Supporting Information

An organic transistor matrix for scalable intracellular action potential recording.

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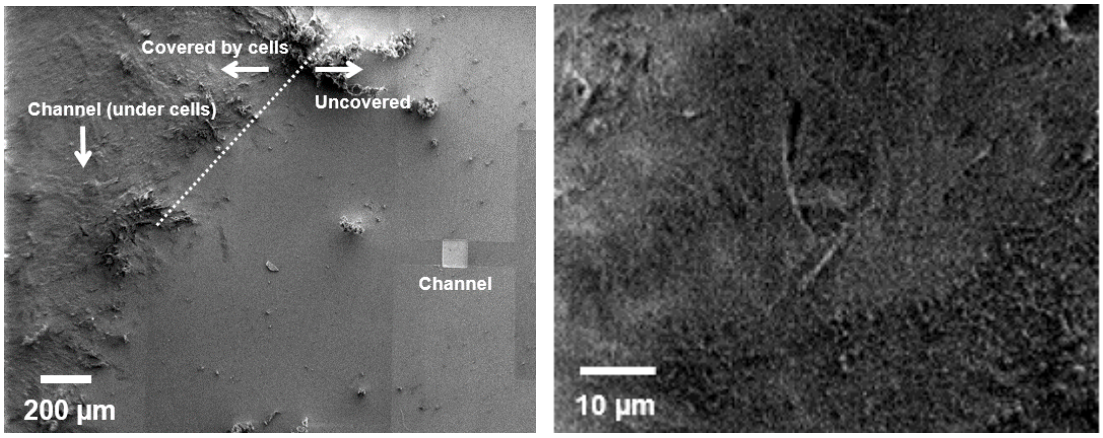

Fig. S1. Scanning electron microscopy (SEM) image of cells on the channel of OECTs. The left image shows the boundary of the region covered by cells and uncovered region. Cells form a tight sheet, and thus the OECT is not visible when it is covered. Right image shows a high-magnification image of the cell sheet.

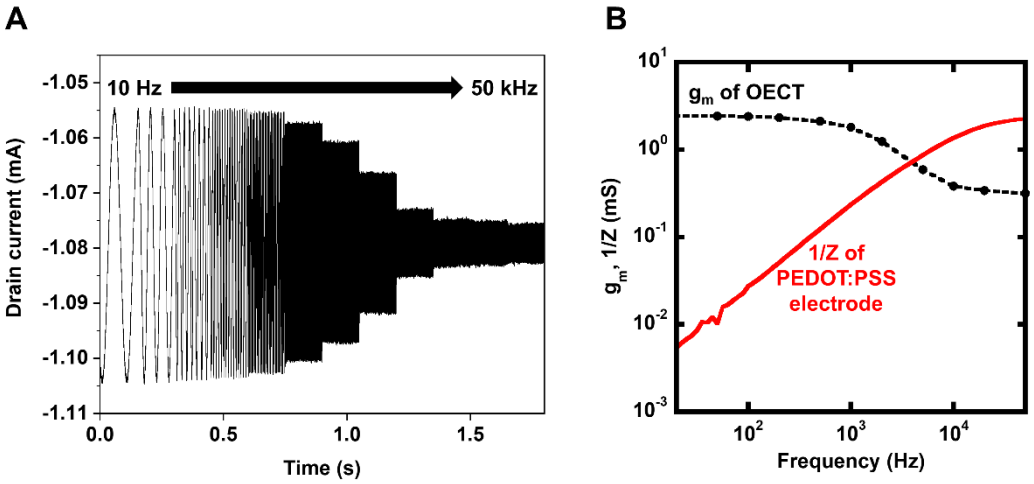

Fig. S2. Frequency response of OECT. (A) Drain current of an OECT while sine waves (20 mV_{pp}) were applied to the gate electrode. Frequency was varied from 10 Hz to 50 kHz for each 0.15 s, and the amplitude of the output current decreased accordingly. (B) Comparison with a PEDOT:PSS electrode of the same scale. Regarding voltage as input and current as output, g_m of OECT and 1/Z of PEDOT:PSS are plotted in the same figure. OECT has a higher output to low frequency input.

