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Strain Induced Superconductivity of RuO_2

Introduction

- Superconductivity occurs when a metal compound conducts with zero resistance after the material is brought to its critical temperature (T_c).
- Prior research found that RuO_2 can superconduct when under c-axis compression.
  - Observed in RuO_2 on TiO_2 (110) and (100)
    - c-axis lattice mismatch = 4.7%
  - Similar research was done with RuO2 on MgF_2, but these did not superconduct.
- c-axis compression can be created by a small lattice mismatch which causes an epitaxial strain.
  - Two methods we rely on for creating an epitaxial strain are in-plane mismatch and the Poisson effect.
- Previously, potentially superconducting RuO_2 has only been grown on TiO_2 and MgF_2.
  - These are the only two existing commercially available rutiles with similar dimensions to RuO_2
- Our research tests synthetic Alexandrite and Topaz as alternative substrates.
  - Both are orthorhombic with favorable octahedral alignment and lattice structure.
  - Our topaz samples didn't create enough strain to support further testing, so Alexandrite is the focus from this point on.

RuO_2	TiO_2	MgF_2
a = b = 4.489 Å	a = b = 4.594 Å	a = b = 4.621 Å
c = 3.105 Å	c = 2.959 Å	c = 3.052 Å

$Al_2SiO_4(F, OH)_2$	Al_2BeO_4
a = 4.665 Å	a = 9.407 Å
b = 8.838 Å	b = 5.478 Å
c = 8.398 Å	c = 4.428 Å

Experimentation

- Samples were gown via molecular beam epitaxy (MBE).
  - Ru metal source and distilled O_3 background
  - Monitored with RHEED imagining
  - Growth temperature from 350 °C to 100 °C
- Measurements included x-ray diffraction (XRD), x-ray reflection (XRR), reciprocal space mapping (RSM), and physical property measurement system (PPMS).
- A temperature series of RuO_2 (001) on Alexandrite (100) samples was grown with varying temperature from 350 °C to 150 °C.
  - 50 °C intervals except 225 °C and 175 °C
- A subsequent thickness series of RuO_2 (001) on Alexandrite (100) grown at 200 °C was grown after identifying favorable results at 200 °C.
  - Includes 14.7 nm (from temperature series), 7.5 nm, and 5.0 nm samples.

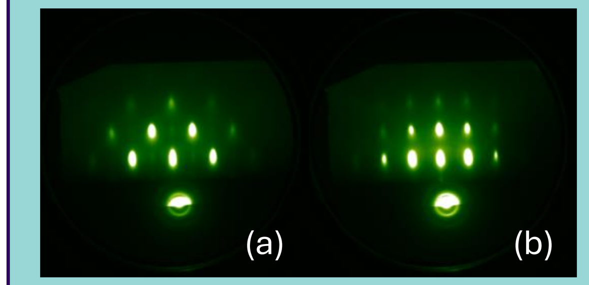

Fig. 1 (a) and (b) are RHEED images from growth of RuO2 (001) on alexandrite (100). This rough pattern is consistent with other rutile films grown in the (100) orientation, and they show the absence of polycrystallinity

