

Nitrogen-containing carbon film derived from vapor phase polymerized polypyrrole as a fast charge/discharge capability anode for lithium-ion batteries

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Experimental Section

Synthesis of N-C film electrode.

PPy film was synthesized by a vapor phase polymerization method. Briefly, Fe (II) *p*-toluenesulfonate (Sigmaaldrich) was coated onto a glass slide substrate from a 20 % solution in *n*-butanol solvent. The coated glass slide was dried on a hot plate with a temperature of 75 °C and then exposed to pyrrole vapor at room temperature. After 15 min, the color of the oxidant coating turned to be dark yellow which indicated the formation of PPy. For pyrolysis of the PPy, the film was firstly peeled off from the glass by soaking in ethanol solvent and then dried in the air by hanging on a stainless steel wire. Then the PPy film was calcined in a stream of Ar at 700 °C for 2 h with the heating rate of 2 °C min⁻¹ to obtain a nitrogen-containing carbon film.

Physical characterizations

The morphologies and microstructure of the samples were monitored using a FEI Nova SEM 230 ultra-high resolution FE-SEM equipped (INCA X-Max 80, Oxford Instruments), and a TEM (JEM-2100F, JEOL Ltd., Japan). The porosity and BET surface areas for the samples were measured using a nitrogen sorption instrument (Micromeritics, ASAP2020). The crystalline property of materials was examined by XRD measurements using a Rigaku D/MAX-2200/PC X-ray diffractometer at 40 kV and 20 mA, with a Cu K α radiation source. The Raman spectroscopies of the PPy and N-C film samples were obtained in Dispersive Raman Microscope (Senterra R200-L, Germany). The surface properties of the samples were analyzed by X-ray

photoelectron spectrometer (XPS, Kratos Axis Ultra DLD).

Electrochemical measurements

The lithium ion battery measurements were performed using 2016 coin cells for half-cell system at room temperature. The N-C film was cut into round pieces with a diameter of 1.4 cm, which was used as the electrode directly and the conducting additive and binder are not required for the electrode fabrication. The electrodes were dried in a vacuum oven at 100 °C for 24 h before being transferred into a glove box. The coin cells were assembled with lithium-metal as counter and reference electrode, Celgard 2400 as the separator, and 1 M LiPF₆/EC/DMC (1:1 by volume ratio) as electrolyte respectively. The charge/discharge electrochemical performances were tested in the potential range of 0.01-3.0 V vs. Li/Li⁺ using a LAND CT2001A model battery test system (Wuhan Jinnuo Electronics, Ltd.) under a constant current mode. The cyclic voltammetry (CV) tests were performed over the potential range of 0.01-3.0 V using a CHI 660 potentiostat with a scan rates from 0.1mV s⁻¹. The EIS testings were conducted using a VersaSTAT 4 potentiostat by using a three-electrode, with the N-C film as a working electrode, a lithium ring as a reference, and a piece of lithium disk as a counter electrode.

