# Magnetic Force Microscopy on $NiCo_2O_4$

*Caleb Schmidt, Dr Xiaoshan Xu*

*Department of Physics and Astronomy, University of Nebraska-Lincoln*

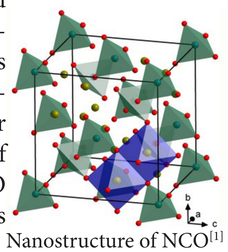
University of Nebraska Lincoln | Nebraska Center for Energy Sciences Research

## Abstract

The spinel $NiCo_2O_4$, or NCO, has gained attention due to recent discoveries. The first of these is that NCO utilized in supercapacitors has demonstrated high capacitances. The higher capacitances of NCO supercapacitors allow increased energy storage, making supercapacitors more competitive against traditional batteries. The second discovery is that NCO thin films, when grown on certain substrates, has an out of plane magnetic component. Usually, these magnetic components would be in-plane. The combination of these phenomena makes NCO thin films worthy materials for characterization. Here, Magnetic Force Microscopy, or MFM, was used to characterize the magnetic domains of the NCO thin films. This research helps us to understand why NCO acts as it does, and to better understand its effects in application.

## NCO Thin Films

NCO thin films have surprisingly different characteristics depending on what kind of substrate it is grown on. Here, NCO was grown on two different kinds of substrates, $Al_2O_3$, and $MgAl_2O_4$, or MAO. The MAO substrates also have different orientations, (111), (110), and (100). The $Al_2O_3$ substrates only have one orientation. The MAO (100) substrates had their magnetic moments directed out of plane. These thin films also displayed overall higher magnetic properties compared to their counterparts. The investigation of these two effects made the MAO (100) substrates the focus of this project.




Nanostructure of NCO[1]

## Citations

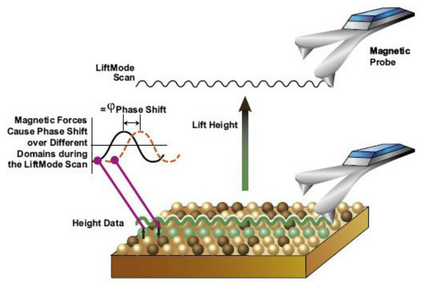
[1] Congmian Zhen et al J. Phys. D: Appl. Phys. 51 145308(2018)

[2] Magnetic Force Microscopy – MFM. Retrieved from https://blog.brukerafmprobes.com/guide-to-spm-and-afm-modes/magnetic-force-microscopy-mfm/

## Magnetic Force Microscopy

Magnetic force microscopy measures the magnetic force on the tip. From this, the magnetic domain walls are found. However, other forces, besides just the magnetic force, can be felt by the tip. To compensate for this, an Atomic Force Microscopy scan is done before the MFM scan to determine the topography of the material. Additionally, to minimize the forces applied on the tip during the MFM scan, the tip is raised, in this case 30nm, to avoid most of the unwanted forces.

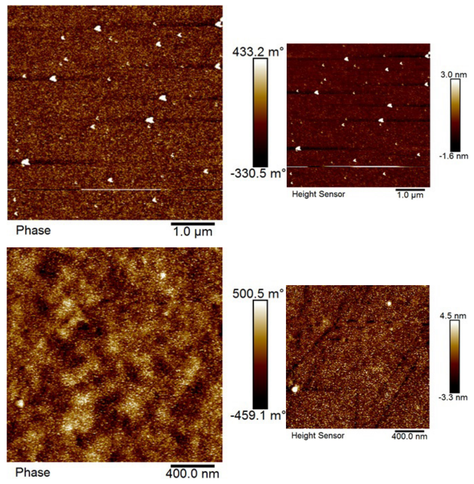
$$\vec{F} = \mu_0(\vec{m} \cdot \nabla)\vec{H}$$



