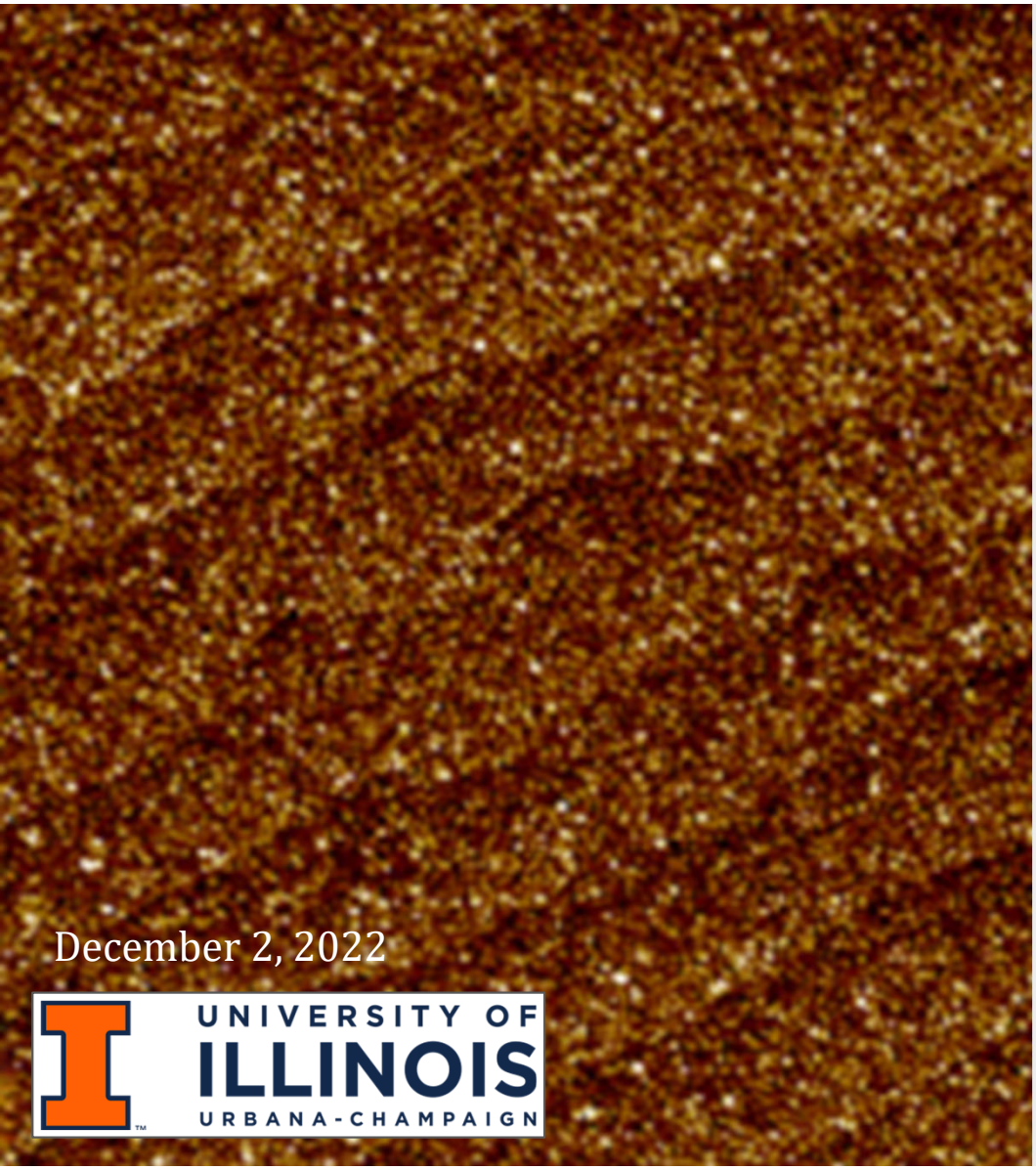


December 2, 2022

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

University of Illinois at Urbana-Champaign

Physics Department

PHYS 596

Journal Club Presentation:

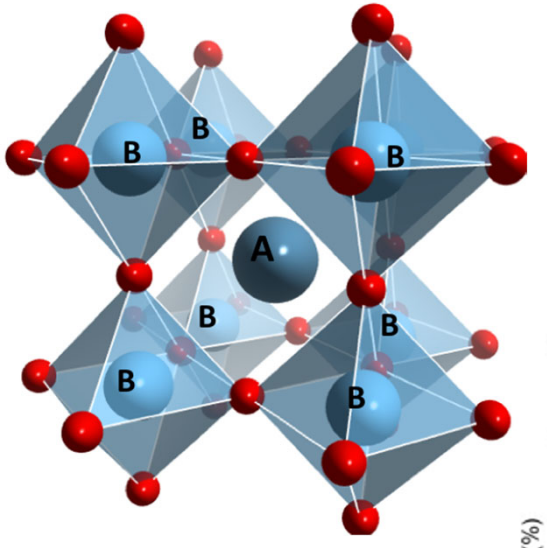
Weak ferromagnetism in $Tb(Fe_{0.2}Mn_{0.2}Co_{0.2}Cr_{0.2}Ni_{0.2})O_3$ high-entropy oxide perovskite thin films

Team 9: Ke Nie, Emma Pappas, Pedro Rivera-Cardona, Sophie Roberts, Kort Beck

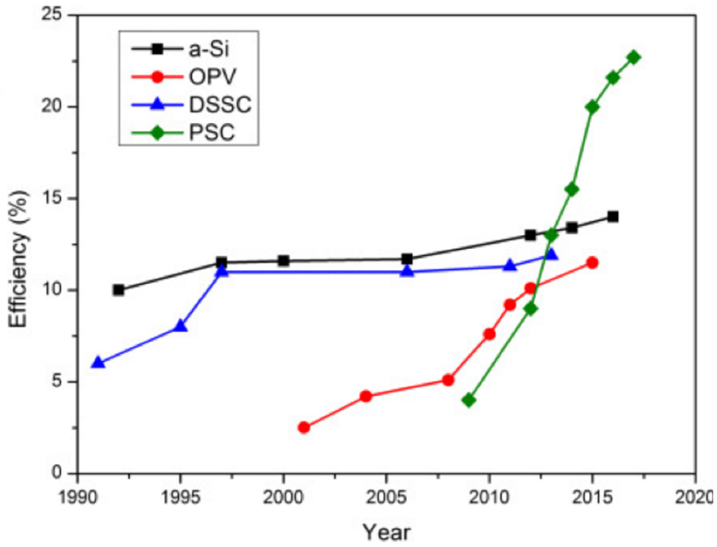
Farhan, Alan, et al. "Weak Ferromagnetism in $Tb(Fe_{0.2}Mn_{0.2}Co_{0.2}Cr_{0.2}Ni_{0.2})O_3$ High-Entropy Oxide Perovskite Thin Films." *Physical Review B*, vol. 106, no. 6, 2022, https://doi.org/10.1103/physrevb.106.l060404.

