Quantitative analysis of bi-directional ablation in pulsed laser deposition

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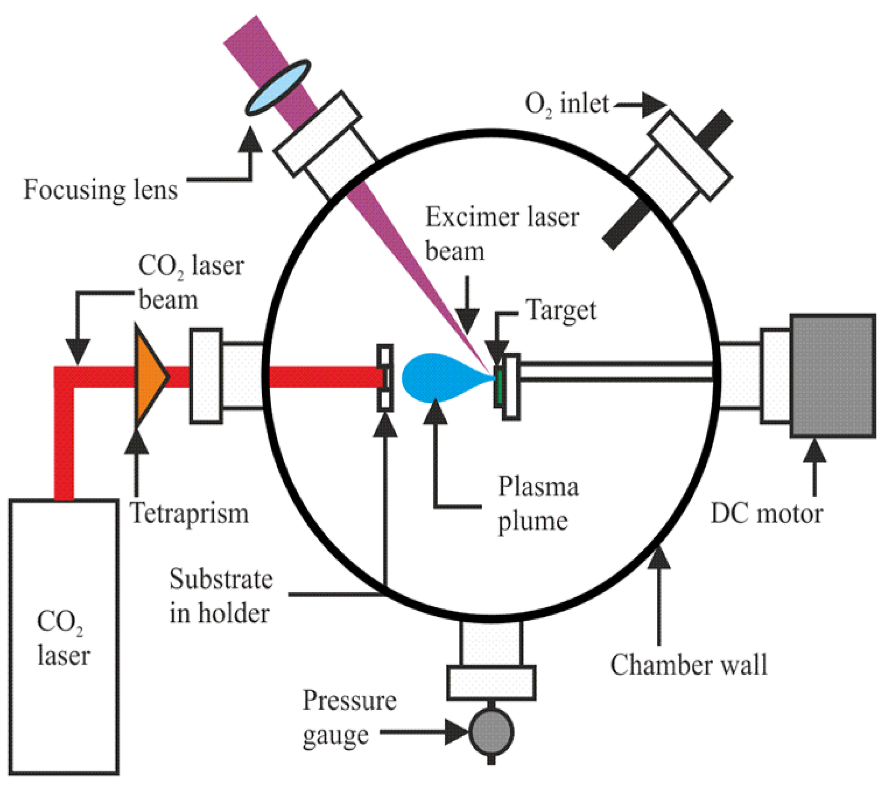
Abstract:
Pulsed laser deposition (PLD) is a versatile technique that can be used to produce thin-film crystalline materials. Here, we present the quantification of film quality improvements and the reduction of target LIPSS (laser induced periodic surface structure) obtained via the implementation of a bi-directional ablation technique. We demonstrate a tenfold reduction in particulate density, twofold reduction in surface roughness, and a fivefold reduction to waveguide losses in YGG (yttrium gallium garnet) films.

Motivation

Despite the numerous advantages of PLD, its Achillies heel is particulates generated during deposition and embedded into the growing film. These particulates can be detrimental for the optical, electrical and/or mechanical properties of the film. If the particulate density could be reduced to negligible levels, PLD would become a more prominent, high-quality crystal-film growing technique.

1. Pulsed Laser Deposition System

- 248 nm, 20 ns pulsed laser ablates target material
- Ablated material deposits onto a heated substrate
- Substrate heated via CO_2 laser to temperatures that can exceed 1000 °C
- Growth rates of 25 µm/hr achievable[1]
- Growths in partial oxygen atmosphere at 0.02 mbar
- Target moved in epitrochoidal motion to increase target utilisation
- Can be configured to provide bi-directional ablation

