28.04.2021.

Resonant X-ray Emission Spectroscopy to reveal coordination of W ions in $CuMo_{1-x}W_xO_4$ thermochromic materials

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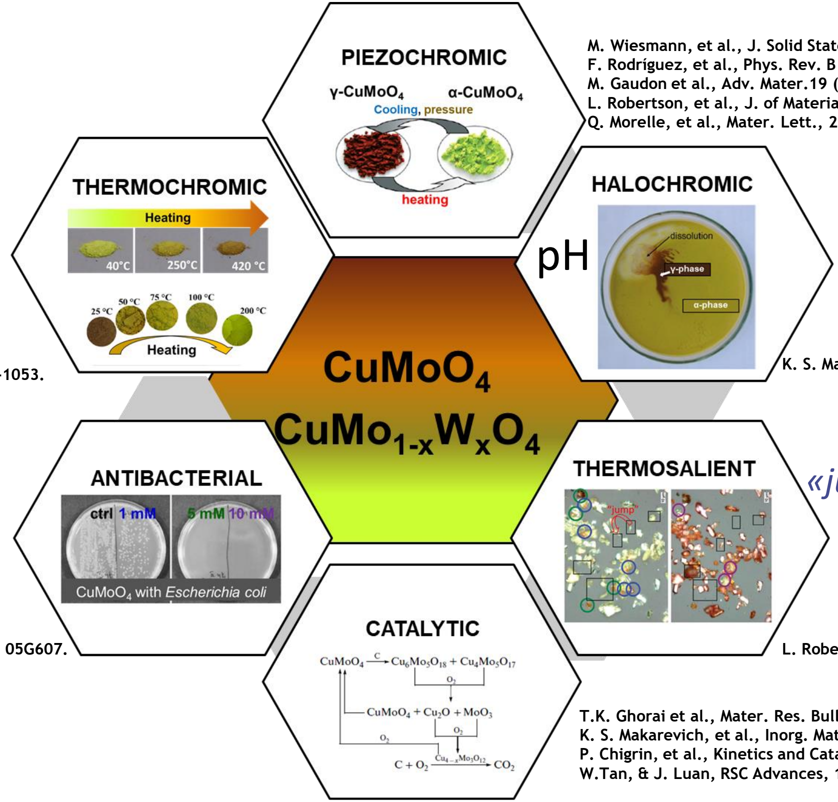
OUTLINE

- General motivation
  - Structural and optical properties of $CuMoO_4$
  - P-T diagram
  - $CuMo_{1-x}W_xO_4$ solid solutions
- XAS study
- Theoretical XANES calculations
- RXES study
- Summary

MOTIVATION I

M. Wiesmann, et al., J. Solid State Chem. 132 (1997) 88-97.
T. G. Steiner, et al., J. Anal. Chem. 370 (2001) 731.
M. Gaudon, et al., Inorg. Chem. 46 (2007) 10200-10207.
I. Yanase, et al., Ceram. Int. 39 (2013) 2059-2064.
L. Robertson, et al., J. of Materials Chem. C 3 (2015) 2918-2924.
N. Joseph, et al. Applied Materials & Interfaces 12.1 (2019) 1046-1053.

D. Tanasic, et al., Biointerphases 12 (2017) 05G607.



M. Wiesmann, et al., J. Solid State Chem. 132 (1997) 88-97.
F. Rodríguez, et al., Phys. Rev. B 61 (2000) 16497.
M. Gaudon et al., Adv. Mater.19 (2007) 3517.
L. Robertson, et al., J. of Materials Chem. C 3 (2015) 2918-2924.
Q. Morelle, et al., Mater. Lett., 253 (2019) 140-143.

K. S. Makarevich, et al., Inorg. Mater. 46 (2010) 1359-1364.

«jumping crystal effect»

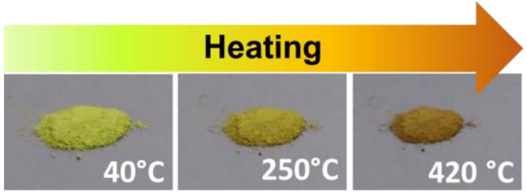
L. Robertson, et al., J. of Materials Chem. C 3 (2015) 2918-2924.