High Entropy Oxides are Scientifically and Technologically Interesting

- Rare-earth transition metal oxide perovskites have the general formula: ABO_3
- $Tb(Fe_{0.2}Mn_{0.2}Co_{0.2}Cr_{0.2}Ni_{0.2})O_3$ (T5BO) are a collection of compounds with interesting magnetoelectric behavior.
- Previous works have studied other high-entropy oxide perovskites (HEOPS) like L5BO (Lanthanum)
- HEOP-based solar cells lead to better energy conversion



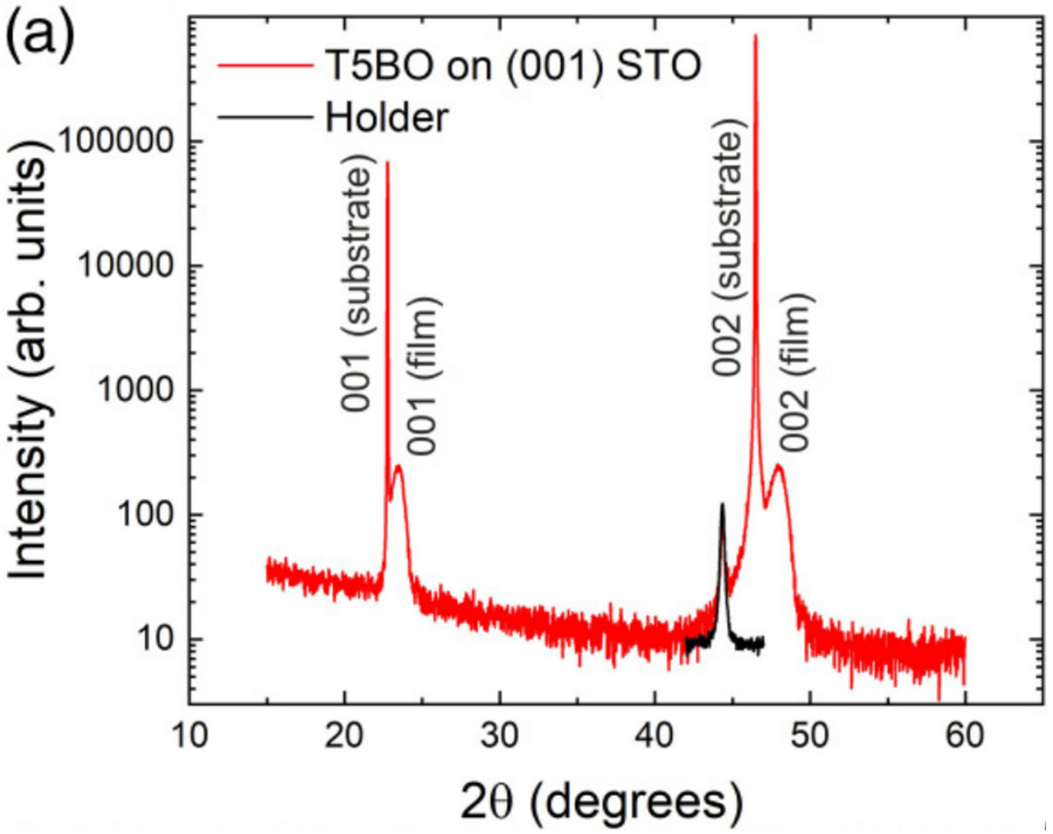
Perovskite (A = rare earth ion; B = 3D transition metal ions; red dots = oxygen)



https://the-gist.org/2020/01/perovskites-best-material-youve-never-heard-of/

Synthesis of T5BO

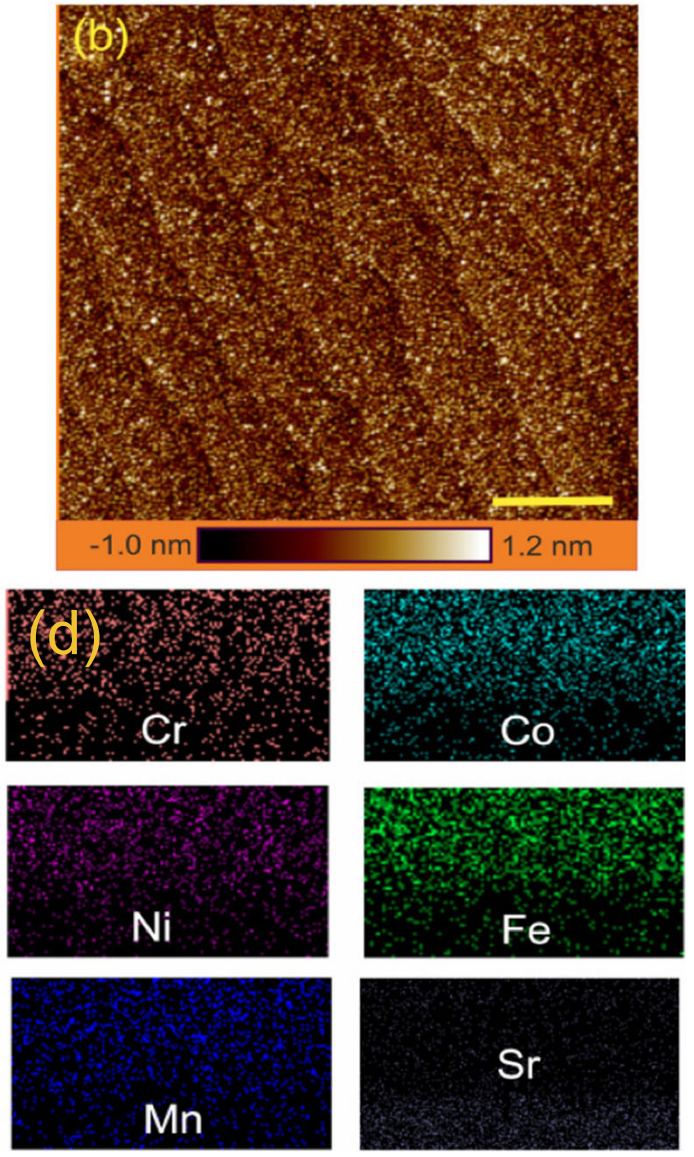
- T5BO thin films were synthesized via pulsed laser deposition (PLD) using a KrF excimer laser (λ = 248 nm) operating at 5 Hz
- Substrates : atomically flat TiO2-terminated SrTiO3 (STO)
- The obtained T5BO thin films are single crystalline



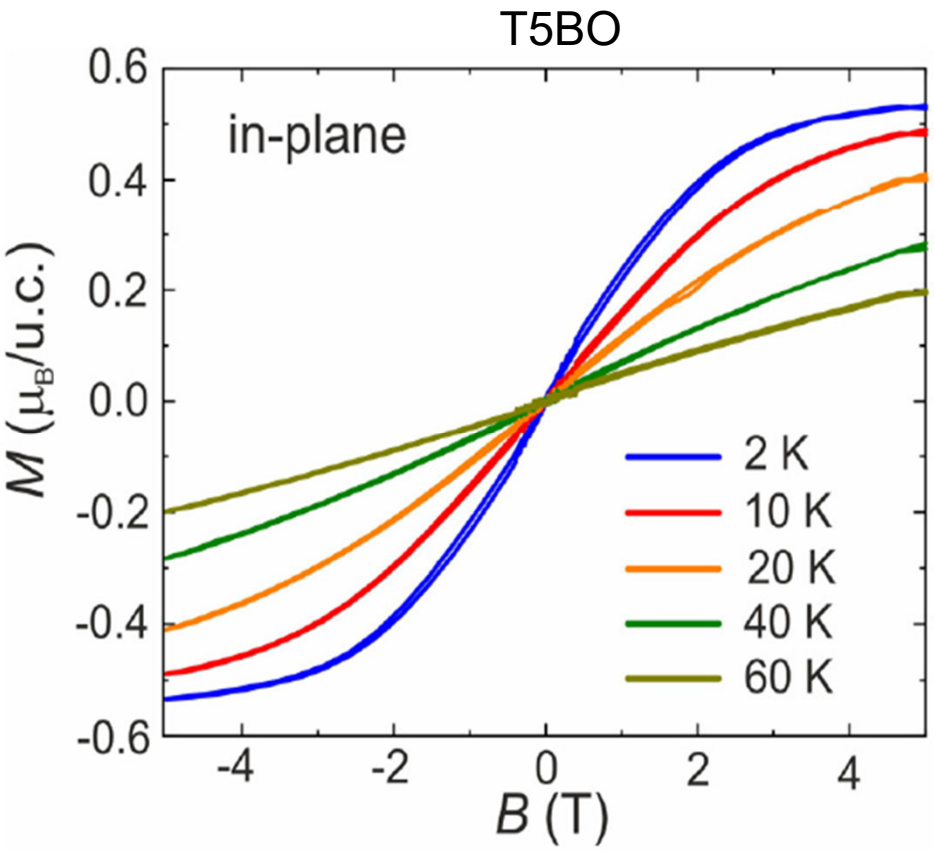
x-ray diffraction (XRD)
Out-of-plane lattice parameter c = 3.761 Å

