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Development of new electrode materials for lithium ion batteries

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DEVELOPMENT OF NEW ELECTRODE MATERIALS FOR LITHIUM ION BATTERIES

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CERTIFICATION

I, Chao Zhong, declare that this thesis, submitted in fulfillment of the requirements for the award of Master of Engineering-Research, in the Institute for Superconducting & Electronic Materials, Faculty of Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Zhong Chao

Chao Zhong

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For my father and mother,

who love and support me all the time

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ABSTRACT

Rechargeable lithium-ion batteries that have been widely used in portable electronic devices are now extended to applications such as electric vehicles (EVs). Therefore, the performance of the rechargeable lithium-ion batteries must continue to be improved in terms of capacity, rate capability, cycle life, etc. In this Master's research study, to contribute to this goal, several materials were characterized and examined for possible applications as anode or cathode for rechargeable lithium-ion batteries. Among the anode candidates, nickel oxide (NiO), copper oxide (CuO) and copper oxide with carbon (CuO-C), and free-standing graphene-silicon (graphene-Si) were studied. Manganese dioxide (MnO_2) was also studied as a cathode material candidate for use in rechargeable lithium-ion batteries.

Hollow spherical NiO particles were prepared using the spray pyrolysis method with different concentrations of precursor for use in rechargeable lithium-ion battery anode. The electrochemical properties of the NiO electrodes, which contained a new type of binder, carboxymethyl cellulose (CMC), were examined for comparison with NiO electrodes with poly(vinylidene) fluoride (PVDF) binder. The electrochemical performance of NiO electrodes using CMC binder was significantly improved. For the cell made from 0.3 mol L^{-1} precursor, the irreversible capacity loss between the first discharge and charge was about 43% and 24% for the electrode with PVDF and CMC binder, respectively. The cell with NiO-CMC electrode has a much higher discharge capacity of 547 mAh g^{-1} compared to that of the cell with NiO-PVDF electrode, which is 157 mAh g^{-1} beyond 40 cycles.

Bare copper oxide and copper oxide–carbon composite were synthesized by a one-step spray pyrolysis method and tested as anode materials combined with CMC or PVDF binder for rechargeable lithium-ion batteries. The results demonstrate that the CuO-carbon composite in conjunction with CMC binder has excellent electrochemical performance, with a capacity of 633 mAh g^{-1} up to 250 cycles at a current density of 100 mA g^{-1}. Usage of the water soluble binder, CMC, not only further confirmed its potential for improving the electrochemical performance of transition metal oxides for use in lithium-ion batteries, but also makes the electrode fabrication process much easier and more environmentally friendly.

Flexible, free-standing, paper-like, graphene-silicon composite materials have been synthesised by a simple, one-step, in-situ filtration method. The Si nanoparticles are highly encapsulated in a graphene nanosheet matrix. The electrochemical results show that graphene-Si composite film has much higher discharge capacity beyond 100 cycles (708 mAh g^{-1}) than that of the cell with pure graphene (304 mAh g^{-1}). The graphene functions as a flexible mechanical support for strain release, offering an efficient electrically conducting channel, while the nanosized silicon provides the high capacity.

Finally, nanocrystalline MnO_2 powders were synthesized by a novel magnetic field assisted hydrothermal method and tested as cathode material in rechargeable lithium-ion batteries. It was found that the morphology of the MnO_2 prepared without magnetic field is characterized by an urchin-like structure, while the MnO_2 prepared in magnetic fields has a rambutan-like structure. A pronounced increase in the

Brunauer-Emmett-Teller (BET) specific surface area was obtained when the intensity of the pulsed magnetic field increased. The battery performance was improved for the samples prepared with magnetic fields. The MnO_2 prepared under a magnetic field of 4 T shows a capacity of 121.8 mAh g^{-1} after 30 cycles, while the MnO_2 prepared without magnetic field only shows 103.0 mAh g^{-1} after 30 cycles.

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