T.K. Ghorai et al., Mater. Res. Bull. 43 (2008) 1770.
K. S. Makarevich, et al., Inorg. Mater. 46 (2010) 1359.
P. Chigrin, et al., Kinetics and Catalysis 54 (2013) 76-80.
W.Tan, & J. Luan, RSC Advances, 10 (2020) 9745-9759.

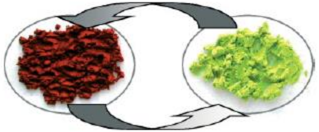
MOTIVATION II

Thermochromism

$CuMoO_4$

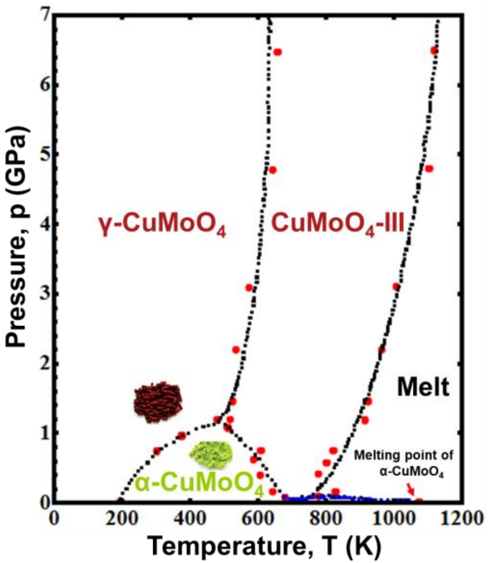


$T \approx 175\ K$



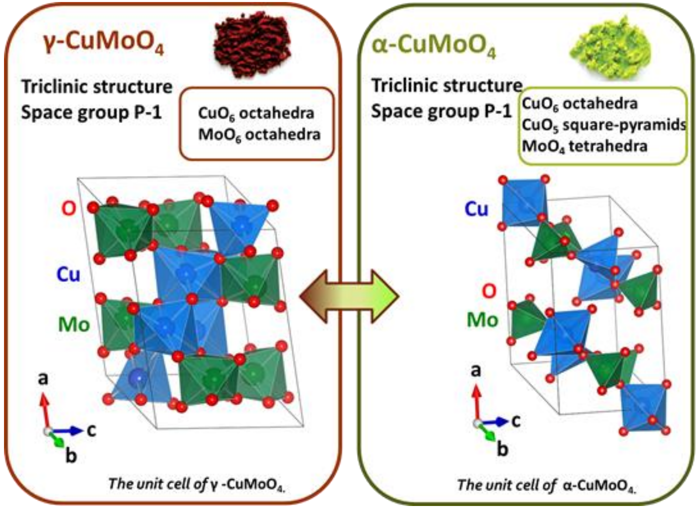
$T \approx 250\ K$

P-T diagram



M. Wiesmann, et al., J. Solid State Chem. 132 (1997) 88.

Structure



$\Delta V \approx 12 - 13\%$

MOTIVATION III

Hysteresis

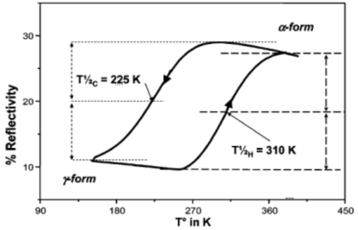


Figure 6. Evolution of the integrated reflectivity percentage in the green zone (500−550 nm) of $CuMo_{0.97}W_{0.03}O_4$ compound with temperature.