Results

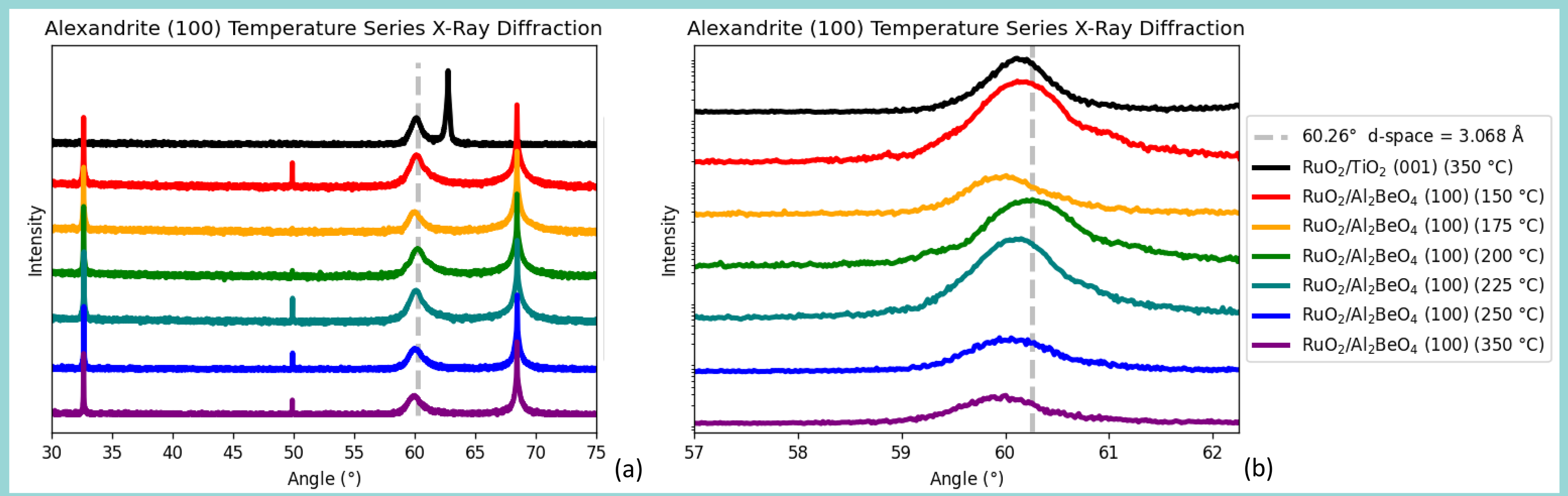

Fig. 2 (a) and (b) are plots of the XRD measurements at the RuO2 002 peak of the RuO2 (001) on Alexandrite (100) temperature series samples. RuO2 (001) on TiO2 (001) is included in black for comparison. A dotted line marks the 2θ angle for the RuO2 002 peak of the 200 ºC sample at 60.26º. Fig. 2(b) is focused on the RuO2 002 peak.

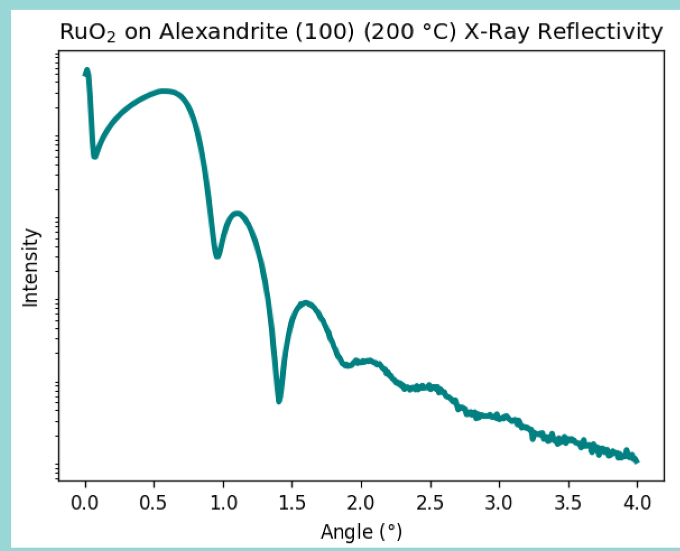

Fig. 3 XRR plot of RuO2 (001) on Alexandrite (100) grown at 200 ºC. This plot indicates a film thickness of approximately 14.7 nm.

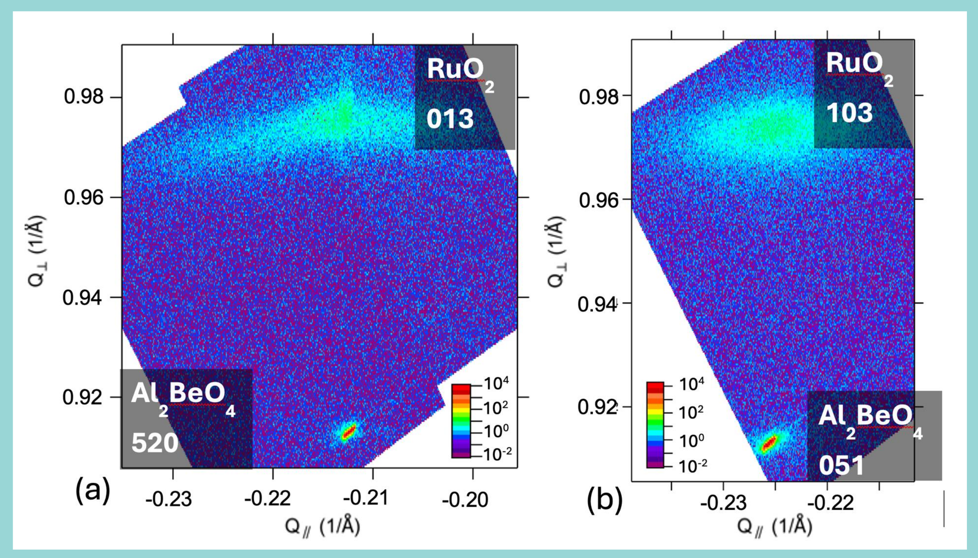

Fig. 4 (a) and (b) are RSM graphs of RuO2 (001) on Alexandrite (100) grown at 200 ºC and 14.7 nm. (a) is measured at the RuO2 013 peak and (b) is measured at the RuO2 103 peak.

