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Data Article

Data on enhanced wireless cell stimulation using soft and improved bipolar electroactive conducting polymer templates

Chunyan Qin[a], Zhilian Yue[a], Xu-Feng Huang[b], Robert J. Forster[c], Gordon G. Wallace[a,*], Jun Chen[a,*]

[a] *ARC Centre of Excellence for Electromaterials Science, Intelligent Polymer Research Institute[1,2], Australian Institute for Innovative Materials, Innovation Campus, University of Wollongong, Squires Way, North Wollongong, NSW 2519, Australia*

[b] *Illawarra Health and Medical Research Institute[3], School of Medicine, University of Wollongong, Wollongong, NSW 2522, Australia*

[c] *National Centre for Sensor Research, School of Chemical Sciences, Dublin City University[4], Dublin 9, Ireland*

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ABSTRACT

Data in this article is associated with our research article "Enhanced wireless cell stimulation using soft and improved bipolar electroactive conducting polymer templates" Qin et al. (2022). Primarily, the present article shows the data of PPy-PMAS/FTO, PPy-PMAS-collagen/FTO and PPy-PMAS-DS-collagen/FTO in conventional electrochemical process and bipolar electrochemical process along with *in situ* spectrometry for comprehensive supplement and comparison to help with better developing modified conducting polymers based bipolar electrochemistry. Secondly, the presented the complete dataset useful for modelling the soft and improved bipolar electroactive conducting polymers focusing on wireless cell (animal and human) stimulation, which are reported

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* Corresponding authors.
E-mail addresses: gwallace@uow.edu.au (G.G. Wallace), junc@uow.edu.au (J. Chen).
Social media: @GordonGWallace (G.G. Wallace)
[1] @IPRI_UOW
[2] @ARC_ACES
[3] @ihmri
[4] @DCU

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in the main article. All data reported were analysed using Origin 2019b 64Bit.

Specifications Table

Subject	Chemistry
Specific subject area	Bipolar Electrochemistry for Wireless Cell Stimulation
Type of data	Graph Figure Video
How data were acquired	CHI-720 Electrochemical Analyzer system Shimadzu UV-vis 3600 HR800 Raman spectrometer IRpretige-21, Shimadzu Scanning electron microscopy (JEOL JSM-7500FA) ZEISS Axiovert microscope (Carl Zeiss, Germany) ZEISS AxioImager microscope (Carl Zeiss, Germany) EZ-S mechanical tester (Shimadzu, Japan)
Data format	Raw Analysed
Parameters for data collection	All experiments for conducting polymers characterizations were carried out in PBS (pH=7.4) environment. The compression testing speed and the tensile testing speed were 200 mm min^{-1} and 1 mm min^{-1}, respectively. PC 12 cells were seeded and cultured in DMEM growth media supplemented with 2 mM glutamine, 5% (v/v) FBS and 10% (v/v) horse serum in a humidified 37 °C incubator with 5% CO_2 atmosphere before further use. For differentiation, a low serum medium (1% horse serum) supplemented with 50 ng/ml NGF was used.
Description of data collection	Primary data (i.e. raw materials, operating data) were collected via operational software with the instruments/manufacturers introductions. Data was processed using Origin 2019b 64Bit, for purposes of data analysis and diagram presentation.
Data source location	Institute: Intelligent Polymer Research Institute/University of Wollongong City/Town/Region: North Wollongong Country: Australia
Data accessibility	With the article and in Mendeley Data http://dx.doi.org/10.17632/j8cxgm5d9k.
Related research article	[1] C. Qin, Z. Yue, X.F. Huang, R.J. Forster, G.G. Wallace, J. Chen, Enhanced wireless cell stimulation using soft and improved bipolar electroactive conducting polymer templates, Appl. Mater. Today. 27 (2022) 101481. 10.1016/j.apmt.2022.101481.

Value of the Data

- The presented data constitute the complete dataset useful for modelling the soft and improved bipolar electroactive conducting polymers focusing on wireless cell stimulation from rat cell line to human cell line point of view.
- The data could be used by researchers as starting point when studying or developing similar improved conducting polymers based bipolar electrochemistry.
- The data can support similar analysis, considering both conventional three-electrode system and bipolar electrochemical system work with *in situ* spectrometry in biological environment (PBS buffer) first, further insights could consider about applications in wireless cell stimulation as we proved.

- All findings have been adopted to support the soft and improved bipolar electroactive conducting polymers based bipolar electrochemistry involved investigations. These studies related to wireless animal cell stimulation transferred to wireless human cell stimulation, which advances the field of biomedical stimulation and other biological systems like control-release system.

1. Data Description

The data presented in this article are related to the research article, "Enhanced wireless cell stimulation using soft and improved bipolar electroactive conducting polymer templates" [1]. The cyclic voltammograms data of synthesizing the PPy-PMAS/FTO, PPy-PMAS-collagen/FTO and PPy-PMAS-DS-collagen/FTO materials are presented in Fig. 1. The redox active molecule, poly(2-methoxyaniline-5-sulfonic acid) (PMAS) is introduced as large size dopant for polypyrrole (PPy) matrix, dextran sulfate sodium salt from Leuconostoc spp. (DS) and collagen (Type I from rat tail) are used as co-dopants here. UV-vis spectra in Fig. 2 and fluorescence labelling in Fig. 3 were utilised to identify successful dopants incorporation within PPy matrixes. Comparative CVs and electrochemical impedance spectroscopy (EIS) of these three PMAS doped PPy films and typical PPy-*p*TS/FTO film in PBS are shown in Fig. 4. Fig. 5 shows the improved bipolar

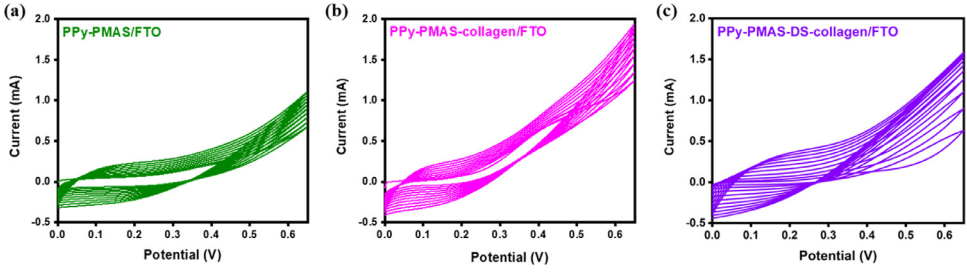


Fig. 1. Electrodeposition of PMAS modified PPy matrixes. Cyclic voltammograms of (a) PPy-PMAS, (b) PPy-PMAS-collagen and (c) PPy-PMAS-DS-collagen films grown onto FTO glass obtained during their synthetic process. Aqueous solution contained 0.2 M Py with dopants like 2 mg/ml PMAS, 2 mg/ml DS, 2 µg/ml collagen respectively. Potentials were recorded vs. a Ag/AgCl reference electrode under scan range of 0 - 0.65 V at a scan rate of 20 mV/s (10 cycles).

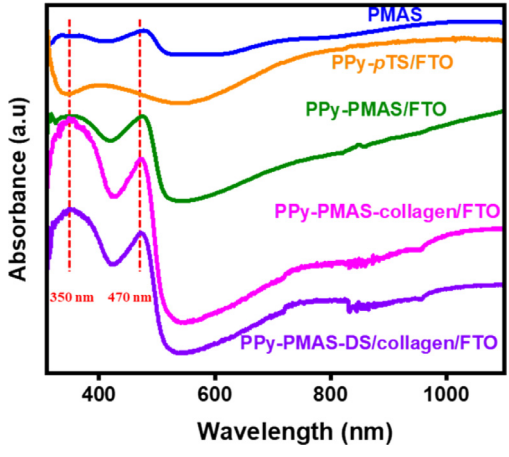


Fig. 2. UV-vis spectra to identify successful PMAS incorporation within PPy matrixes. UV-vis spectra were acquired within the wavelength range of 300–1100 nm.

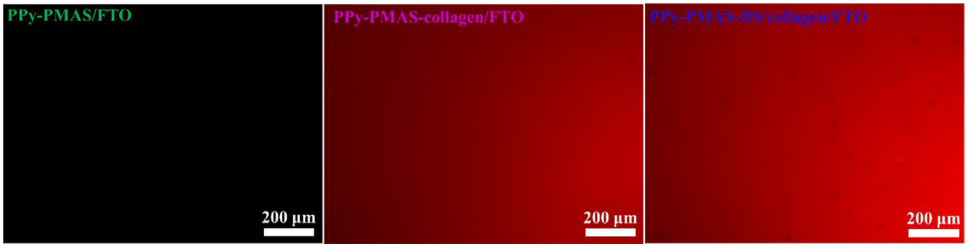


Fig. 3. Fluorescent labelling to identify successful collagen incorporation within PPy matrixes. Images of PPy-PMAS/FTO, PPy-PMAS-collagen/FTO and PPy-PMAS-DS-collagen/FTO after using the same fluorescent labelling method from our previous work [3]. Scale bar: 200 μm.

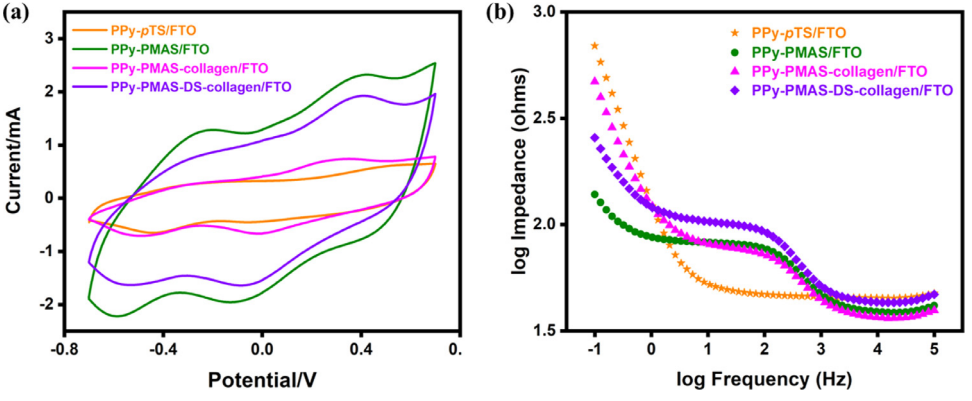


Fig. 4. Increased electroconductivity of PPy matrixes due to PMAS dopant. (a) Cyclic voltammetry (CV) and (b) Electrochemical impedance spectroscopy (EIS) to identify the electrochemical activity of synthesized PMAS incorporated PPy matrixes in PBS (pH = 7.4). CV of PPy-PMAS-DS-collagen/FTO, PPy-PMAS-collagen/FTO, PPy-PMAS/FTO and PPy-*p*TS/FTO at a scan rate of 100 mV/s. EIS of them over a frequency range of 0.1 Hz-10^5 Hz.