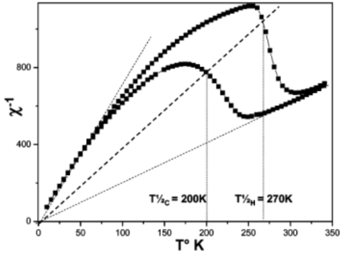
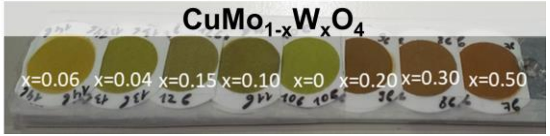
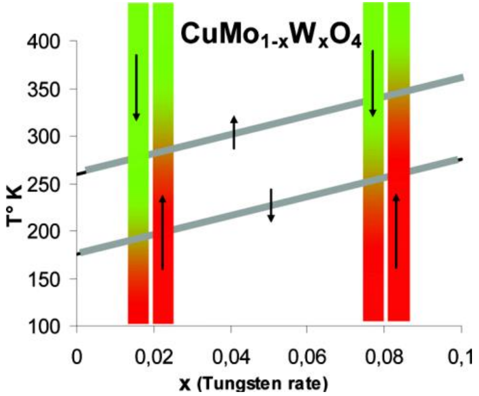


Figure 8. Evolution of the magnetic susceptibility of the $CuMo_{0.95}W_{0.05}O_4$ compound with the temperature.

M. Gaudon, et al., Inorg. Chem. 46 (2007) 10200-10207.
T. Ito, et al., Chem. of Mat., 21 (2009)3376-3379.

Adaptable thermochromism





M. Gaudon, et al., Inorg. Chem. 46 (2007) 10200-10207.
X. Wu, et al., Mater. Res. Express 7 (2020) 016309.

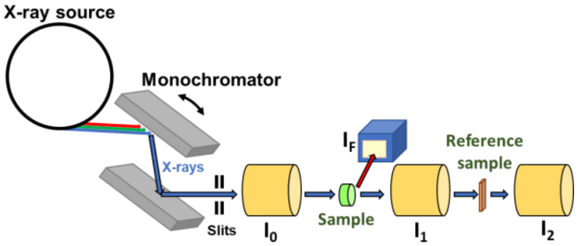
Questions

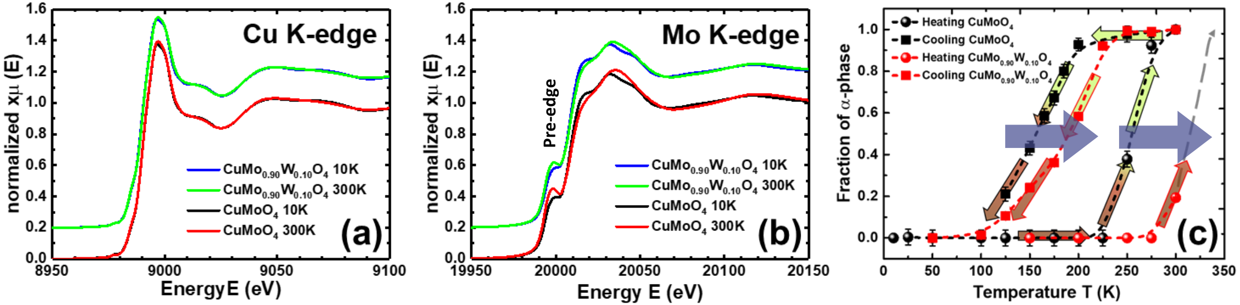
-Can we detect the hysteresis of the phase transition by probing the local structure of the material?

-What is the role of W in these solid solutions?

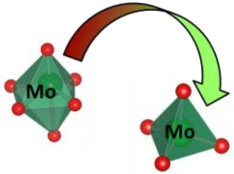
X-RAY ABSORPTION SPECTROSCOPY STUDY

PETRA III beamline P65





Pre-edge shoulder $1s(Mo) \rightarrow 4d\ (Mo) + 2p\ (O)$



Analysis of the Mo K-edge XANES allows one to reconstruct hysteresis that describes the phase transition.