Characterization of T5BO

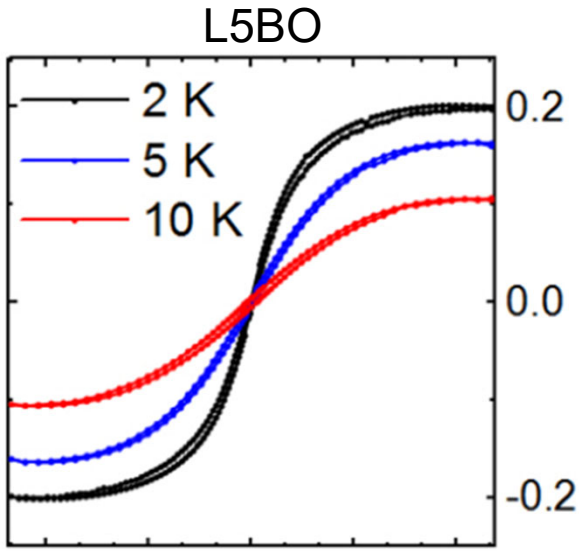
- **(b)** Atomic force microscopy (AFM) was performed to determine the surface morphology. Average roughness was 0.523 nm
- **(d)** Energy dispersive x-ray (EDX) spectroscopy shows homogeneous distribution of Fe, Mn, Co, Cr, Ni
- The magnetic properties were recorded using a superconducting quantum interference device (SQUID)
- Element-by-element magnetic contributions were measured via x-ray absorption spectroscopy (XAS) and x-ray magnetic circular dichroism (XMCD)



Magnetic Analysis | T5BO is ferromagnetic

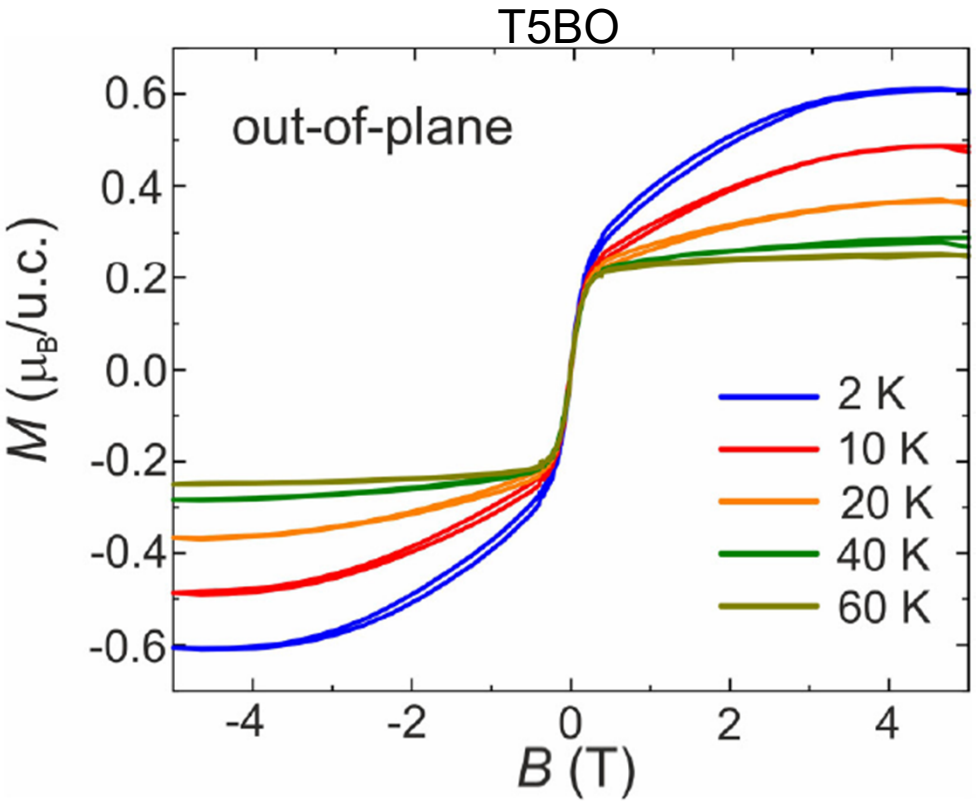


- Magnetic hysteresis loops have small openings
- Negligible magnetic hysteresis of the magnetization
- In-plane magnetization curves similar to L5BO