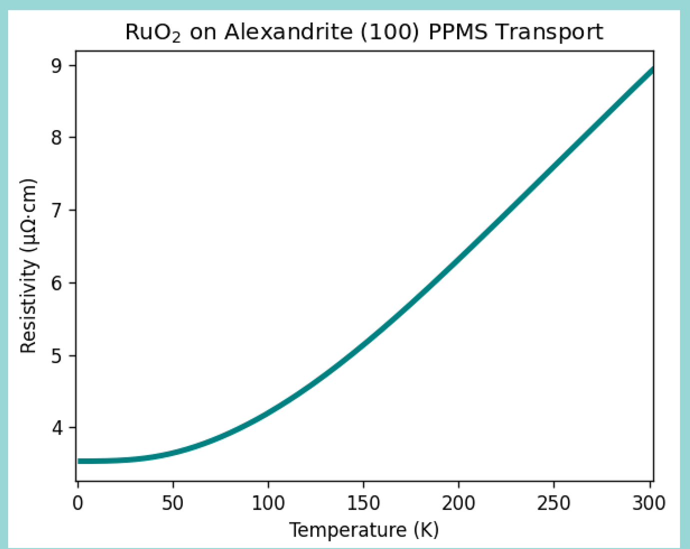

Fig. 5 PPMS transport plot of RuO2 (001) on Alexandrite (100) grown at 200 ºC and 14.7 nm. Lowest recorded resistivity at 1.8 K was 3.534 µΩ•cm.

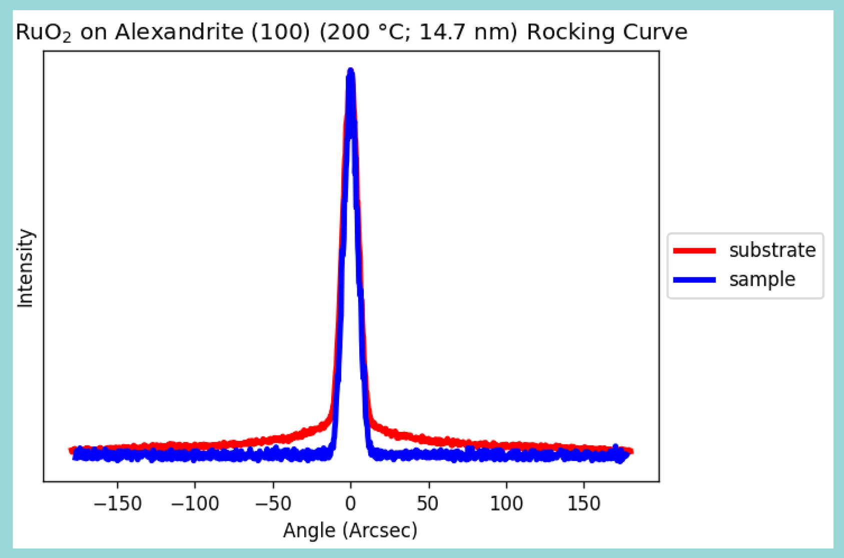

Fig. 6 Rocking curve plot of RuO2 (001) on Alexandrite (100) grown at 200 ºC and 14.7 nm. Full width half max (FWHM) for the film is 10.44 arcsec and for the substrate is 11.88 arcsec.

