

ARTICLE

## Supplementary information

### Exploring Response Time and Synaptic Plasticity in P3HT Ion-Gated Transistors for Neuromorphic Computing: Impact of P3HT Molecular Weight and Film Thickness

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**Table S1.** Figures of merit for different MWs [EMIM][TFSI]-gated P3HT transistors at different  $V_{gs}$  scan rates (100, 50, and 25 m V s<sup>-1</sup>).

MW	$V_{gs}$ scan rate (mV s <sup>-1</sup> )	ON/OFF	$V_{th}$ (V)	Mobility (cm <sup>2</sup> V <sup>-1</sup> s <sup>-1</sup> )	Charge carrier density (cm <sup>-2</sup> )
Low	25	$(0.8 \pm 1.6) \times 10^3$	$-0.32 \pm 0.03$	$0.20 \pm 0.03$	$(1.6 \pm 0.2) \times 10^{15}$
	50	$(2.1 \pm 0.1) \times 10^3$	$-0.34 \pm 0.03$	$0.26 \pm 0.09$	$(1.2 \pm 0.1) \times 10^{15}$
	100	$(1.6 \pm 0.2) \times 10^3$	$-0.34 \pm 0.05$	$0.33 \pm 0.02$	$(0.9 \pm 0.3) \times 10^{15}$
Intermediate	25	$(2.1 \pm 0.7) \times 10^3$	$-0.44 \pm 0.02$	$0.16 \pm 0.02$	$(2.0 \pm 0.8) \times 10^{15}$
	50	$(3.0 \pm 0.5) \times 10^3$	$-0.44 \pm 0.04$	$0.19 \pm 0.05$	$(1.6 \pm 0.5) \times 10^{15}$
	100	$(2.0 \pm 0.3) \times 10^3$	$-0.44 \pm 0.01$	$0.25 \pm 0.04$	$(1.2 \pm 0.2) \times 10^{15}$
High	25	$(3.5 \pm 0.5) \times 10^3$	$-0.45 \pm 0.2$	$0.13 \pm 0.09$	$(2.3 \pm 0.09) \times 10^{15}$
	50	$(3.0 \pm 0.1) \times 10^3$	$-0.45 \pm 0.01$	$0.16 \pm 0.06$	$(1.9 \pm 0.3) \times 10^{15}$
	100	$(1.9 \pm 0.3) \times 10^3$	$-0.45 \pm 0.01$	$0.22 \pm 0.01$	$(1.4 \pm 0.2) \times 10^{15}$

The threshold voltage,  $V_{th}$ , was determined by linearly extrapolating the  $I_{ds}$ - $V_{gs}$  curve within the linear regime. The ON/OFF ratio, derived from the transfer curves, represents the ratio of  $I_{ds}$  at a constant  $V_{gs}$  in the ON and OFF states ( $I_{on}/I_{off}$ ).<sup>1</sup>

We calculated the charge carrier density ( $\rho$ , cm<sup>2</sup>), and then the mobility ( $\mu$ , cm<sup>2</sup>V<sup>-1</sup>s<sup>-1</sup>), from the transfer characteristics with  $V_{gs}$  sweeping rates of 25, 50, and 100 mVs<sup>-1</sup> at  $V_{ds} = -0.2$  V (Table S2).<sup>2</sup>

