CHAPTER 5

CONCLUSIONS AND SUGGESTIONS

5.1 The NiO films sparked on flexible Cr/Au coated PET substrates

In conclusion, NiO films were successfully fabricated by a sparking method and characterized for electrochemical energy-storage applications. The sparked NiO films exhibited excellent electrochemical energy storage performances with a high specific charge capacity of 402.75 C g^{-1} at a discharge current of 1 A g^{-1} and 88% capacity retention after 1000 cycles at a high discharge current of 40 A g^{-1}. The remarkable specific charge capacity could be attributed to the high electroactive surface area of highly porous films containing NiO nanoparticles. The key advantages of this technique include its convenient, low-temperature operation, and the low-cost system. Thus, the sparking method holds a promise as a practical and effective preparation technique of highly porous metal oxide films suitable for energy-storage applications.

5.2 The NiO film on Ni foams

In summary, the NiO/Ni foam electrodes were fabricated by a sparking method with varying sparking times from 45 to 180 min and systematically characterized for electrochemical energy storage applications. The structural characterizations by SEM, EDS, TEM, XPS and Raman spectroscopy revealed that the diameter of sparked NiO nanoparticles and the pore size of the porous NiO network simultaneously increased while the contribution of $Ni(OH)_2$ species on NiO surface decreased with increasing sparking time. From CV and GCD measurements, the optimal sparking time of 45 min resulted in the highest energy storage performances having high specific capacities of 920 C g^{-1} at 1 A g^{-1} and 699 (76% of 920) C g^{-1} at 20 A g^{-1} as well as a good cycling performance with 96% retention after 1000 cycles at a current density of 4 A g^{-1} and a low ESR of 0.4 Ω. The attained performances could be attributed to highly porous and very small NiO nanoparticles on large surface area 3D Ni foam structure as well as the higher contribution of active $Ni(OH)_2$ surface species. Therefore, the optimized NiO/Ni

foam electrode fabricated by the sparking method is a highly promising candidate for electrochemical energy storage applications.

5.3 Suggestions for future works

In this work, the key advantages of the sparking method include its convenient, low-temperature operation, and the low-cost system. Thus, the sparking method holds a promising route as a practical and effective preparation technique of highly porous metal oxide films suitable for energy-storage applications. The following suggestions for the future works on the fabrication and the characterization.

5.3.1 Although the results achieved with the present sparking method parameters are considered decent, some parameters including scanning speed and the number of scanning cycles should be investigated for optimal structure and electrochemical energy storage performances.

5.3.2 This process can be synthesized various transition metal oxide nanostructures including In_2O_3, Co_3O_4, V_2O_5, TiO_2 and ZnO, MoO_3 nanoparticles, etc. Thus, it should be further focused on the fabrication of the composite electrode, for example, the NiO and other transition metal oxide nanoparticles.

5.3.3 To achieve the high-performance electrode, the NiO films should be prepared by mixing or hybrid with the carbonaceous materials.

5.3.4 The pure NiO nanoparticles/films could be obtained by annealing the samples at the optimal time and temperature. The Mixed phase of NiO such $Ni(OH)_2$, NiOOH and so on might be had an effect on the electrochemical properties.

5.3.5 The effect of the thickness of NiO films should be considered, related to the specific capacity and their electrochemical performances.

5.3.6 The comparison of conductive current collector properties of the Cr/Au coated flexible PET substrates and Ni foam should be further considered. The difference in specific surface area, conductivities and the adhesion properties of NiO on the conductive substrates may influence their electrochemical properties.