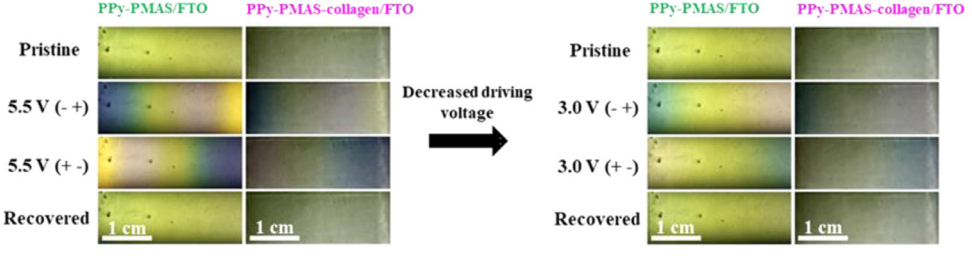


Fig. 5. Improved bipolar electrochemical activity due to PMAS incorporation. Optical images of PPy-PMAS/FTO and PPy-PMAS-collagen/FTO films in our previous developed bipolar electrochemical setting up under driving voltage of 5.5 V (left) and 3.0 V (right). Scale bar:1 cm.

electrochemical activity of PPy-PMAS/FTO and PPy-PMAS-collagen/FTO films in our previous developed bipolar electrochemical set-up. The schematic diagram of the devices for bipolar electrochemistry with *in situ* UV is illustrated in Fig. 6. All spectro-electrochemical data (*in situ* UV spectrometry with bipolar electrochemical system in Fig. 7, *in situ* UV-vis with conventional electrochemical system in Fig. 8, *ex situ* UV spectrometry and FTIR spectrometry data before and after underwent bipolar electrochemical process in Fig. 10) were obtained and analysed to identify the bipolar electrochemical activation [2,3]. Fig. 9 displays the morphologies of these three PMAS doped PPy films before and after underwent bipolar electrochemical pro-

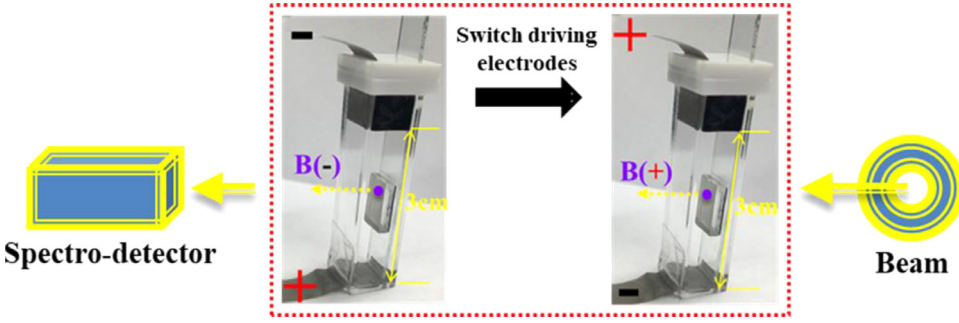


Fig. 6. ***In situ*** **UV-vis absorption spectra combined with bipolar electrochemical system.** Digital image is the home-made bipolar - UV cell.

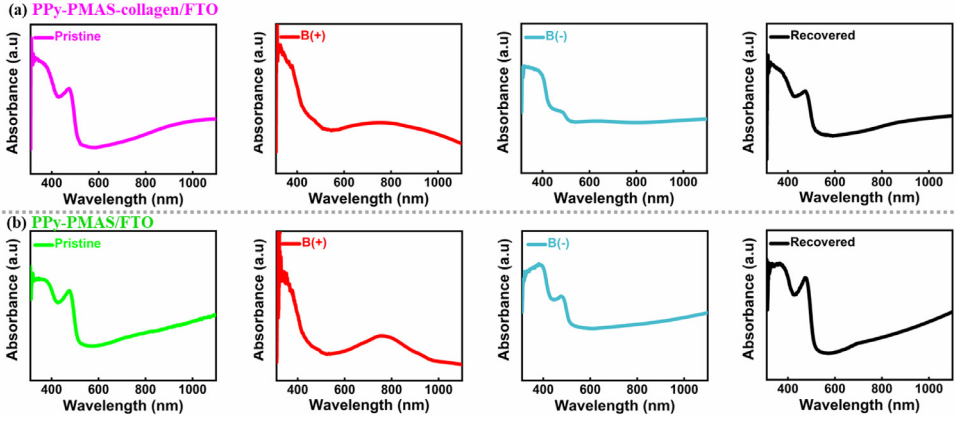


Fig. 7. *In situ* UV spectra of (a) PPy-PMAS-collagen/FTO and (b) PPy-PMAS/FTO under driving voltage of 5.5 V were acquired within the wavelength range of 300–1100 nm in PBS using home-made bipolar - UV cell (set-up shown in Fig. 6).

cess. The optimal BPES protocol is utilized for studies of PC 12 cell proliferation and differentiation. Date of biocompatibility in Fig. 11, cell viability in Fig. 12, cell proliferation in Figs. 13 and 14 and cell differentiation in Figs. 15–17 are reported. The unit of total cell numbers in Fig. 14 was described as cells per square centimetre. Fig. 18 describes the synthetic procedure for PMAS doped PPy powders. The corresponding data on SEM in Fig. 19 and Raman, FTIR in Fig. 20 are comprehensive supplement for physical analysis of PMAS doped PPy powders, while the SEM data in Fig. 21, Raman, FTIR in Fig. 22 and resistance (ohm/cm) data of PEDOT-PSS, PPy-PMAS/PEDOT-PSS, PPy-PMAS-collagen/PEDOT-PSS and PPy-PMAS-DS-collagen/PEDOT-PSS in Fig. 23 are supplementary analysis for soft bipolar electrodes. Figs. 24 and 25 display the PPy-PMAS-collagen/PEDOT-PSS film during mechanical tests. The cytocompatibility of soft bipolar electrodes is shown in Fig. 26. The according PC 12 cell proliferation data (Figs. 27–29) and PC 12 cell differentiation data (Figs. 30–32) can also be available. All relevant raw data are available in Mendeley Data: http://dx.doi.org/10.17632/j8cxgm5d9k[4].

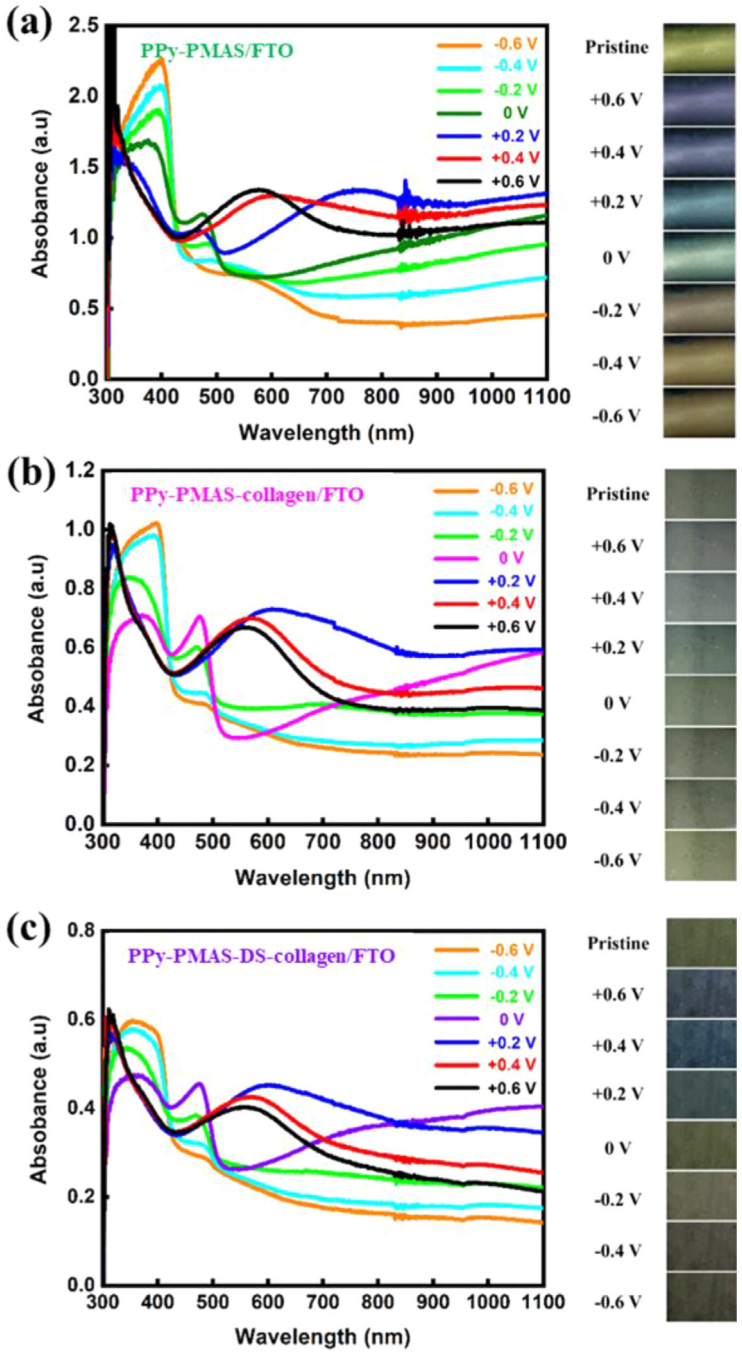


Fig. 8. ***In situ*** **UV-vis absorption spectra combined with the conventional three-electrode electrochemical system.** *In situ* UV-visible absorption spectra in the range of 300 - 1100 nm and according colours of (a) PPy-PMAS/FTO, (b) PPy-PMAS-collagen/FTO and (c) PPy-PMAS-DS-collagen/FTO obtained after applied consecutive potentials from -0.6 V to +0.6 V. All potentials are vs. a Ag wire reference electrode and keep 30 s poise time in PBS (pH = 7.4).

