

## Supplementary Information:

### An Animal Liver Derived Non-noble Catalyst for Oxygen Reduction with High Activity and Stability

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## **Experimental Section**

### **Material syntheses**

The pristine PL was cooked thoroughly, and dried in an air-circulating oven at 80 °C to obtain the precursor. The precursor was carbonized at 900 °C in an inert atmosphere. The precursor was performed at 200 °C for 0.5 h at a heating rate of 2°C/min in an inert atmosphere, and subsequently it was performed at 900°C for 2 h at a heating rate of 5°C/min in an inert atmosphere, and then the sample was cooled under the same atmosphere from 900°C to 60°C. After that, the black carbon was transferred into a milling tank and grinded on a planetary ball mill (Nanjing Chishun Science & Technology Co., Ltd. PM) for 4 h at 250 rpm. The resulting black carbon powder was pre-leached in 0.5 M H<sub>2</sub>SO<sub>4</sub> at 80°C for 8 h, followed by thoroughly washed in de-ionized water and absolute ethyl alcohol, and then dried at 80°C under vacuum. Finally, the product was heat-treated again at 900°C for 2 h in nitrogen

atmosphere to obtain the CPL catalyst (denoted as CPL900). As comparison, the pristine PL was also carried out at the temperature 800°C and 1000°C in the similar way to obtain the CPL800 and CPL1000 catalysts. In addition, CPL-Fe catalyst was also obtained in a similar way by adding iron into PL (the iron mass content as expressed as Fe/PL was 0.04 wt%). The specific synthesis process of CPL-Fe catalyst is shown in **Fig. S2**.

### **Material Physical and Chemical Characterizations**

Catalyst phase was analyzed using D/Max-RB X-ray Powder Diffractometer (XRD) with Cu-K $\alpha$  radiation, and the XRD patterns were recorded between 10° and 80° and a powder diffraction file database was used to assign the diffractograms. The morphology of the samples were analyzed using JSM-7100F field emission scanning electron microscope (SEM) and JEM-2100F high-resolution transmission electron microscopy (TEM). Nitrogen adsorption-desorption isotherms were recorded at 78 K with a Micromeritics ASAP 2020 Brunauer Emmett Teller (BET) analyzer. The electronic structure of surfaces for the catalyst was performed using VG-Multi-lab2000 X-ray photoelectron spectroscopy (XPS). Accurate iron content of these catalysts was performed using inductively coupled plasma–atomic emission spectrometry (ICP-AES). Raman measurement was performed on a LabRAM Aramis Raman spectrometer with a laser wavelength of 514.5 nm

### **Electrochemical characterizations**

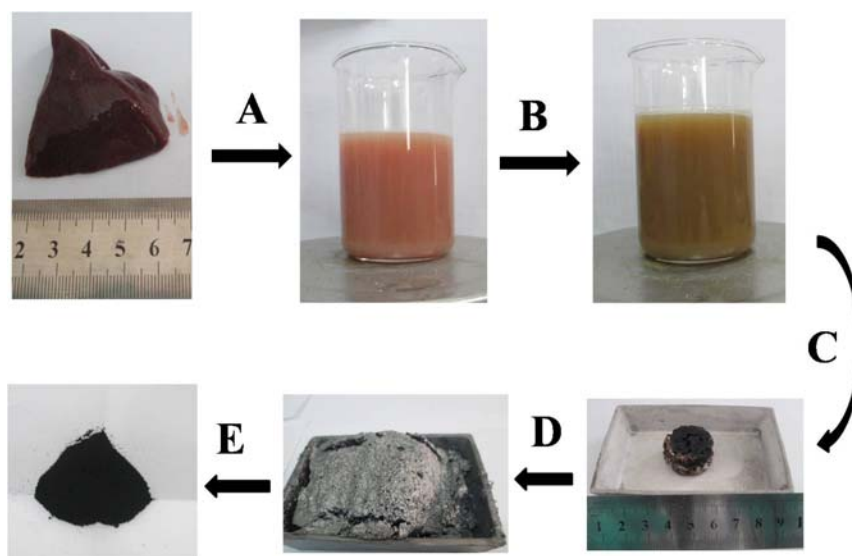
To prepare the working electrode, a homogeneous catalyst ink was made by mixture of 5.0 mg catalyst, 25  $\mu$ L Nafion ionomer solution (5 wt%, DuPont) and 0.475 mL