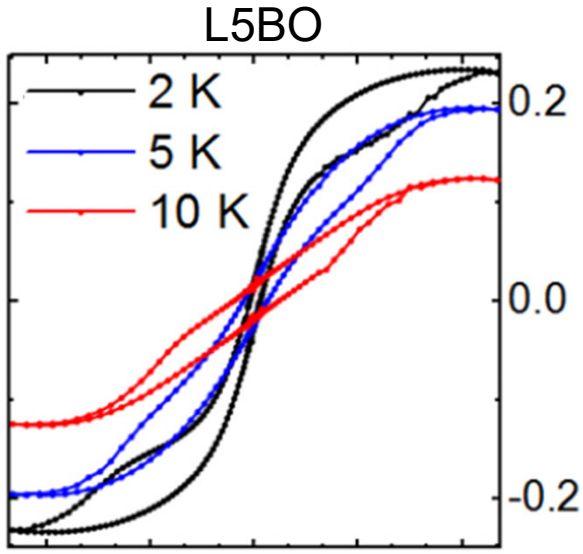


Y. Sharma, Q. Zheng, et al., Phys. Rev. Materials **4**, 014404 (2020).

T5BO has perpendicular magnetic anisotropy

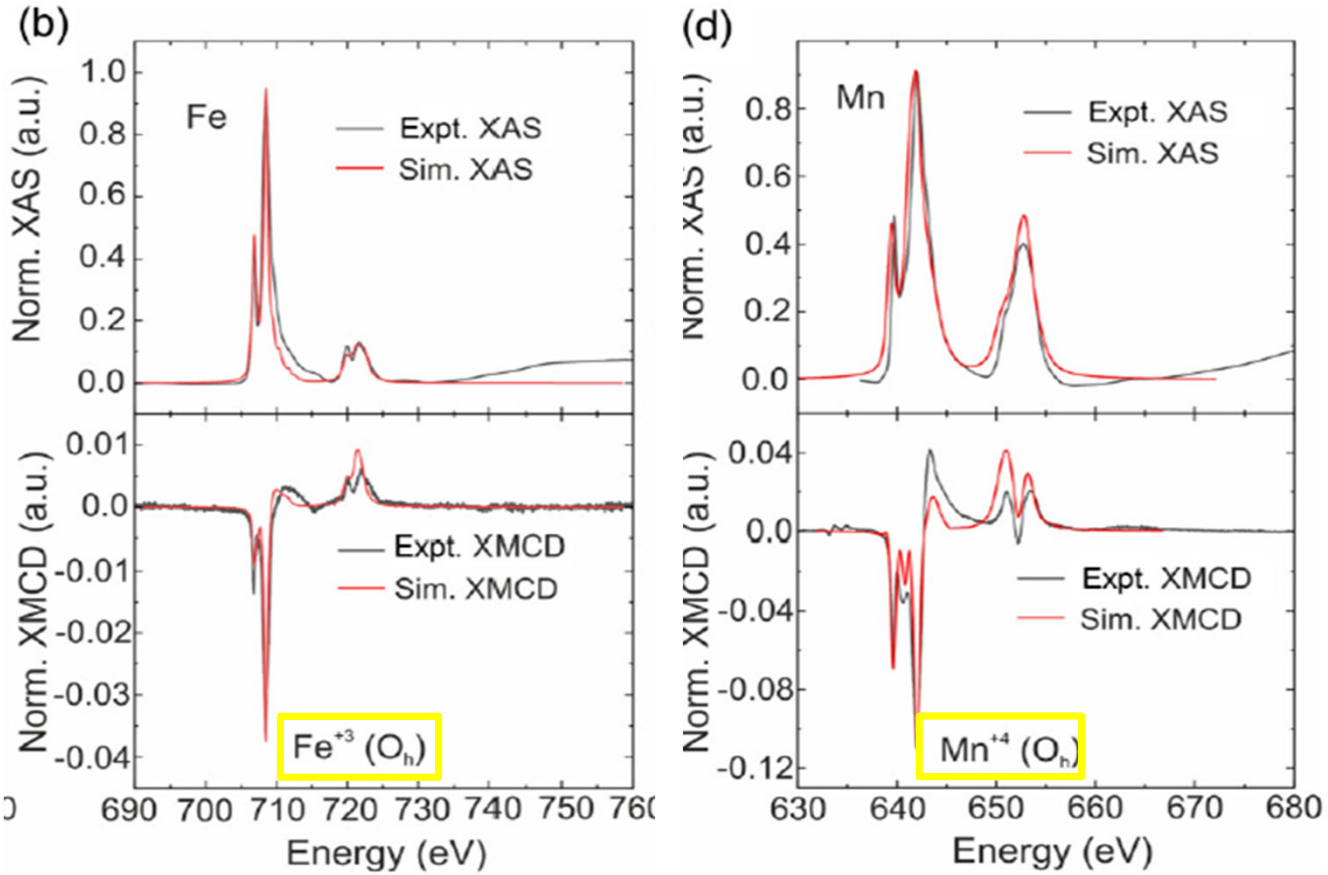


- T5BO has a wasp-waisted hysteresis at 2K
- No opening at zero
- Out-of-plane magnetization curves different from L5BO



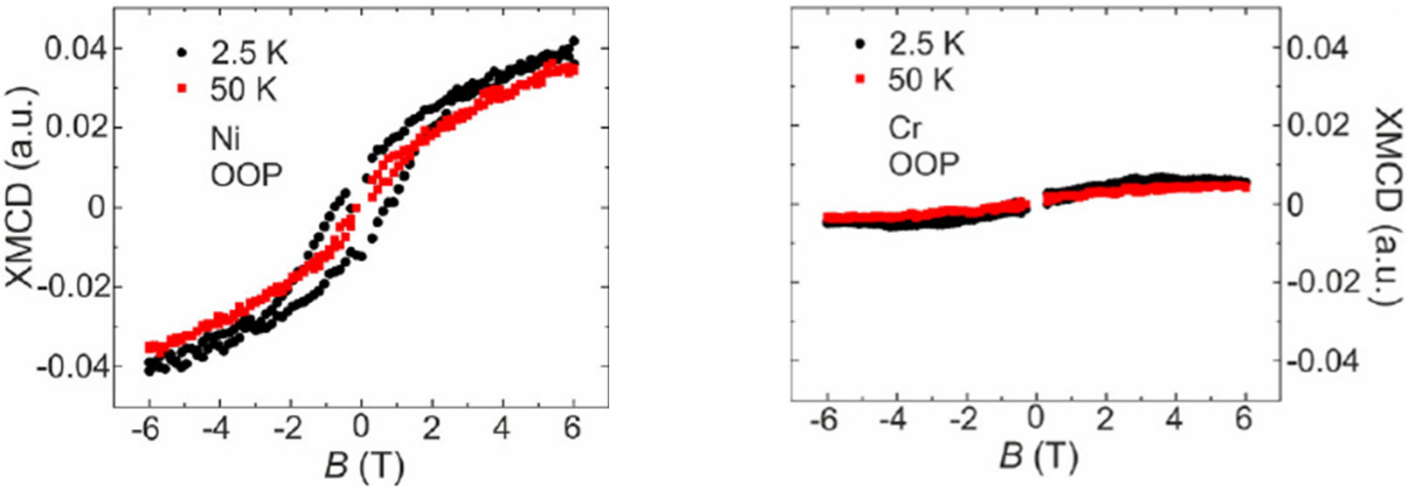
Y. Sharma, Q. Zheng, et al., Phys. Rev. Materials **4**, 014404 (2020).

Magnetic contributions per transition metal element



- XAS and XMCD allow to determine the valencies of the elements
- Bonds involving Fe and Cr are known to support antiferromagnetism
- Bonds involving Mn4+ - O - Co2+ and Mn4+ - O - Ni2+ are known to support ferromagnetism
- T5BO is ferromagnetic

XMCD Hysteresis Loops for different transition elements



- Element-sensitive XMCD hysteresis loops different from the macroscopic hysteresis loops.
- Ni shows the largest opening in its hysteresis curve and Cr features the weakest hysteresis.

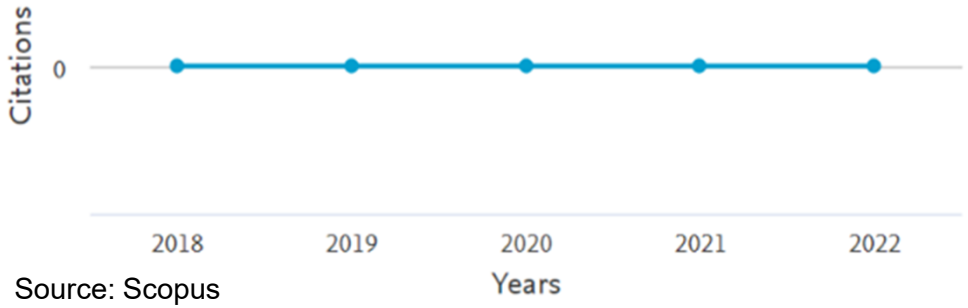
Critical Analysis

- Provides both macroscopic and element-wise measurements.
- Does not provide enough physical interpretations and comparisons were offered for the audience.
- The article lacks mention of practical applications for T5BO HEOP thin films.
  - Energy storage, data storage, sensing
- Due to the diversity of employed techniques, prior knowledge is needed for understanding this paper, which makes it less accessible to the general public.

