Electronic Supplementary Material

Activated carbon induced oxygen vacancies-engineered nickel ferrite with enhanced conductivity for supercapacitor application

Xicheng Gao, Jianqiang Bi (✉), Linjie Meng, Lulin Xie, Chen Liu

Key Laboratory for Liquid-Solid Structural Evolution and Processing of Materials, Ministry of Education, School of Materials Science and Engineering, Shandong University, Jinan 250061, China

E-mail: bjq1969@163.com

Materials characterizations

The phase contents of the original $NiFe_2O_4$ sample were calculated using K values according to the XRD pattern. The relative content can be calculated as follows:

$$W_{\mathrm{NiFe_2O_4}} = \frac{I_{\mathrm{NiFe_2O_4}} * K_{\mathrm{Fe_2O_3}}}{I_{\mathrm{NiFe_2O_4}} * K_{\mathrm{Fe_2O_3}} + I_{\mathrm{Fe_2O_3}} * K_{\mathrm{NiFe_2O_4}}}, (1)$$

$$W_{\mathrm{Fe_2O_3}} = \frac{I_{\mathrm{Fe_2O_3}} * K_{\mathrm{NiFe_2O_4}}}{I_{\mathrm{NiFe_2O_4}} * K_{\mathrm{Fe_2O_3}} + I_{\mathrm{Fe_2O_3}} * K_{\mathrm{NiFe_2O_4}}}, (2)$$

where I and W refer to the diffraction intensity and mass fraction, respectively. $K_{\mathrm{NiFe_2O_4}}$ and $K_{\mathrm{Fe_2O_3}}$ are 4.85 and 3.26, respectively, which are obtained from the standard PDF cards.

Results and discussion

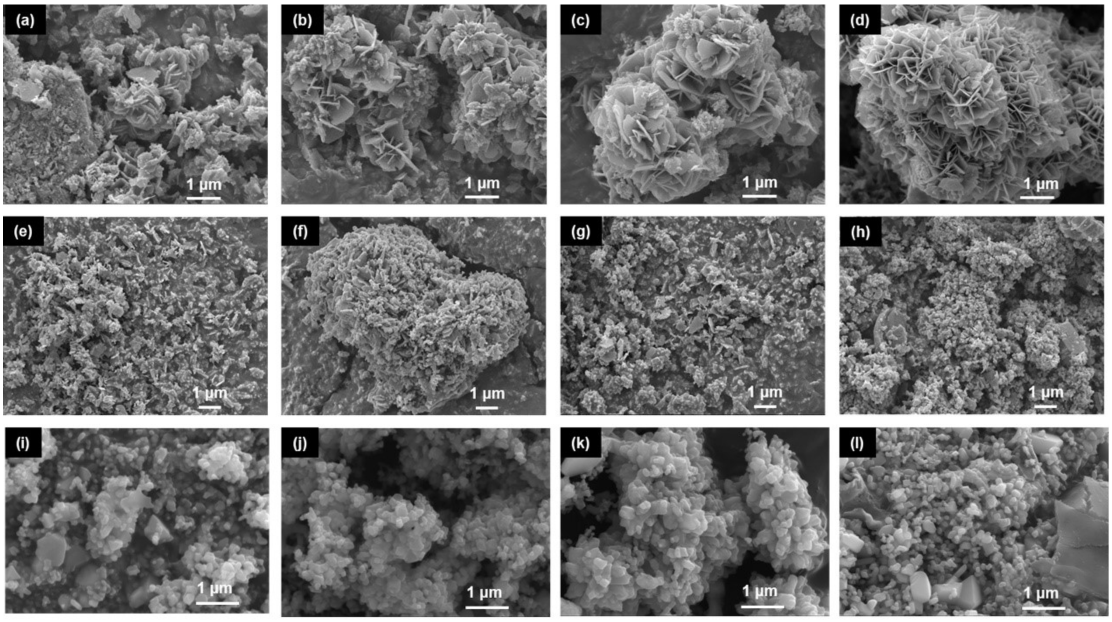

Fig. S1 SEM images of oxygen vacancies-engineered $NiFe_2O_4$ with different heat treatment temperatures and masses of activated carbon: (a) 400 ℃, 0.1 g; (b) 400 ℃, 0.2 g; (c) 400 ℃, 0.3 g; (d) 400 ℃, 0.4 g; (e) 500 ℃, 0.1 g; (f) 500 ℃, 0.2 g; (g) 500 ℃, 0.3 g; (h) 500 ℃, 0.4 g; (i) 600 ℃, 0.1 g; (j) 600 ℃, 0.2 g; (k) 600 ℃, 0.3 g; (l) 600 ℃, 0.4 g.