ultra pure water. The working electrode was prepared by loading  $0.3 \text{ mg cm}^{-2}$  sample on a glassy carbon electrode. As a benchmark, the commercial Pt/C (20 wt%, JM) catalyst was also spread onto the surface of a glassy carbon disk electrode in a similar way, the Pt loading was  $20 \text{ } \mu\text{g Pt}\cdot\text{cm}^{-2}$ . All the electrochemical properties of the catalysts were measured using a conventional three compartment electro-chemical cell in 0.1M KOH aqueous solution. Counter and reference electrodes were a platinum wire and an Ag/AgCl (saturated KCl solution) electrode, respectively. Working electrode was constructed with a glassy carbon disk electrode coated with the catalyst layer. The ORR activity was carried out using rotating disk electrode (RDE) technique by linear sweep voltammetry (LSV) in the potential range of -0.8 to 0.2 V (vs. Ag/AgCl) with a scan rate of  $5 \text{ mV s}^{-1}$  at different rotation rate from 400 to 2000 rpm in an  $\text{O}_2$ -saturated 0.1M KOH solution. Cyclic voltammetry (CV) curves were collected in the potential range of -0.8 to 0.2 V (vs. Ag/AgCl) with a scan rate of  $50 \text{ mV s}^{-1}$  in an  $\text{O}_2$ -saturated 0.1M KOH solution. The tolerance of the catalysts were investigated by CV, LSV and current vs time (i-t) chronoamperometric response during a constant potential at -0.5 V in ( $\text{O}_2$ -saturated,  $\text{O}_2$ +CO and  $\text{O}_2$ +3 M  $\text{CH}_3\text{OH}$ ) 0.1 M KOH solution. ORR stabilities of the catalysts was investigated by i-t chronoamperometric response of the PL-Fe and Pt/C during a constant potential at -0.35 V at a rotation rate of 1600 rpm in  $\text{O}_2$ -saturated 0.1 M KOH. After i-t chronoamperometric response, the ORR steady-state polarization measurement was conducted in  $\text{O}_2$ -saturated 0.1 M KOH electrolyte with scanning rates of  $5 \text{ mV s}^{-1}$  and rotation rate at 1600 rpm.

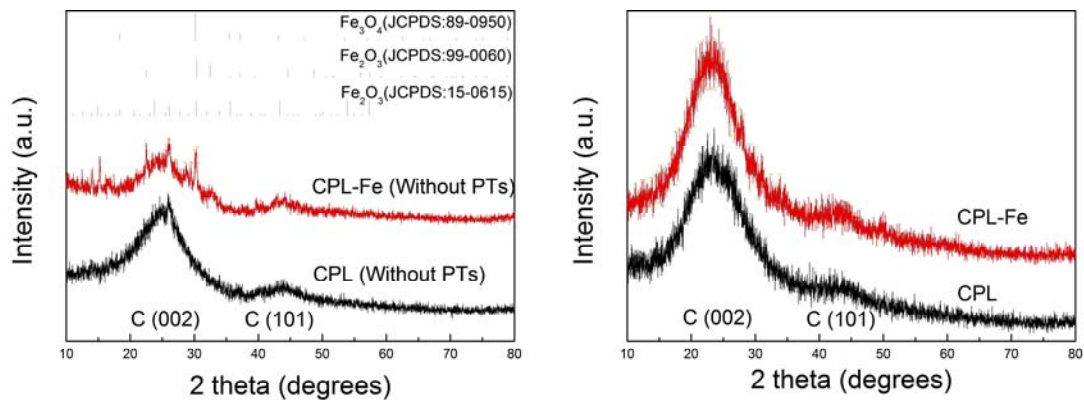
**Table S1** The composition of PL.