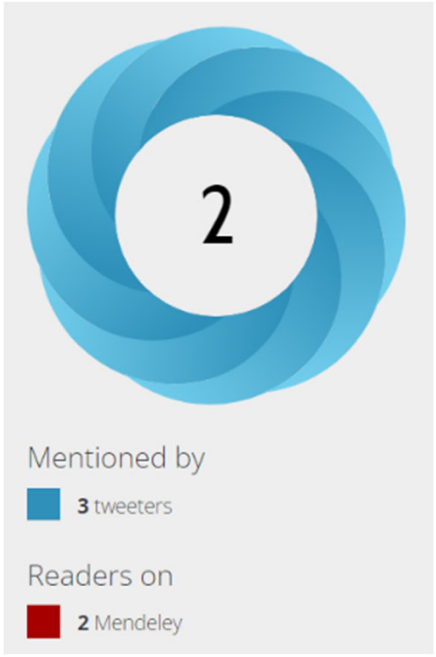
Source: Economic Times

Citation evaluation

- Published in August 2022
- No citations yet
- Not apparent how the field will evolve due to this paper yet
- So far, there are no other papers were T5BO is synthesized or studied



Source: Scopus

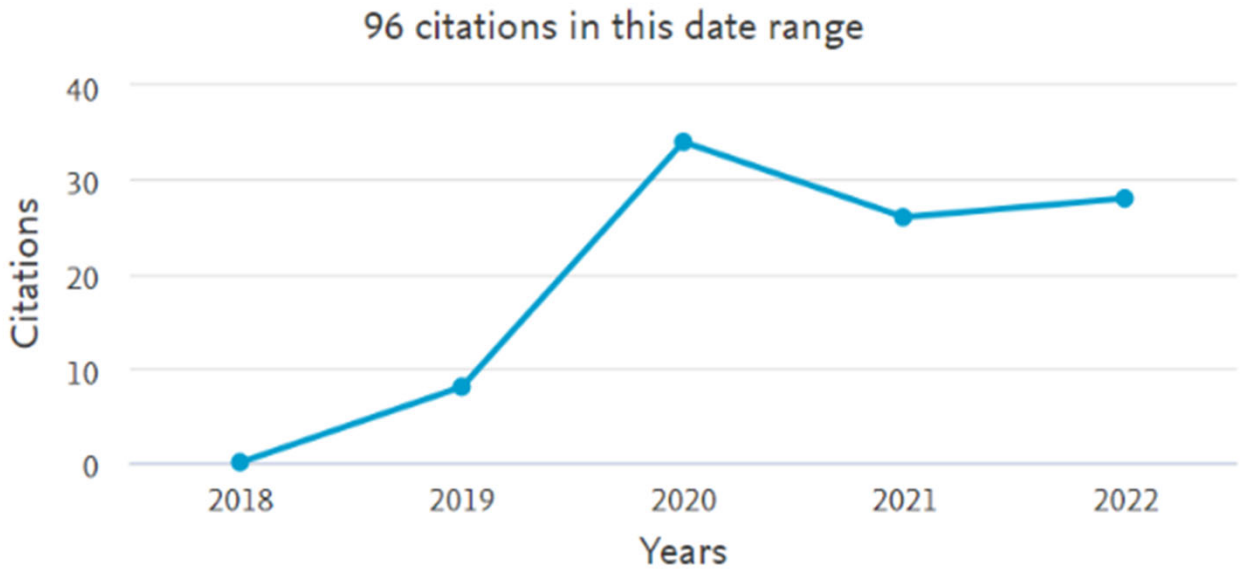


Source: Altmetric

TITLE	CITED BY	YEAR
Weak ferromagnetism in $Tb(Fe_{0.2}Mn_{0.2}Co_{0.2}Cr_{0.2}Ni_{0.2})O_3$ high-entropy oxide perovskite thin films A Farhan, F Stramaglia, M Cocconcelli, N Kuznetsov, L Yao, A Kleibert, ... Physical Review B 106 (6), L060404		2022

Source: Google Scholar

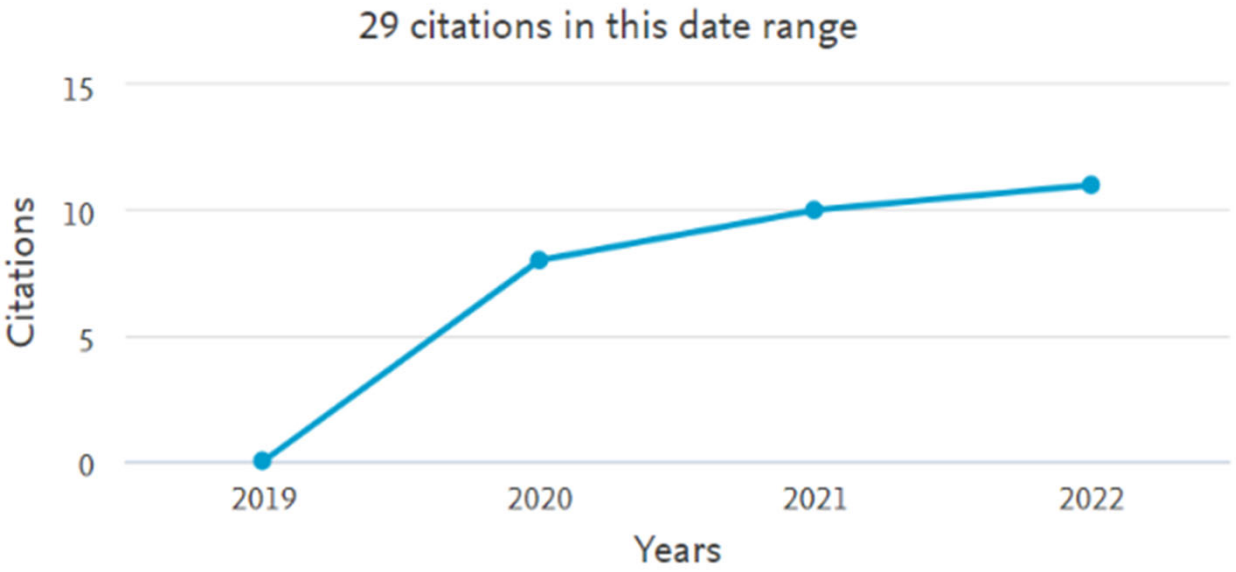
Citation evaluation - Similar Papers



Source: Scopus

Witte, Ralf, et al. “High-Entropy Oxides: An Emerging Prospect for Magnetic Rare-Earth Transition Metal Perovskites.” Physical Review Materials, vol. 3, no. 3, 2019, https://doi.org/10.1103/physrevmaterials.3.034406.