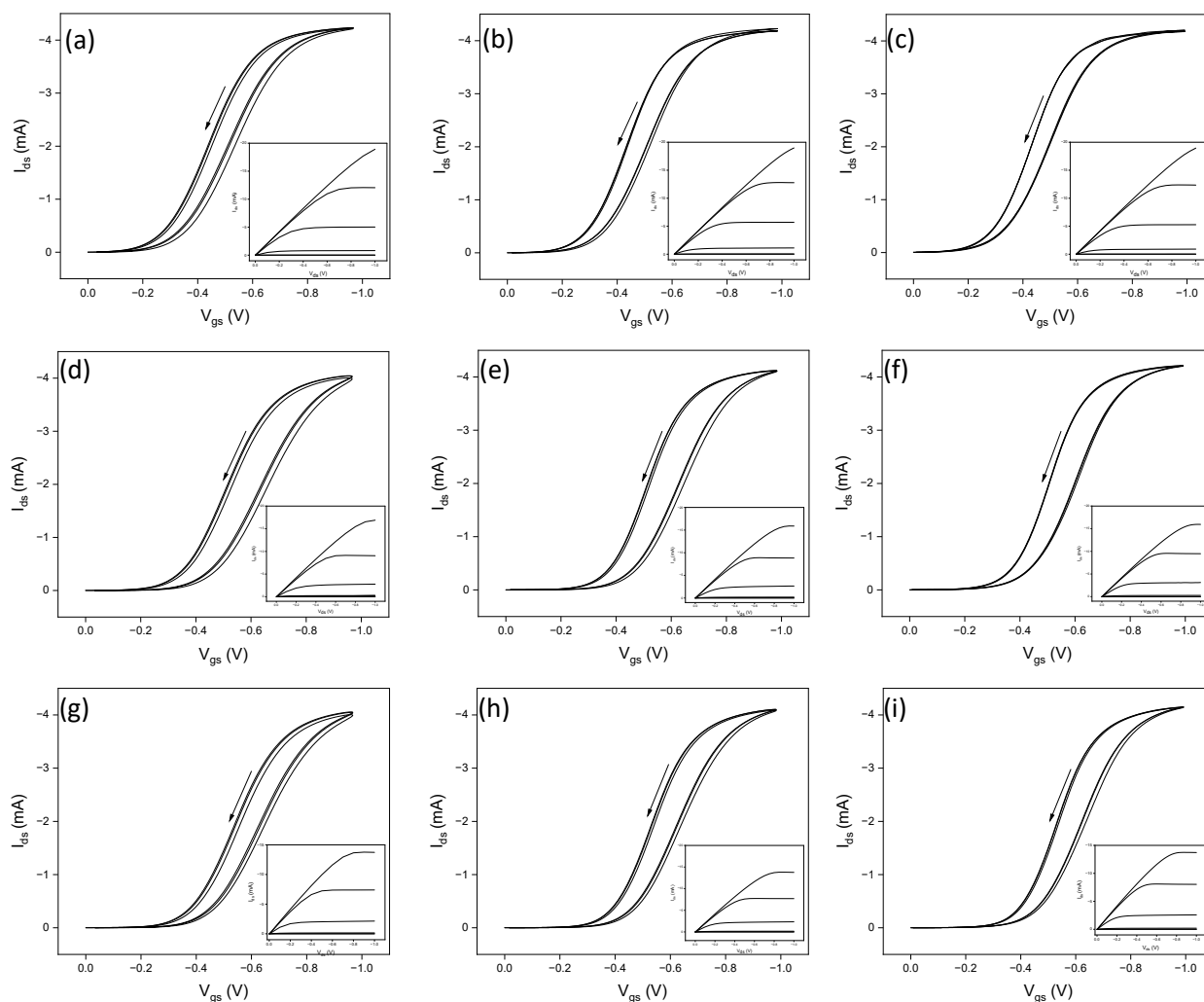
$$\rho = \frac{Q}{eA} = \frac{\int I_g dV_{gs}}{eAr_v}$$

The charge carrier density was calculated from the equation:  $\rho = \frac{Q}{eA} = \frac{\int I_g dV_{gs}}{eAr_v}$ ,  $Q$  signifies the quantity of charge accumulated during the forward scan in the transfer curve (derived from the integration of  $I_{gs}$  with  $V_{gs}$ ),  $A$  is the area of the P3HT film interfaced with the ionic liquid (4 mm×9 mm),  $e$  is the elementary charge, and  $r_v$  is the scan rate of  $V_{gs}$ .<sup>3,4</sup>