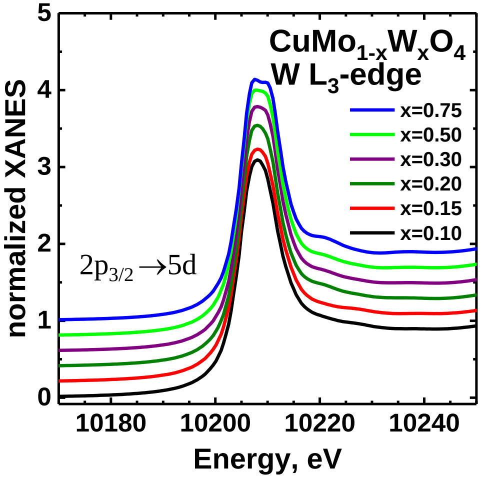
I. Jonane, A. Cintins, A. Kalinko, R. Chernikov, A. Kuzmin, Low Temp. Phys. 44 (2018) 434-437.
I. Jonane, A. Cintins, A. Kalinko, R. Chernikov, A. Kuzmin, Rad. Phys. Chem. 175 (2020) 108411.

W L_3-EDGE: EXPERIMENT VS. THEORY

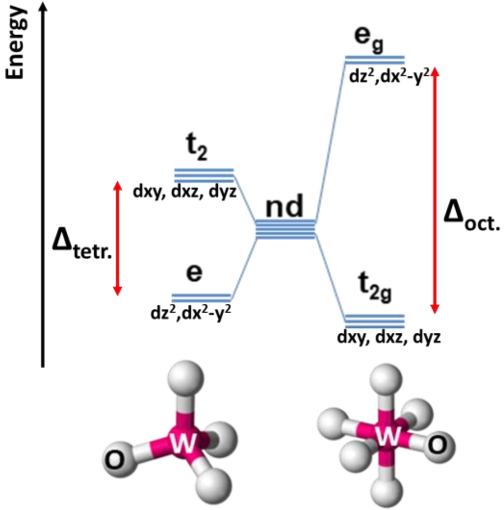
Experiment

Crystal field splitting

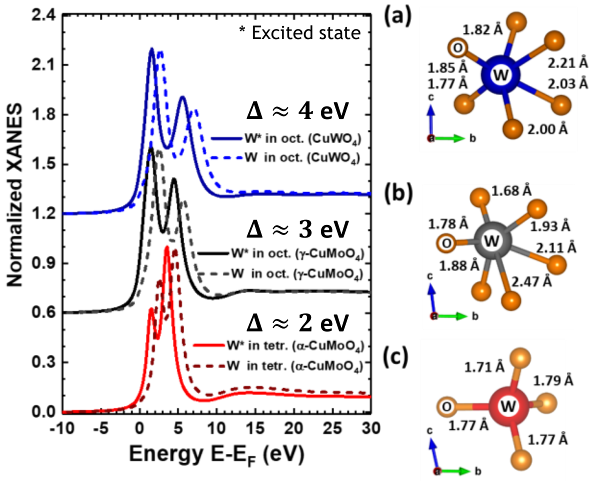
FDMNES



$$2p_{3/2}\ \Gamma_{hole} \approx 4.57\ eV$$



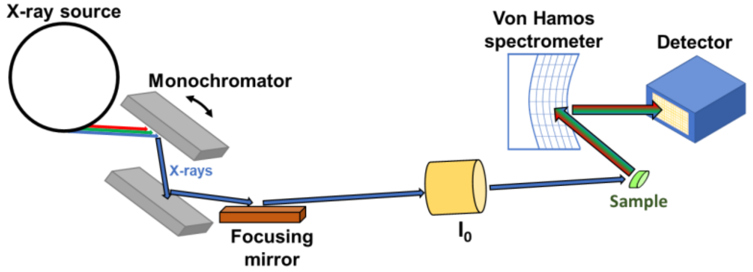
$e:t_2 = 2:3$ $t_{2g}:e_g = 3:2$

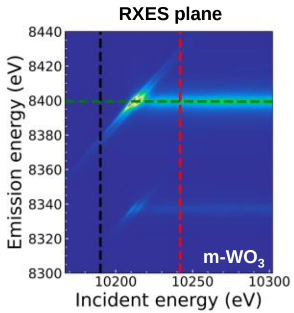


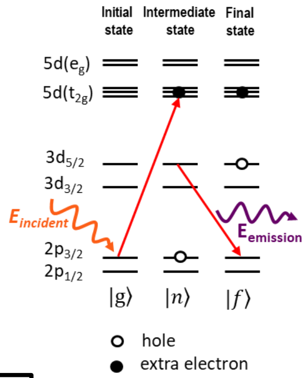
$$\Gamma_{hole} = 1\ eV$$

RESONANT X-RAY EMISSION SPECTROSCOPY EXPERIMENT

PETRA III P64 Advanced X-ray Absorption Spectroscopy beamline







Experimental details:

- High flux ($5 \cdot 10^{11}$photons/s)
- Si(311) monochromator
- 100x240 μm focused beam