SEM images of the samples with different heat treatment temperatures and masses of activated carbon are shown in Fig. S1. It can be seen that morphologies of samples with the heat treatment temperature of 400 ℃ are almost identical to the original samples. While with the temperature rising to 500 ℃, the morphologies of nanosheets are obviously broken. When the temperature arrives at 600 ℃, phenomenon of recrystallized appears and distinct particles replace nanosheets. In addition, morphologies of the samples with different masses of activated carbon are also analyzed by SEM. As seen, the mass of activated carbon has little effect on the morphology of the samples

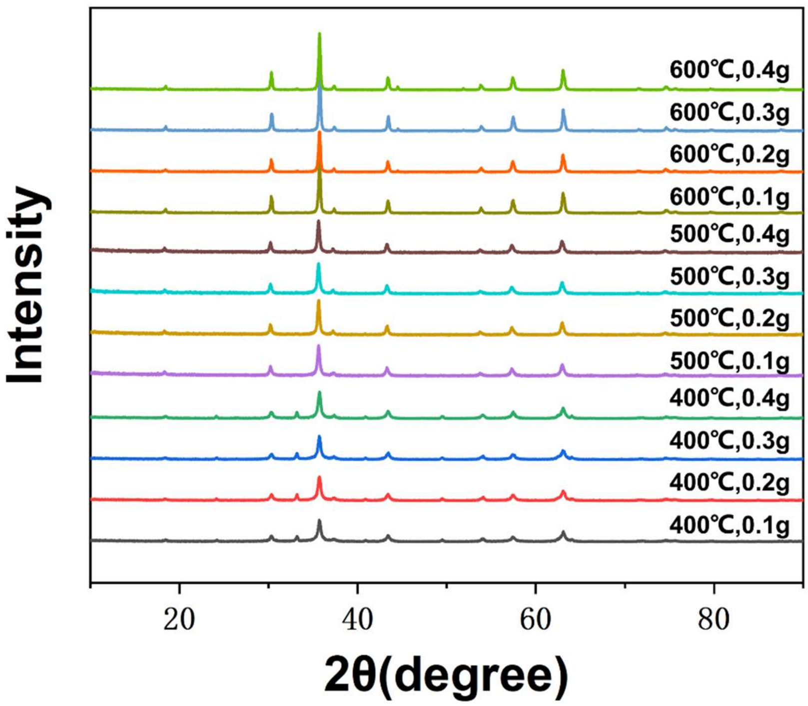

Fig. S2 XRD patterns of oxygen vacancies-engineered $NiFe_2O_4$ with different heat treatment temperatures and masses of activated carbon

XRD patterns of oxygen vacancies-engineered $NiFe_2O_4$ with different heat treatment temperatures and masses of activated carbon are shown in Fig. S2. It can be seen that a little Fe_2O_3 impurities exist in all of the samples obtained in 400 ℃. In addition, as the heat treatment temperature increasing, crystallinities of the samples are getting better and better. While the masses of activated carbon have little effect on the components of the samples.

According to the results of SEM images and XRD patterns, 500 ℃ is considered to be the best reaction temperature for the production of oxygen vacancies-engineered $NiFe_2O_4$. The samples with activated carbon masses of 0.1, 0.2, 0.3 and 0.4 g are marked as NFO-C-0.1, NFO-C-0.2, NFO-C-0.3 and NFO-C-0.4, respectively.