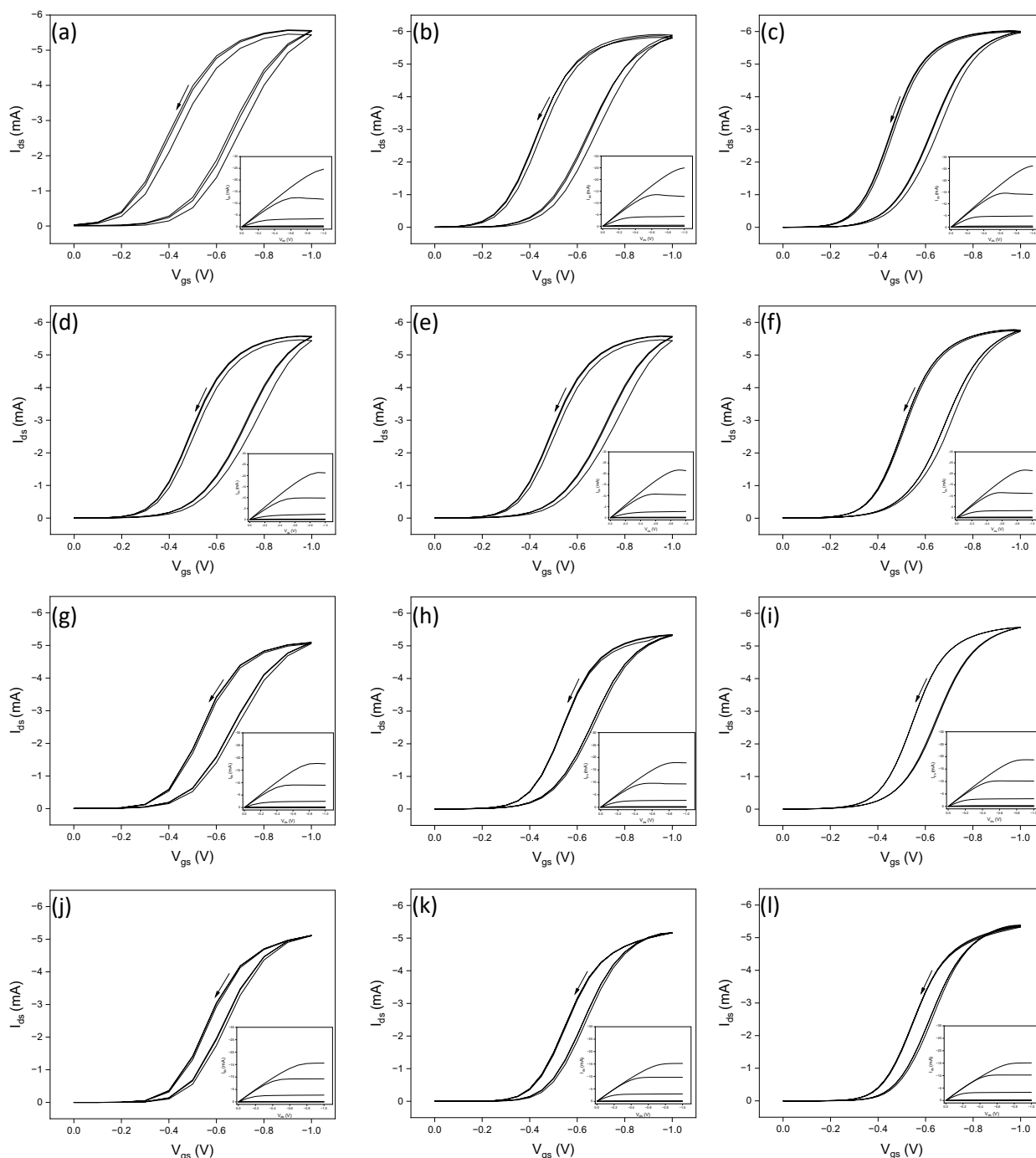
The charge carrier mobility, and  $\mu$ , was obtained by  $\mu = \frac{L I_{ds}}{WQV_{ds}}$ .<sup>5</sup>

**Table S2.** Figures of merit for different spin coating speeds [EMIM][TFSI]-gated P3HT transistors at different  $V_{gs}$  scan rates (100, 50, and 25 m V s<sup>-1</sup>).