Project	Content	Project	Content
Protein	19.3 g	Calcium	6 mg
Fat	3.5 g	Magnesium	24 mg
Carbohydrates	5 g	Iron	22.6 mg
Cholesterol	288 mg	Zinc	5.78 mg
Vitamin A	5 mg	Copper	0.65 mg
Thiamine	0.21 mg	Manganese	0.26 mg
Riboflavin	2.08 mg	Potassium	235 mg
Niacin	15 mg	Sodium	68.6 mg
Vitamin C	20 mg	Phosphorus	310 mg
Vitamin E	0.86 mg	Ash	1.5 g

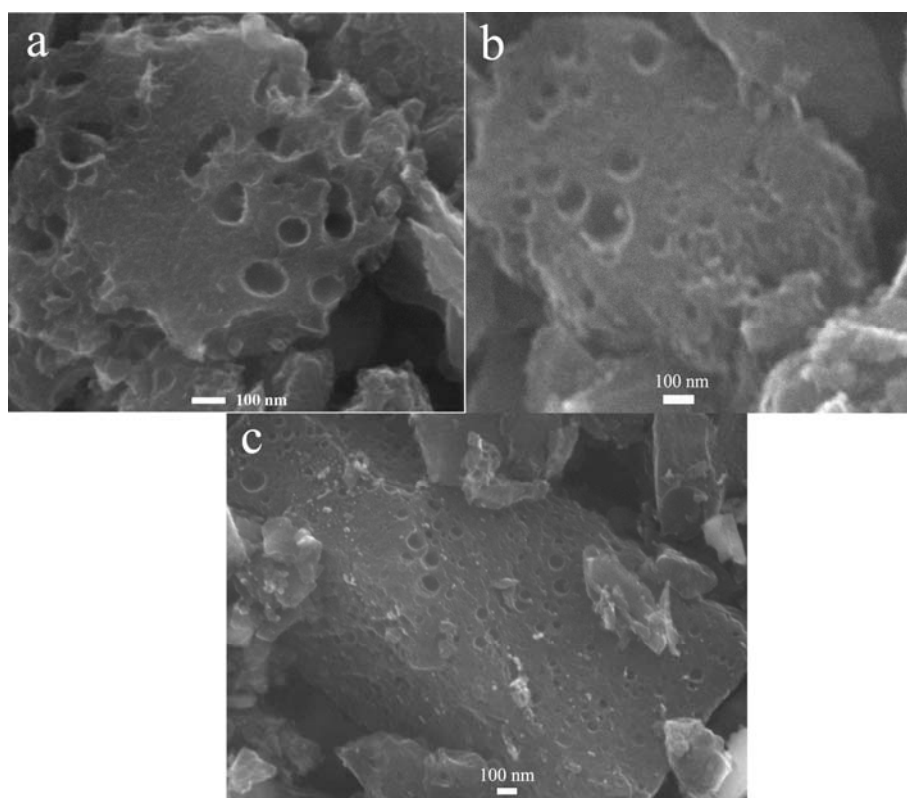
Ref. 1 P. P. SiMa, Y. Zhang, *Swing Production*, 2011, **4**, 75-76.