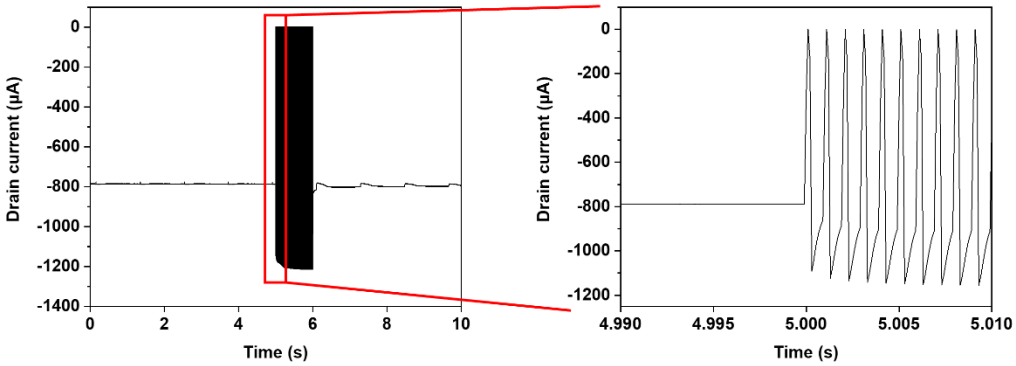

Fig. S3. Waveform of the drain current while a pulse voltage was applied to the drain electrode. Applied pulse made a round trip between −600 mV for 0.75 ms and 0 V for 0.25 ms with a rising time of 0.25 μs. The waveform does not show square shape because of undershoot and delayed response. It should be noted that the sampling rate was 10 kHz, so that the number of the data point was 10 for 1 cycle and the sharpness of peaks are possibly exaggerated.

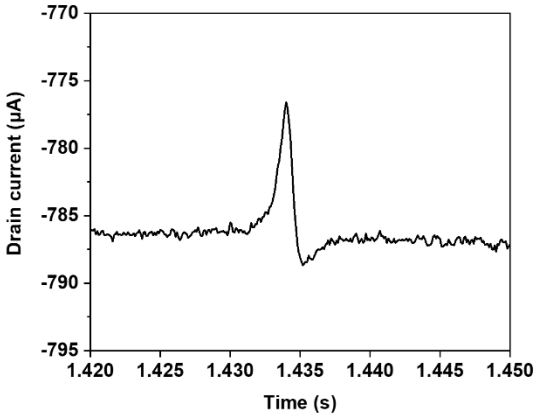

Fig. S4. Magnified figure of the recorded peak before the pulse input.

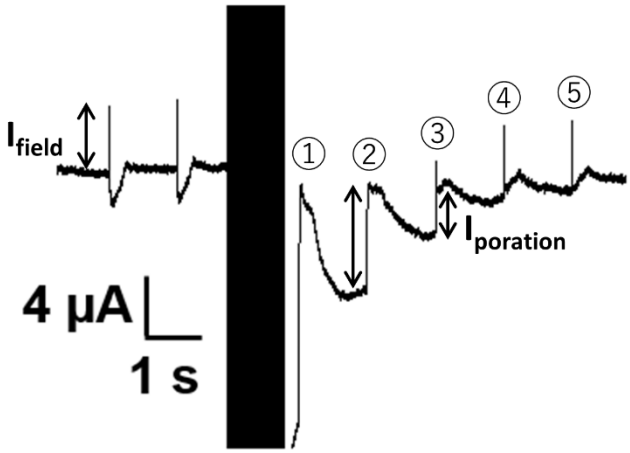

Fig. S5. Example of the procedure to count peaks and measure the amplitude of the induced peaks.

