Low Pressure Chemical Vapor Deposition of Nickel Oxide for Use as Anode Material in Lithium-Ion Batteries

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1. Introduction

Lithium-ion batteries have a variety of applications, from usage in power tools and cell phones, to electric vehicles and pacemakers[1]. NiO is a promising anode material for Li-ion batteries due to its relatively high theoretical capacity (712 mAh/g vs. graphite anode's 372 mAh/g), easy synthesis, cost efficiency, and 2 equivalents of Li^+ per mole (graphite allows less than 0.5 equivalents)[2]. Furthermore, current anode designing processes involve mechanically binding materials to current collectors, which has been shown to inhibit the long term cycling ability of NiO anodes developed this way. Our research involves using Low Pressure Chemical Vapor Deposition (LPCVD) at 600°C to chemically bind nickel-based materials to stainless steel 304 current collectors and testing their electrochemical properties.

2. NiO/α-Ni(OH)$_2$

$$Ni(acac)_2 \xrightarrow[O_2,\ Ar]{\Delta\ (600°C)} \text{metallic Ni} \xrightarrow[Air]{\Delta\ (600°C)} NiO/\alpha\text{-}Ni(OH)_2$$

1a)

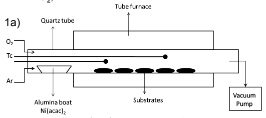


Fig 1a. Setup for deposition of NiO/α-Ni (OH)$_2$

LPCVD chamber pressure => 3.7 Torr

2a)

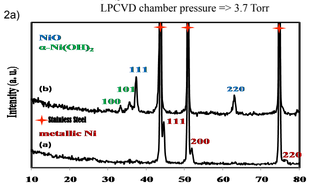


Fig 2a. XRD patterns for NiO and Ni (OH)$_2$ (pre- and post-annealing)

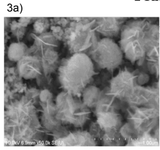
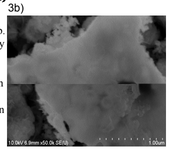
3a)  3b) 

Fig 3a and 3b. SEM imagery of NiO/α-Ni (OH)$_2$. Taken at x59k magnification

3. Ni(OH)$_2$

$$Ni(OH)_2 + 2Li^+ \rightarrow 2LiOH + Ni$$
$$Ni(OH)_2 + OH^- \leftrightarrow NiOOH + H_2O + e^-$$

$$Ni(acac)_2 \xrightarrow[O_2,\ Air]{\Delta\ (600°C)} Ni(OH)_2$$

1b)

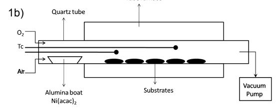


Fig 1b. Setup for deposition of Ni(OH)$_2$

LPCVD chamber pressure => 4.3 Torr

2b)

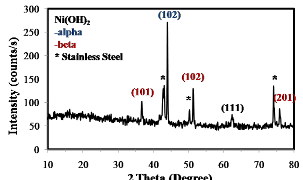


Fig 2b. XRD patterns for as deposited Ni(OH)$_2$ α- and β-orientation peaks are shown.

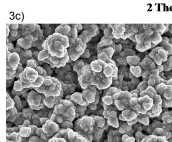
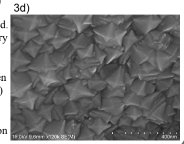
3c)  3d) 

Fig 3c and 3d. SEM imagery of NiO/α-Ni (OH)$_2$. Taken at x8k (left) and x120k (right) magnification

4. NiO

$$NiO + 2Li^+ \rightarrow Li_2O + Ni^+$$

$$Ni(acac)_2 \xrightarrow[O_2]{\Delta\ (600°C)} NiO$$

1c)

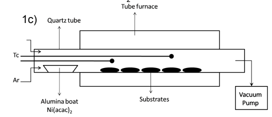


Fig 1c. Setup for deposition of NiO

LPCVD chamber pressure => 6.3 Torr

2c)

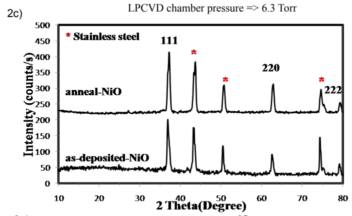


Fig 2c. XRD patterns for as-deposited and annealed NiO.

