Magnetic Properties of Polycrystalline $NiCo_2O_4$ from Solid State Reaction

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Motivation for Research

- Oxides, compared to pure metals, usually are poor conductors. It is of interest that some display high magnetization or conductivity. **$NiCo_2O_4$, or Nickel Cobalt Oxide (NCO) has been shown to have both.**
- NCO has a Curie temperature of 420K.[2] **It is theorized that a different stoichiometry of NCO could have an even higher Curie temperature.** This could allow applications for spintronics or in supercapacitors.[1,3]
- NCO has a crystalline structure called a spinel (fig 1b). Different ratios of Ni, Fe, and Co can create stable spinel structures (fig 1a). The metal ions bind at two different types of sites formed by the oxygen (fig 1c). Increasing the Ni to Co ratio could raise the Curie temperature.[2]

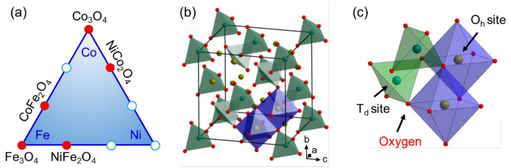


Figure 1 – Xu, et al[2]

Method

- Cobalt oxide and nickel oxide are mixed as powders in different ratios. The mixture is pressed and annealed at 900C for 12 hours.
- After annealing, the pressed target is ground into powder again and a small amount is scanned with the XRD machine.*
- Samples showing NCO peaks are measured with the SQUID.** Scans taken find the hysteresis loop of the material, if ferromagnetic, and the temperature dependence.

*XRD utilizes Bragg's law of diffraction to learn how far apart layers of the crystal are from signature peaks. (fig 2) This can identify constituent crystal structures of a sample.

**The SQUID is used to collect data about the magnetic properties of the material (fig 3).

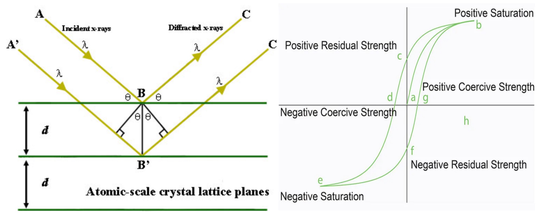


Figure 2 - https://serc.carleton.edu/

Figure 3 - https://idealmagnetsolutions.com/

Results

- **Effect of Multiple Calcinations -** As can be seen from (fig 4), multiple rounds of annealing causes the peaks signature of the spinel structure to increase relative to those signature of nickel oxide. This signifies an increase in amount of NCO in the sample.
- **Hysteresis Loops Show Ferromagnetic Behavior** – The data for figures 5,6 shows ferromagnetic and paramagnetic behavior at 20K. The coercive field is around 100 Oe, which matches NCO expectations. The drop in saturation field at 300K (fig 7,8) shows a lower Curie temperature than expected, which matches non-optimal NCO.[3] Figures 6,8 show the straight line background subtracted from figures 5,7 respectively. What remains is the ferromagnetic behavior, which should be NCO.
- **Field Cooled Scan Strange Result –** For a ferromagnetic material, it is expected to have a linear decay to a constant saturation after the Curie temperature. It is also expected that at low temperatures the saturation will decrease. The lack of this behavior is unexpected here (fig 9). The data seems to fit an exponential decay, though after around 200K it is possible the data is fitting linearly.

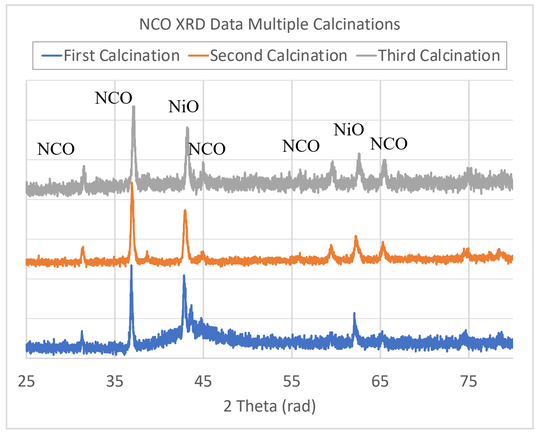
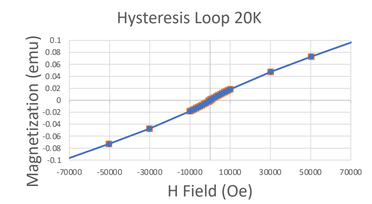


Figure 4 – Sample of NiO and Co_3O_4 mixed in a Ni/Co molar ratio of 1:2



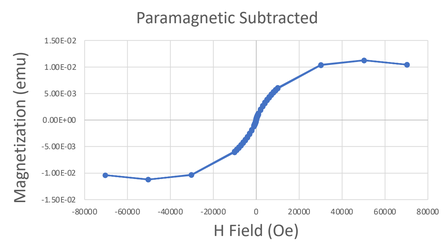
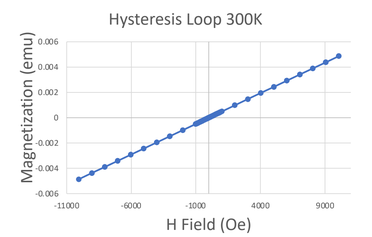


Figure 5,6 – Sample from figure 4 after 3 calcinations



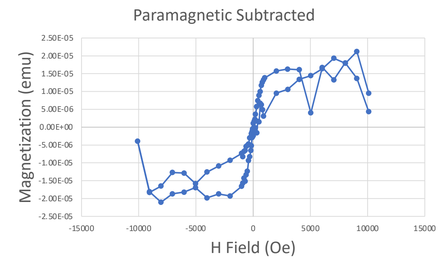


Figure 7,8 – Same sample at 300K

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Sources

1. https://doi.org/10.1016/j.jallcom.2021.159409
2. https://doi.org/10.48550/arXiv.2206.02021
3. https://doi.org/10.1063/5.0095326

Conclusions

- The XRD data shows that more NCO is being formed with multiple calcinations. This is an effective method of producing NCO.
- The SQUID data shows presence of non-optimal NCO.
- If possible, the process should be refined to produce optimal NCO.

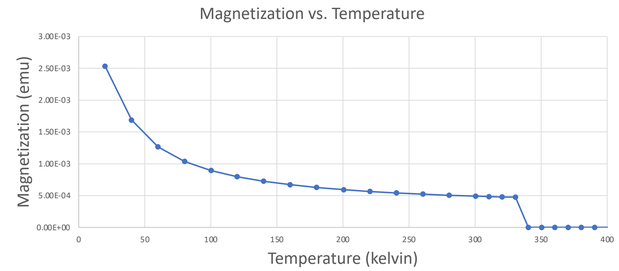

Figure 9 – Field cooled at 5T – sudden drop at 340K is from dislodging of the sample