

Development of Deep Learning Model for Laser Micropatterning Using Spatial Data of Periodic Structures

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Objectives: Bioinspired periodic surface structures have garnered attention due to their excellent water-repellent properties. To fabricate such microstructures at the micrometer scale, ultrashort-pulsed lasers are particularly suitable owing to their high material selectivity and flexibility. However, femtosecond-pulsed laser processing involves multiple nonlinear phenomena, such as laser energy absorption, heat conduction, and ablation, making it difficult to accurately predict the resulting surface morphology. The purpose of this study is to propose a deep learning model capable of estimating the three-dimensional (3D) micropatterned surface geometry by incorporating the periodic characteristics of processed surfaces, such as surface roughness, waviness, and periodic patterns.

Methods: An aluminum alloy (A5052P) was used as the workpiece material, and a femtosecond-pulsed laser (Carbide CB5, Light Conversion) in conjunction with an f 56 focusing lens was employed to fabricate a series of samples with micropatterned surfaces. The processing conditions included 10 fluence levels, 5 overlap ratios, and 5 line pitches. For each condition, cross-sectional profiles were measured at 12 points along the circumference of the laser spot, and mirrored data were generated, resulting in a total of 6,000 data samples. These profiles were then subjected to fast Fourier transform (FFT) to extract periodic structural spatial data (periodic data). Using both the structural and periodic data, a neural network model was developed to predict the cross-sectional geometry (Fig. 1). All data were divided into training and validation sets in a ratio of 8:2. The deep learning algorithms employed included a multilayer perceptron and a fully connected neural network, implemented using PyTouch (<https://pytouch.org/>).

Results and Discussion: The 2D surface geometries predicted by the trained deep learning model showed better agreement with measured results when periodic data were included (Fig. 2). In this case, the smooth L1 loss and root mean square error (RMSE) of the learning curve were 0.85 and 0.664, respectively.

Conclusion: These results suggest the feasibility of constructing a deep learning model that achieves high accuracy in 3D prediction by incorporating periodic data.

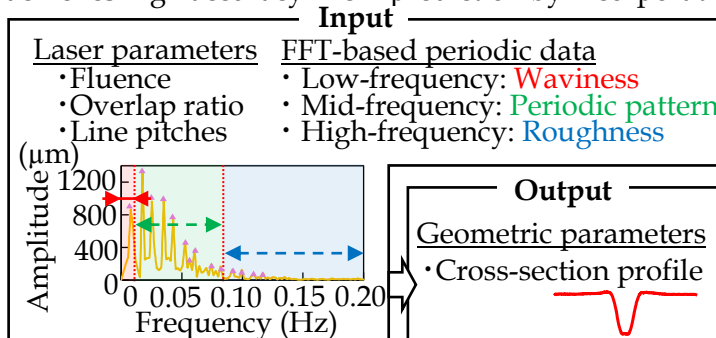


Fig. 1 Development of a deep learning model for surface geometries by ultrashort-pulsed laser processing.

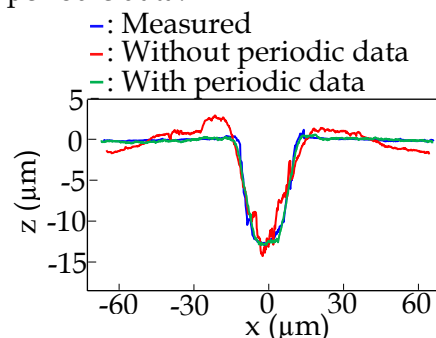


Fig. 2 Comparison of prediction accuracy with and without FFT information.