Wu, *Macromol. Rapid Commun*. **2011**, *32*, 1569.

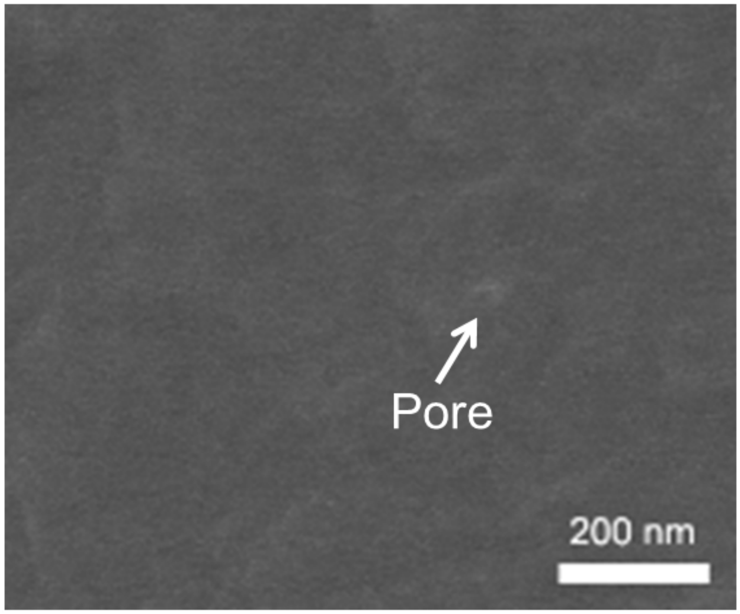

Fig. S3. SEM image of a part of PCTE/wax-SEBS surface.

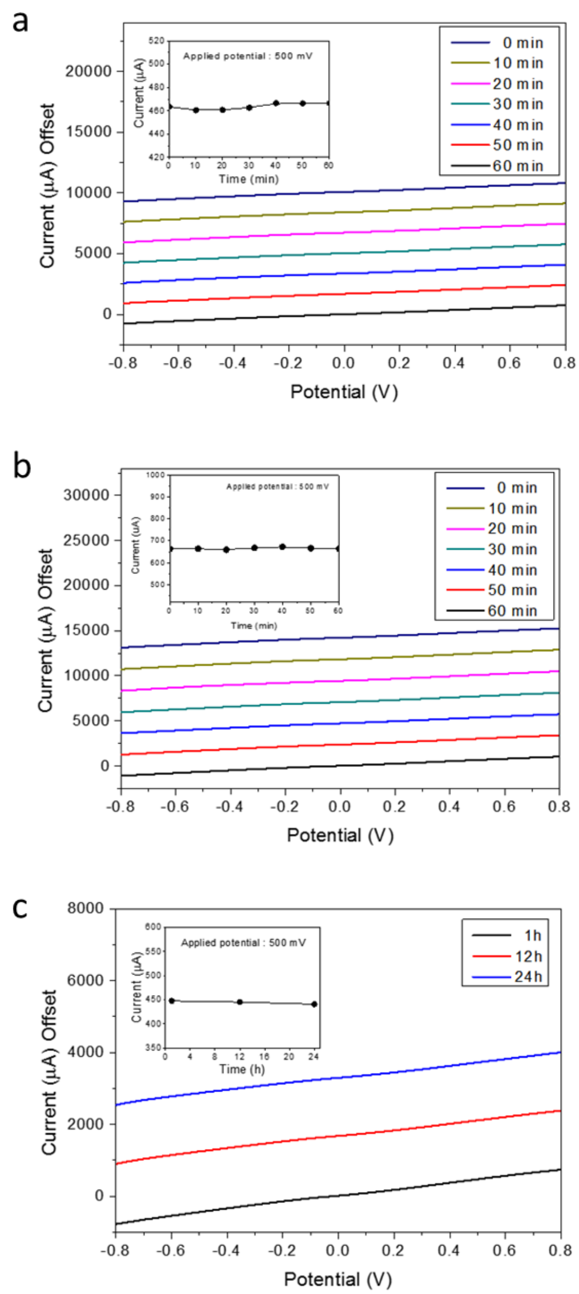

Fig. S4. **Time dependence of the ionic current vs. potential through the PCTE membrane**. (a) at 23 ^{o}C, (b) 41 ^{o}C (inset: ionic current vs. operation time). (c) Current flow vs. potential for longer time (1, 12, and 24h) at applied voltage of 500 mV.