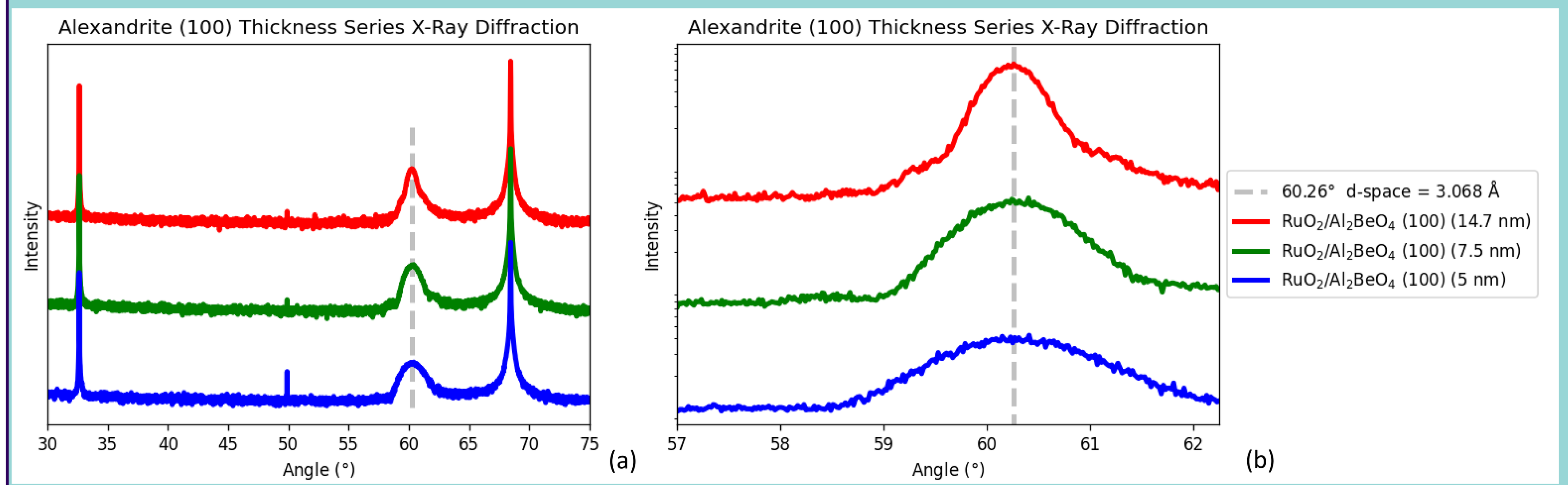

Fig. 8 (a) and (b) are XRD measurements of the RuO2 (001) on Alexandrite (100) samples grown at 200 ºC in the thickness series. The dotted line marks the RuO2 002 peak at a 2θ of 60.26º.

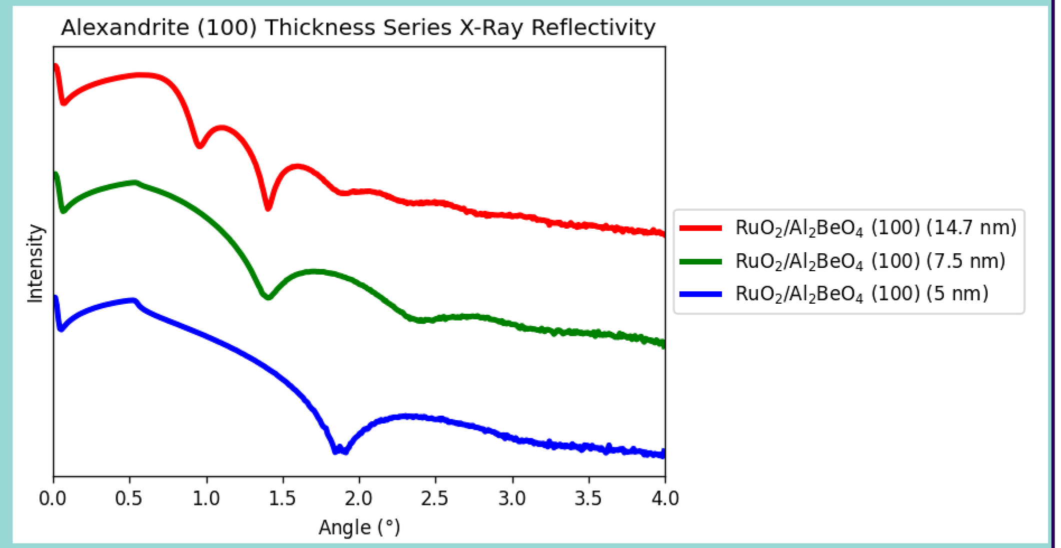

Fig. 9 XRR measurements of the RuO2 (001) on Alexandrite (100) samples grown at 200 ºC in the thickness series.