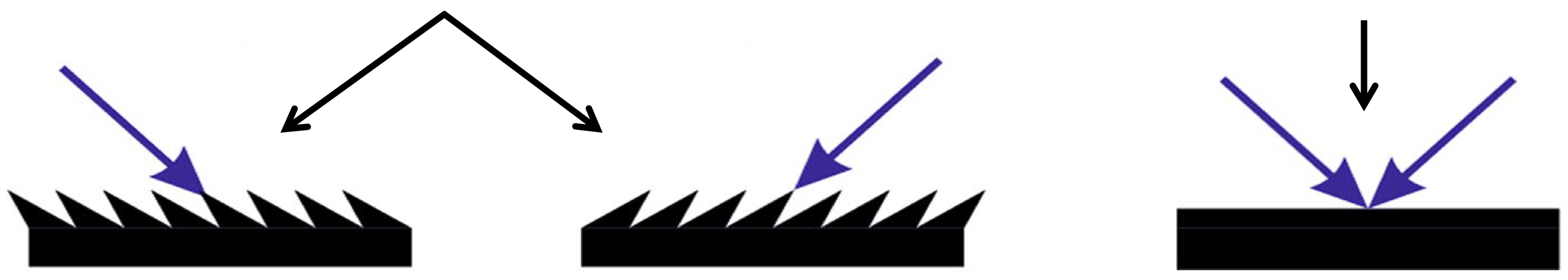


2. Bi-directional Ablation

Hypothesis

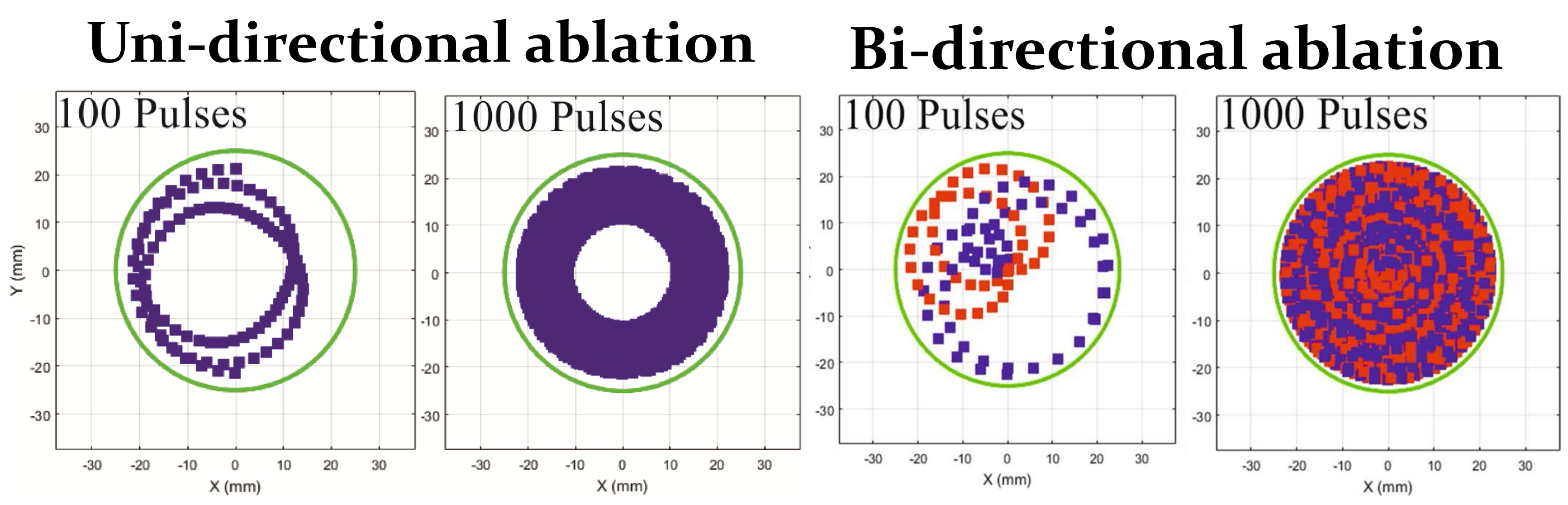
Uni-directional ablation →Directional LIPSS