- Von Hamos-type spectrometer with Si(444) analyzer crystals
- Dectris 2D Pilatus 300 K detector (High-resolution < 1 eV)
- Liquid nitrogen cryostat Linkam THMS600 for low T measurements

$$\Gamma\tau \geq \frac{\hbar}{2}$$

$2p_{3/2}\ \Gamma_{hole} \approx 4.57\ eV$

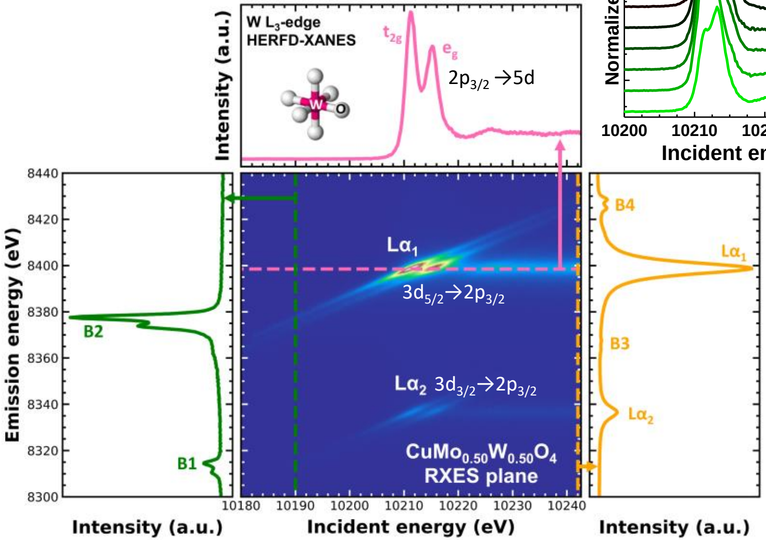
$3d_{5/2}\ \Gamma_{hole} \approx 2.01\ eV$

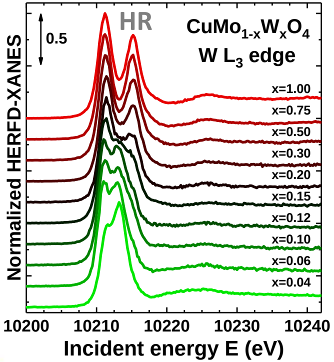
W.A. Caliebe, et al., AIP Conf. Proc. 2054 (2019) 060031.
A . Kalinko, et al., J. Synchrotron Rad. 27 (2020) 31-36.

Experimental resolution is of the order of the core hole lifetime broadening.

RXES PLANE

High-energy resolution
fluorescence detected XANES
(HERFD-XANES)
$E_e = 8398.5 \pm 0.2$ eV





Below the resonance
$E_i = 10190$ eV

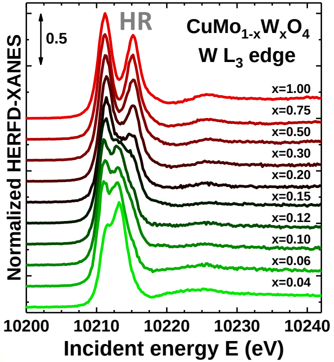
Above the resonance
$E_i = 10242$ eV

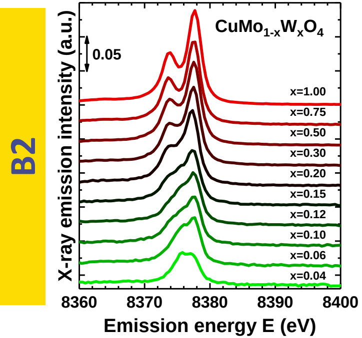
High-energy resolution off-resonant
X-ray emission spectra