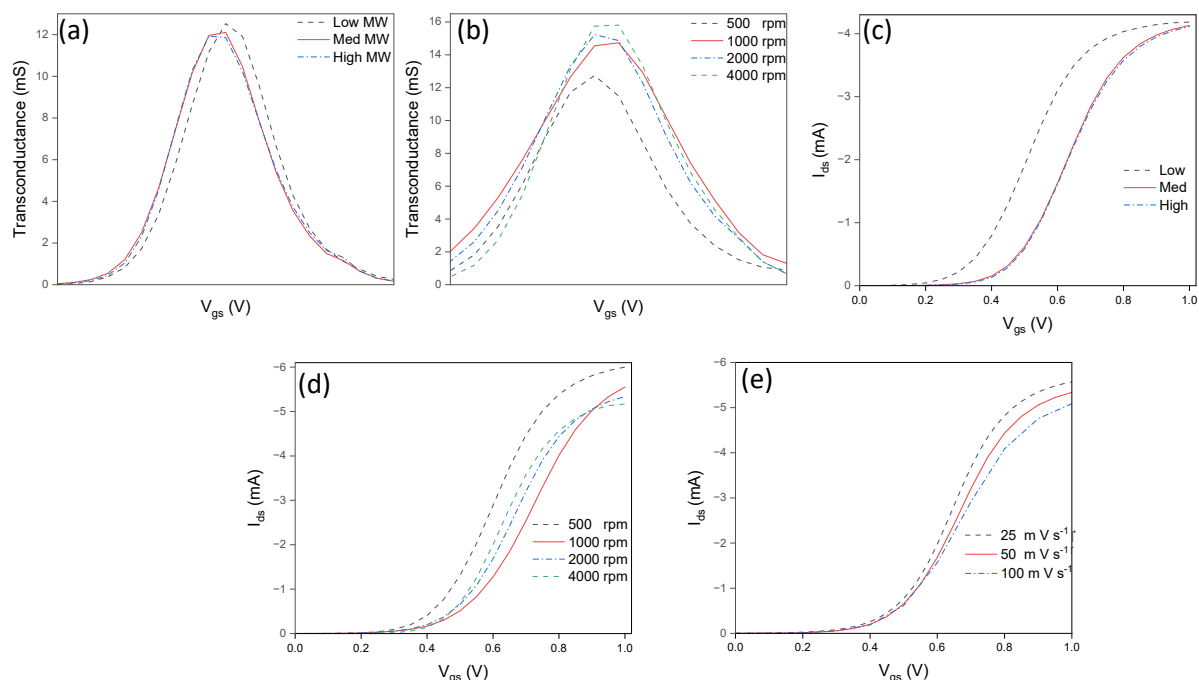
Spin coating speed (rpm)	$V_{gs}$ scan rate (m V s <sup>-1</sup> )	ON/OFF	$V_{th}$ (V)	Mobility (cm <sup>2</sup> V <sup>-1</sup> s <sup>-1</sup> )	Charge carrier density (cm <sup>-2</sup> )
500	25	$(3.1 \pm 1.6) \times 10^3$	$-0.43 \pm 0.02$	$0.10 \pm 0.03$	$(3.4 \pm 1.2) \times 10^{15}$
	50	$(2.0 \pm 1.1) \times 10^3$	$-0.44 \pm 0.02$	$0.12 \pm 0.04$	$(2.8 \pm 0.9) \times 10^{15}$
	100	$(1.2 \pm 0.8) \times 10^3$	$-0.45 \pm 0.03$	$0.16 \pm 0.04$	$(2.1 \pm 0.5) \times 10^{15}$
1000	25	$(1.5 \pm 0.3) \times 10^3$	$-0.48 \pm 0.06$	$0.25 \pm 0.07$	$(1.9 \pm 0.5) \times 10^{15}$
	50	$(2.6 \pm 1.5) \times 10^3$	$-0.49 \pm 0.06$	$0.33 \pm 0.08$	$(1.4 \pm 0.3) \times 10^{15}$
	100	$(2.2 \pm 1.2) \times 10^3$	$-0.50 \pm 0.07$	$0.52 \pm 0.08$	$(8.2 \pm 0.6) \times 10^{14}$
2000	25	$(2.0 \pm 1.0) \times 10^3$	$-0.46 \pm 0.02$	$0.20 \pm 0.06$	$(1.5 \pm 0.1) \times 10^{15}$
	50	$(2.7 \pm 0.3) \times 10^3$	$-0.47 \pm 0.02$	$0.26 \pm 0.07$	$(1.2 \pm 0.1) \times 10^{15}$
	100	$(1.7 \pm 0.2) \times 10^3$	$-0.45 \pm 0.03$	$0.34 \pm 0.10$	$(8.1 \pm 0.7) \times 10^{14}$
4000	25	$(1.0 \pm 1.0) \times 10^4$	$-0.44 \pm 0.03$	$0.34 \pm 0.11$	$(8.2 \pm 0.8) \times 10^{14}$
	50	$(8.6 \pm 6.2) \times 10^3$	$-0.44 \pm 0.02$	$0.45 \pm 0.11$	$(6.3 \pm 0.6) \times 10^{14}$
	100	$(5.1 \pm 3.0) \times 10^3$	$-0.44 \pm 0.02$	$0.61 \pm 0.17$	$(4.6 \pm 0.3) \times 10^{14}$



