Pulsed Laser Deposition of Ho_2O_3 thin films for Nano-Photonics

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Introduction

Scaling down laser wavelengths to the X-ray range presents significant challenges. In 1974, Fisher [1] proposed the idea of using a single crystal as a distributed feedback medium for generating X-ray lasers. However, due to the complexity of growing such crystals at small scales (e.g., 1 µm³), this concept has yet to be realized experimentally. Building on Fisher's idea, we conducted theoretical analyses on various materials for their potential use in X-ray lasers. Our results [2] indicate that Ho_2O_3 is one of the most promising compounds due to its versatile material properties.

The key challenges to be addressed in this study are as follow:

Q1. Is there a distortion of crystal symmetry?

Q2. Is the stoichiometry preserved?

Q3. Is the lattice parameter of the grown film comparable with the starting material?

Q4. What is the thickness of the grown film?

Experimental Methods

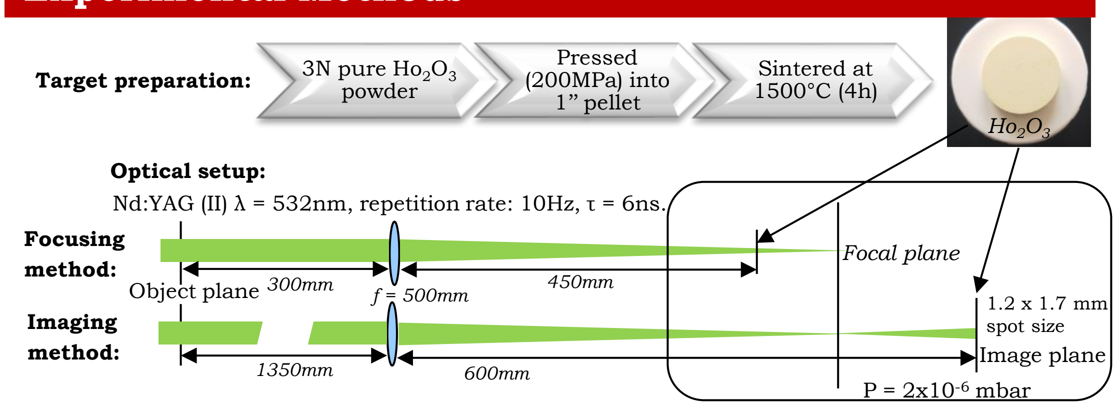


Figure 1: *Shows the optical setup, one with focused beam and another with imaged beam used in this work.*

Crystallography Studies of Target and Thin Films

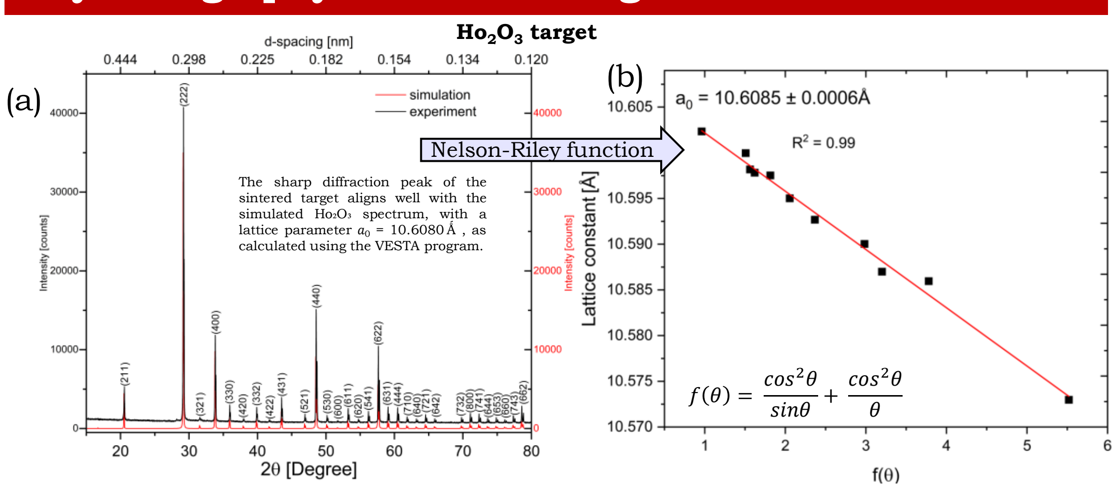


Figure 2: *XRD measurement of sintered Ho_2O_3 target (a) and (b) calculation of lattice parameter using Nelson-Riley function.*