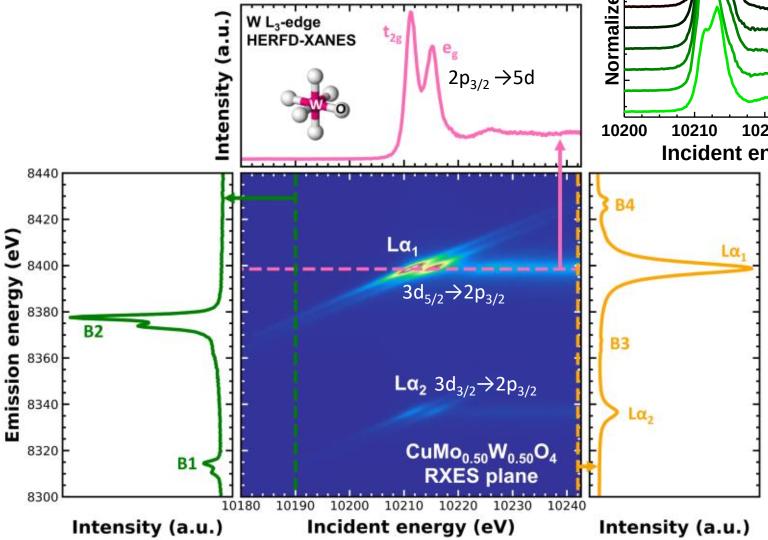
RXES PLANE

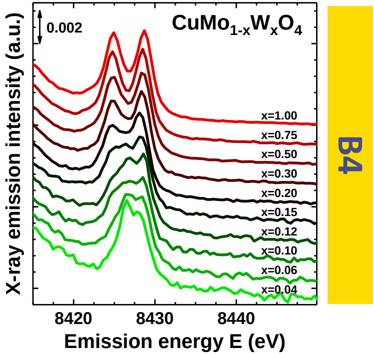
High-energy resolution fluorescence detected XANES (HERFD-XANES)