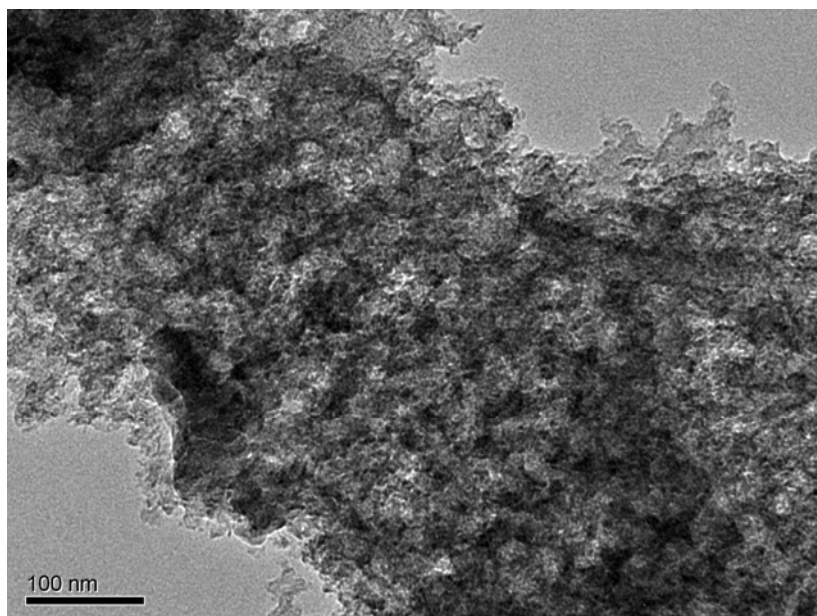
**Fig. S1** Schematic of the synthesis process of the PL-Fe catalyst. (A) Crushing the PL and mixing with water. (B) Adding  $\text{FeCl}_3$  solution. (C) Cooking and drying the mixture. (D) The precursor is carbonized in an inert atmosphere. (E) Post-treatment (PTs) including ball milling, acid leaching and the second heat treatment.



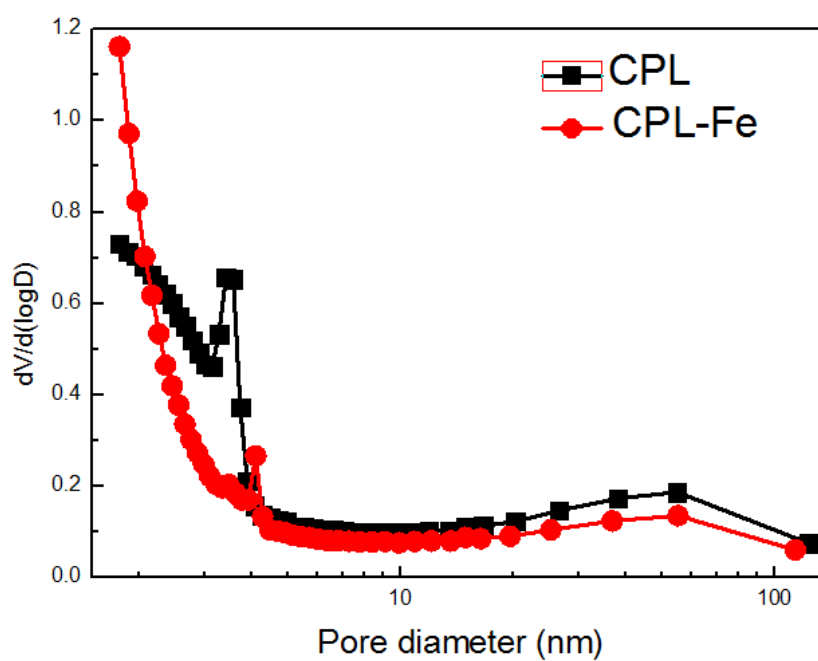
**Fig. S2** XRD patterns of the sample of CPL and CPL-Fe in the first heat treatment at 900°C (a), the CPL and CPL-Fe samples after the PTs (b).