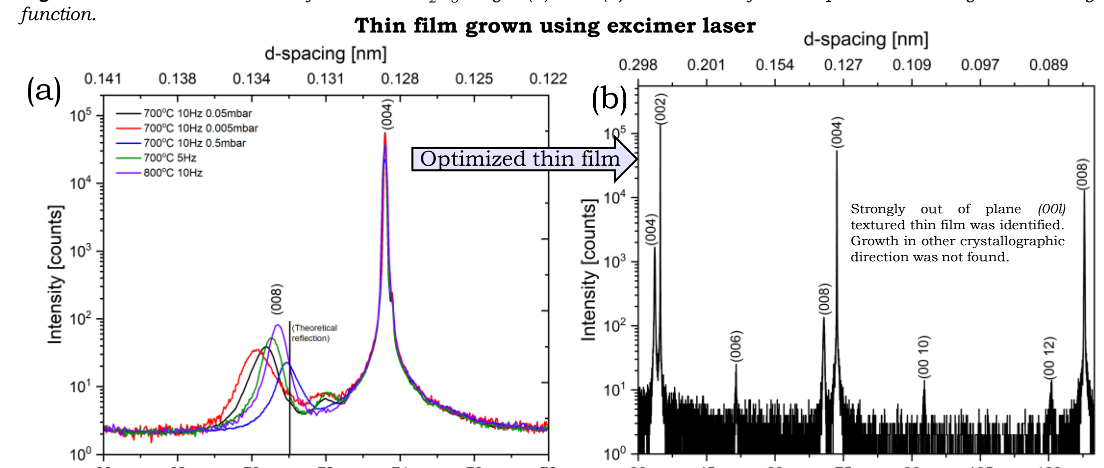
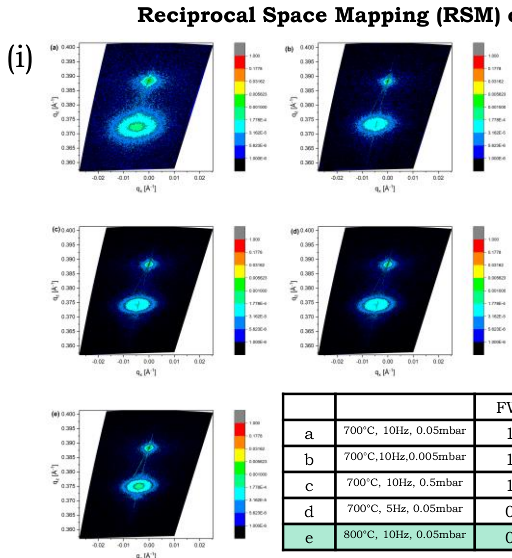
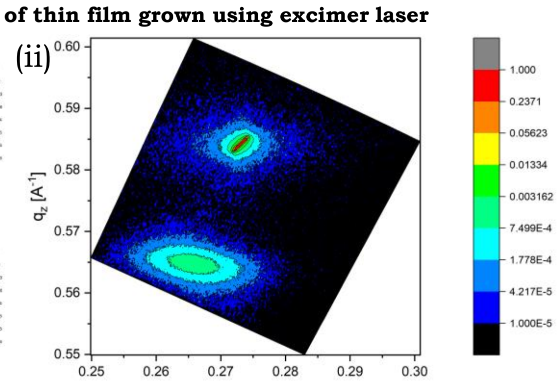


Figure 3: *XRD measurement of Ho_2O_3 thin film grown at different conditions (a) and (b) out-of-plane measurement of Ho_2O_3 grown at 800°C.*

Reciprocal Space Mapping (RSM) of thin film grown using excimer laser



		FWHM
a	700°C, 10Hz, 0.05mbar	1.07
b	700°C,10Hz,0.005mbar	1.34
c	700°C, 10Hz, 0.5mbar	1.44
d	700°C, 5Hz, 0.05mbar	0.94
e	800°C, 10Hz, 0.05mbar	0.82



In-plane lattice parameter (a=b) **10.61 Å**.
Out-plane lattice parameter (c) **10.62 Å**.

