Supporting Information:

Time domain characterization method

The measurement was done by using a potentiostat (PARSTAT *2273*, Princeton Applied Research) controlled by a computer using a PowerSuite electrochemical software and its analog signal output was connected to a high sample rate oscilloscope to enhance the resolution at very short time (< 1 μs).

Charge and capacitance responses under step voltage for the RC circuit in figure 1(b)

The charge response under a step voltage can be obtained by integrating eq. (1)

$$\text{Charge Density}\ (t) = (VC_D/2S)(1 - \exp(- t/\tau_{DL}))$$

where t is time. The capacitance C in unit area is Charge Density/V which is

$$C = (C_D/2S)(1 - \exp(- t/\tau_{DL}))$$

where S is the surface area and τ_{DL} depends on gap distance d. At $t = \tau_{DL}$, $C = 0.316\ C_D/S$. As shown in figure 4 and figure 7, C at $t = \tau_{DL}$ does not depend on thickness d, indicating that C_D is thickness independent for the thickness d studied.

Differential capacitance as a function of time

The differential capacitance Delta(Q)/delta(V) was calculated by fixing delta(V) = 1 V, and plot Q(1 V)/1 V, (Q(2V)-Q(1V))/1 V, and (Q(3V)-Q(2V))/1 V vs. time .

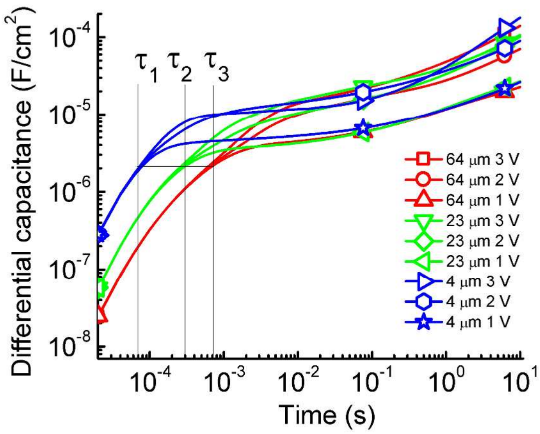

Figure 1. The differential capacitance as a function of time for the ionic liquid [C_4mim][PF_6] under 1 V , 2 V and 3 V at the membrane thickness of d = 4 μm, 23 μm, and 64 μm. τ_1, τ_2, and τ_3 are τ_{DL} for 4, 23, 64 μm thick ionic systems. The error bar is indicated by the size of the symbols in the figure.

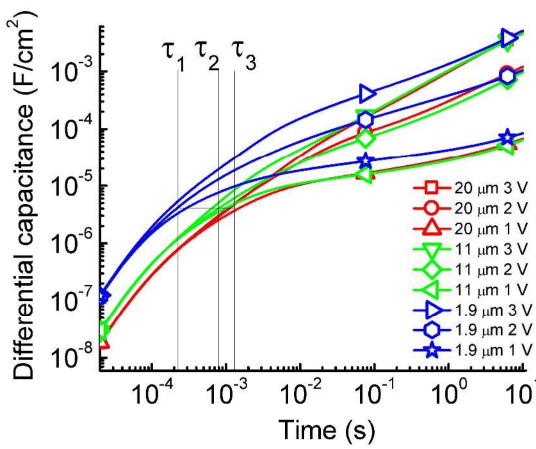

Figure 2. The differential capacitance as a function of time for the Aquivion film with 40 wt% uptake of [C_2mim][TfO] under 1 V , 2 V and 3 V at the membrane thickness of d = 1.9 μm, 11 μm, and 20 μm. τ_1, τ_2, and τ_3 are τ_{DL} for membranes of 1.9, 11, and 20 μm. The error bar is indicated by the size of the symbols in the figure.