Bi-directional ablation →LIPSS cancel out



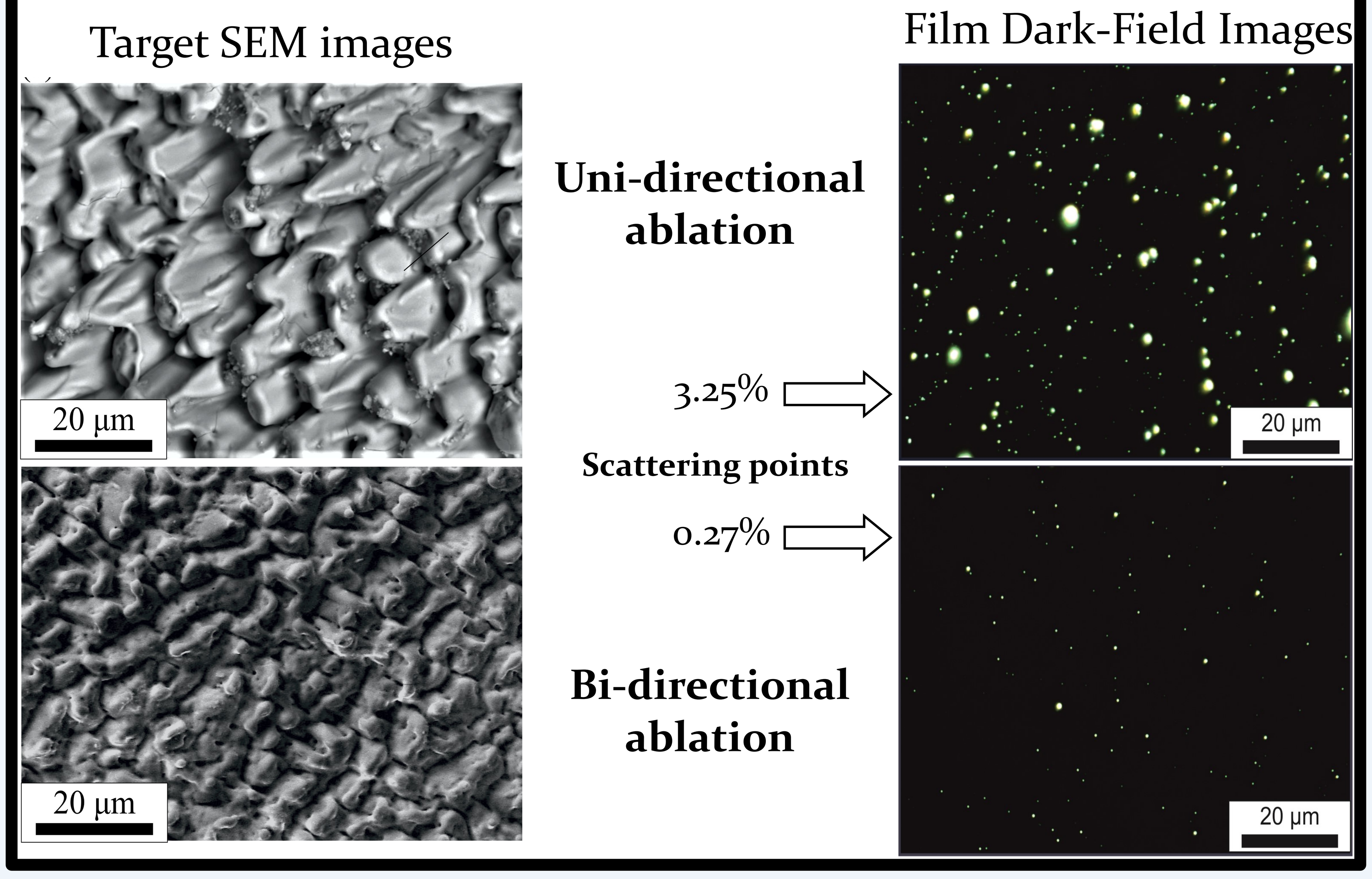
Simulations

Simulations of the location of ablation on the target with uni-directional ablation and bi-directional ablation (red and purple spots indicate ablation from 45° and −45° respectively [2])

