interconnected structure of these nanospheres. As can be seen, the outer partially graphitic carbon layer with a thickness of 3∼8 nm is uniform and continuous, and the inner magnetite cores with average diameter of ∼50 nm consist of several Fe_3O_4 nanocrystals with an average size of ∼9 nm. The lattice *d*-spacings of 0.483 and 0.252 nm corresponding to (111) and (311) planes of Fe_3O_4, respectively, are identified in Fig. 3(c and d). In order to quantify the weight percentage of Fe_3O_4 in these nanospheres, TGA was carried out and the data are shown in Fig. 4(a). The material is heated to 1000 °C under air so that Fe_3O_4 is oxidized to Fe_2O_3 and carbon is oxidized to CO_2. From the remaining weight of Fe_2O_3, the original weight fraction of Fe_3O_4 is calculated to be 62.64%.

The as-obtained Fe_3O_4@C nanospheres were also characterized by Raman spectroscopy in detail to further validate the presence of partially graphitic carbon on the Fe_3O_4 nanocrystals. Representative Raman spectrum is shown in Fig. 4(b). The spectrum was collected within the 800–2000 cm^{-1} range, corresponding to the spectral region that provides the most valuable data on the structure of carbon materials. The recorded spectrum shows two broad Raman bands at about 1365 and 1589 cm^{-1}. The latter band corresponds to the E_{2g} mode (stretching vibrations) in the basal plane of the crystalline graphite (G graphitic peak). The width of the G-band is related to the extent of disorder within the carbon sp^2 plane graphene layer. The band located at 1365 cm^{-1} (D-band) is associated with disorder, it being allowed by zone edge modes of the graphite structure that becomes active due to the lack of long range order in amorphous and quasi-crystalline forms of carbon materials. The peak intensity ratio between D and G

bands (I_D/I_G) generally provides a useful index for comparing the degree of crystallinity of various carbon materials, i.e., smaller the ratio of I_D/I_G, higher the degree of ordering in the carbon material. The I_D/I_G ratio for our Fe_3O_4@C nanospheres was calculated to be ∼0.86, demonstrating that the carbon in the nanospheres we obtained is partially graphitic, which will be beneficial for achieving better electronic conduction between adjacent Fe_3O_4 nanocrystals. Nitrogen adsorption–desorption measurements are carried out at 77 K to study the textural characteristics of the Fe_3O_4@C nanospheres. As shown in Fig. 4(c), the isotherm profile of the sample can be categorized as type I with small a hysteresis loop observed at a relative pressure of 0.9–1.0, indicating that the pores inside the sample consist of micropores and mesopores, as further verified by the pore size distribution in Fig. 4(d). The BET specific surface area is measured to be 191.16 m^2/g, which is much higher than that of commercial Fe_3O_4 nanoparticles (about 2 m^2/g). It is believed that the relatively large specific surface area is beneficial for electrolyte access [20]. The nitrogen adsorption/desorption isotherm study (Fig. 4(d)) shows that the pores inside the sample consist of mesopores and micropores and the pore size distribution lies in 0.6–34.5 nm range. The pore volume of the product determined by the Barrett–Joyner–Halenda method is 0.63 cm^3/g. Combining the result with SEM measurements, the porous structure containing mesopores may benefit to the electrolyte ion diffusion to active sites with less resistance and tolerate the volume change of the Fe_3O_4 nanocrystals during charge/discharge cycles [20,34].

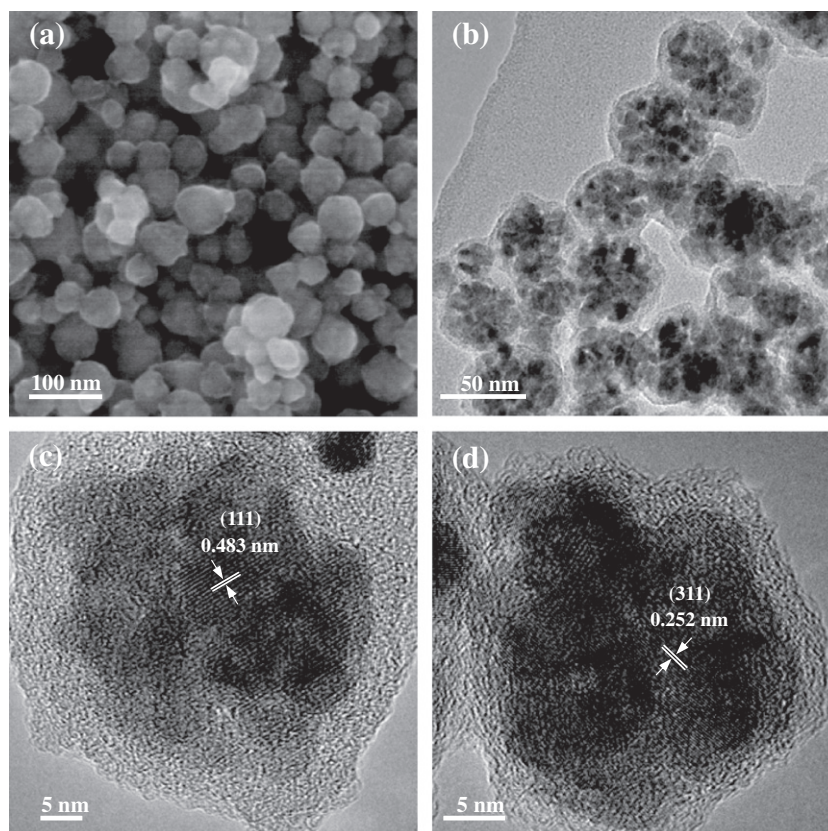Fig 5 shows the electrochemical performance of the Fe_3O_4@C nanospheres. As shown in Fig. 5(a), CV was applied

Fig. 3 – (a) SEM image of the Fe_3O_4@C nanospheres. (b–d) TEM images of the Fe_3O_4@C nanospheres.