Citation evaluation - Similar Papers



Source: Scopus

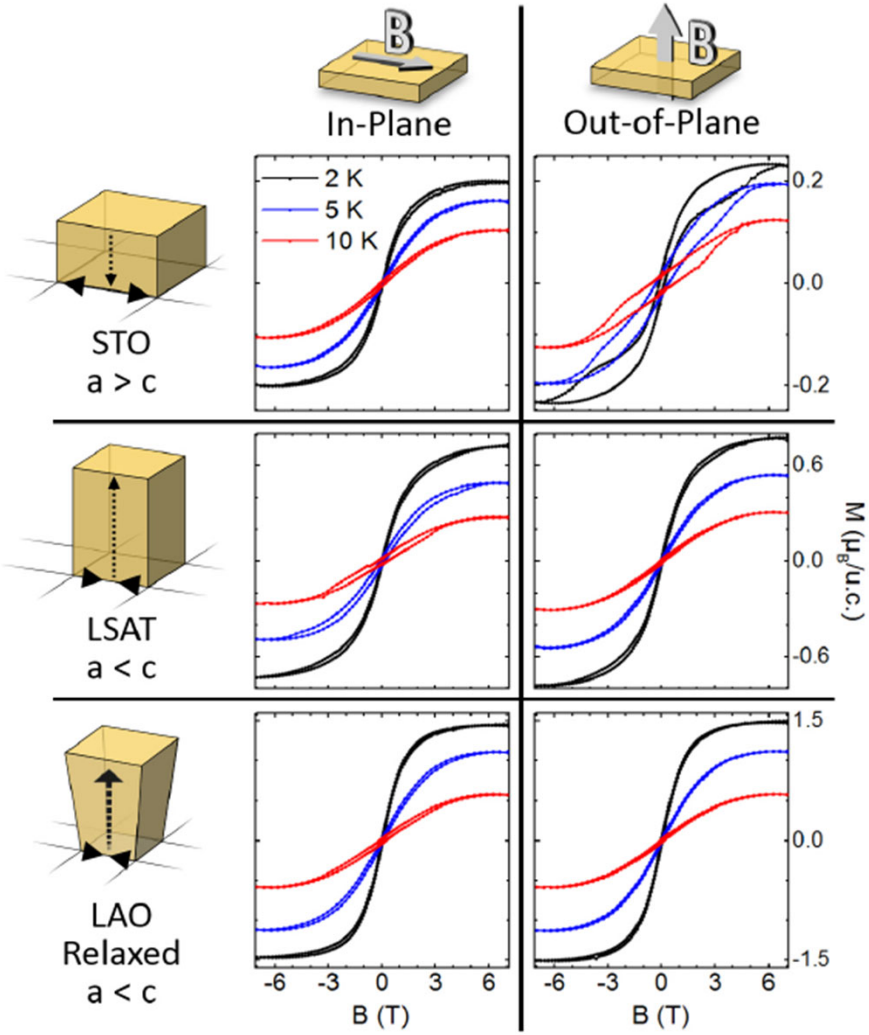
Sharma, Yogesh, et al “Magnetic Anisotropy in Single-Crystal High-Entropy Perovskite Oxide $La(Cr_{0.2}\ Mn_{0.2}\ Fe_{0.2}\ Co_{0.2}\ Ni_{0.2})O_3$ Films.” Physical Review Materials, vol. 4, no. 1, 2020, https://doi.org/10.1103/physrevmaterials.4.014404.

Future Work

Different substrates induce different lattice strain.

L5BO was grown on different substrates, which affected its magnetic hysteresis curves.

How do different strains affect T5BO?



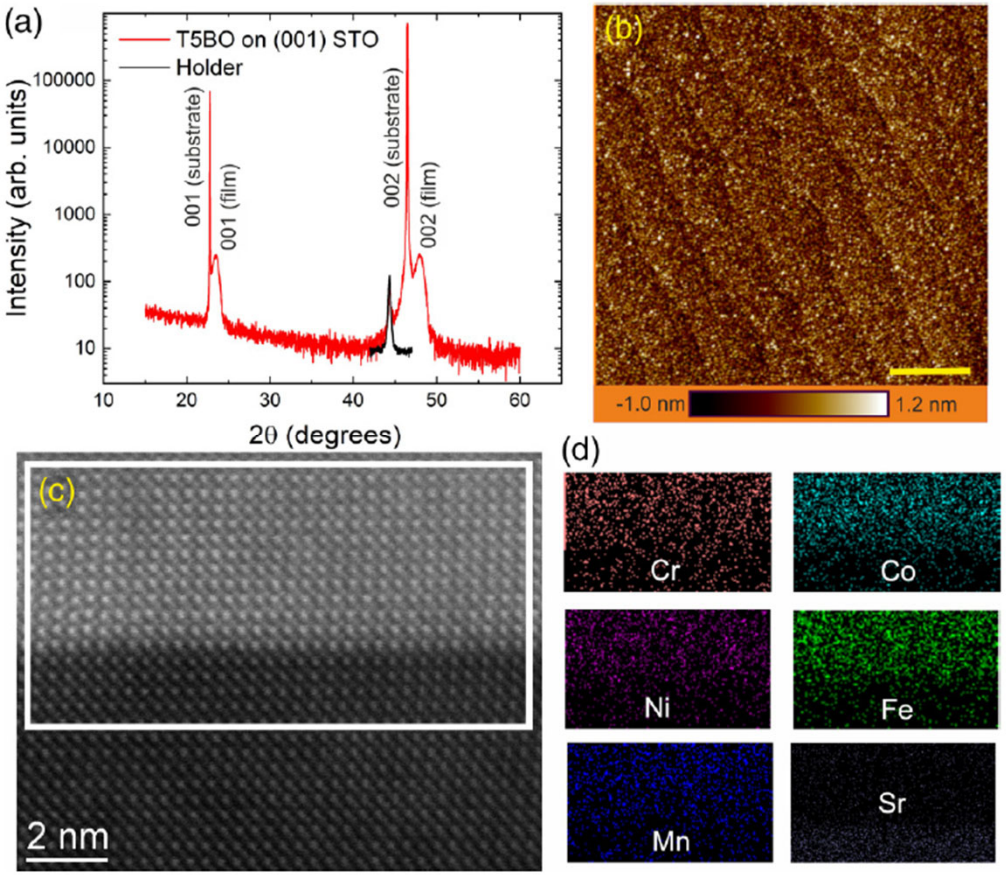
Y. Sharma, Q. Zheng, et al., Phys. Rev. Materials **4**, 014404 (2020).

Conclusion: The main takeaways from this paper

- T5BO HEOP thin films have interesting properties for solar cells and laser systems
- Combinations involving Mn4+ and Co2+ are the drivers for ferromagnetism in T5BO
- Most combinations involving Fe and Cr support antiferromagnetism
- Might be a common feature on HEOPs
- Growing T5BO on different substrates still needs to be explored