Figure 4: *Symmetrical (002) RSM measurement of Ho_2O_3 grown at different conditions (i) and (ii) asymmetrical (113) RSM measurement of Ho_2O_3 grown at 800°C.*

Benchmarking Nd:YAG (II) with Excimer laser

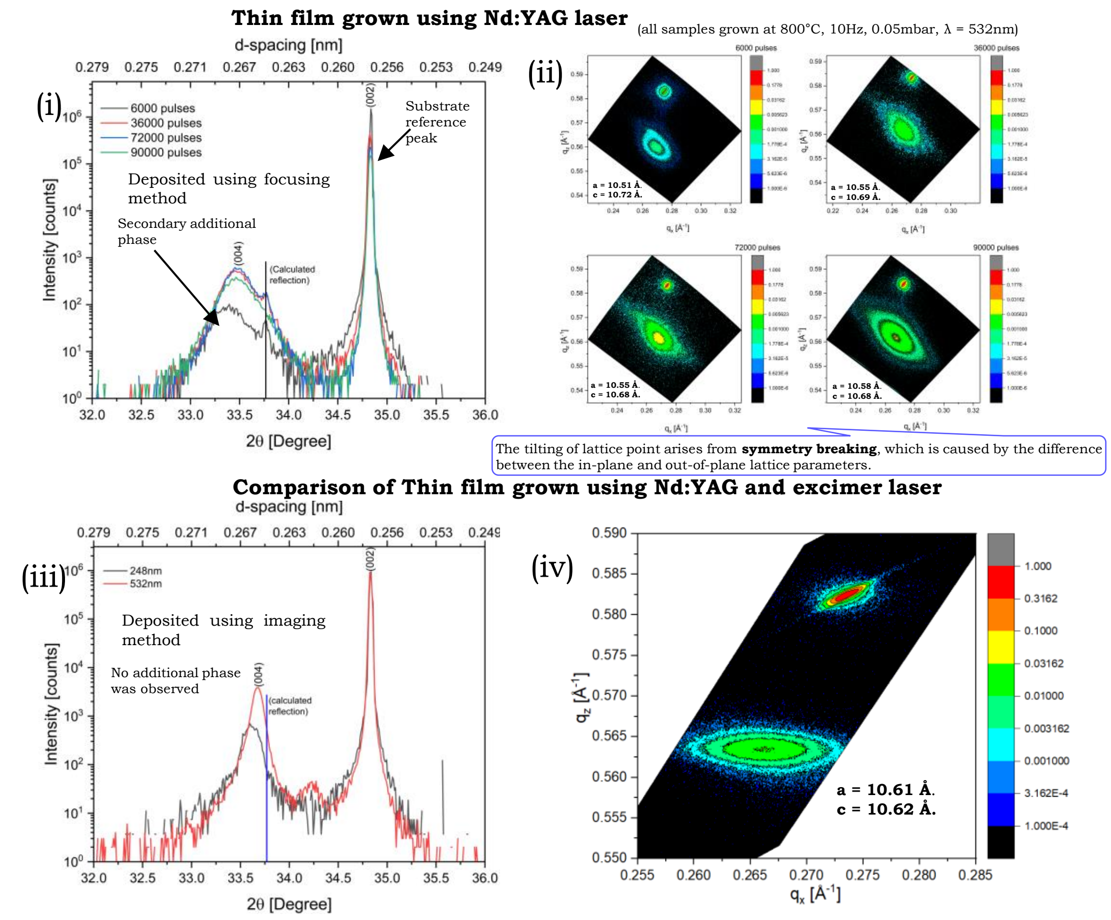


Figure 5: *XRD measurement of Ho_2O_3 thin film using 532nm laser (focused spot) (i), comparison of thin film grown using 532 nm and 248 nm laser (imaged spot) (iii), asymmetrical (113) RSM measurement of samples grown using 532 nm laser (focused spot)(ii) and imaged spot (iv).*