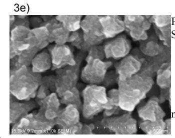
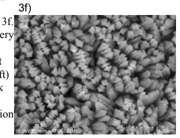
3e)  3f) 

Fig 3e and 3f. SEM imagery of NiO. Taken at x110k (left) and x40k (right) magnification

5. Cyclic Voltammetry

4a.

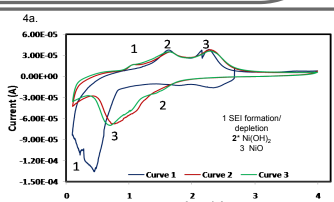


Fig 4a. Cyclic voltammetry of NiO/Ni(OH)$_2$ prior to cycling.

4b.

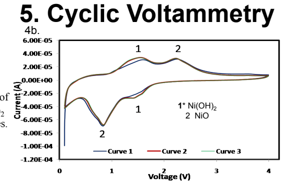


Fig 4b. Cyclic voltammetry of NiO/Ni(OH)$_2$ after 15 cycles.

4c.

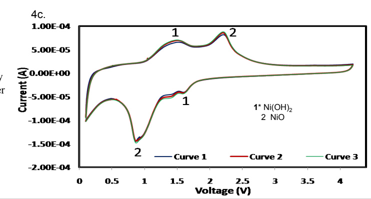
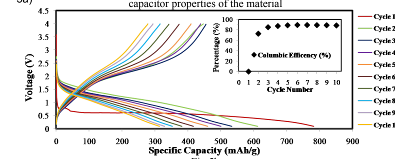


Fig 4c. Cyclic voltammetry of NiO/Ni(OH)$_2$ after 30 cycles.

6. Galvanostatic Charge-Discharge

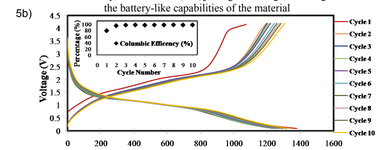
5a)

Fig 5a. First 10 cycles of NiO charge-discharge, showing the pseudo capacitor properties of the material

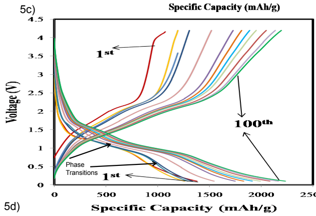


5b)

Fig 5b. First 10 cycles of NiO/Ni(OH)$_2$ charge-discharge, showing the battery-like capabilities of the material



5c)



5d)

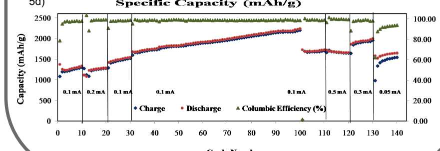


Fig 5c and 5d. Long-term cycling and columbic efficiency of NiO/Ni(OH)2. Shown with varying currents.

7. Conclusions

- The direct growth of pure NiO, pure Ni(OH)$_2$, and a mixture of both onto stainless steel 304 current collectors via LPCVD was successful
- The XRD and SEM revealed nanoparticles from the as-deposited material where as the annealed material was identified as crystalline structure(s).
- The pure-NiO cell's electrochemical properties exhibit the performance of a capacitor[4].
- The NiO/Ni(OH)$_2$ cell's electrochemical properties exhibit the performance of a battery[4].
  - The durability and binding of the material to the substrate proved stronger than what is indicated in literature
- Thus, chemical bonding proves to be more reliable than polymer and/or additives.

8. Future Work

- Decrease deposition time to generate a more uniform class of nanomaterials
- Transition into removing liquid electrolyte from the electrode, and use LiPON, solid state electrolyte, to manufacture solid state batteries.
- Run cyclic voltammetry on α-Ni(OH)$_2$ and β-Ni(OH)$_2$

9. Acknowledgments

This material is based upon work supported by the National Science Foundation under the NSF EPSCoR Cooperative Agreement No. EPS-1003897 with additional support from the Louisiana Board of Regents

10. References

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