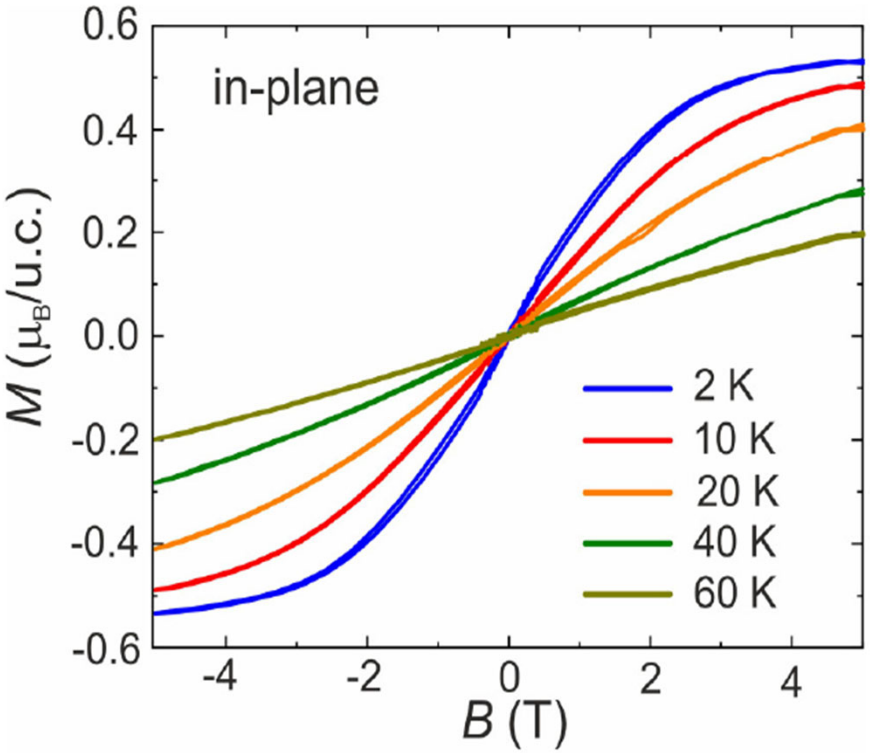
Extra slides

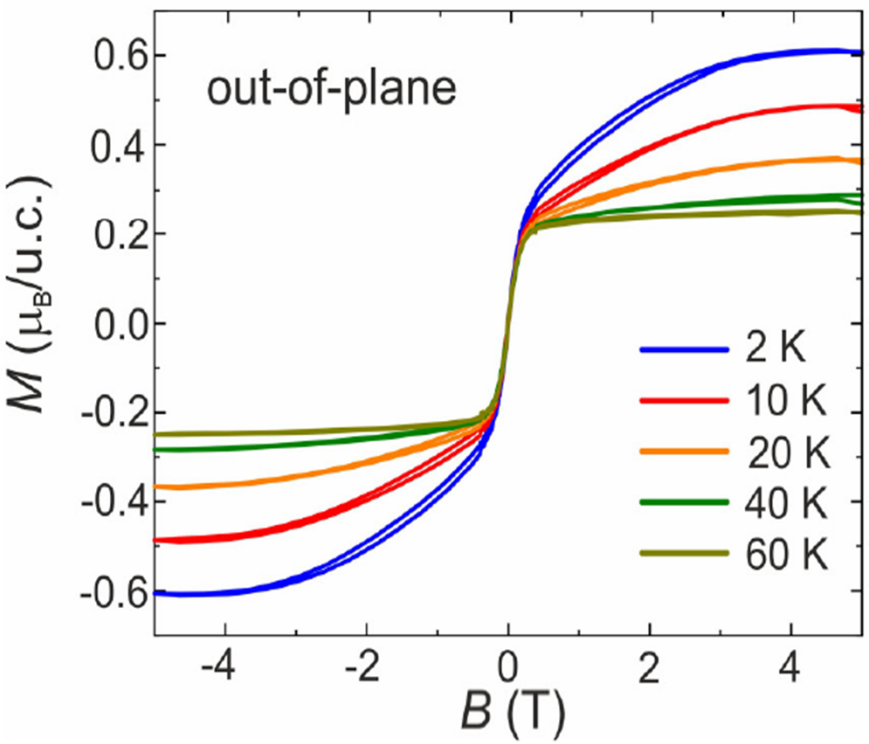
Growth of the thin films using Pulsed Laser Deposition (PLD)



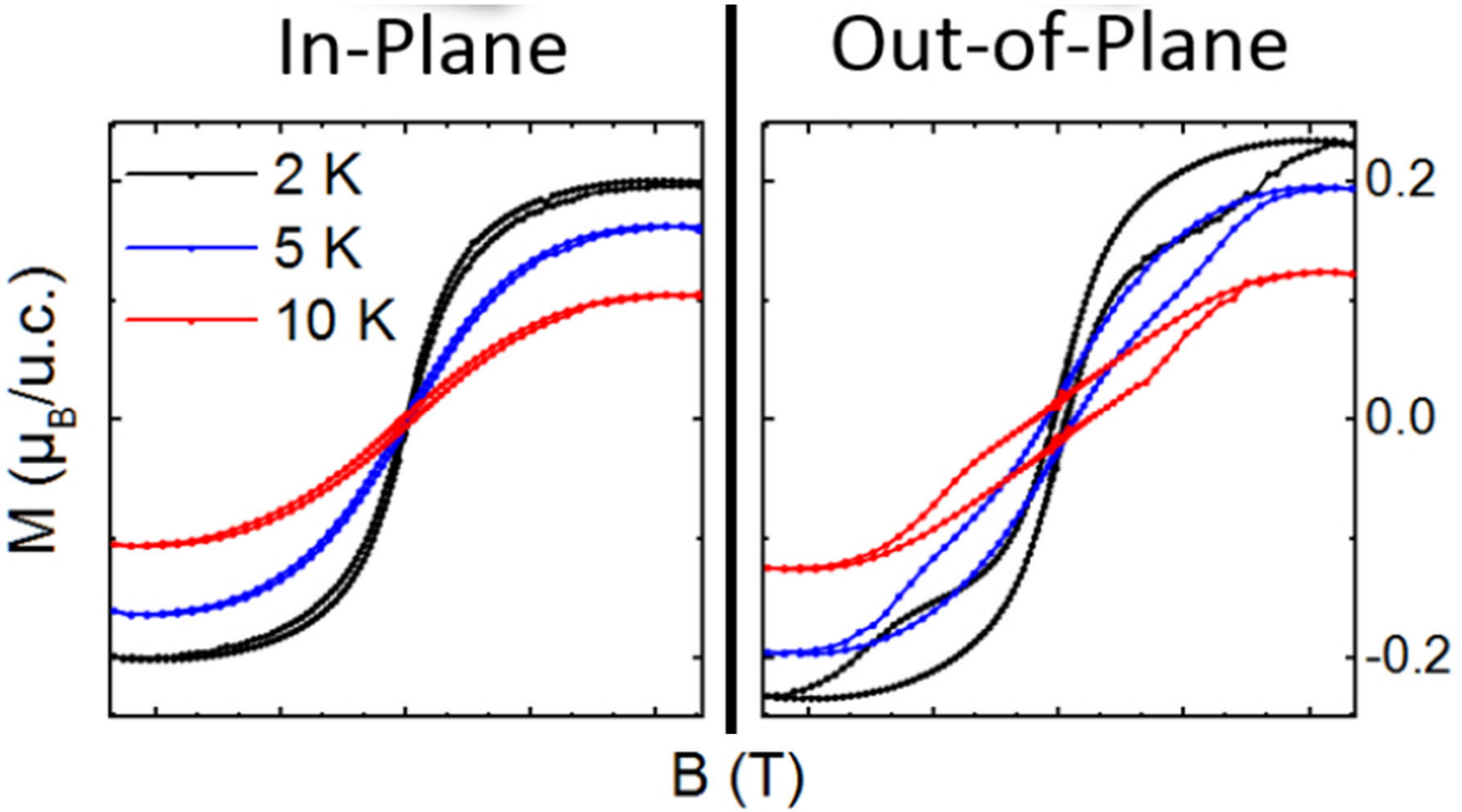
- The thin films are single crystalline
- Growth of T5BO on STO induces tensile film strain
- Scanning transmission electron microscopy (STEM) shows low density of structural defects
- Energy dispersive x-ray (EDX) spectroscopy shows homogeneous distribution of Fe, Mn, Co, Cr, Ni