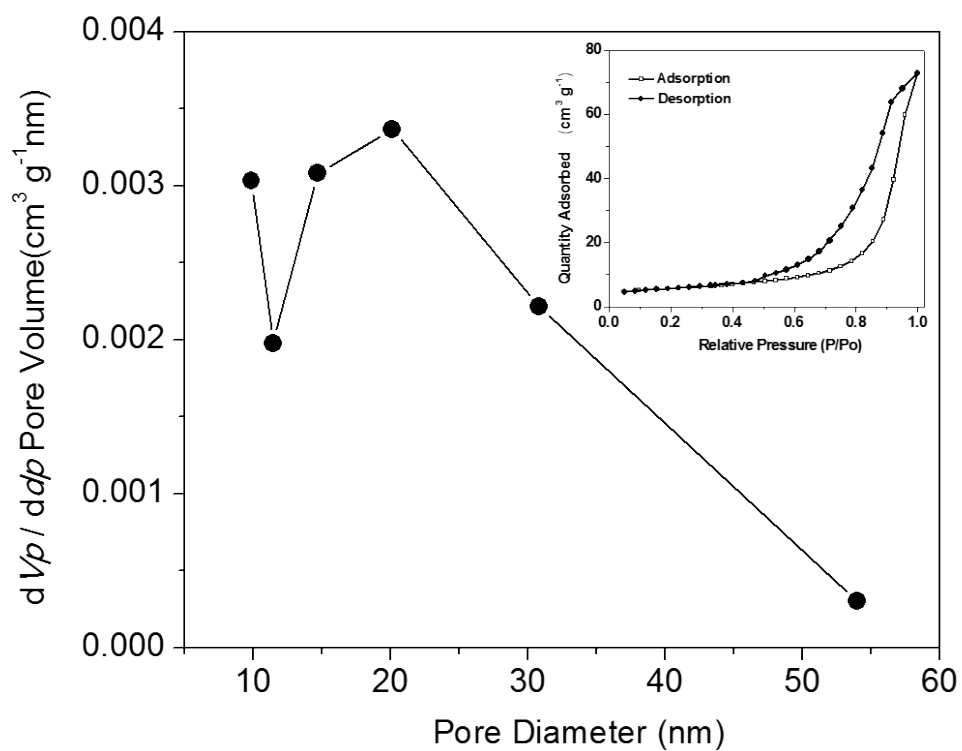


Figure S1 .BJH pore size distribution plot and nitrogen adsorption-desorption isotherms (inset) of N-C film.

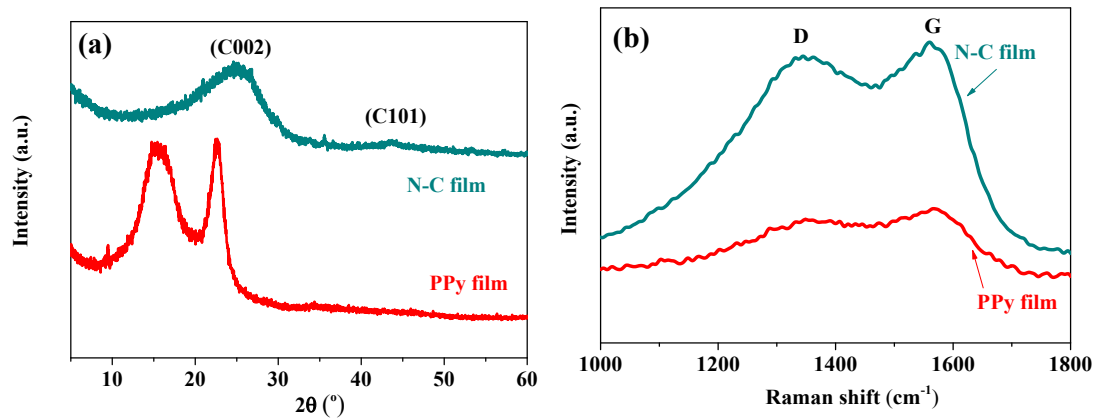


Figure S2 XRD patterns (a) and Raman spectra (b) of vapor phased polymerized PPy film and the corresponding N-C film.

