

PROCEEDINGS

A Generative Framework for Inverse Design of Three-Dimensional Fiber-Woven Aerogel Photonic Crystals with Spectral-Selective Radiative Control

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ABSTRACT

Aerogels are widely used as high-temperature thermal insulation materials in aerospace applications; however, their high transmittance in the mid-infrared range leads to significant radiative heat transfer under extreme thermal conditions. Conventional strategies that incorporate randomly distributed opacifiers rely on scattering or absorption to suppress radiation. Such approaches are inherently based on disordered media and therefore lack spectral selectivity, making it difficult to achieve targeted control over specific wavelength bands. Introducing photonic crystals with periodic dielectric structures offers a promising route toward spectrally selective regulation. However, the strongly nonlinear relationship between structural parameters and optical responses in photonic crystals renders conventional forward design and evolutionary optimization approaches inefficient and computationally prohibitive. In addition, most existing studies are limited to one-dimensional multilayer films or two-dimensional geometries, while systematic design of complex three-dimensional multilayer structures remains largely unexplored. A periodic fiber-woven aerogel photonic crystal architecture is proposed, and the design space is extended to fully three-dimensional multilayer systems. To address the resulting high-dimensional and strongly coupled design problem, a conditionally guided generative modeling framework is developed, enabling efficient learning of structure-spectrum relationships while accounting for structural complexity, interlayer coupling, and material diversity. The proposed approach generates multiple candidate structures within seconds during inference and achieves high reflectivity (>0.8) in the mid-infrared range, leading to significantly enhanced thermal insulation performance. This framework provides a practical and physically grounded solution for the intelligent design of high-performance thermal protection materials.

KEYWORDS

Fiber-woven aerogel; photonic crystal; thermal protection; mid-infrared spectral control; inverse design

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