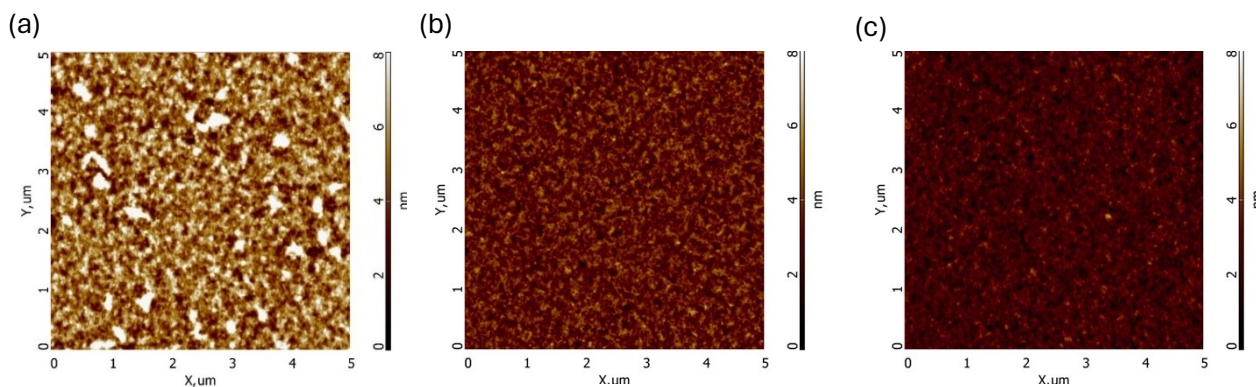
**Figure S1.** Transfer characteristics in the linear regime ( $V_{ds} = -0.2$  V, (3 cycles)) at  $V_{gs}$  scan rate 100, 50, and 25  $\text{m V s}^{-1}$  (inset: output characteristic with  $V_{gs} = 0, -0.2, -0.4, -0.6, -0.8, -1$  V and  $V_{ds}$  100, 50, and 25  $\text{m V s}^{-1}$  scan rate) for [EMIM][TFSI]-gated transistors based on a, b, c) low MW d, e, f) intermediate MW g, h, i) high MW P3HT.