Stoichiometry Studies of grown Films

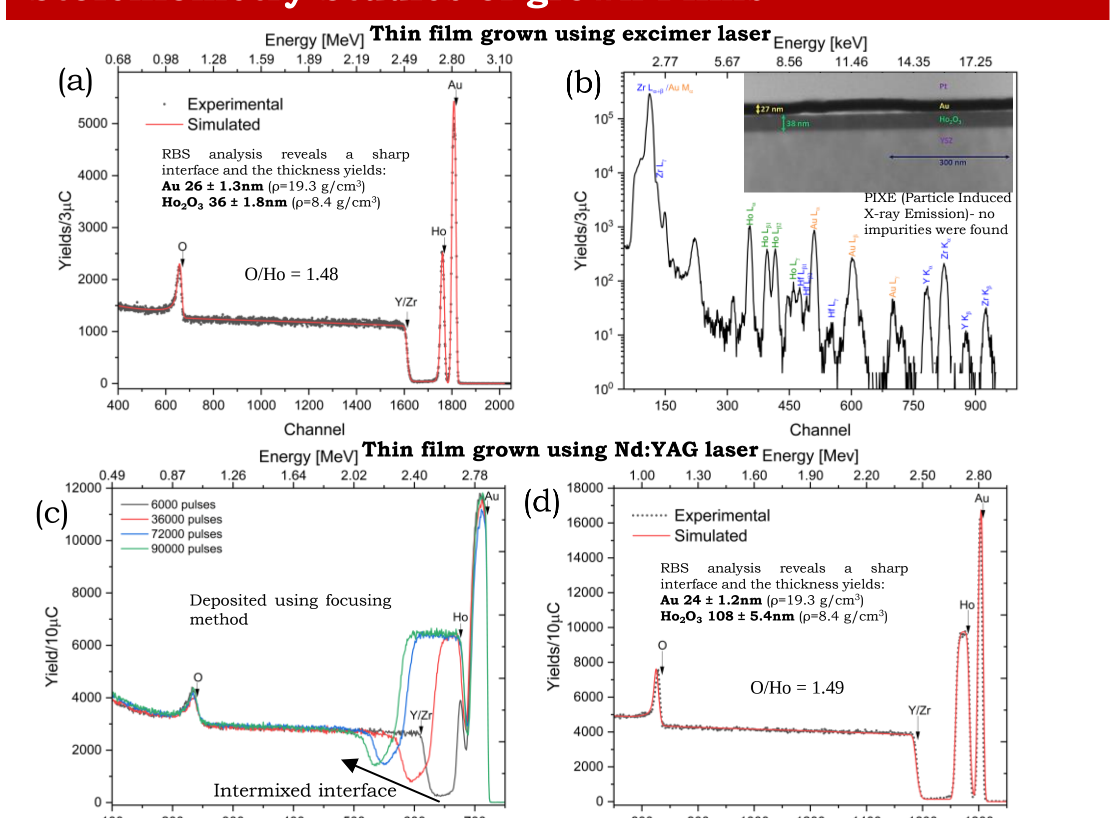


Figure 6: *RBS (Rutherford Backscattering Spectroscopy) measurement of Ho_2O_3 thin film grown at 800°C (248 nm) at ^{16}O resonance condition (a), PIXE measurement of same thin film sample shows no impurities, with the insert shows the cross-section of thin film with thickness 38nm (b), RBS measurement of thin film grown using 532 nm at different pulse count (focused spot)(c) and RBS measurement of thin film using 532 nm laser (imaged spot)(d).*

Conclusions

A1. Crystal symmetry was distorted when using the focusing method. This distortion was due to the strong collision of the species with the substrate, leading to intermixing with the substrate material.

A2. The grown thin films were stoichiometrically accurate, with an O/Ho ratio of 1.49, which aligns well with the theoretical value of 1.5.

A3. Lattice parameters were calculated from asymmetrical RSM (113) measurements, yielding a value of 10.61 Å, which agrees closely with the starting material value of 10.6085 Å.

A4. The film thickness for 6000 pulses was determined to be 36 ± 1.8 nm, closely matching the cross-sectional image thickness of 38 nm. Similarly, for 18000 pulses, the film thickness was calculated to be 108 ± 5.4 nm.

Overall, the Ho_2O_3 thin film growth was optimized on YSZ substrate at 800°C and 10 Hz, yielding a thickness of 108 nm.

References

1. FISHER, Robert A. Possibility of a distributed-feedback x-ray laser. *Applied Physics Letters*, 1974, Vol. 24, No. 12, pp. 598-599.
2. Sharath Rameshbabu, and Davide Bleiner. "Röntgen materials for x-ray lasers-on-a-chip." In *Compact Radiation Sources from EUV to Gamma-rays: Development and Applications*, vol. 12582, pp. 95-103. SPIE, 2023.

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