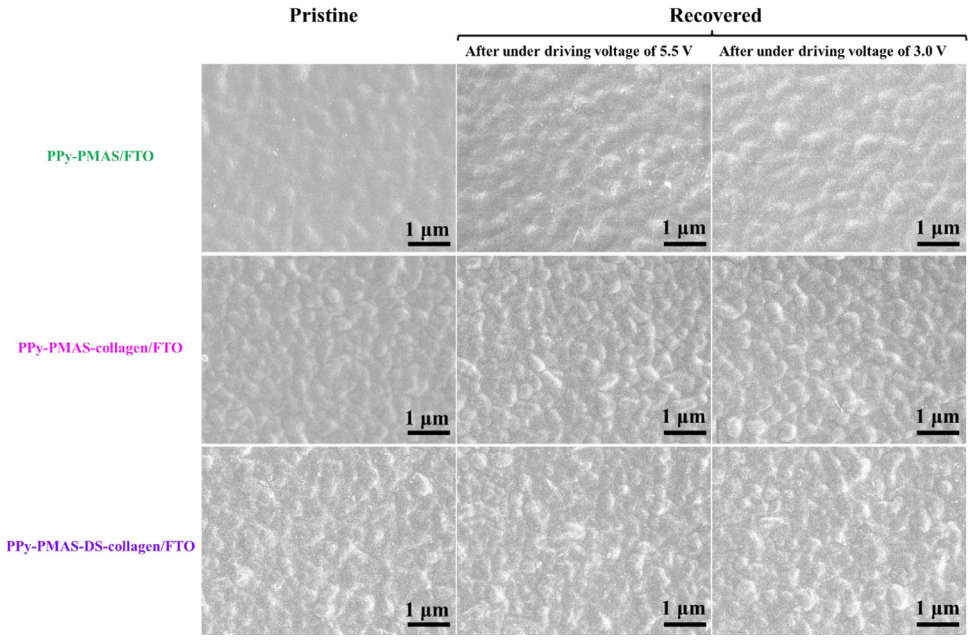


Fig. 9. Scanning electron microscopy (SEM) images of synthesized PPy-PMAS/FTO, PPy-PMAS-collagen/FTO and PPy-PMAS-DS-collagen/FTO before (pristine) and after (recovered) bipolar testing. All samples were tested in PBS under 5.5 V or 3.0 V driving voltage, and then taken out from electrolyte solution, subsequently rinsed with Milli-Q water and allowed to dry before performing SEM characterizations. Scale bar:1 μm.

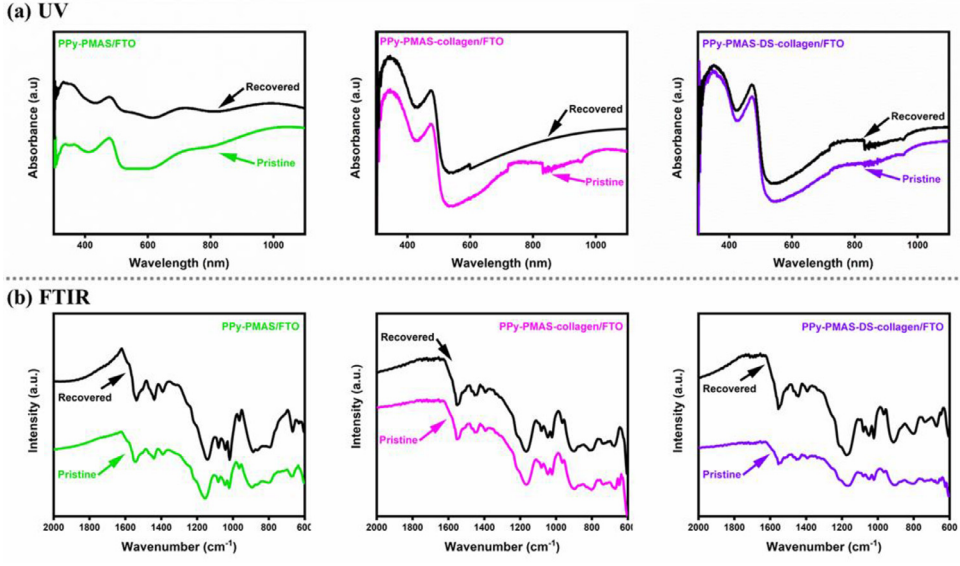


Fig. 10. Characterizations of synthesized PPy-PMAS/FTO, PPy-PMAS-collagen/FTO and PPy-PMAS-DS-collagen/FTO before (pristine) and after (recovered) bipolar testing. (a) UV and (b) FTIR spectrometry were performed under identical bipolar testing. All samples were tested in PBS under 5.5 V driving voltage, and then taken out from electrolyte solution, subsequently rinsed with Milli-Q water and allowed to dry before all *ex situ* spectra characterizations.

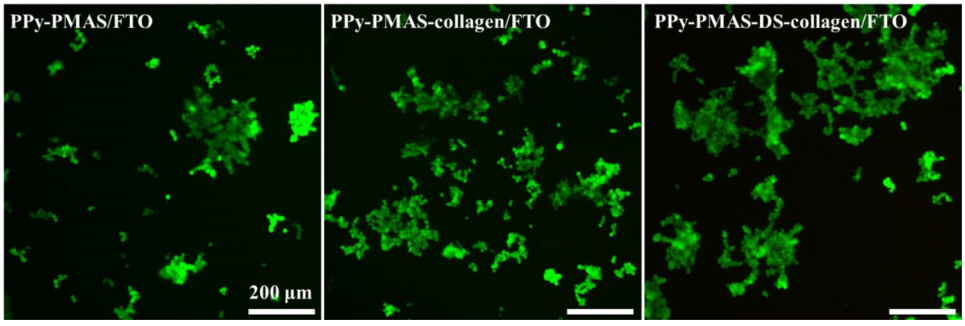


Fig. 11. Good biocompatibility of PMAS modified PPy matrixes as cell supportive substrates. Images of PC 12 cells on day 7 after cyto-compatibility assessment via live/dead assay. Calcein-AM (green) present live cells and PI (red) were on behalf of dead cells. Cells were cultured on all substrates in growth media over one week at initial cell seeding density of 6000 cells/cm^2 without BPES. Scale bar: 200 μm.

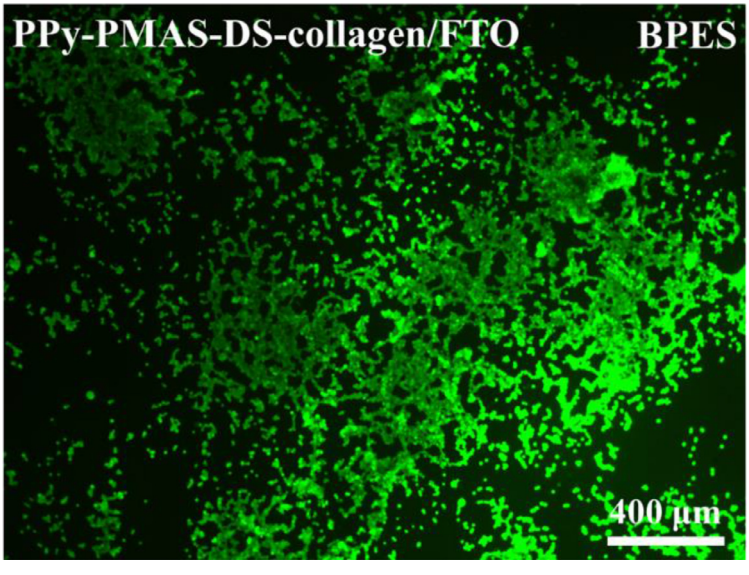


Fig. 12. High cell viability with BPES. Images of PC 12 cells on day 7 after BPES treatment via live/dead assay. Calcein-AM (green) present live cells and PI (red) were on behalf of dead cells. PC 12 cells were cultured on PPy-PMAS-DS-collagen/FTO an initial seeding density of 20,000 cells/cm^2 in growth media over total one week. BPES: Cells were stimulated on day 2 for 8 h per day in continuous three days, then standard cultured in the following three days after stimulation finished. Scale bar: 400 μm.