$E_e = 8398.5 \pm 0.2$ eV







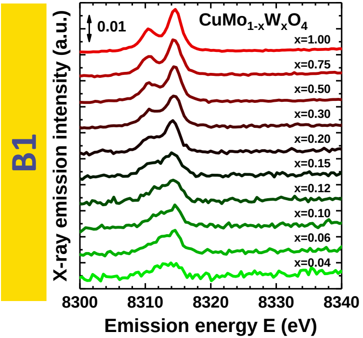


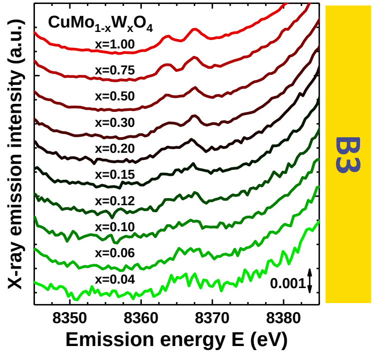
Below the resonance

$E_i = 10190$ eV

Above the resonance

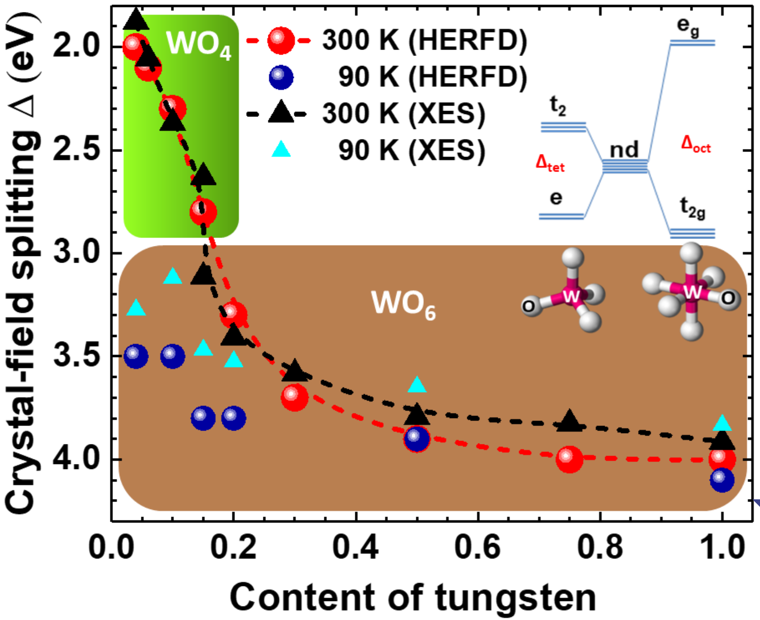
$E_i = 10242$ eV

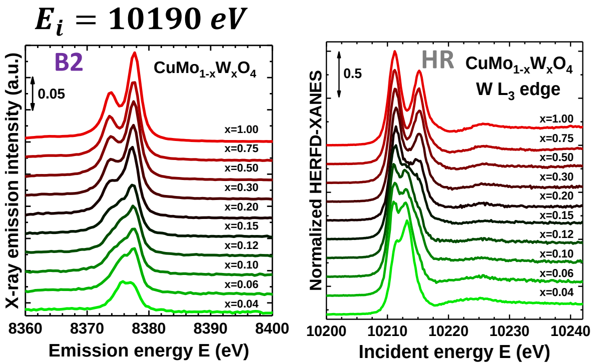


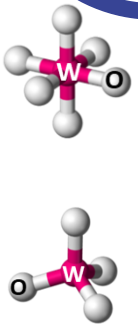


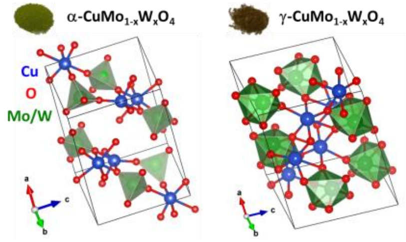
High-energy resolution off-resonant X-ray emission spectra

