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Learning dynamics in ultrafast laser self-organization

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Abstract

We demonstrate that ultrafast laser irradiation dynamically reshapes metallic surfaces through a cumulative, self-adaptive process that exhibits learning-like dynamics. Each laser pulse modifies the surface morphology, and the resulting structures progressively optimize energy absorption through feedback-driven reorganization. These imprints encode not only local polarization effects but also a cooperative evolution strategy, where morphological complexity increases over time to accommodate optical constraints.

This behavior emerges from the interaction between thermoconvective instabilities, near-field electromagnetic effects, and dissipative self-organization in the transient molten phase [1]. By combining experimental analysis with thermodynamic modeling and a neural solver trained to predict optical responses via Maxwell's equations, we uncover how surface patterns evolve toward configurations that enhance light-matter coupling.

The evolving surface complexity [2] reflects an intrinsic form of material adaptation, where local responses are shaped by global feedback. This framework connects ultrafast non-equilibrium physics with learning dynamics in physical systems, providing new insight into controlled energy deposition and the design of functional photonic surfaces. These results open routes for tunable absorption and the broader understanding of self-organized complexity in far-from equilibrium matter.

References

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