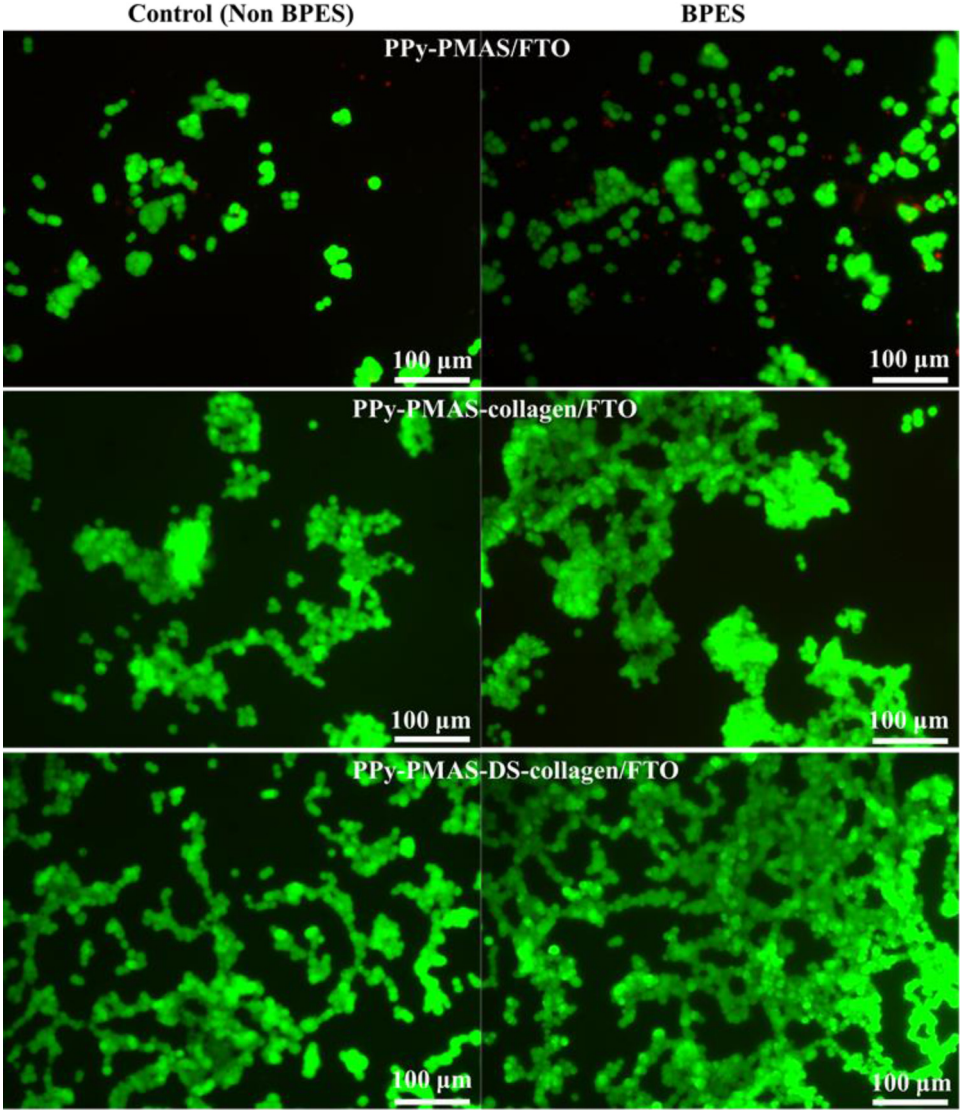
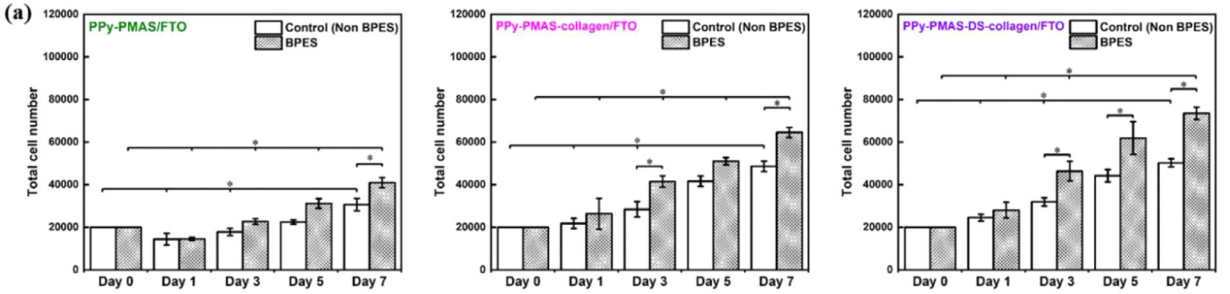


Fig. 13. Enhanced cell proliferation due to improved bipolar electroactivity of PPy matrixes with PMAS modification. Images of PC 12 cells on day 7 via calcein AM and PI staining. PC 12 cells were cultured on PMAS modified PPy matrixes at an initial seeding density of 20000 cells/cm^2 in growth media over total one week. BPES: Cells were stimulated on day 2 for 8 h per day in continuous three days, then standard cultured in the following three days after stimulation finished. Control (Non BPES): cells were standard cultured with no BPES. Scale bar: 100 μm.



(b)

Time Point	PPy-PMAS/FTO		PPy-PMAS-collagen/FTO		PPy-PMAS-DS-collagen/FTO	
	Total Cell Numbers (cells/cm²)		Total Cell Numbers (cells/cm²)		Total Cell Numbers (cells/cm²)	
	Control (Non BPES)	BPES	Control (Non BPES)	BPES	Control (Non BPES)	BPES
Day 0	20000	20000	20000	20000	20000	20000
Day 1	14445.0 ± 2709.3	14595.5 ± 822.1	21849.0 ± 2355.4	26399.0 ± 7259.8	24521.5 ± 1618.9	28112.2 ± 3720.3
Day 3	17830.5 ± 1685.9	22768.6 ± 1261.7	28450.8 ± 3656.5	41500.4 ± 2621.3	31933.8 ± 1971.3	46424.7 ± 4549.1
Day 5	22495.0 ± 998.1	31187.9 ± 2236.5	41674.8 ± 2434.0	51015.7 ± 1689.0	44239.6 ± 2948.5	61885.2 ± 7734.4
Day 7	30661.3 ± 2906.8	40975.1 ± 2434.4	48651.0 ± 2443.7	64568.0 ± 2317.8	50266.8 ± 1903.1	73544.7 ± 2859.2

Fig. 14. Enhanced cell proliferation due to improved bipolar electroactivity of PPy matrixes with PMAS modification. (a, b) Numbers of PC 12 cells calculated via PicoGreen assay at various time points with statistical analysis using two-way ANOVA. PC 12 cells were cultured on PMAS modified PPy matrixes at an initial seeding density of 20000 cells/cm^2 in growth media over total one week. BPES: Cells were stimulated on day 2 for 8 h per day in continuous three days, then standard cultured in the following three days after stimulation finished. Control (Non BPES): cells were standard cultured with no BPES. Data are represented as mean ± standard deviation (SD) and "*" ($P < 0.0001$) was used to indicate significance.

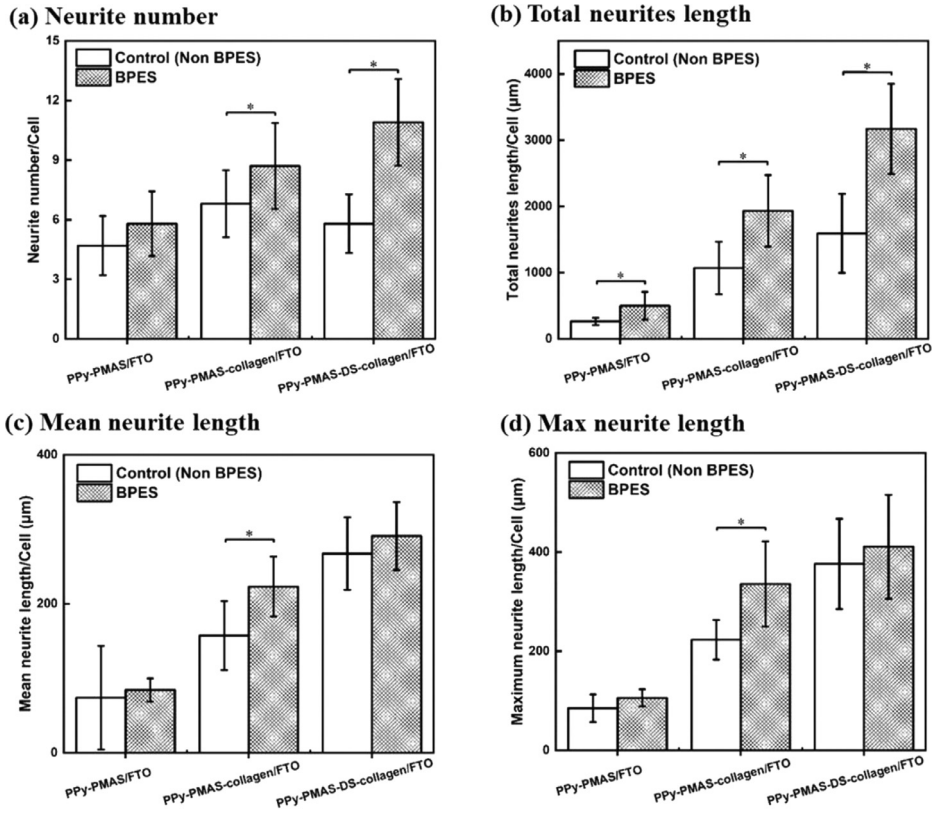


Fig. 15. Enhanced cell differentiation due to improved bipolar electroactivity of PPy matrixes with PMAS modification. Assessments of neurite number and neurite growth of cells cultured on PMAS modified PPy matrixes, including (a) the total neurite number per cell, (b) the total length of neurites per cell, (c) mean neurite length per cell, and (d) maximum neurite length per cell. Statistical analysis used one-way ANOVA. Data are represented as mean ± standard deviation (SD) and "*" ($P < 0.05$) was used to indicate significance.

Materials	Neurite number/Cell		Total neurite length/Cell (μm)		Mean neurite length/Cell (μm)		Max neurite length/Cell (μm)	
	Control (Non BPES)	BPES	Control (Non BPES)	BPES	Control (Non BPES)	BPES	Control (Non BPES)	BPES
PPy-PMAS/FTO	4.7 ± 1.5	5.8 ± 1.6	264.4 ± 56.0	501.3 ± 208.3	73.9 ± 69.5	84.4 ± 15.4	85.1 ± 27.7	105.9 ± 17.5
PPy-PMAS-collagen/FTO	6.8 ± 1.7	8.7 ± 2.2	1072.0 ± 394.8	1933.3 ± 538.9	157.5 ± 46.3	223.1 ± 40.1	223.1 ± 40.1	335.6 ± 85.9
PPy-PMAS-DS-collagen/FTO	5.8 ± 1.5	10.9 ± 2.2	1593.8 ± 596.1	3172.1 ± 680.2	267.4 ± 48.7	291.0 ± 45.6	376.1 ± 91.1	410.8 ± 104.8

Fig. 16. Enhanced cell differentiation due to improved bipolar electroactivity of PPy matrixes with PMAS modification. Assessments of neurite number and neurite growth of cells cultured on PMAS modified PPy matrix, including the sum neurite number per cell, the total length of neurites per cell, mean neurite length per cell, and maximum neurite length per cell. Data are represented as mean ± standard deviation (SD).