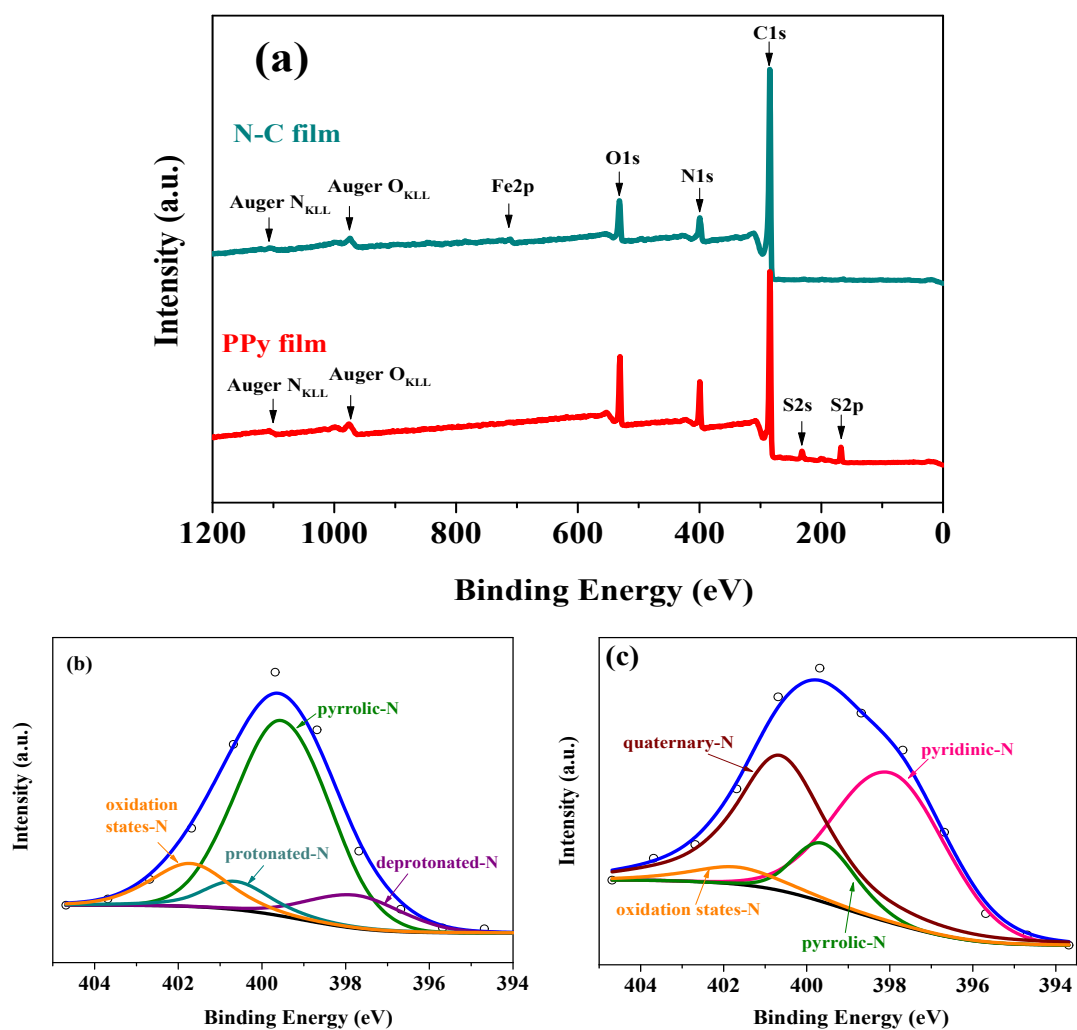


Figure S3 XPS survey spectra (a) and high-resolution XPS spectra of N1s of the PPy film (b) and N-C film (c).

Table S1. Elemental composition of polypyrrole (PPy) films and N-C Films.

	%at. C	%at. N	%at. O	%at. S	%at. Fe
PPy	78.6	11.4	8.8	1.2	--
N-C	85.6	8.1	6.1	--	0.2

