

Localization and diffusive transport in photonic correlated disorder materials

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Abstract— We investigate a special class of disordered photonic heterostructures, hyperuniform disordered (HuD) photonic structures, that allows to deterministically tailor Anderson localization and diffusive transport.

Keywords— Hyperuniformity, Scanning Near-field Microscopy. Disorder is traditionally regarded as a detrimental element in photonic systems, often associated with unwanted scattering losses, localization effects, and poor reproducibility. However, over the past two decades, this perspective has shifted significantly as it has become clear that disorder, when properly engineered, can serve as a powerful design parameter [1,2]. In particular, correlated disorder systems have emerged as a versatile platform for controlling light-matter interaction beyond the constraints of periodic photonic crystals and fully random media. By embedding structural correlations into otherwise disordered arrangements, it is possible to tailor optical transport, density of states, and scattering properties in ways that are inaccessible to either extreme [3]. Among correlated disordered systems, Hyperuniform Disordered (HuD) materials have attracted growing attention in photonics due to its unique statistical and physical properties. Hyperuniform structures are characterized by anomalously suppressed density fluctuations at large length scales, resulting in a vanishing structure factor in the long-wavelength limit [4]. This property places hyperuniform systems in an intermediate regime between crystalline order and complete randomness. Unlike periodic lattices, hyperuniform structures lack Bragg peaks and long-range translational symmetry, yet they retain a form of hidden order that strongly influences wave propagation. In photonic systems, disorder hyperuniformity has been shown to enable phenomena traditionally associated with periodic media, such as isotropic photonic band gaps [5,6], while preserving the robustness and fabrication tolerance of disordered architectures. This combination is particularly appealing for applications requiring omnidirectional light control, including waveguiding, light confinement, and enhanced emission control. Furthermore, the absence of long-range periodicity reduces sensitivity to defects and allows for

greater flexibility in device geometry, which is advantageous for integrated photonics and three-dimensional photonic materials.

Here, Taking advantage of the combination of the HuD design in slab platforms, optically activated with embedded quantum dots, and near-field hyperspectral imaging with sub-wavelength resolution, we investigated light localization in HuD networks, and unveil different physical mechanism that lead to the formation of different kind of defects with different localization lengths and Q factors [7-10]. The possibility of detecting different regimes of light confinement in a system, whose structuring is at the junction between fully-ordered and completely random systems, open routes yet to be explored for addressing basic physics and practical applications of correlated disorder materials.

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