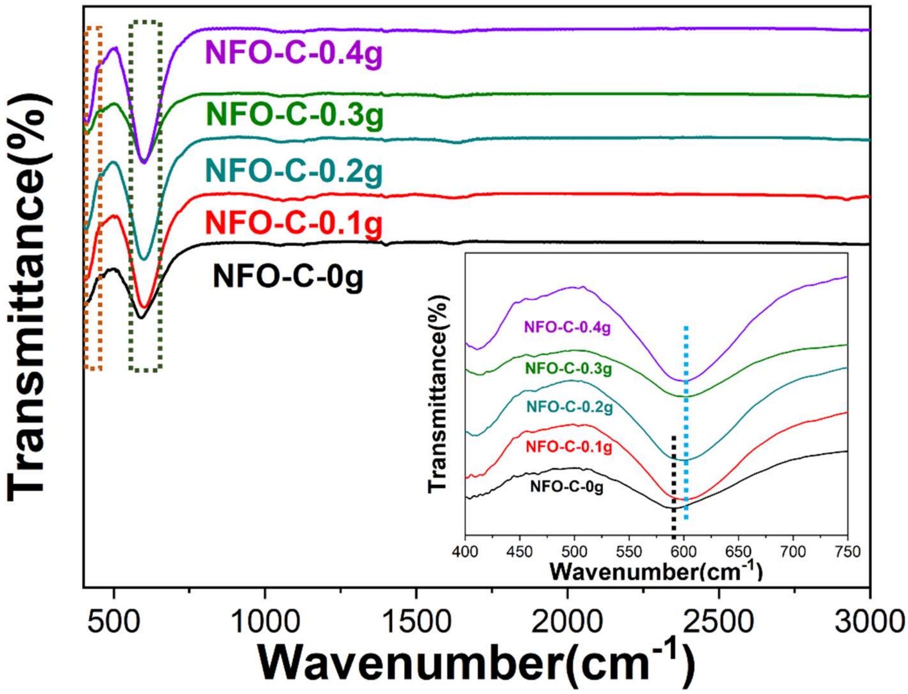

Fig. S3 FTIR patterns of the original $NiFe_2O_4$ and oxygen vacancies-engineered $NiFe_2O_4$ heat-treated at 500 °C with different masses of activated carbon.

Figure S3 shows FTIR patterns of the original $NiFe_2O_4$ and oxygen vacancies-engineered $NiFe_2O_4$ heat-treated at 500 °C with different masses of activated carbon. From what we can see, all of the samples have distinct peaks at the wavenumber of 404–410 cm^{-1} and 589–601 cm^{-1}. Meanwhile, compared with the original $NiFe_2O_4$ sample, phenomena of peaks shift appear in all of the samples after heat treatment with activated carbon, which can prove the successfully formation of oxygen vacancies.