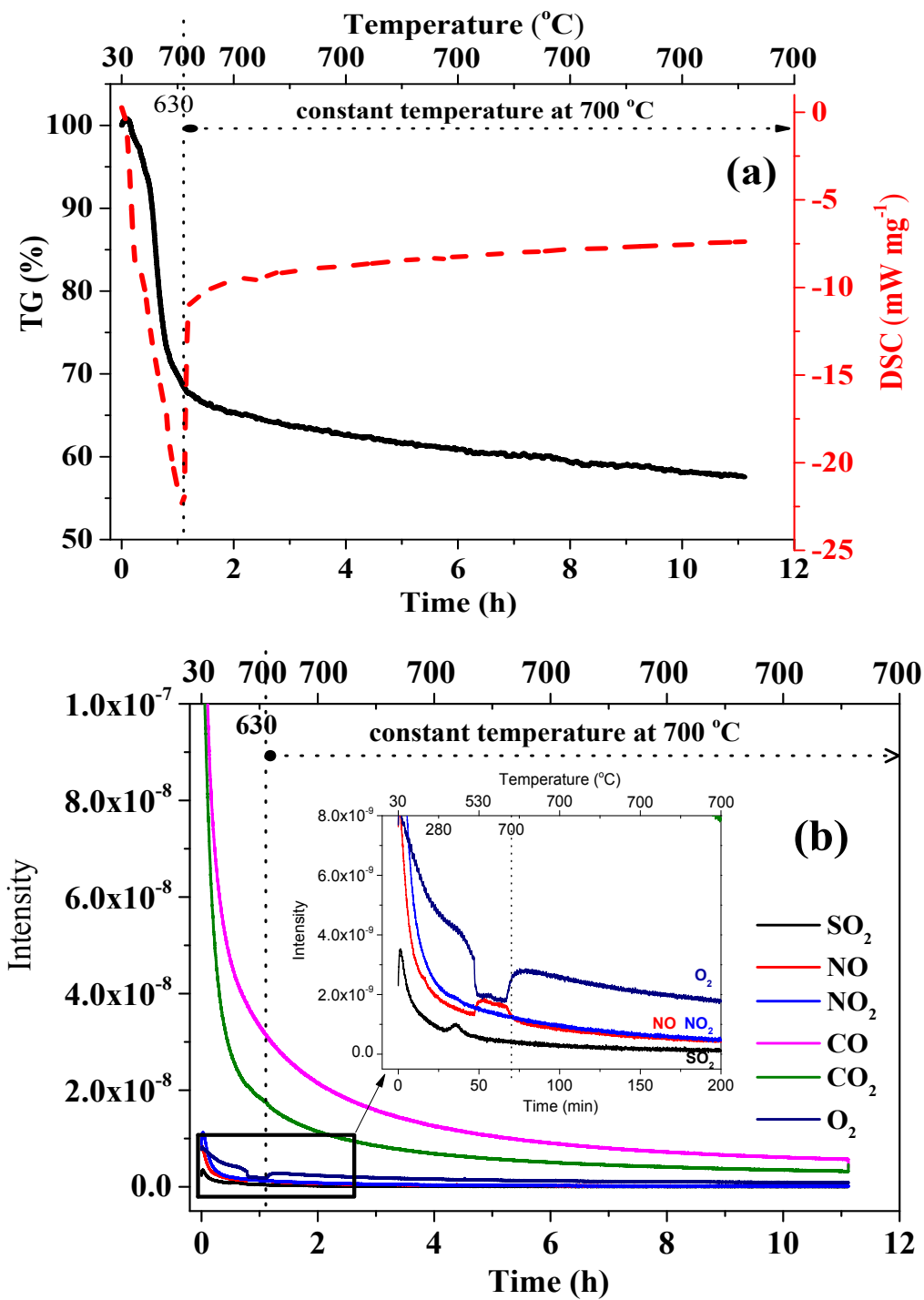


Figure S4 (a) TG-DSC curves of calcination process of PPy film from room temperature to 700 °C in Ar atmosphere with a heating rate of 10 °C min⁻¹ and the temperature was held at 700 °C for 10 h; (b) MS profiles of released gases during heating process of TG.

Table S2. Comparison of the rate and cycling capability of N-C film synthesized in this work with those of carbonized products from PPy and other polymers reported in the literatures

Samples	Preparation method of conductive polymer	Initial current densities (mA g ⁻¹)	Initial reversible capacity (mAh g ⁻¹)	High current densities (mA g ⁻¹)	Corresponding capacity (mAh g ⁻¹)	Capacity retention (%)	Ref.
Free-standing N-C film	vapor phase polymerization of pyrrole	500	908.4	5000	502 after 50 cycles	55.3	This work
Carbon nanospheres	Chemical oxidation of pyrrole	60	420	3000	190	45.2	1
Porous Carbon Nanofibers	Chemical oxidation of pyrrole	0.5C	400	30C	155.4 after 400 cycles	38.9	2
Non-graphitic carbon nanotubes	Chemical oxidation self-assembly of pyrrole	100	635.7	4000	280.1 after 60 cycles	44.1	3
carbon nanofiber webs	modified oxidative template assembly route of pyrrole	100	1280	2000	943 after 600 cycles	73.7	4
N-rich porous carbon spheres	Chemical oxidation +Template etching technology of pyrrole	500	666	3000	215 after 20 cycles	32.3	5
Mesoporous nitrogen-rich carbons	Pyrolyze protein	100	1780	4000	205 after 90 cycles	11.5	6
Porous carbon foams	pyrolysis of phenolic resin from a dual-template approach	0.1C	156	0.1C	about 80 after 50 cycles	51.3	7
Carbon Nanofibers	electrospun polyacrylonitrile membranes.	100	340	1000	152.7 after 80 cycles	44.9	8