**Fig. S3** SEM images containing macropores in CPL-Fe catalyst.



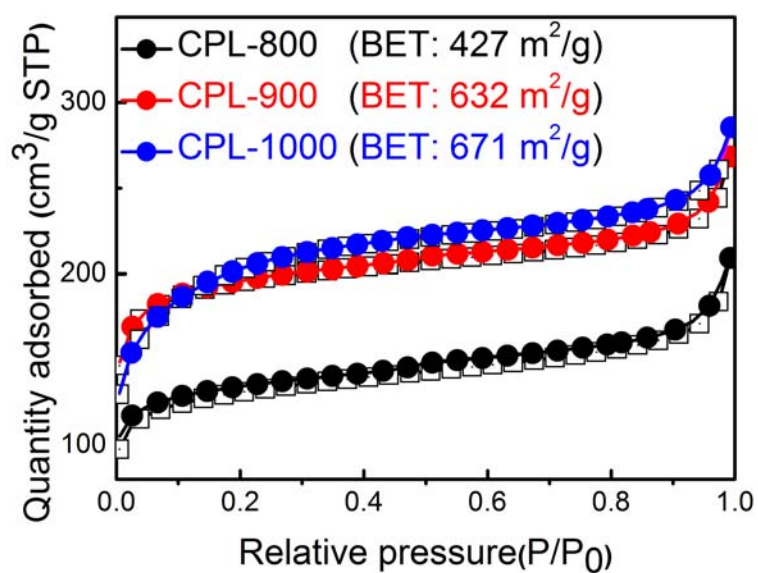
**Fig. S4** The high-resolution HRTEM image of CPL-Fe catalyst.



**Fig. S5** Pore size distribution of CPL and CPL-Fe catalysts.

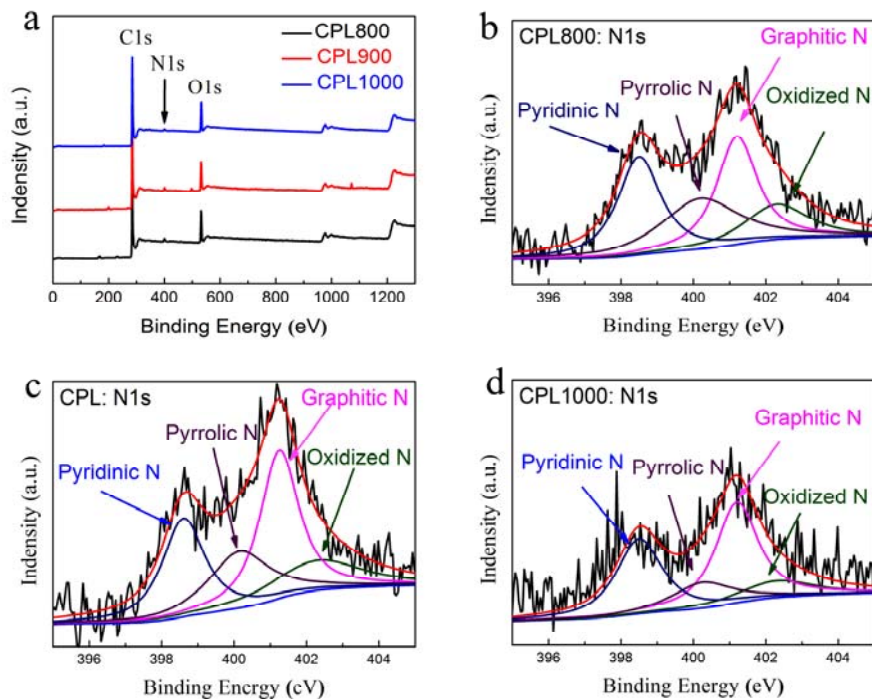
**Table S2** The content of C, N, O and different types of N contents of CPL and CPL-Fe catalysts.

Sample	C at%	O at%	N at%	Oxidized N %	Graphitic N %	Pyrrolic N %	Pyridinic N %
CPL	86.40	11.01	2.59	16.98	36.67	21.23	25.86
CPL-Fe	88.89	8.68	2.43	13.58	39.91	15.22	30.86