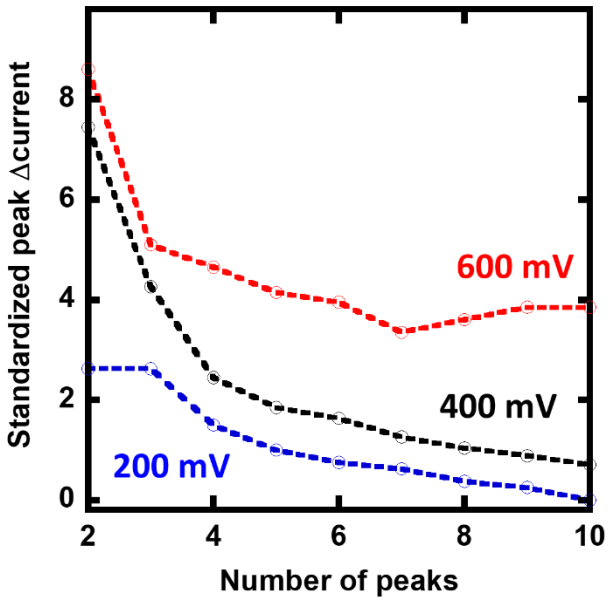

Fig. S6. The effect of the applied drain voltage on the duration and amplitude of the induced peaks. An OECT with a channel size of 100 × 100 μm^2 was used for plotting this

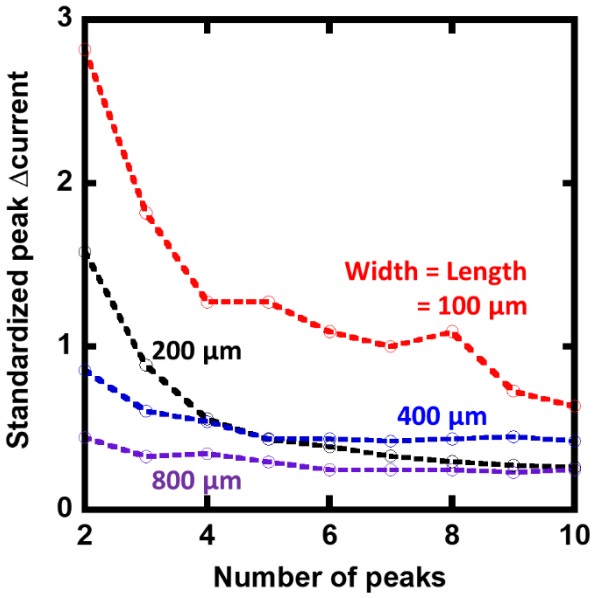

Fig. S7. Duration and amplitude of induced peaks versus variable channel sizes. Compared to Fig. 4B, this sample has a larger overlap (100 µm) between Au drain/source electrode and the PEDOT:PSS channel.

