# High-resolution Imaging and Spectroscopy of Co Oxide Octahedral Nanoparticles


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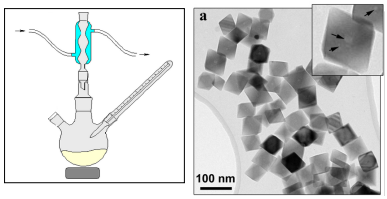
## Motivation

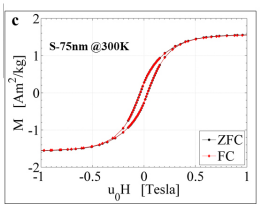
❖ Antiferromagnetic CoO has a very large magnetocrystalline anisotropy energy, which is comparable to that of the hard magnet SmCo. When it is used as a matrix for nanomagnets, it enhances or sustains the ferromagnetic properties of the nanomagnets by exchange bias [1]. Here, we assess whether size, strain or interface effects can induce ferromagnetism in Co oxide nanoparticles themselves.

## Synthesis & Morphology



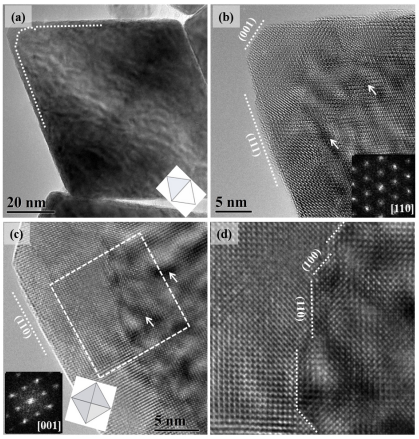

Thermodecomposition of cobalt (II) acetate tetrahydrate in trioctylamine and oleic acid.

## Magnetism

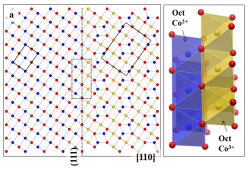



Room temperature ferromagnetism in Co oxide NPs revealed by SQUID.

## HR-TEM imaging

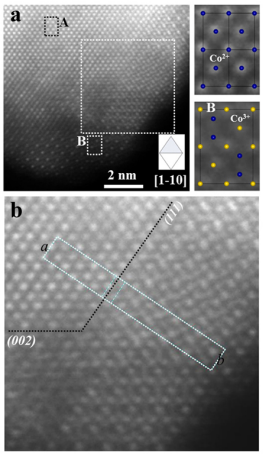


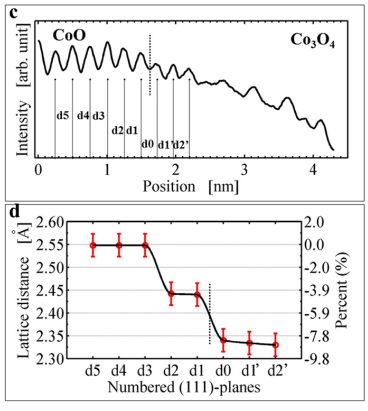

- **Octahedral shape**
- **CoO core**
- **$Co_3O_4$ shell**
- **{111} Interfaces**



Atomic Interface Model

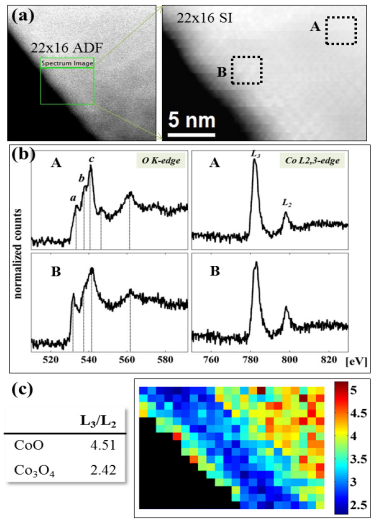
## HR-STEM imaging

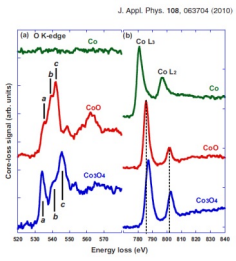



**a)** Atom-column-resolved HAADF image of the edge of a [1-10]-oriented CoO octahedron acquired in STEM mode at 80 kV using an ADF inner detector angle of 80 mrad and a probe size of 0.1nm. The core region A and the shell region B are overlaid by [1-10]-oriented atomic unit cells of CoO and $Co_3O_4$. **b)** Enlargement of the interface area shows a (111)-type interface between CoO and $Co_3O_4$. **c)** Intensity profile of the outlined area. **d)** Measured (111) plane lattice spacings at the interface region.

## STEM-EELS




Phase identification [2]:

- Characteristic O K-edge
- Intensity ratio $I(L_3)/I(L_2)$

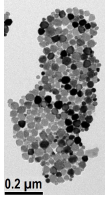
**a)** STEM-EELS spectrum image (SI) with 22x16 pixels, acquired at 80 kV using a probe size of 1 nm. **b)** Background-subtracted EEL spectra from the core (A) and shell (B) regions. **c)** $I(L_3)/I(L_2)$ map determined from the spectrum image using a second derivative method.

## ...Conclusion

- Octahedrally-shaped CoO nanocrystals have been synthesized and show unexpected ferromagnetic properties.
- A combination of high-resolution imaging and spectroscopic techniques provides comprehensive atomistic and electronic information about individual nanocrystals.
- Ferromagnetism in these nanocrystals may originate from the epitaxial {111}CoO/$Co_3O_4$ interface.

## Future work...

- Off-axis electron holography for nm-resolved magnetic characterization to study local intra-particle magnetic properties, as well as collective inter-particle magnetic interactions and dipolar magnetism in magnetic particle assemblies.
- Combined atomically-resolved STEM-EELS and first-principles calculations to understand the unexpected ferromagnetic properties of Co oxide nanocrystals.




## References


[1] V. Skumryev. et. Al. *Beating the superparamagnetic limitwith exchange bias.* Nature, **423** (2003), 850 .
[2] Y. Zhao et al. *In situ electron energy loss spectroscopy study of metallic Co and Co oxides.* J. Appl Phys. **108** (2010), 063704.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