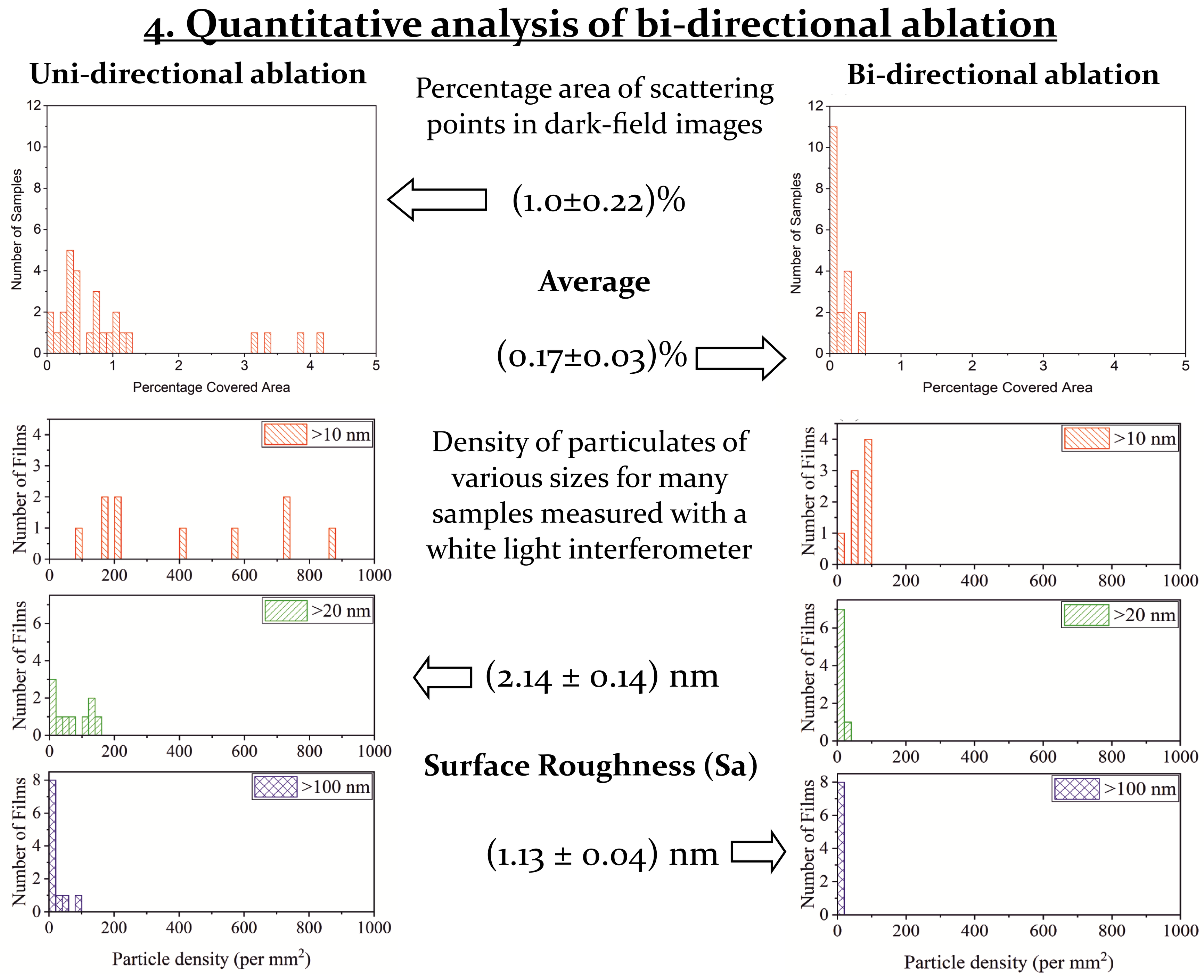


Bi-directional ablation in action

3. Bi-directional ablation results



4. Quantitative analysis of bi-directional ablation



5. Planar waveguide applications

- For planar waveguide applications, low linear propagation loss is required
- The table shows the decrease in propagation loss of various YGG films
- Demonstrates a strong correlation between loss and particulate density

Ablation Technique	Loss (dB/cm)	Dark-field scattering points (/100µm²)
Uni-directional	0.8-7.0	243-1232
Bi-directional	0.17-0.36	22-97

6. Summary

We have developed a novel PLD method for reducing the particulate density in the grown crystal films. We show bidirectional PLD produces an order of magnitude lower particulate density and 50% smoother films. Films with propagation loss of < 0.2 dB/cm have been achieved and, with additional optimisation of this bi-directional technique, further improvements in film quality will be realised.

References

[1] J. I. Mackenzie, S. V. Kurilchik, J. J. Prentice, J. A. Grant-Jacob, L. G. Carpenter, J. C. Gates, P. G. R. Smith, C. B. E. Gawith, H. Riris, A. W. Yu, and R. W. Eason "1.6-µm Er:YGG waveguide amplifiers", Proc. SPIE 10896, Solid State Lasers XXVIII: Technology and Devices, 1089604 (7 March 2019); doi: 10.1117/12.2513665; https://doi.org/10.1117/12.2513665

[2] Prentice, J.J., Grant-Jacob, J.A., Kurilchik, S.V., Mackenzie, J.I. and Eason, R.W., 2019. Particulate reduction in PLD-grown crystalline films via bi-directional target irradiation. *Applied Physics A*, *125*(2), p.152.

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