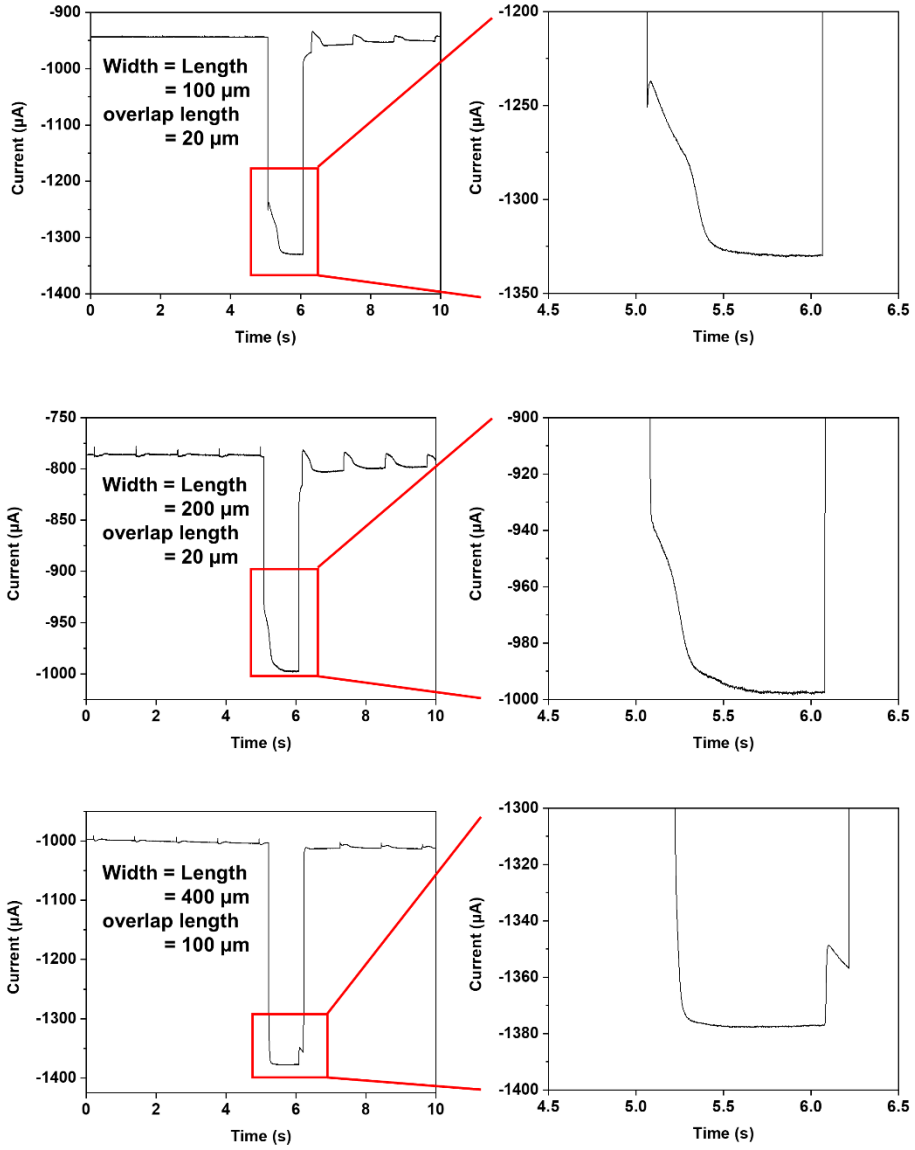

Fig. S8. Electroporation-induced peaks overlapped with the undershoot current during the cyclic pulse input. The amplitude of the drain-source voltage and pulse was 600 mV. The amplitude of peaks recorded during the input is larger than that recorded after the input.

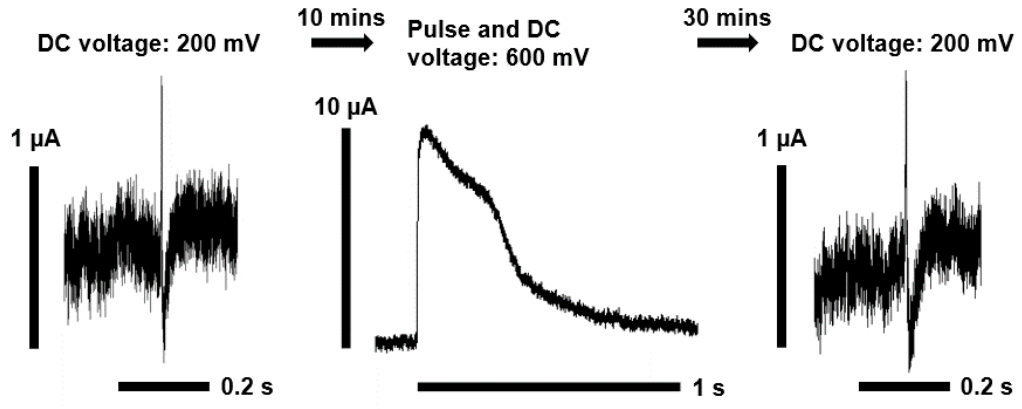

Fig. S9. Effect of intracellular action potential recording using electroporation on the field potential recorded after sufficient rest time.