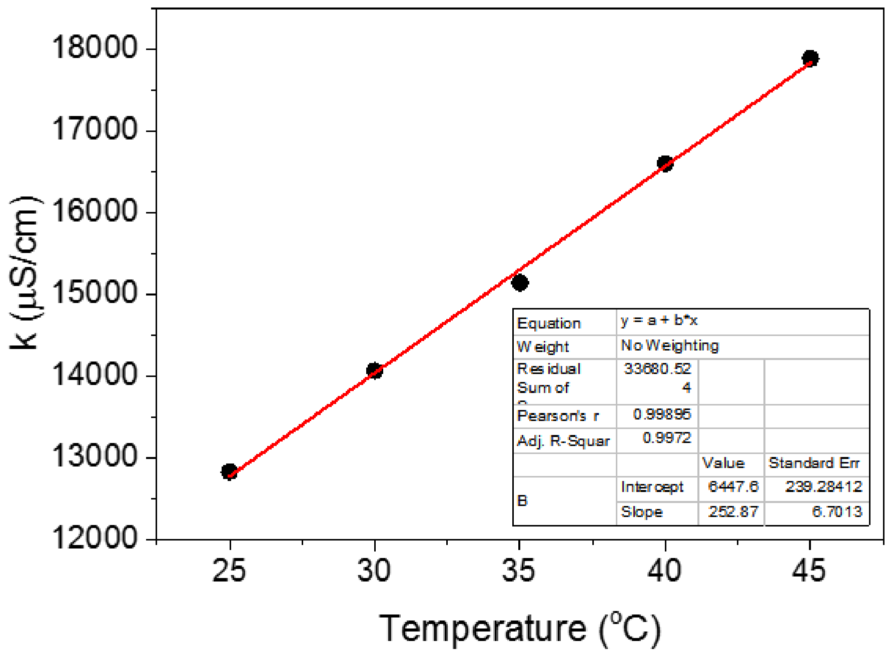

Fig. S5. The plot from the recommended electrolytic conductivity (κ) values for 0.1 mol aqueous potassium chloride solutions at temperatures from 25 to 45 ˚C.[1] All *k* values are given in units of μS cm^{-1}.

Reference

[1] Y. C. Wu, W. F. Koch, K. W. Pratt, *J. Res. Natl. Inst. Stand. Technol*. **1991**, *96*, 191.

The simulation of current change according to the temperature

Generally, the flowing current into the channel is expressed as followed equation.

$$i = \sigma \frac{A}{L} V \qquad (1)$$

Where σ is proportional constant, A channel area, L channel length, V the voltage.
From equation (1), A and L is fixed. If V is constantly given, current i is dependent on A.
Therefore,

$$di = dA \qquad (2)$$

However, if the volume expansion coefficient of wax is C,

$$\frac{dV / V}{dT} = C \qquad (3)$$

From (3), if the thermal expansion of wax composite is applicable to the geometry of Figure 2E
and

$$\frac{dV}{V} = CdT \qquad (4)$$

where V is the volume of composite of wax-SEBS and T temperature.
As shown in Figure 2E, the volume of wax-SEBS in the height L can expressed as following. We just consider the volume expansion of wax composite in the x direction.

$$V = \pi(r_0^2 - r_i^2)L \qquad (5)$$

Then,

$$dV = -2\pi r_i dr_i L \qquad (6)$$

From (4) and (6), we get

$$dV = VCdT = \pi(r_0^2 - r_i^2)L \cdot C \cdot dT = -2\pi r_i dr_i L \qquad (7)$$

and

$$-2r_i dr_i = C(r_0^2 - r_i^2)dT \qquad (8)$$

Therefore, we get

$$\frac{-2r_i}{r_0^2 - r_i^2} dr_i = CdT \tag{9}$$

Channel area A is

$$A = \pi r_i^2 \tag{10}$$

This means

$$dA = 2\pi r_i dr_i \tag{11}$$

Also, from (1) and (2), the small change of current, is

$$di = \sigma \frac{V}{L} dA \tag{12}$$

From (11) and (12),

$$di = \sigma \frac{V}{L} 2\pi r_i dr_i \tag{13}$$

From (9), $dr_i = \frac{r_0^2 - r_i^2}{-2r_i} CdT$ then substitute into (13) to get

$$di = -\pi\sigma \frac{V}{L} (r_0^2 - r_i^2) CdT \tag{14}$$

From (14), r_i can be expressed as the function of T. If equation (9) is integrated, r_i is obtained as $f(T)$,

$$\int \frac{-2r_i}{r_0^2 - r_i^2} dr_i = \int CdT \tag{15}$$

In this experiment, the volume of mixture is expanded as increasing the temperature. Then,

$$\int \frac{-2r_i}{r_0^2 - r_i^2} dr_i = -\int CdT \tag{16}$$

The left side of the equation becomes

$$\int \frac{-2r_i}{r_0^2 - r_i^2} dr_i = ln\left(r_i^2 - r_0^2\right) \tag{17}$$

The right side of the equation becomes

$$\int -CdT = -CT \tag{18}$$

From (17) and (18),

$$ln\left(r_i^2 - r_0^2\right) = -CT + c_1 \tag{19}$$

and

$$r_i^2 - r_0^2 = e^{-CT + c_1} = c_2 e^{-CT} \tag{20}$$

Then,

$$r_i^2 = r_0^2 + c_2 e^{-CT} \tag{21}$$

Substitute (21) into (14) to get

$$di = -\pi\sigma \frac{V}{L}\left\{r_0^2 - \left(r_0^2 + c_2 e^{-CT}\right)\right\} CdT$$

$$\pi\sigma \frac{V}{L} c_2 e^{-CT} CdT = c_3 e^{-CT} dT \tag{22}$$

If the temperature changes from T_0 to T, the current change is obtained by integrating (22)

$$i\Big]_{i_0}^{i} = -\frac{c_3}{C} e^{-CT}\Big]_{T_0}^{T} \tag{23}$$

$$i - i_0 = c_4\left(e^{-CT} - e^{-CT_0}\right) \tag{24}$$

Therefore,

$$i = i_0 + c_4\left(e^{-CT} - e^{-CT_0}\right) \tag{25}$$

$$i = i_0 + c_5\left(e^{-T} - e^{-T_0}\right) \tag{26}$$