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Carbon fibre microelectrodes for neuroscience applications

Jian Fang
Deakin University

Zhigang Xie
Deakin University

Gordon G. Wallace
University of Wollongong, gwallace@uow.edu.au

Xungai Wang
Deakin University

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Abstract

Microelectrodes have shown outstanding performance in neural signal recording, neural stimulation and electrochemical sensing1,2. Compared with their micro-sized counterparts, microelectrodes normally exhibit improved signal-to-noise ratio, fast response time and can work with limited sample volumes. Microelectrodes are required to have good biocompatibility, low electrical impedance and long-term stability in many biomedical applications. Carbon fibres are manufactured from polymeric precursor fibres through carbonization, and high carbon content makes carbon fibres electrically conductive, corrosion resistant, biologically safe and inert3. Therefore, carbon fibre has been considered as an ideal candidate for making microelectrodes.

In this work, single carbon fibres were loaded into capillary tubes and fabricated into microelectrodes. The surface of the microelectrodes was functionalized with electrochemically reduced graphene oxide (rGO) sheets, decorated with carbon dots (CDs). It has been demonstrated that this surface modified microelectrode could achieve a high sensitivity and selectivity in detecting dopamine (DA), in the presence of ascorbic acid (AA) and uric acid (UA).

Keywords

neuroscience, microelectrodes, fibre, applications, carbon

Disciplines

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Carbon Fibre Microelectrodes for Neuroscience Applications

Jian Fang[1, 2], Zhigang Xie[1, 2], Gordon Wallace[1, 3], Xungai Wang[1, 2]
[1]ARC Centre of Excellence for Electromaterials Science (ACES)
[2]Australian Future Fibres Research and Innovation Centre (AFFRIC), Institute for Frontier Materials, Deakin University, VIC, Australia
[3]Intelligent Polymer Research Institute (IPRI), University of Wollongong, NSW, Australia
xwang@deakin.edu.au

INTRODUCTION

Microelectrodes have shown outstanding performance in neural signal recording, neural stimulation and electrochemical sensing[1,2]. Compared with their micro-sized counterparts, microelectrodes normally exhibit improved signal-to-noise ratio, fast response time and can work with limited sample volumes. Microelectrodes are required to have good biocompatibility, low electrical impedance and long-term stability in many biomedical applications. Carbon fibres are manufactured from polymeric precursor fibres through carbonization, and high carbon content makes carbon fibres electrically conductive, corrosion resistant, biologically safe and inert[3]. Therefore, carbon fibre has been considered as an ideal candidate for making microelectrodes.

In this work, single carbon fibres were loaded into capillary tubes and fabricated into microelectrodes. The surface of the microelectrodes was functionalized with electrochemically reduced graphene oxide (rGO) sheets, decorated with carbon dots (CDs). It has been demonstrated that this surface modified microelectrode could achieve a high sensitivity and selectivity in detecting dopamine (DA), in the presence of ascorbic acid (AA) and uric acid (UA).

APPROACH

Unsized carbon fibres without any surface treatment were used in this work. Graphene oxide was prepared via the Hummer[4] method and water-soluble carbon dots with strong blue fluorescence were synthesized through a hydrothermal process using sodium citrate and ammonium bicarbonate as the starting materials.

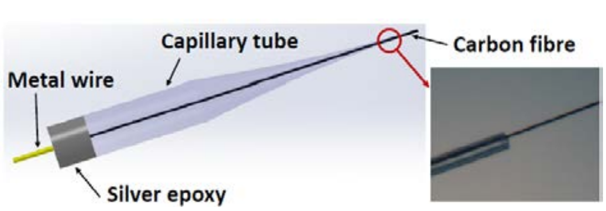

Figure 1. Illustrated structure of carbon fibre microelectrode

Three kinds of carbon fibres were used during the microelectrode preparation in this work: pure carbon fibres (CF), carbon fibres with electrochemically reduced GO on the surface (rGO/CF) and carbon fibres modified with electrochemically reduced GO and carbon dots (rGO+CD/CF). The structure of the fabricated carbon fibre microelectrode is illustrated in Figure 1. One end of the carbon fibre was sealed in a pulled capillary tube while the other end was bonded through conductive epoxy to a gold wire for electrical connection.

RESULTS AND DISCUSSION

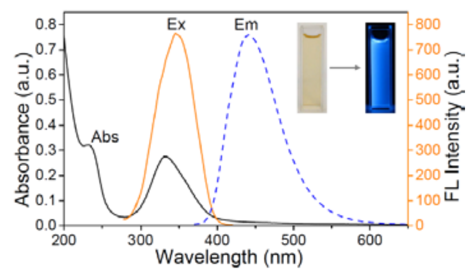

Figure 2. UV absorption (Abs), fluorescence excitation (Ex) and emission (Em) spectra of aqueous CD solution, the inset are the pictures of the solution before and after 365 nm UV radiation.