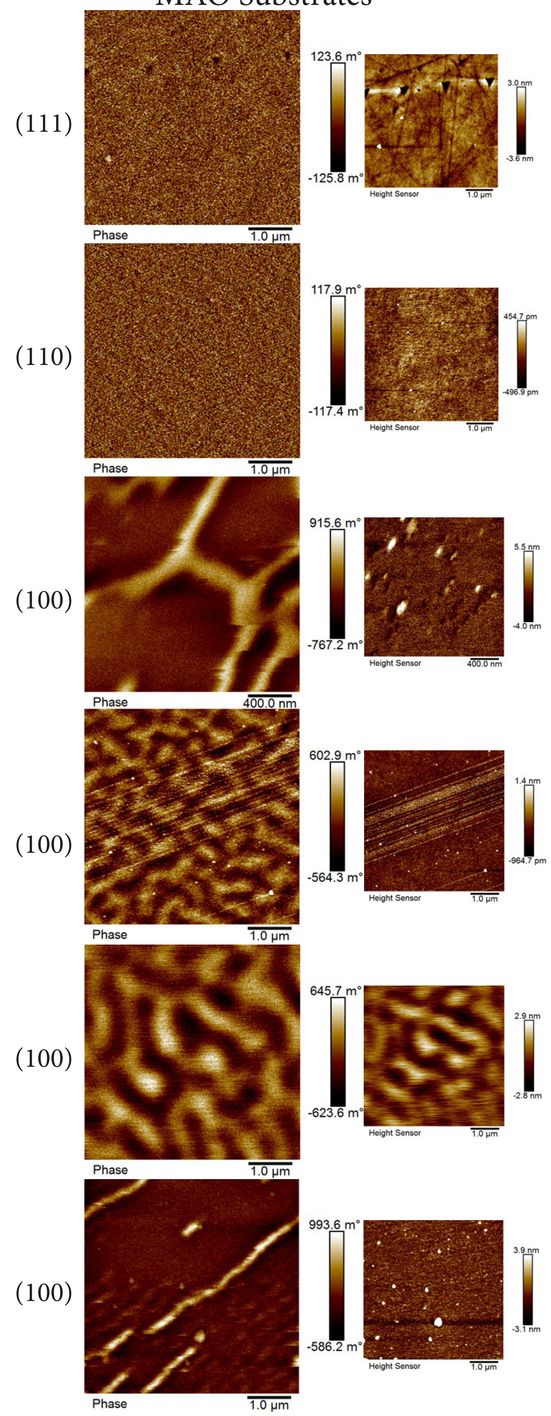

The MFM Scan[2]

## $Al_2O_3$ Substrates

The NCO grown on $Al_2O_3$ substrates displayed no significant magnetic domains detectable to the MFM scans. This agrees with other measurements indicating NCO grown on $Al_2O_3$ has no or minimal out of plane magnetic moment.



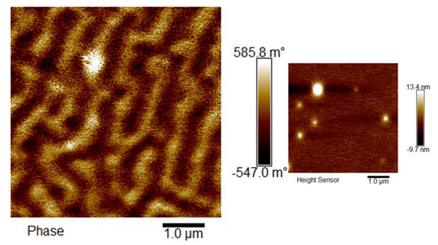

## MAO Substrates



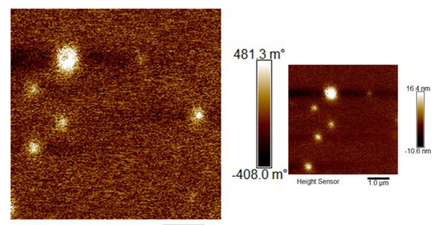

## Effects of Magnetization

A magnetic field of about 400 Gauss was applied to the thin film. This resulted in significant magnetization of the thin film, implying a high switchability for this material.

### Before Magnetization




### After Magnetization




## Conclusions

The magnetic anisotropy of the varying NCO thin films is shown to be predominantly in plane with $Al_2O_3$, MAO (111), and MAO (110) substrates. The MAO (100) substrates display remarkable out of plane magnetization and have natural magnetic domains of a few hundred nanometers. This indicates NCO grown on MAO (100) has great potential in magnetic storage. Additionally, the switchability for these thin films is quite high as the thin film was highly magnetized by a 400 Gauss magnetic field.

## Acknowledgements

This work is supported by funding received from Nebraska Public Power District through the Nebraska Center for Energy Sciences Research. Special thanks to Corbyn Mellinger, Ankit Pant, and Xiaozhe Zhang for supplying the thin film samples.

The University of Nebraska does not discriminate based upon any protected status. Please see go.unl.edu/nondiscrimination.

©2017. PL1701.

University of Nebraska Lincoln