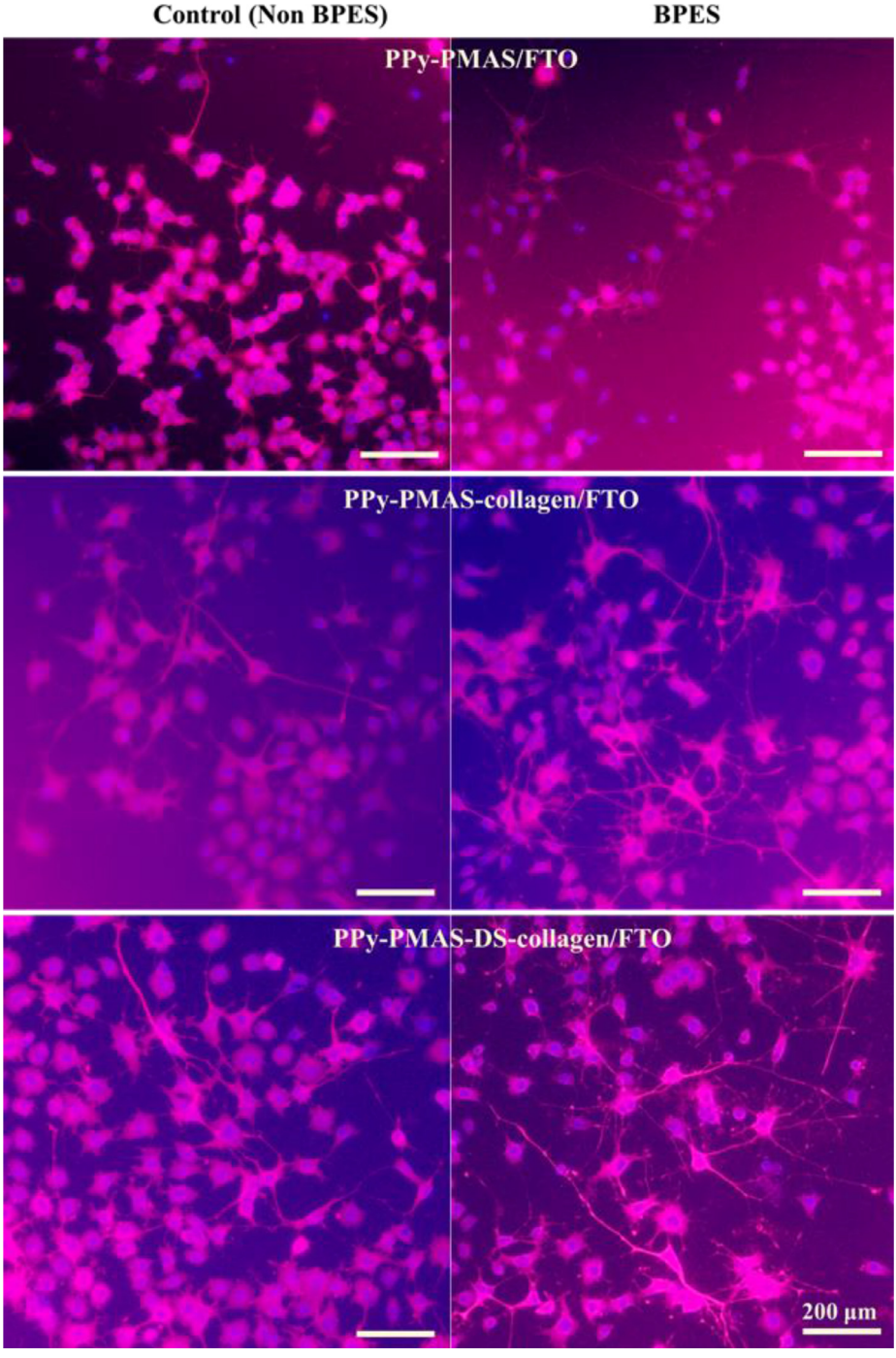


Fig. 17. Enhanced cell differentiation due to improved bipolar electroactivity of PPy matrixes with PMAS modification. Immunofluorescent images of PC 12 cells on day 7 with or without BPES treatment. Cells were cultured on PMAS modified PPy matrixes in differentiation media over one week. BPES: cells were stimulated on day 2 for 8 h per day in continuous three days, then standard cultured in the following three days after stimulation finished. Control (Non BPES): cells were standard cultured with no BPES. Scale bar: 200 μm.

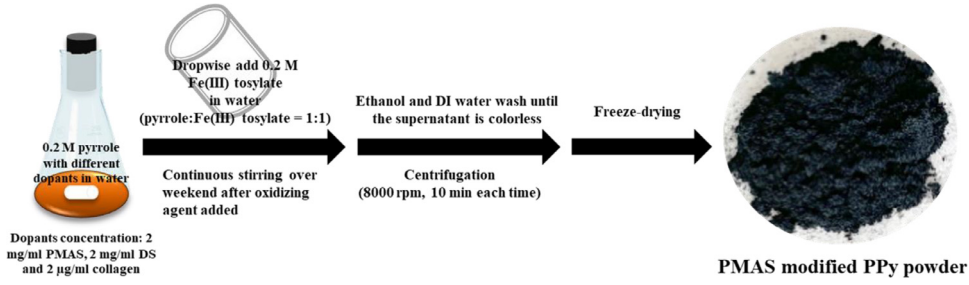


Fig. 18. Procedure of chemically synthesis to prepare PMAS modified PPy powder.

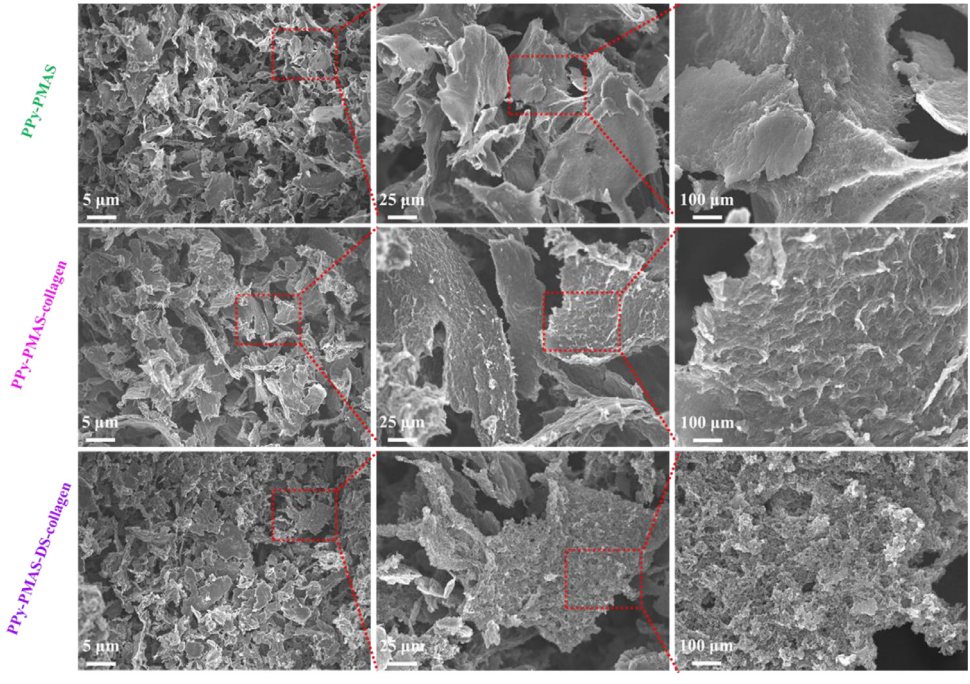


Fig. 19. SEM characterization of chemically prepared PMAS modified PPy powder.

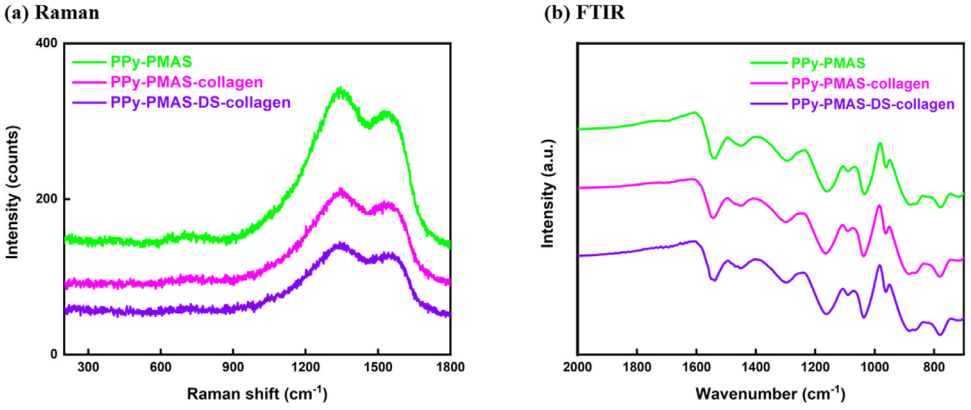


Fig. 20. (a) Raman and (b) FTIR spectra of as-synthesized PMAS modified PPy powder.

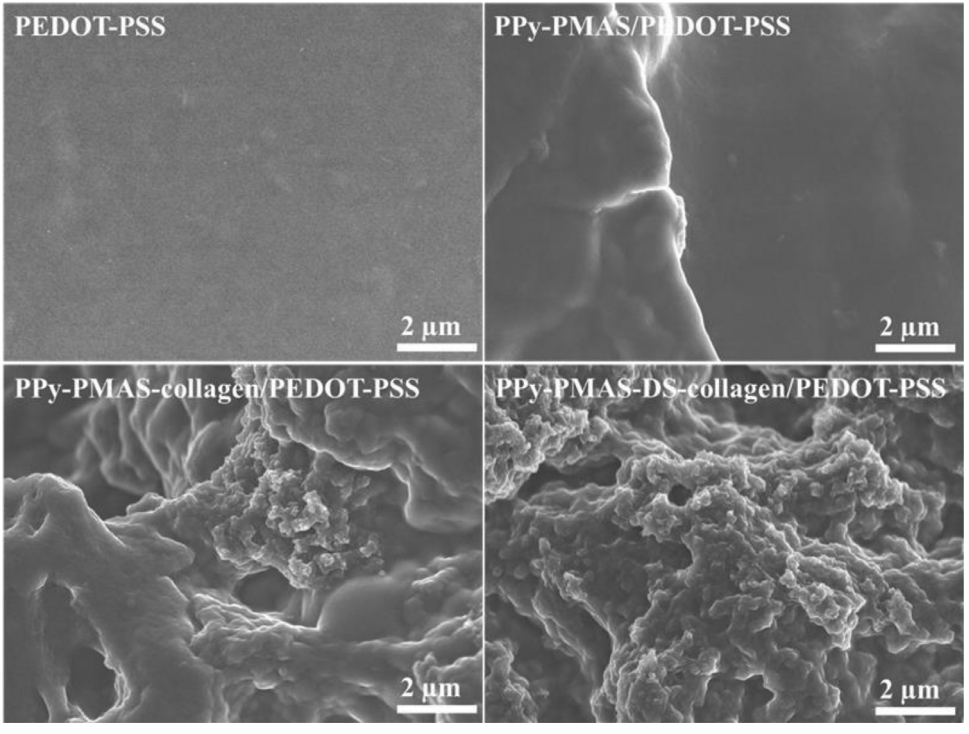


Fig. 21. SEM characterization of prepared soft bipolar electrodes.