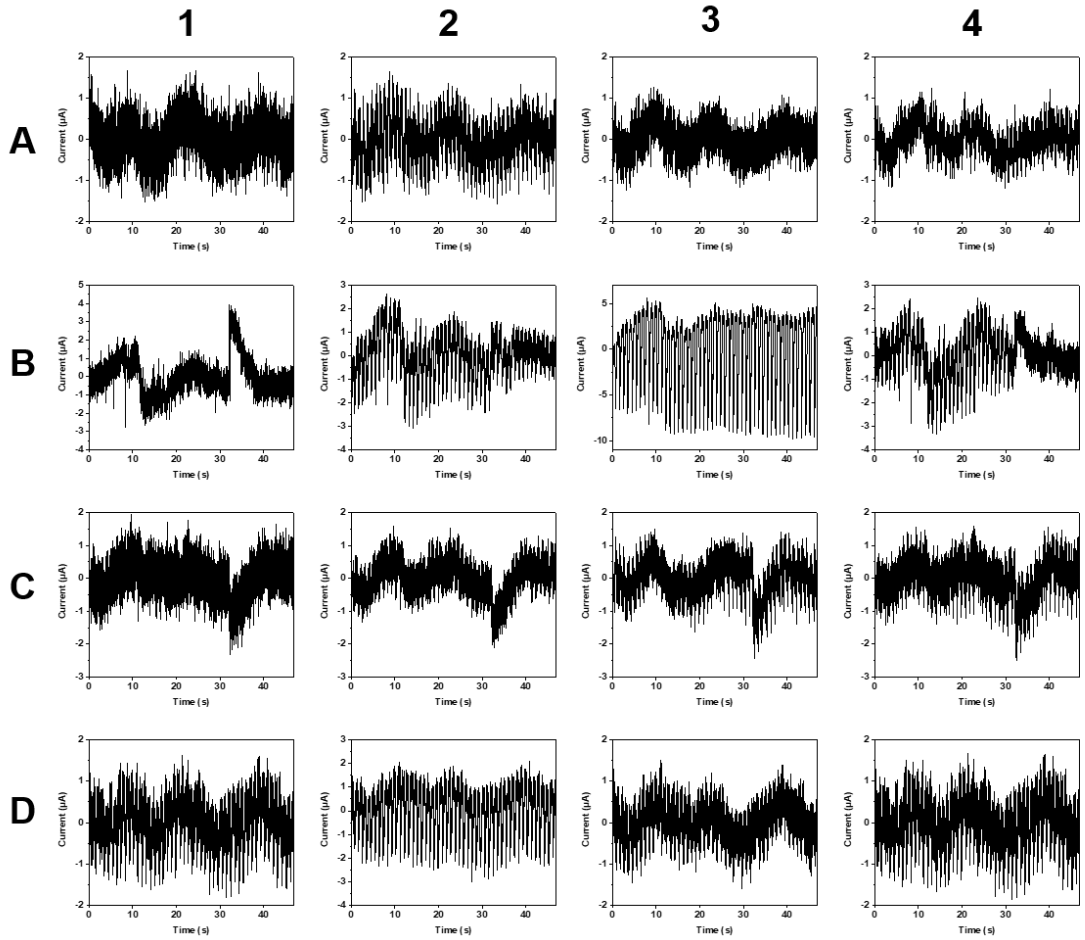

Fig. S10. Action potential mapping recorded by a 4×4 OECT matrix. Data used in figure 5 are displayed with a longer time window. Most of sensors such as (B-3) continuously recorded peaks, but some sensors such as (B-2) and (B-4) recorded smaller signal or failed recording after 30 seconds.