T5BO is ferromagnetic with perpendicular magnetic anisotropy





Comparing to L5BO's different out-of-plane behavior



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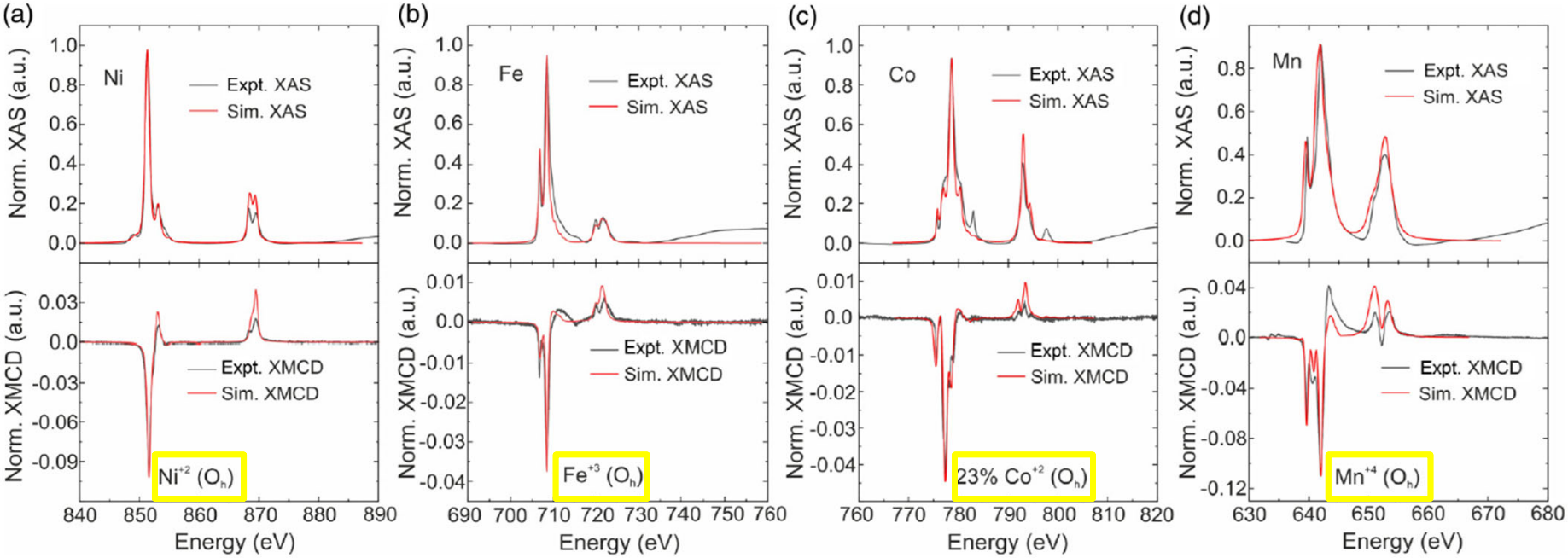
Magnetic contributions per transition metal element



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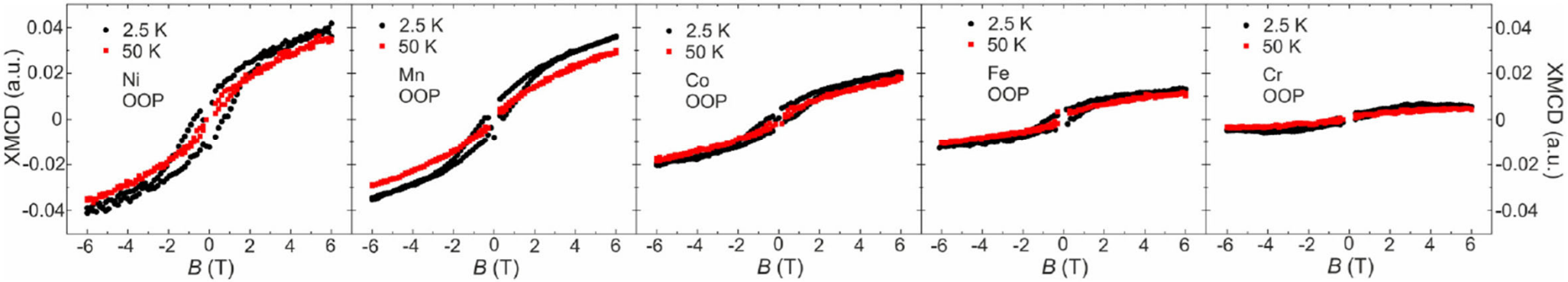
T5BO is ferromagnetic

XMCD Hysteresis Loops for all 5 transition elements



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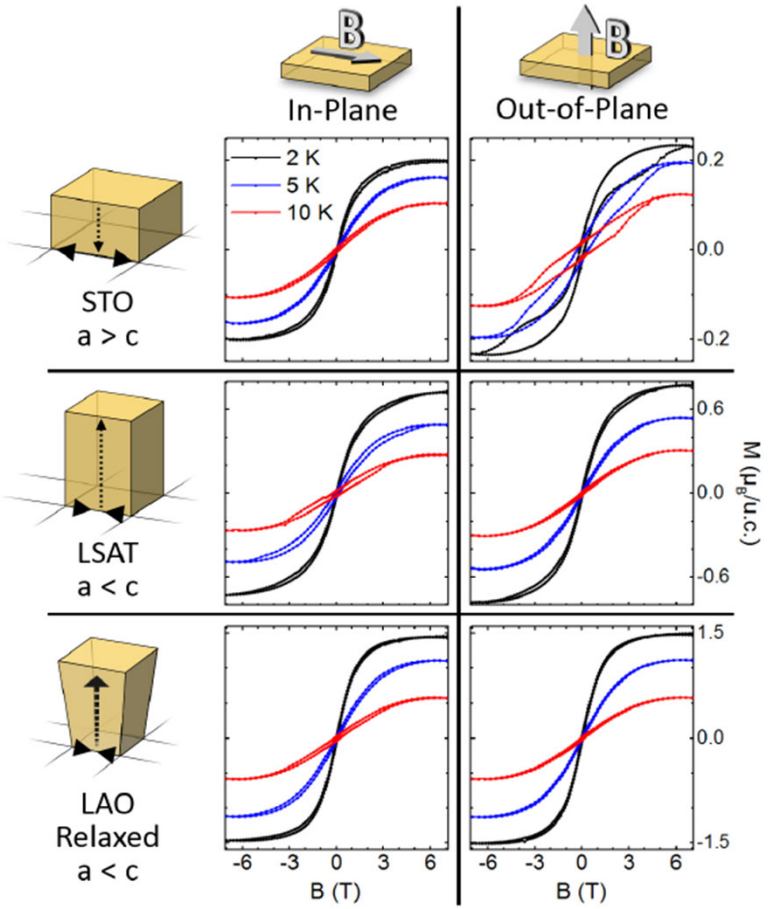
L5BO was grown on different substrates



Different substrates induce different lattice strain. It would be interesting to see how different strains affect T5BO.

Procedure

- T5BO thin films were synthesized via pulsed laser deposition (PLD)
- Similar methods were used to synthesize L5BO which also yield to a high quality material
- Energy-dispersive X-ray spectroscopy (EDX) measurements were done on T5BO HEOP thin films to confirm homogeneous distribution of transition metal elements
- The magnetic properties of T5BO were recorded using a superconducting quantum interference device (SQUID)
- X-ray absorption spectroscopy (XAS) and x-ray magnetic circular dichroism (XMCD) for element-wise study of T5BO thin films
- Macroscopic magnetic response is compared with XMCD measurements for understanding how different elements contribute to the magnetic properties.

December 2, 2022

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