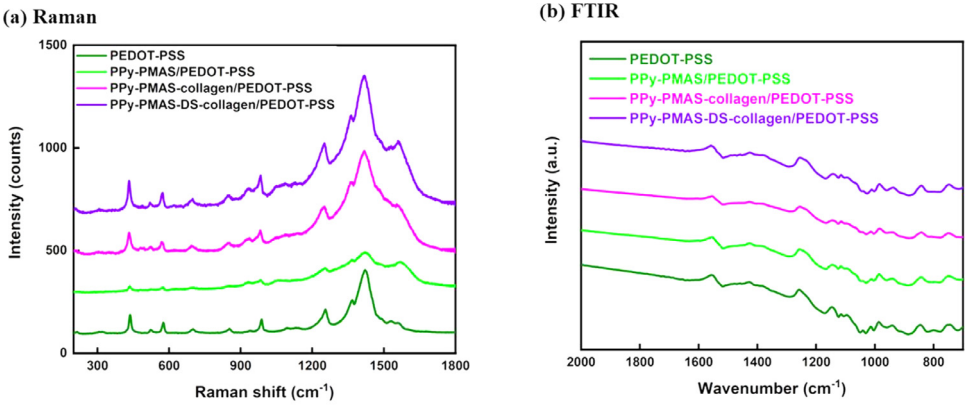


Fig. 22. (a) Raman and (b) FTIR spectra of all synthesized soft bipolar electrodes.

Soft bipolar electrodes	Resistance (ohm/cm)
PEDOT-PSS	26.4 ± 3.5
PPy-PMAS/PEDOT-PSS	23.8 ± 4.0
PPy-PMAS-collagen/PEDOT-PSS	26.0 ± 3.6
PPy-PMAS-DS-collagen/PEDOT-PSS	48.8 ± 7.4

Fig. 23. Resistance of prepared soft bipolar electrodes.

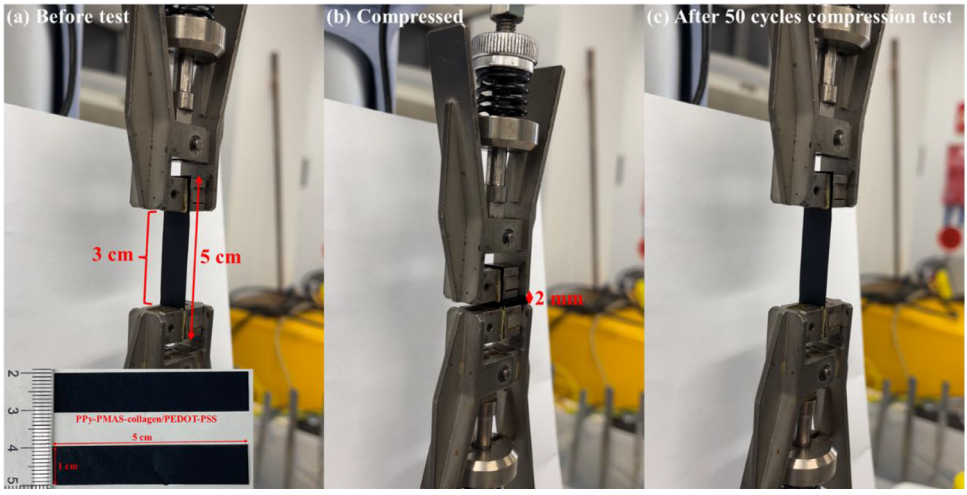


Fig. 24. Photographs of the different states of PPy-PMAS-collagen/PEDOT-PSS film during a compression cycle test. (a) Original state of the PPy-PMAS-collagen/PEDOT-PSS film before test, test film length is 3 cm, inserted image at left bottom is prepared films (5 cm × 1 cm). (b) Compressed state of the PPy-PMAS-collagen/PEDOT-PSS film during a compression test (compressed to 93.33%). (c) Ending state of the PPy-PMAS-collagen/PEDOT-PSS film after 50 cycles compression test.

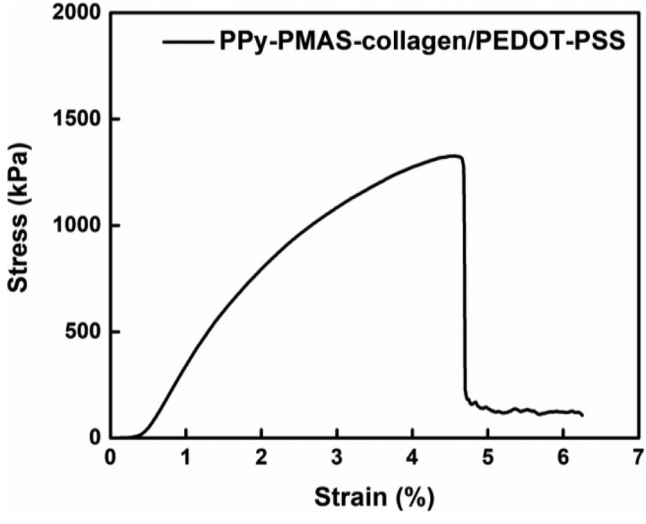


Fig. 25. Stress-strain curve of PPy-PMAS-collagen/PEDOT-PSS film during a tensile test.

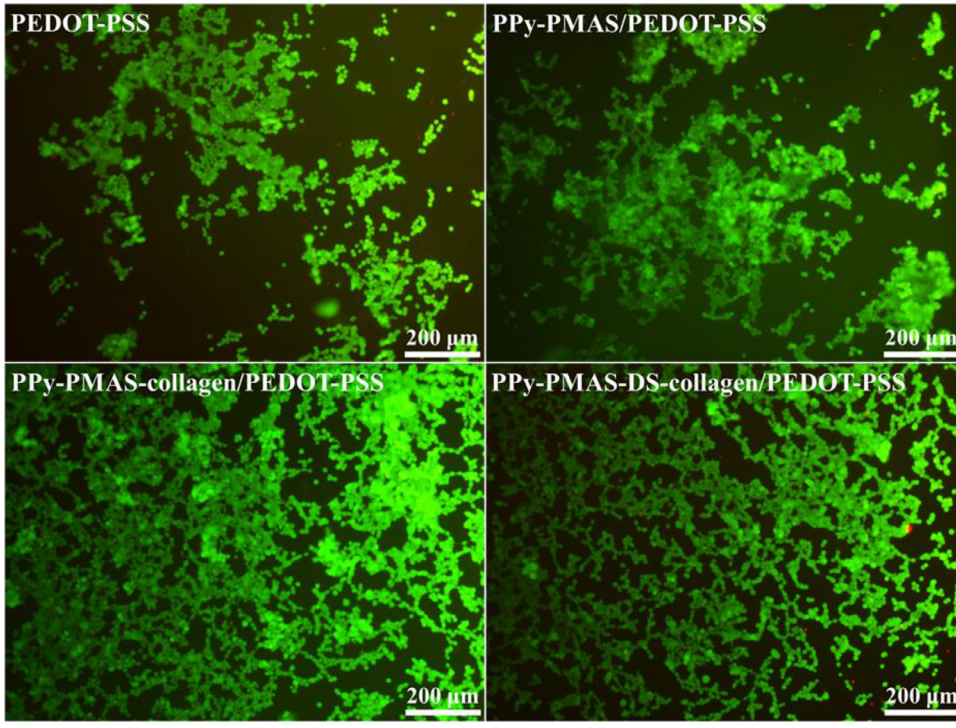


Fig. 26. Excellent biocompatibility of soft bipolar electrodes as cell supportive substrates. Images of PC 12 cells on day 7 after cyto-compatibility assessment via live/dead assay. Calcein-AM (green) present live cells and PI (red) were on behalf of dead cells. Cells were cultured on prepared soft bipolar electrodes in growth media over one week at initial cell seeding density of 6000 cells/cm^2 without BPES treatment. Scale bar: 200 μm.

PPy-PMAS-collagen/PEDOT-PSS

Time Point	Total Cell Numbers (cells/cm^2)	
	Control (Non BPES)	BPES
Day 0	20000	20000
Day 1	16559.5 ± 1153.3	35615.4 ± 266.3
Day 3	32790.1 ± 2020.8	58675.0 ± 3515.1
Day 5	74881.2 ± 3042.1	105898.9 ± 4641.0
Day 7	104000.0 ± 5470.2	136097.4 ± 4097.1

Fig. 27. Supported PC 12 cell proliferation on soft bipolar PPy-PMAS-collagen/PEDOT-PSS electrode. Numbers of PC 12 cells calculated via PicoGreen assay at various time points with statistical analysis.