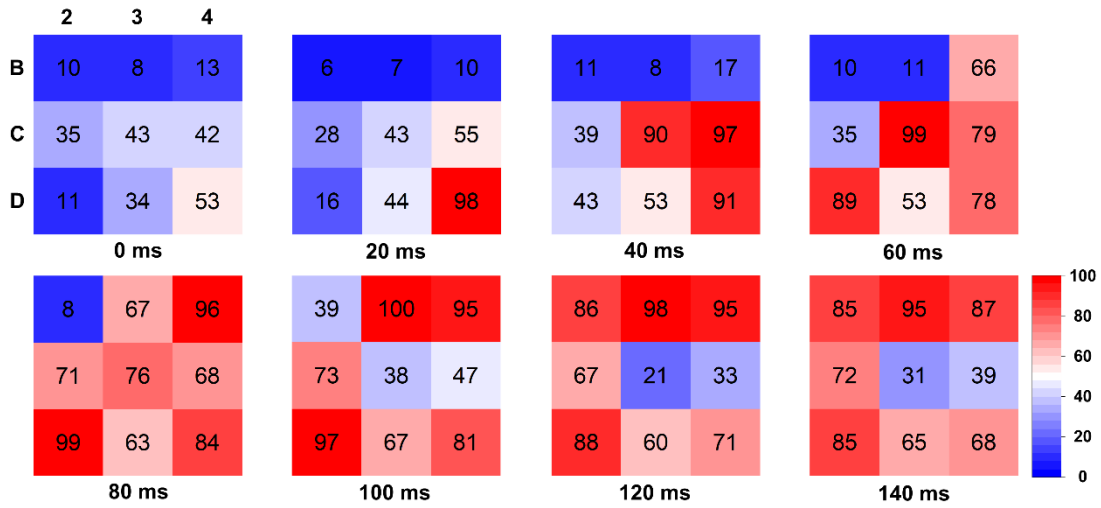

Fig. S11. Heat map showing the propagation of cardiac potential recorded by 4 × 4 OECT matrix. Recorded potentials are standardized to 0 - 100 scale: the minimum and maximum value recorded in the pixel corresponds to 0 and 100, respectively. 0 ms in the figure corresponds to 0.86 s in Fig. 5C. Scan line A and data line 1 was omitted because most of cell did not catch any signal.