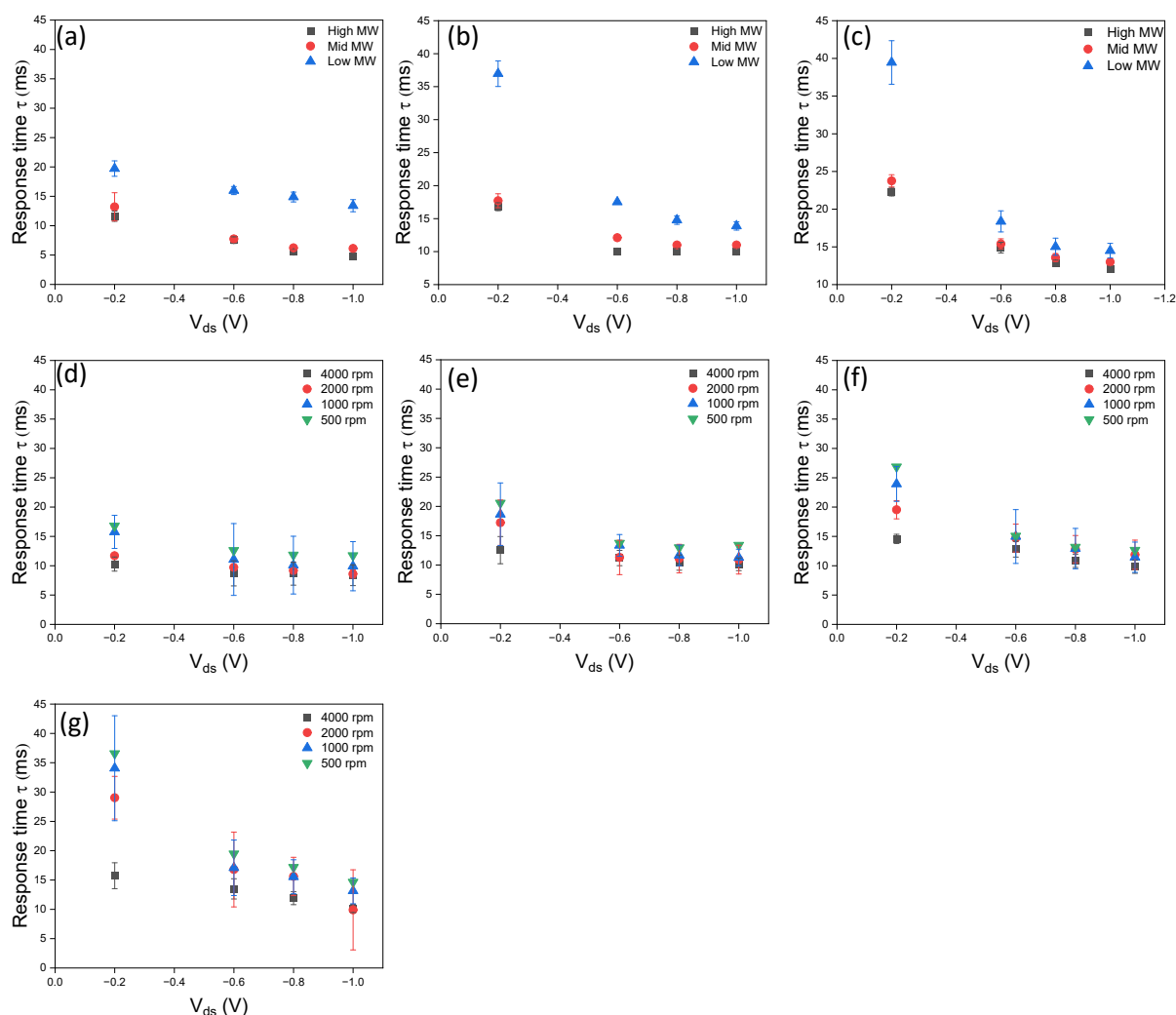
**Figure S2.** Transfer characteristics in the linear regime ( $V_{ds} = -0.2$  V, (3 cycles)) at  $V_{gs}$  scan rate 100, 50, and 25 m V s<sup>-1</sup> (inset: output characteristic with  $V_{gs} = 0, -0.2, -0.4, -0.6, -0.8, -1$  V and  $V_{ds}$  100, 50, and 25 m V s<sup>-1</sup> scan rate) for [EMIM][TFSI]-gated transistors P3HT transistors prepared with spin coating speed a, b, c) 500 rpm d, e, f) 1000 rpm g, h, i) 2000 rpm j, k, l) 4000 rpm.



**Figure S3** Transconductance curve for [EMIM][TFSI]-gated transistors based on P3HT deposited at a) high MW (blue line), intermediate MW (red line), and low MW (black line) at 1000 rpm during 30 s b) spin coating rate 500 rpm (black line), 1000 rpm, (red line), 2000 rpm (blue line), and 4000 rpm (green line), on 30 seconds with intermediate MW.  $I_{ds}$  level ( $V_{ds} = -0.2$  V) at  $V_{gs}$  50 m V s<sup>-1</sup> scan rate for [EMIM][TFSI]-gated transistors based on P3HT deposited at c) high MW (blue line), intermediate MW (red line), and low MW (black line) d) spin coating rate 500 rpm (black line), 1000 rpm (red line), 2000 rpm (blue line), and 4000 rpm (green line), on 30 seconds with intermediate MW e) intermediate MW and 1000 rpm at  $V_{gs}$  25 (black line), 50 (red line), and 100 (blue line) m V s<sup>-1</sup> scan rate.



**Figure S4** AFM height images of (a) low MW, (b) intermediate MW and (c) high MW with a same height scale of 0 to 8 nm.



**Figure S5** Transient response of an [EMIM] [TFSI]-gated P3HT transistor with high, intermediate, and low MW for  $V_{gs} =$  a)  $-0.5$  V, b)  $-0.8$  V, and c)  $-1$  V at different  $V_{ds}$ . The duration time of the  $V_{gs}$  bias is 200 ms. Transient response of [EMIM][TFSI]-gated P3HT transistors prepared with spin coating rate 500, 1000, 2000, and 4000 rpm, on 30 seconds with intermediate MW with  $V_{gs} =$  d)  $-0.5$  V, e)  $-0.8$  V, f)  $-1$  V, and g)  $-1.2$  V at different  $V_{ds}$ . The duration of the  $V_{gs}$  bias is 200 ms.

## References

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