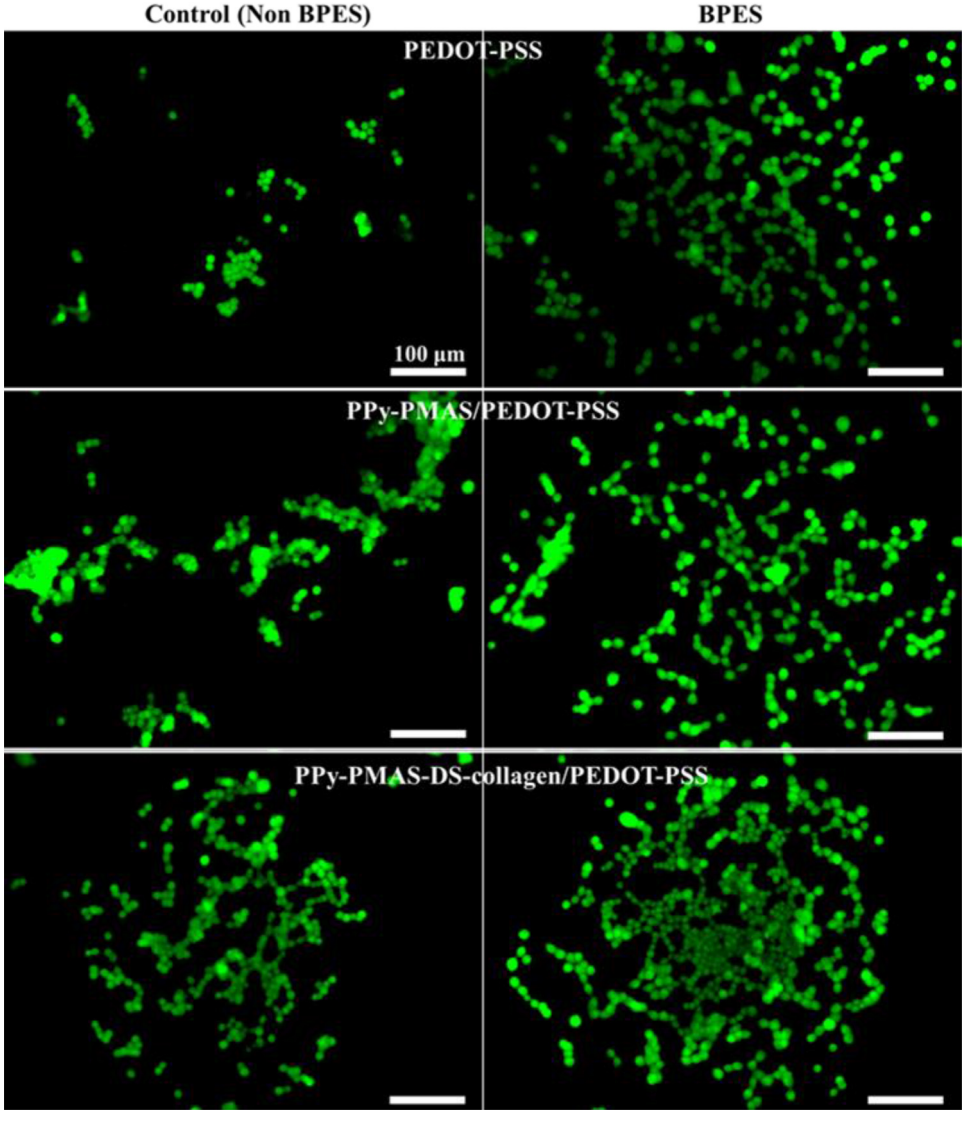
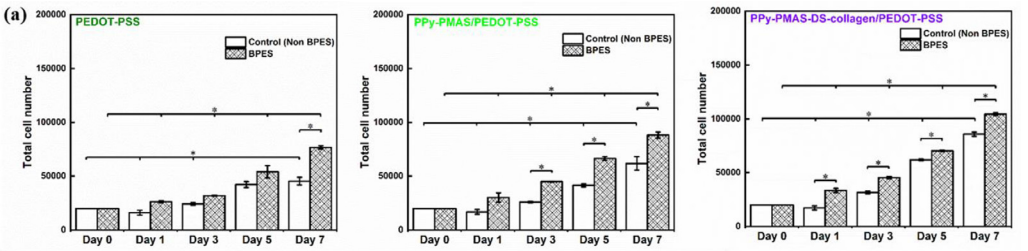


Fig. 28. Supported PC 12 cell proliferation on soft bipolar electrodes. Images on day 7 via live/dead assay using calcein AM (green: live) and PI (red: dead) staining. PC 12 cells were cultured on soft bipolar electrodes at an initial seeding density of 20000 cells/cm^2 in growth media over total one week. BPES: Cells were stimulated on day 2 for 8 h per day in continuous three days, then standard cultured in the following three days after stimulation finished. Control (Non BPES): cells were standard cultured without BPES. Scale bar: 100 μm.



(b)

Time Point	PEDOT-PSS		PPy-PMAS/PEDOT-PSS		PPy-PMAS-DS-collagen/PEDOT-PSS	
	Total Cell Numbers (cells/cm^2)		Total Cell Numbers (cells/cm^2)		Total Cell Numbers (cells/cm^2)	
	Control (Non BPES)	BPES	Control (Non BPES)	BPES	Control (Non BPES)	BPES
Day 0	20000	20000	20000	20000	20000	20000
Day 1	16200.4 ± 2262.9	26298.6 ± 884.7	16844.3 ± 2218.7	30180.4 ± 4302.6	17292.2 ± 1821.4	33421.4 ± 1941.6
Day 3	24412.0 ± 1226.7	31873.9 ± 605.0	25959.6 ± 634.1	44897.3 ± 416.2	31485.7 ± 1326.1	45332.1 ± 1127.5
Day 5	42197.8 ± 2724.5	54091.7 ± 5831.6	41481.3 ± 1417.4	66566.4 ± 1746.4	61926.4 ± 833.7	70293.2 ± 487.7
Day 7	45353.7 ± 3572.3	76717.2 ± 1549.4	61819.1 ± 6315.3	88122.7 ± 2780.6	85697.0 ± 1898.2	104459.4 ± 1429.9

Fig. 29. Supported PC 12 cell proliferation on soft bipolar electrodes. (a-b) Numbers of PC 12 cells calculated via PicoGreen assay at various time points with statistical analysis using two-way ANOVA. PC 12 cells were cultured on soft bipolar electrodes at an initial seeding density of 20000 cells/cm^2 in growth media over total one week. BPES: Cells were stimulated on day 2 for 8 h per day in continuous three days, then standard cultured in the following three days after stimulation finished. Control (Non BPES): cells were standard cultured without BPES. Data are represented as mean ± standard deviation (SD) and "*" ($P < 0.0001$) was used to indicate significance.

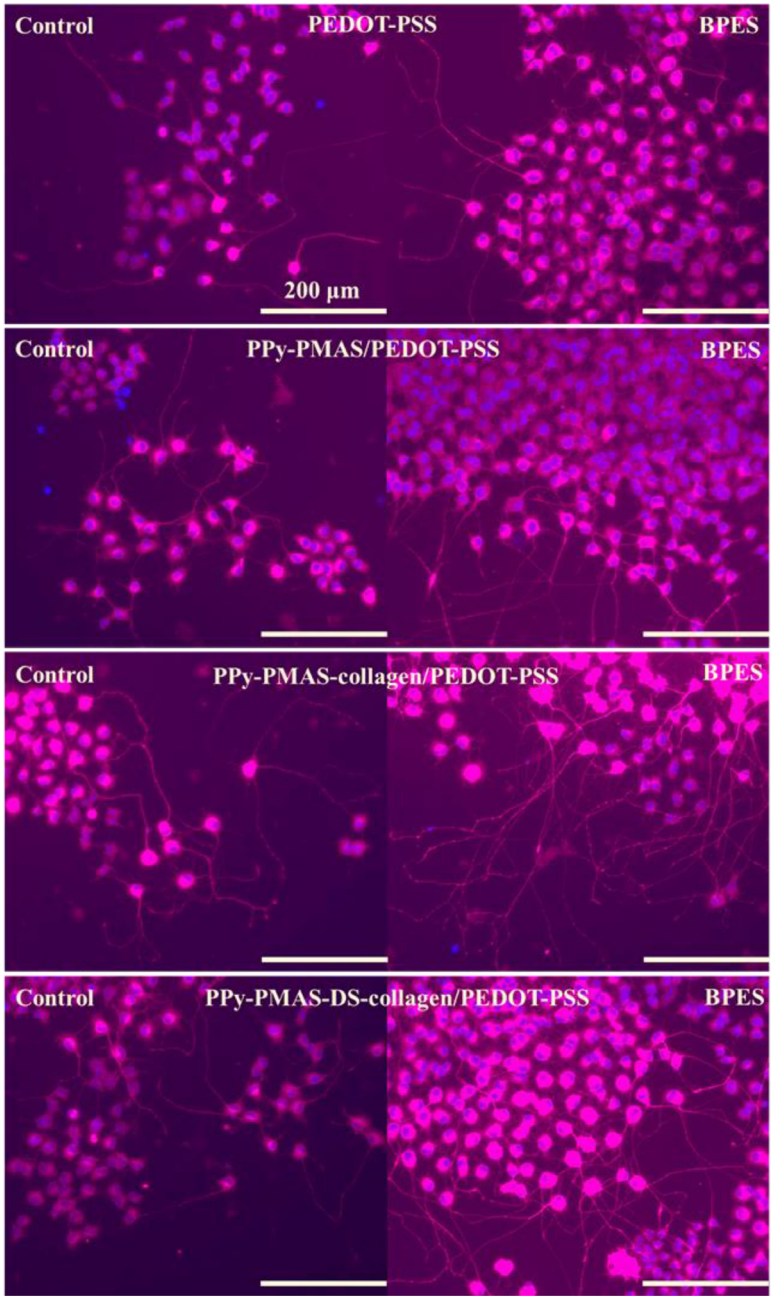


Fig. 30. Supported PC 12 cell differentiation on soft bipolar electrodes. Immunofluorescent staining images of PC 12 cells. PC 12 Cells were cultured on soft bipolar electrodes. BPES: Cells were stimulated on day 2 for 8 h per day in continuous three days, then standard cultured in the following three days after stimulation finished. Control (Non BPES): cells were standard cultured with no BPES. Scale bar: 200 μm.