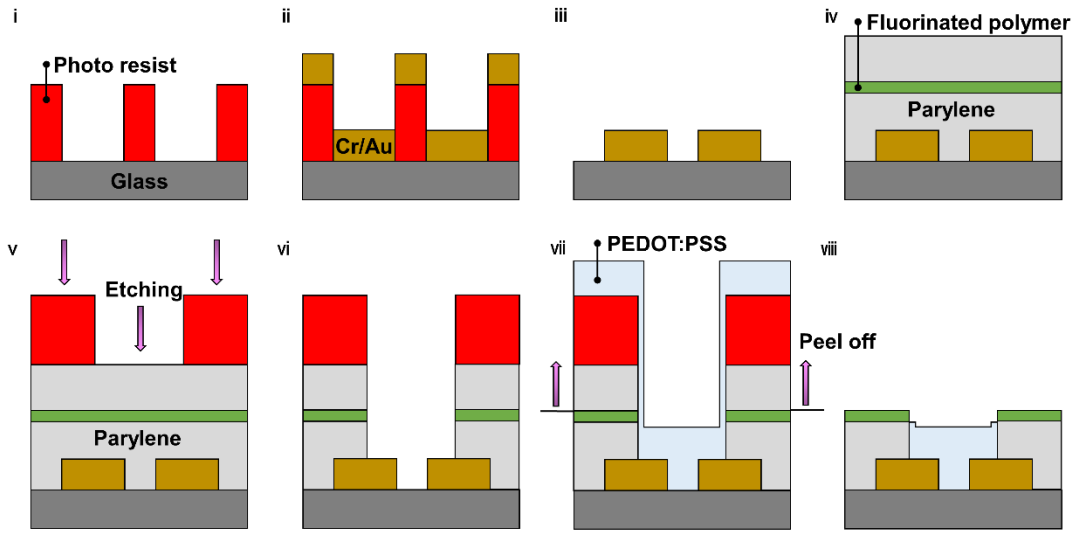

Fig. S12. Schematic illustration of the fabrication process for a single OECT. Au electrode was patterned by a liftoff process (i-iii), and the entire surface was covered with a double parylene layer sandwiching a fluorinated polymer (iv). Then, the PEDOT:PSS channel was patterned by a physical peel-off of the sacrificial second parylene layer (v-viii).

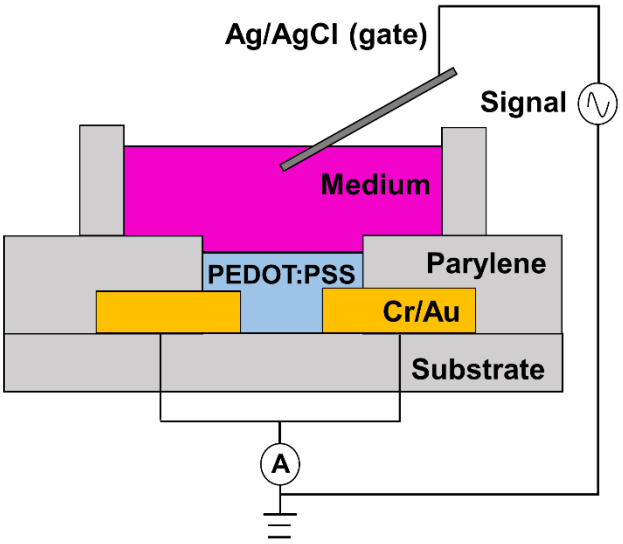

Fig. S13. PEDOT:PSS electrode configured by shorting the drain and source electrode of an OECT.

Table S1. Interval of action potential peaks before and after the pulse input.

	Width, Length (μm)	Overlap (μm)	Interval (s) (Before)	Interval (s) (After)
Sample 1	100	20	1.17	1.18
Sample 2	200	20	1.19	1.19
Sample 3	400	20	1.26	1.24
Sample 4	800	20	1.18	1.18
Sample 5	100	100	1.14	1.14
Sample 6	200	100	1.12	1.16
Sample 7	400	100	1.19	1.16
Sample 8	800	100	1.14	1.18

Table S2. Comparison between this work and the exiting microelectrode arrays for intracellular recordings. Please note that it is difficult to make an exact comparison although they are summarized here. For example, one research used HL-1 cells and another used hiPSC-derived cardiomyocytes. Also, to calculate the success rate of intracellular access, one research considered all pixels, another ignored pixels which is not covered by cells, and another counted the number of wells containing multiple sensors instead of the number of pixels.

	Surface structure	Voltage for stimulation	Other input for stimulation	Success rate of Intracellular access	Local amplifier	Matrix	Fabrication platform
H. Hayes, *et al.*, 2019. [26]	Planar	± 1 V	-	>90 % of 42 wells	-	No	Commercial device (Axion BioSystems, Inc.)
B. Desbiolles, *et al.*, 2019. [24]	3D nanovolcano	-	-	6 out of 21 pixels	-	No	Low temperature process (<135 ℃) featuring ion beam etching
J. Abbott, *et al.*, 2017. [23]	3D nanopillar array	± 1.2 V	-	>30 % (1024 pixels)	CMOS	Yes	Fabricated on CMOS manufactured by Taiwan Semiconductor Manufacturing Company
M. Dipalo, et al., 2018. [33]	Planar (Porous Pt)	-	Laser sweep	>3500 out of 4096 pixels	CMOS	Yes	Fabricated on commercial CMOS (3Brain AG)
This work	Planar (PEDOT:PSS)	0.6 V	-	6 out of 16 pixels	OECT	Yes	Low temperature process (<140 ℃)