RESULTS – COMPOSITION EFFECT



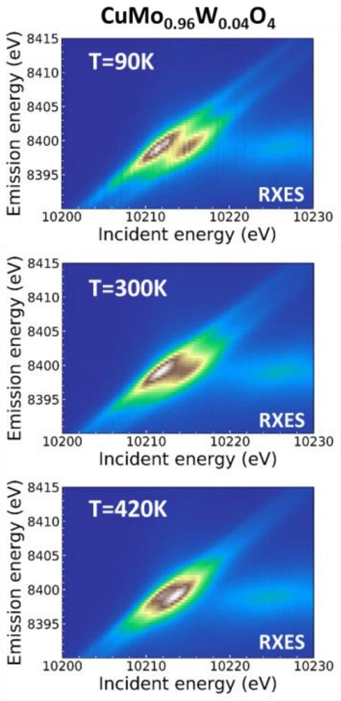


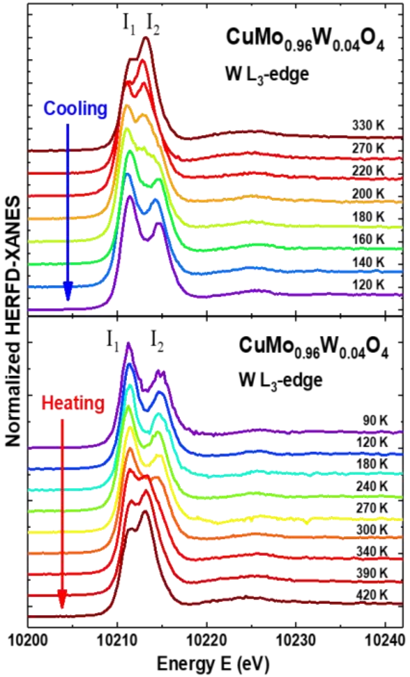


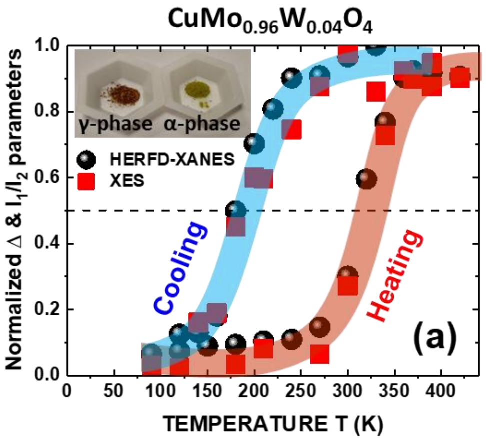


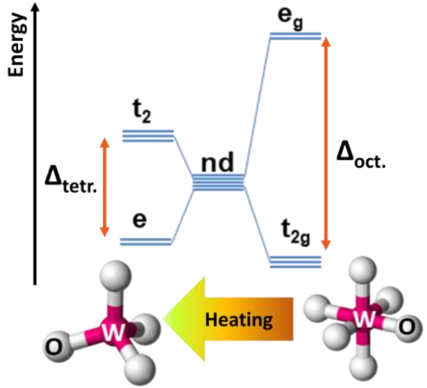
W ions in $CuMo_{1-x}W_xO_4$ solid solutions have octahedral coordination for x>0.15 at all temperatures, whereas their coordination changes from tetrahedral to octahedral upon cooling for smaller tungsten content. Nevertheless, some amount of tungsten ions co-exists in the octahedral environment at room temperature for x<0.15.

RESULTS – TEMPERATURE EFFECT





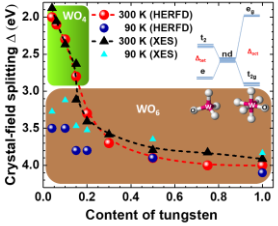




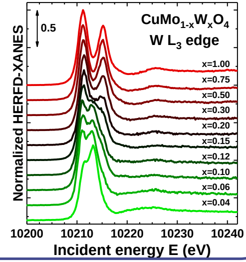
RXES measurements were successfully employed to determine the hysteretic behaviour of the structural phase transition between the α and γ phases in $CuMo_{1-x}W_xO_4$ solid solutions on cooling and heating.

SUMMARY

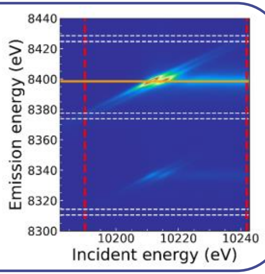
The analysis of the RXES plane provides useful bulk sensitive information on the coordination of tungsten atoms and allows one to determine the **crystal-field splitting parameter** Δ for the 5d(W)-states.



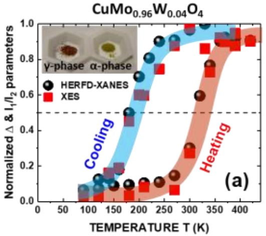
The analysis of the RXES planes shows a clear advantage over conventional XANES due to revealing spectral features with much **higher resolution**.



This information can be extracted from the RXES plane by analysing **HERFD-XANES** and the high energy resolution **off-resonant X-ray emission spectra** excited below and above resonance conditions.



RXES method is well suited for **in-situ measurements** and was used here to determine the hysteretic behaviour of the first-order structural phase transition between α and γ phases in $CuMo_{1-x}W_xO_4$ solid solutions on cooling and heating, even at low (x < 0.10) tungsten content.



For more details:

I. Pudza, A.Kalinko, A. Cintins, A.Kuzmin, Acta Mater. 205 (2021) 116581.

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FLPP
FUNDAMENTĀLO UN LIETIŠĶO PĒTĪJUMU PROJEKTI

THANK YOU

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