Supporting Information

Strategies for Interface Issues and Challenges of Neural Electrodes

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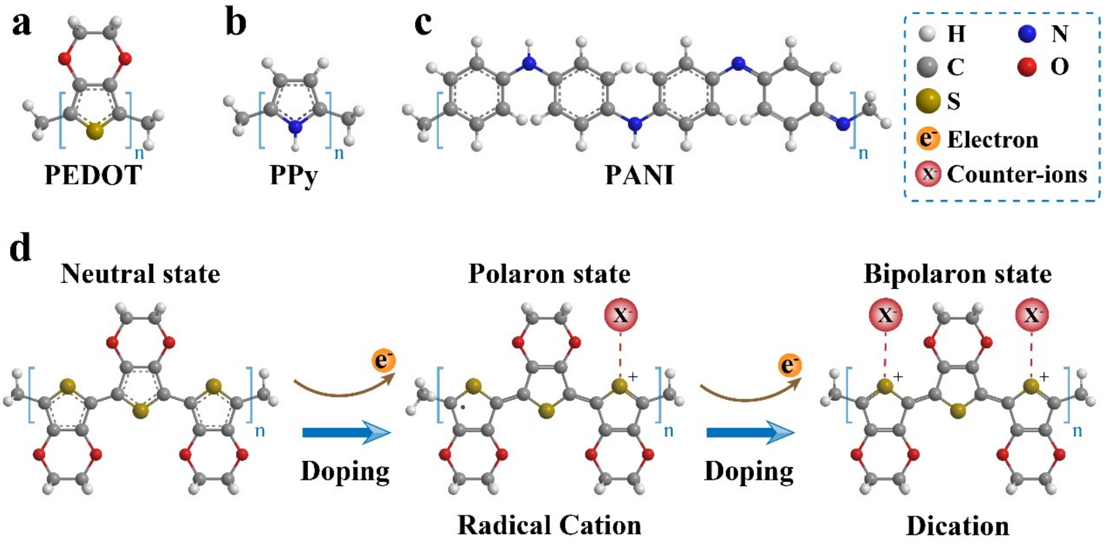

Fig. S1. Schematic representation of common conductive polymers (a) PEDOT, (b) PPy, and (c) PANI, diagram of (d) polymer conductivity mechanism (PEDOT as an example).

The electron conductivity of conductive polymers is derived from the delocalization of π bond electrons on the conjugated backbone structure. The ionic dopant (e.g., PSS in PEDOT:PSS, and tosylate (Tos) in PEDOT:Tos)[1, 2] can make the conductive polymer generate free radicals to form a polaron when paired with the dopant, and then be further oxidized to a bipolaron. Thereby generating additional electrons or holes to enhance the conductivity of the polymer.

Table S1. The parameters for evaluating the electrochemical performance of neural electrodes.

Parameters	Evaluation standard	Refs
Charge storage capacity (CSC)	Higher CSC can transfer more charges, and thus the greater the signal strength of the stimulation.	[3, 4]
Impedance	Lower impedance can decrease thermal noise, which makes electrophysiological signal monitoring more detailed.	[5, 6]
Charge injection limit (CIL)	Higher CIL can facilitate a large amount of charge transfer, which improves the ability of the electrode to stimulate neurons.	[7, 8]

Table S2. the charge transfer mechanism, material, and evaluation parameters of neural electrodes.

Charge transport mechanism	**Materials**	**Classification of electrodes**	**Evaluation parameters**
Electrons	Metal electrode	Nanometal electrode	Impedance, charge injection limit (CIL), charge storage capacity (CSC), biocompatibility, mechanical, high density
		Composite metal electrode	
	Carbon-based flexible electrode	Graphene electrode	
		Carbon nanotube electrode	
Ions	Hydrogels	Ion conductive hydrogel	
		Ion-conducting organohydrogel	
Electrons and ions	Conductive polymers	Polypyrrole	
		Poly (3, 4-ethylenedioxythiophene) and its derivatives	
	Composite material	Conductive polymers and composites	
		Hydrogel and composites	

Table S3. Comparison of electrochemical parameters and preparation methods of neural electrodes.

Material	**Method**	**Impedance at 1 kHz (KΩ)**	**CSC[a] (mC/cm^2)**	**CIL[b] (mC/cm^2)**	**Refs**
Pt-nanograss	Chemical deposition	99.52	–	0.3	9
Pt/EGaIn[c]	Screen printing	250 ± 40	-	-	10
Nanoporous Pt	Electrodeposition	2.4	□≈1.2	3	11
Au nanoparticles	LOR[d] and sputtering deposition	0.6	-	-	12
GF[e]-PC[f]-20	Wet spinning and coating	51.47 ± 44	798 ± 110	8.9 ± 1.3	5
Graphene	Laser pyrolysis and chemically doped	0.52	-	3.1	13
CNT array	Chemical vapor deposition	3	–	1–1.6	14
CNT fiber	Wet-spinning	14.09 ± 0.3	372	6.52	15
PEDOT–CNT Microelectrodes	Electropolymerization	15.51 ± 1.19	-	1.21 ± 0.02	16
PEDOT-CNT nanotunnel	Electrospinning and electrodeposition	2.6 ± 0.4	26.3 ± 2.4	-	17
PEDOT/CNT	Electrodeposition	15	6	1.25	18
PEDOT/PSS	Deposition	4	123	2.92	19
PPy/SWCNTs	Electrodeposition	2.06	1244	7.5	20
PPy/PSS	Electrodeposition	2.2	705	5	20
PPy/Cl	Electrodeposition	2.82	495	3.2	20
SF[g] organohydrogel	UV irradiation	>0.04 at 0.1-100 kHz	-	-	21
GelMA[h]/PEDOT: PSS	UV irradiation	261 at 1Hz	-	-	22
Alg-PAAm[i]	UV irradiation and deposition	25 at 1 Hz	-	-	23

[a] charge storage capacity, [b] charge injection limit, [c]eutectic gallium–indium, [d] bi-layer lift-off resist, [e] graphene-fiber, [f] parylene-C, [g] silk fibroin, [h]gelatin methacryloyl, [i]alginate-polyacrylamide

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