**Fig. S6** N<sub>2</sub> adsorption-desorption isotherms of CPL800, CPL900 and CPL1000, respectively.

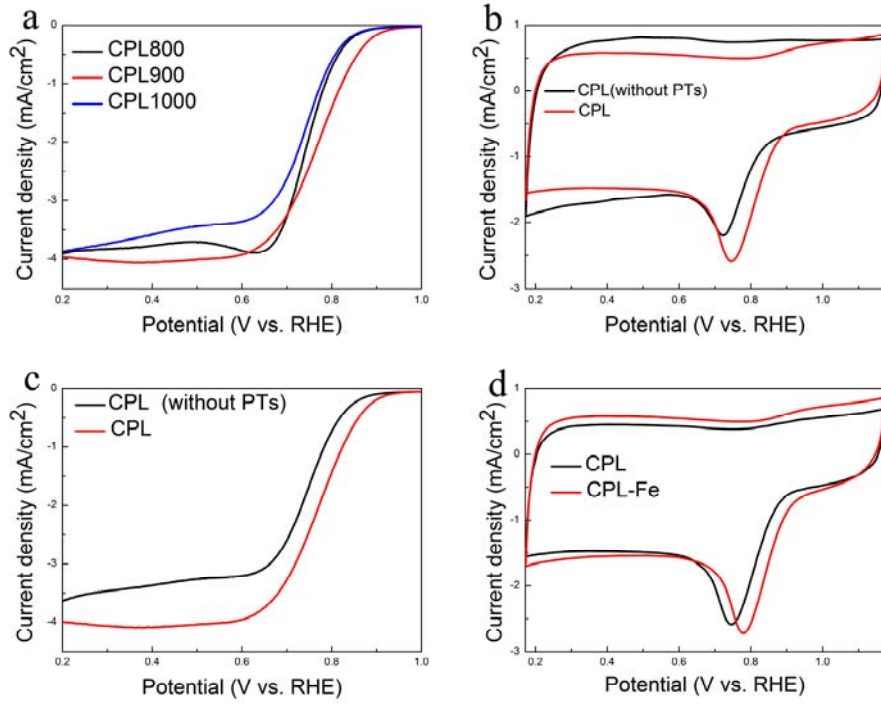




**Fig. S7** XPS survey spectra (a) and N1s regional spectra (b-d) of CPL800, CPL900 and CPL1000, respectively.

**Table S3** The content of C, N, O and different types of N contents of CPL800, CPL900 and CPL1000, respectively.

Sample	C at%	O at%	N at%	Oxidized N %	Graphitic N %	Pyrrolic N %	Pyridinic N %
CPL800	84.48	12.74	2.78	14.94	29.85	26.29	28.92
CPL900 /CPL	86.40	11.01	2.59	16.98	36.67	21.23	25.86
CPL1000	85.31	13.12	1.57	11.79	40.78	14.72	32.71



**Fig. S8** LSV curves for the CPL catalysts at the different heat treatment temperature from 800°C to 1000°C (a); CV (b) and LSV (c) curves for the CPL catalyst and without PTs in O<sub>2</sub>-saturated 0.1 M KOH, respectively; LSV curves for the CPL, CPL-Fe and Pt/C catalysts in O<sub>2</sub>-saturated 0.1 M KOH electrolyte with scanning rates of 5 mV s<sup>-1</sup> and rotation rate at 1600 rpm (d).

### The Koutecky-Levich (K-L) equation

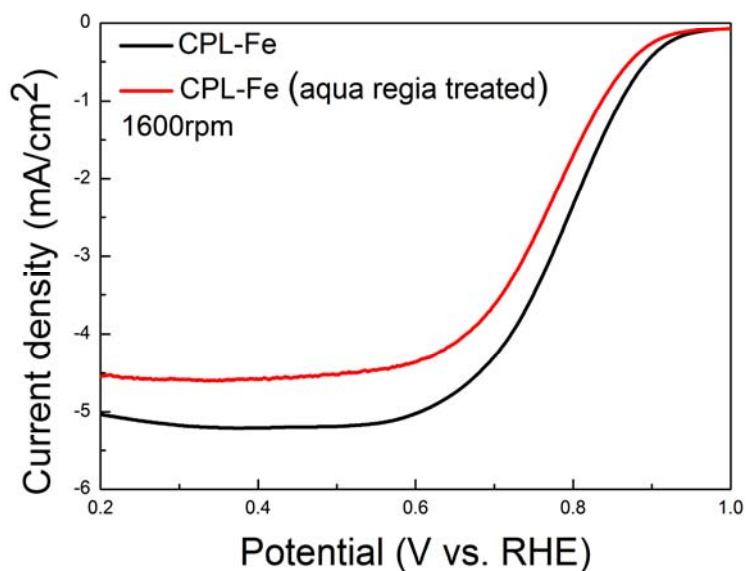
The K–L equation as given below:

$$\frac{1}{J} = \frac{1}{J_L} + \frac{1}{J_K} = \frac{1}{B\omega^{1/2}} + \frac{1}{J_K} \quad (1)$$

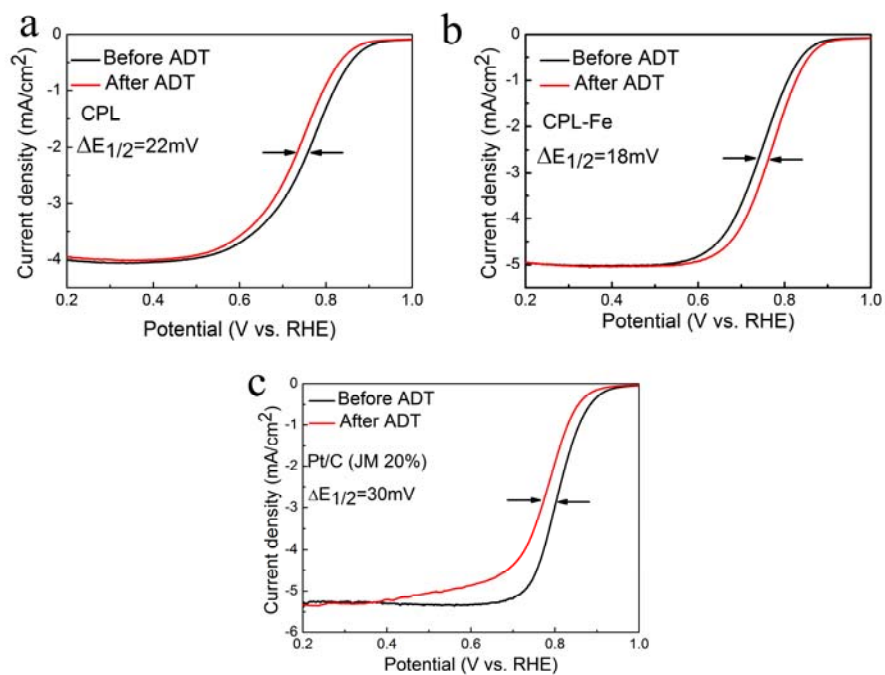
$$B = 0.62nFC_0(D_0)^{2/3}\nu^{-1/6} \quad (2)$$

where J denotes the measured current density, J<sub>K</sub> is the kinetic current density, J<sub>L</sub> is the diffusion-limited current density, ω is the electrode rotation rate, F is the Faraday constant (96485 C mol<sup>-1</sup>), C<sub>0</sub> is the bulk concentration of O<sub>2</sub> (1.2×10<sup>-3</sup> mol L<sup>-1</sup>), D<sub>0</sub> is

the diffusion coefficient of  $O_2$  ( $1.9 \times 10^{-5} \text{ cm}^2 \text{ s}^{-1}$ ) and  $\nu$  is the kinetic viscosity of the electrolyte ( $1.0 \times 10^{-2} \text{ cm}^2 \text{ s}^{-1}$ ).



**Fig. S9** ORR polarization curves for CPL-Fe and the sample of CPL-Fe was treated by aqua regia in  $O_2$ -saturated 0.1 M KOH at 1,600 rpm with scanning rates of  $5 \text{ mV s}^{-1}$ .



**Fig. S10** ORR polarization curves for CPL, CPL-Fe and Pt/C catalysts before and after accelerated durability test (ADT) of 5000 cycles from 0.6 to 1 V.