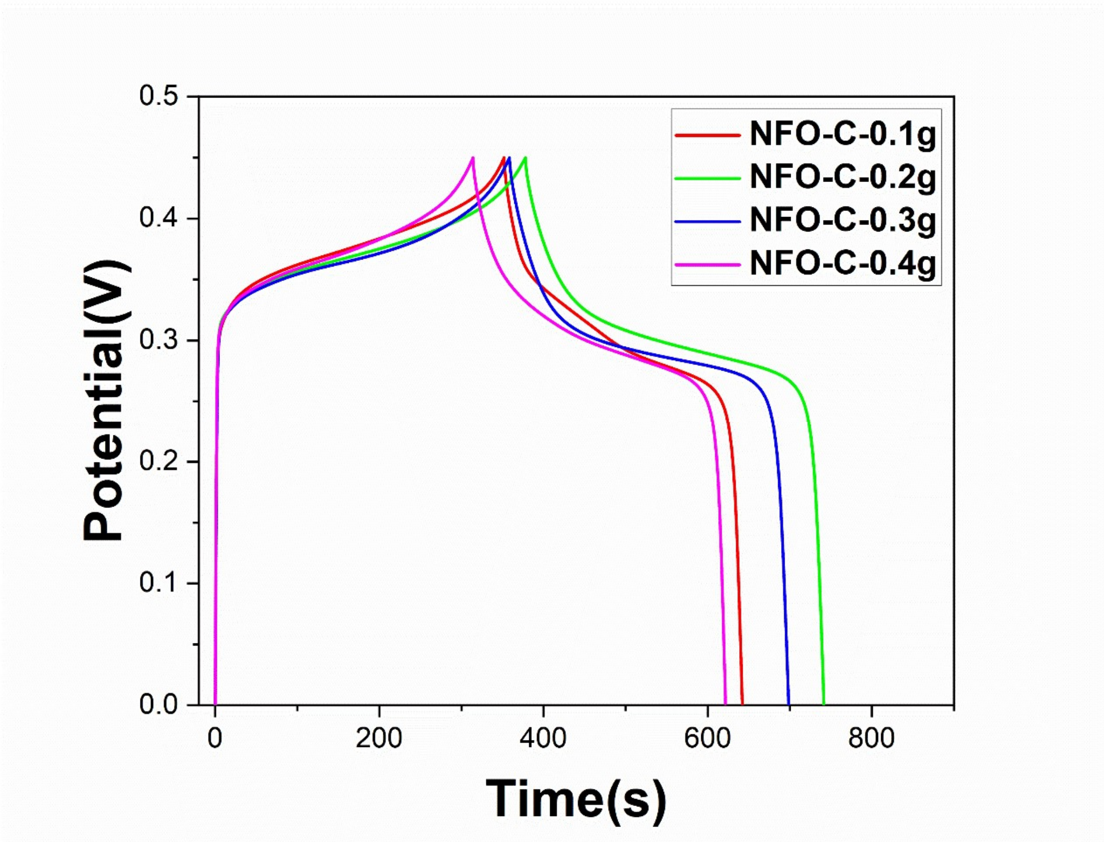

Fig. S4 GCD curves of the oxygen vacancies-engineered $NiFe_2O_4$ heat-treated at 500 °C with different masses of activated carbon.

Figure S4 shows GCD curves of the oxygen vacancies-engineered $NiFe_2O_4$ heat-treated at 500 °C with different masses of activated carbon. Calculated through Eq. (1), specific capacitances of NFO-C-0.1 g, NFO-C-0.2 g, NFO-C-0.3 g and NFO-C-0.4 g are 645, 808, 756 and 683.3 F/g. Hence, heat treatment temperature of 500 °C with 0.2 g activated carbon is proved to be the best reaction condition for the formation of oxygen vacancies-engineered $NiFe_2O_4$.

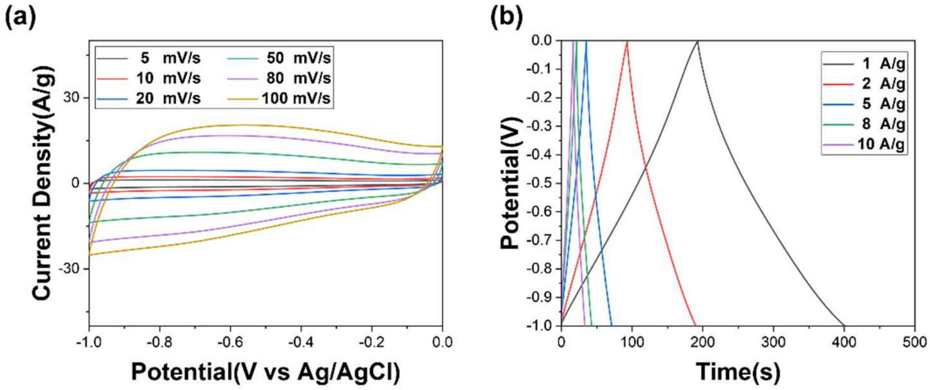

Fig. S5 (a) CV curves and (b) GCD curves of activated carbon.

Figure S5(a) shows CV curves of activated carbon at different scan rates. The typical rectangular shape indicates an ideal electric double layer capacitor. Besides, Fig. S5(b) displays GCD curves of activated carbon at different current densities. The calculated specific capacitances are 207.9, 193.6, 178.5, 170.4 and 166.0 F/g at 1, 2, 5, 8 and 10 A/g.