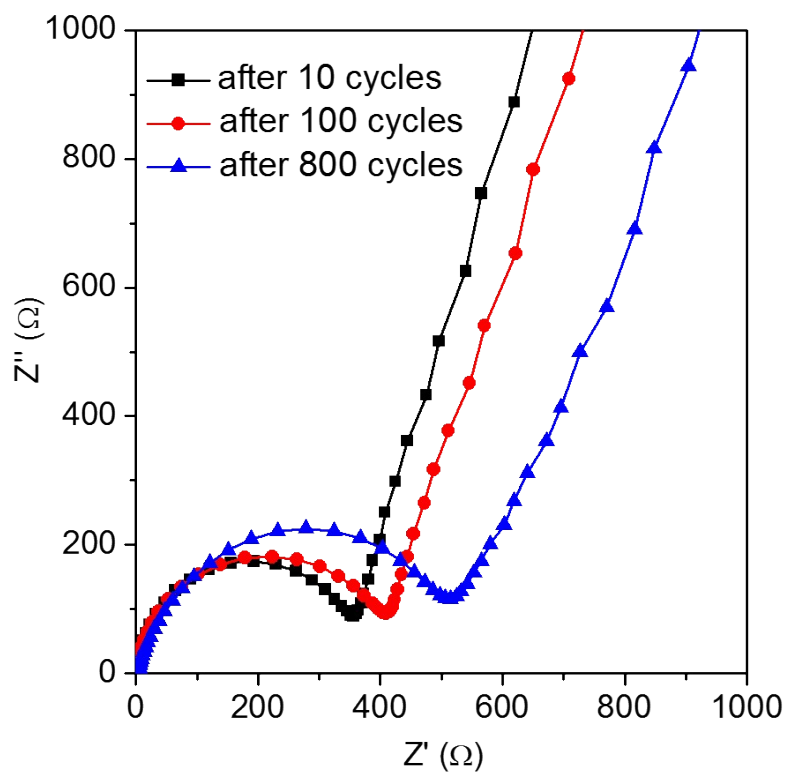


Figure S5 Nyquist plots of the N-C film electrode after different cycles obtained by applying a sine wave with amplitude of 10.0 mV over the frequency range of 100 kHz-100 mHz.

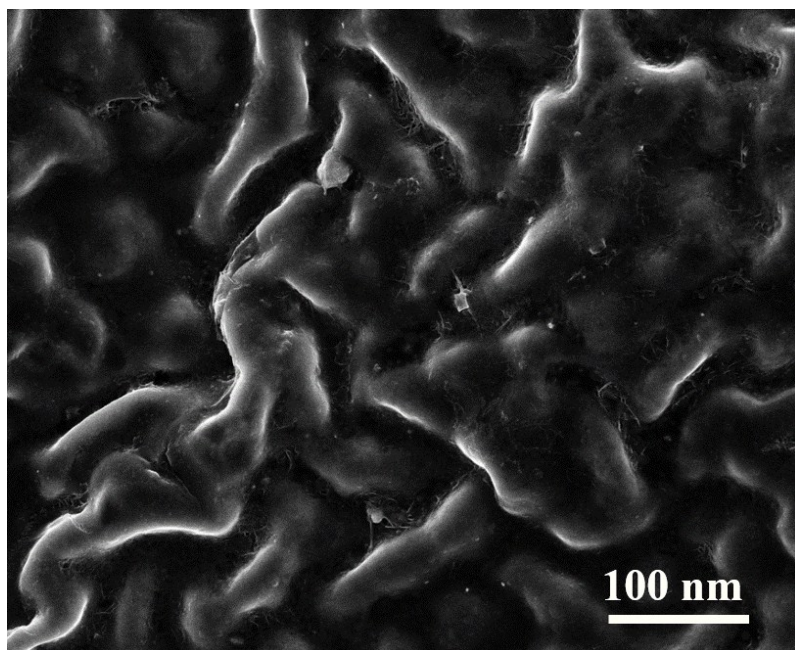


Figure S6 SEM image of N-C film electrode after 100 charge-discharge cycles.

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