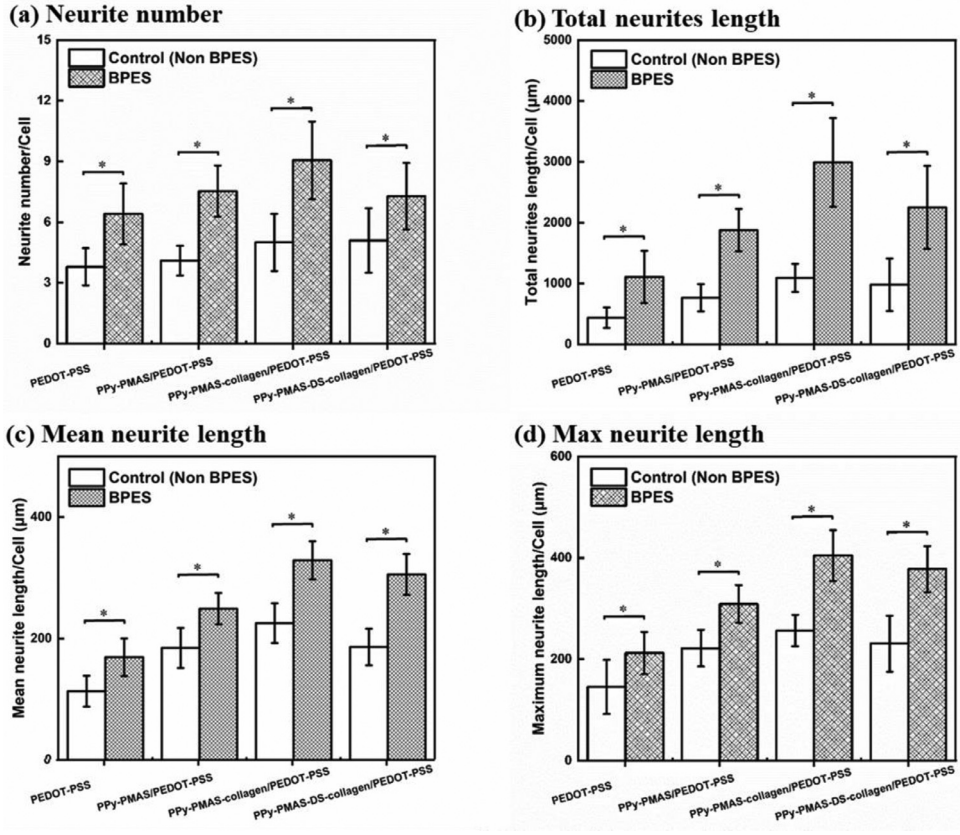


Fig. 31. Supported PC 12 cell differentiation on soft bipolar electrodes. Assessments of neurite number and neurite growth of cells, including (a) the total neurite number per cell, (b) the total length of neurites per cell, (c) mean neurite length per cell, and (d) maximum neurite length per cell. PC 12 Cells were cultured on soft bipolar electrodes. BPES: Cells were stimulated on day 2 for 8 h per day in continuous three days, then standard cultured in the following three days after stimulation finished. Control (Non BPES): cells were standard cultured with no BPES. Statistical analysis used one-way ANOVA. Data are represented as mean ± standard deviation (SD) and "*" ($P < 0.05$) was used to indicate significance.

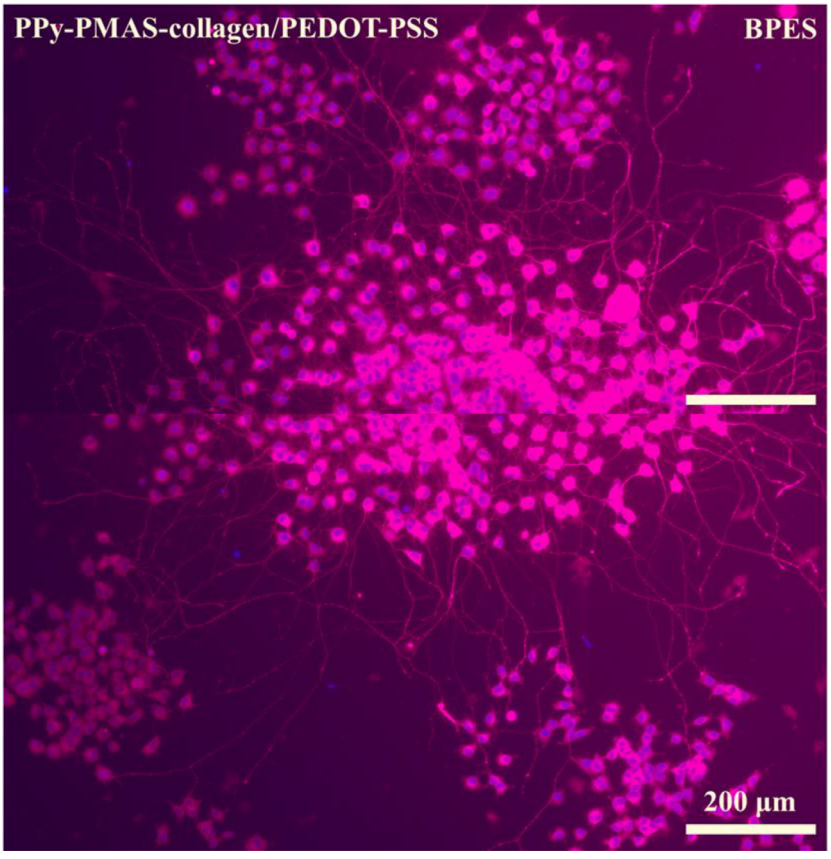


Fig. 32. Highlights of enhanced PC 12 cell behaviour on soft PPy-PMAS-collagen/PEDOT-PSS electrode with BPES. Immunofluorescent staining images of PC 12 cells on PPy-PMAS-DS-collagen/PEDOT-PSS with BPES. BPES: Cells were stimulated on day 2 for 8 h per day in continuous three days, then standard cultured in the following three days after stimulation finished. Scale bar: 200 µm.

2. Experimental Design, Materials and Methods

2.1. Materials Synthesis

The preparation of the PPy-PMAS/FTO, PPy-PMAS-collagen/FTO and PPy-PMAS-DS-collagen/FTO were carried out by cyclic voltammetry (CV) using an CHI-720 Electrochemical Analyzer system in a standard three-electrode electrochemical cell, which configures a platinum (Pt) sheet counter electrode (1 cm × 3 cm), an Ag/AgCl reference electrode, and a FTO-glass working electrode (1 cm × 2 cm). Depositions were obtained from three different aqueous solutions: (a) containing 0.2 M distilled pyrrole (Py) with 2 mg/ml PMAS, (b) with addition of 2 µg/ml collagen in solution (a), (c) with addition of 2 mg/ml DS and 2 µg/ml collagen in solution (a). The electrodeposition runs with a potential range of 0 - 0.65 V at a scan rate of 20 mV/s. After polymerization, all films were thoroughly rinsed with Milli-Q water and allowed to dry under ambient conditions before further characterization and investigation.

2.2. Design and Methods

Electrochemical activities of synthetic materials were evaluated using cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS). CVs of synthesized PPy-PMAS/FTO, PPy-PMAS-collagen/FTO and PPy-PMAS-DS-collagen/FTO were carried out with a potential range of -0.7 V to +0.7 V at a scan rate of 100 mV/s, while EIS were performed over the frequency range of 0.1 Hz to 100 kHz using an AC signal with +50.0 mV vs the reference electrode, using the CHI-720 Electrochemical Analyzer system. Both electrochemical tests were taken place in PBS buffer (pH = 7.4).

Different spectroscopy technologies including UV, Raman and FTIR have been employed to work with the bipolar electrochemistry system and the conventional three-electrodes electrochemical system for comprehensive comparison. *Ex situ* UV spectra (Shimadzu UV-vis 3600) were collected from 300 nm - 1100 nm. *In situ* UV-vis spectra were recorded simultaneously with the bipolar electrochemistry system within the range of 300 nm - 1100 nm under driving voltage of 5.5 V in PBS (pH = 7.4). *In situ* UV-vis spectra were obtained simultaneously with the conventional three-electrodes electrochemical system within the range of 300 nm - 1100 nm under different applied potentials (from -0.6 V to +0.6 V) in PBS (pH = 7.4) as well. *Ex situ* Raman spectra (HR800 Raman spectrometer, Japan) were obtained by 10 s data collection within the wavenumber range of 500 cm^{-1} - 2000 cm^{-1}, using excitation laser at 632.81 nm with a low laser power (less than 10 mW) and × 50 WLD objective lens. FTIR spectra were collected using a FT-IR spectrometer (IRpretige-21, Shimadzu) over a range of 600 cm^{-1} - 2000 cm^{-1}.

All SEM images of PPy-PMAS/FTO, PPy-PMAS-collagen/FTO and PPy-PMAS-DS-collagen/FTO before (pristine) and after (recovered) bipolar testing were acquired using microscopy (JEOL JSM-7500FA). All samples were tested in PBS under 5.5 V or 3.0 V driving voltage, and then taken out from electrolyte solution, subsequently rinsed with Milli-Q water and allowed to dry before performing SEM characterizations under same scale bar: 1 µm. The surface morphology of fluorescently labelled PPy-PMAS/FTO, PPy-PMAS-collagen/FTO and PPy-PMAS-DS-collagen/FTO samples were examined in using a ZEISS Axiovert microscope.

Images of stained cells were acquired using a ZEISS Axiovert microscope (substrates are transparent) and a ZEISS AxioImager microscope (substrates are non-transparent). Calcein AM and PI staining (live/dead assay) was used to observe the cell morphology and cell viability. The numbers of adherent cells on different time plots were quantified using a Quant-iTTM PicoGreen dsDNA Assay Kit in accordance with the manufacturer's instructions. Numbers of triplicate samples were measured with a microplate reader (POLARstar Omega, Germany) at 485-12/520 nm. Tubulin staining was employed to identify specific protein expression of neuronal differentiation. Treated cells were fixed on day 7 in 3.7% paraformaldehyde at RT for 10 min and washed with PBS twice, afterwards permeabilized with methanol:acetone (50:50) on ice for 5 min, and washed with PBS twice. The cells were then blocked in 10% donkey serum with 0.1% w/v Tween-20 in PBS at RT for at least 2 h, incubated with mouse anti-β-tubulin III (Convance, Australia) in 10% donkey serum with 0.1% w/v Tween-20 in PBS at 4 °C overnight, and Alexafluo 546 anti-mouse secondary antibody (Invitrogen, Australia) at 37 °C for at least 2 h. The nuclei were counterstained with 4′-6-diamidino-2-phenylindole (DAPI) (Invitrogen, Australia) for 5 min at RT. Images then were acquired using relevant microscopes.

The compression cycle test was carried out using an EZ-S mechanical tester (Shimadzu, Japan). The machine was equipped with a 10 N load cell. The compression testing speed and the tensile testing speed were 200 mm min^{-1} and 1 mm min^{-1}, respectively.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this article.

Data Availability

Data on enhanced wireless cell stimulation using soft and improved bipolar electroactive conducting polymer templates (Original data) (Mendeley Data).

CRediT Author Statement

Chunyan Qin: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft, Writing – review & editing; **Zhilian Yue:** Resources, Supervision, Writing – review & editing; **Xu-Feng Huang:** Resources, Supervision, Writing – review & editing; **Robert J. Forster:** Writing – review & editing; **Gordon G. Wallace:** Conceptualization, Resources, Visualization, Supervision, Project administration, Funding acquisition, Writing – review & editing; **Jun Chen:** Conceptualization, Resources, Visualization, Supervision, Project administration, Funding acquisition, Writing – review & editing.

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