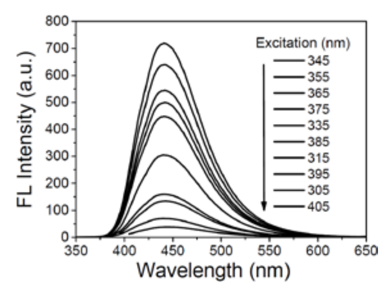

Figure 3. Emission spectra of the CD solution at different excitation wavelengths

Carbon dots are a new type of fluorescent carbon nanomaterials with versatile surface chemistry and non-toxic nature. They have been intensively investigated in many biomedical applications, especially biosensing and bioimaging[5]. The UV absorption, fluorescent excitation and emission spectra of the CDs are shown in Figure 2.

It can be seen that the positions of UV absorption maximum peak (332 nm) and fluorescent excitation peak (345 nm) are very close. The inset image clearly shows the bright blue light displayed from the CD solution under UV light with excitation at 365 nm, which is corresponding to its emission spectra, also shown in Figure 2. It has also been observed that the

CDs exhibited the highest fluorescent intensity when they were excited at 345 nm (Figure 3).

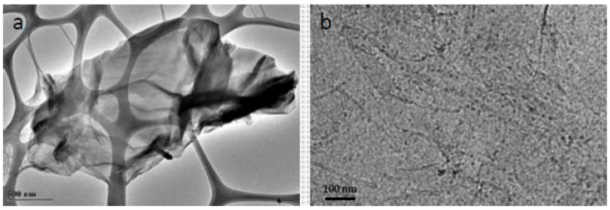

Figure 4. TEM images of GO sheets without (a) and with (b) carbon dot decoration.

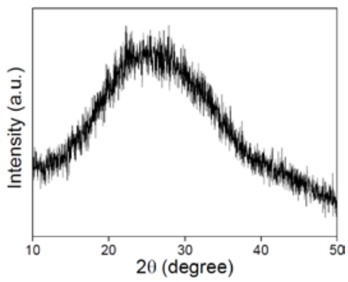

Figure 5. XRD pattern of the CD

Through the strong covalent bonding, CDs can be easily decorated onto GO sheets. The difference between pristine and decorated GO sheets is clearly seen in the TEM images in Figure 4. The broad diffraction peak in the XRD result has also confirmed the amorphous nature of the CDs (Figure 5).

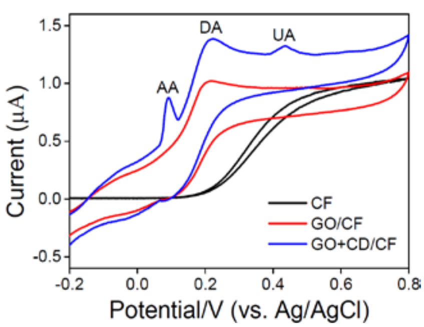

Figure 6. CV responses (scan rate: 100 mV/s) of a 0.1 M PBS solution (pH 7.0) containing 100 μM DA, 1 mM AA and 100 μM UA on three different carbon fibre microelectrodes

Cyclic voltammetry (CV) of a 100 μM DA solution (with 1 mM AA and 100 μM UA) was carried out for the three kinds of microelectrodes prepared in this work. As shown in Figure 6, due to limited surface area of pure carbon fibres, none of the three neurotransmitters in the solution was identified by the CF microelectrode. After GO sheets were electrochemically deposited and reduced onto pure carbon fibres, an obvious oxidation peak at 0.197 V was shown on the rGO/CF microelectrode, however it's still not sensitive enough to detect AA and UA in the same solution.

By decorating the GO sheets with carbon dots, oxidation peak of all three neurotransmitters in the solution can be found on the CV curve of the rGO+CD/CF microelectrode. This significant improvement has probably been contributed by increased surface area and improved electrostatic interaction.

CONCLUSION

Graphene oxide sheets have been decorated with carbon dots, electrochemically reduced and deposited onto carbon fibre surface for detecting low concentration dopamine (DA), ascorbic acid (AA) and uric acid (UA) in aqueous solution. The decoration of carbon dots leads to significantly improved sensitivity and selectivity of the surface modified carbon fibre microelectrodes, which can be attributed to increased accessible surface area and enhanced electrostatic interaction with DA. The results suggest that surface modified carbon fibre maybe an ideal microelectrode material for various neuroscience applications, such as biosensing and neuro signal recording.

KEYWORDS

Carbon fibre, Microelectrode, Neurotransmitter, Neuroelectrode

ACKNOWLEDGMENT

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