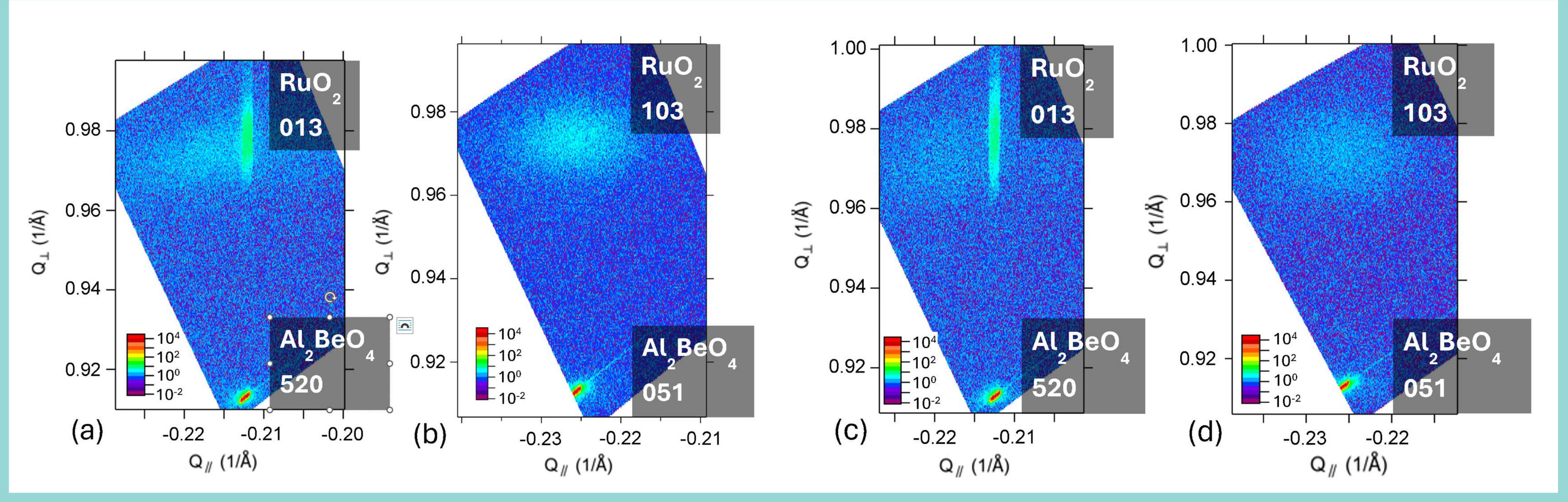

Fig. 10 RSM measurements of the RuO2 (001) on Alexandrite (100) samples grown at 200 ºC with film thicknesses of 7.5 nm and 5.0 nm. (a) is measured at the RuO2 013 peak and (b) is measured at the RuO2 103 peak for the 7.5 nm sample. (c) is measured at the RuO2 013 peak and (d) is measured at the RuO2 103 peak for the 5.0 nm sample.

Analysis

- Comparing XRDs of the temperature series shows that the RuO_2 (001) on Alexandrite (100) grown at 200 °C had the greatest c-axis compression and exceeded that of RuO_2 (001) on TiO_2 (001).
- The XRR of the 200 °C sample features relatively less noise than XRRs for RuO2 (001) on TiO2 (001).
- PPMS transport for the 200°C sample indicates a metallic nature (decreasing resistivity with decreasing temperature), but no superconductivity is observed down to 1.8 K.
- The rocking curve for the 200 °C sample shows high crystal quality despite the high strain.
  - Indicated by the small full width half max
- The RSM for the 200 °C sample displays a commensurate strain as the film peak is inline with the substrate peak, but the dispersion at the film peak indicates it is beyond the onset of relaxation.
- A thickness series was conducted to grow RuO_2 (001) on Alexandrite (100) at 200 °C before the onset of relaxation.
- XRDs for the thickness series observed no change in c-axis compression with varying film thickness.
- XRR plots of the thickness series reciprocated the same trends in relative clarity as seen for the original 200 °C sample.
- The RSM graphs for the thickness series show a decreasing film peak dispersion with decreasing thickness.
  - 5 nm sample is near the onset of relaxation.
  - No effect on c-axis compression (supports XRD)

Conclusions

- RuO_2 (001) on Alexandrite (100) peaked in c-axis compression at 200 ºC.
- Varying film thickness did not affect c-axis compression
  - It only affected how commensurately strained the film was.
- RuO_2 (001) on Alexandrite (100) exhibited greater c-axis compression and surface quality than RuO_2 (001) on TiO_2 (001) and MgF_2 (001) substrates.
- No superconductivity was observed down to 1.8 K
- Further PPMS will use Helium-3 to measure down to 0.4 K for a potential suppressed T_c.
- Further research will explore other rutile oxides grown on Alexandrite (100) (i.e. Iridium Dioxide)

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