Scanning Near-Field Optical Microscopy on Hyperuniform Disordered photonic materials

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Abstract: A special class of disordered photonic heterostructures, hyperuniform disordered (HuD) photonic structures, allows to deterministically tailor Anderson localization and diffusive transport. Here, we detect for the first time the presence of level repulsion between delocalized states in a HuD photonic platform, by means of the Scanning Near-field Optical Microscopy technique.

Disordered photonic nanostructures have attracted tremendous interest in the past three decades, not only due to the fascinating and complex physics of light transport in random media, but also for peculiar functionalities in a wealth of interesting applications. Recently, the interest in dielectric disordered systems has received new inputs by exploiting the role of short and long-range spatial correlations within scatterer configurations. Hyperuniform disordered (HuD) photonic materials [1], that share features of photonic crystals and random systems, are an example of engineered disorder to control, through short range-order, both spectral and momentum responses of light.

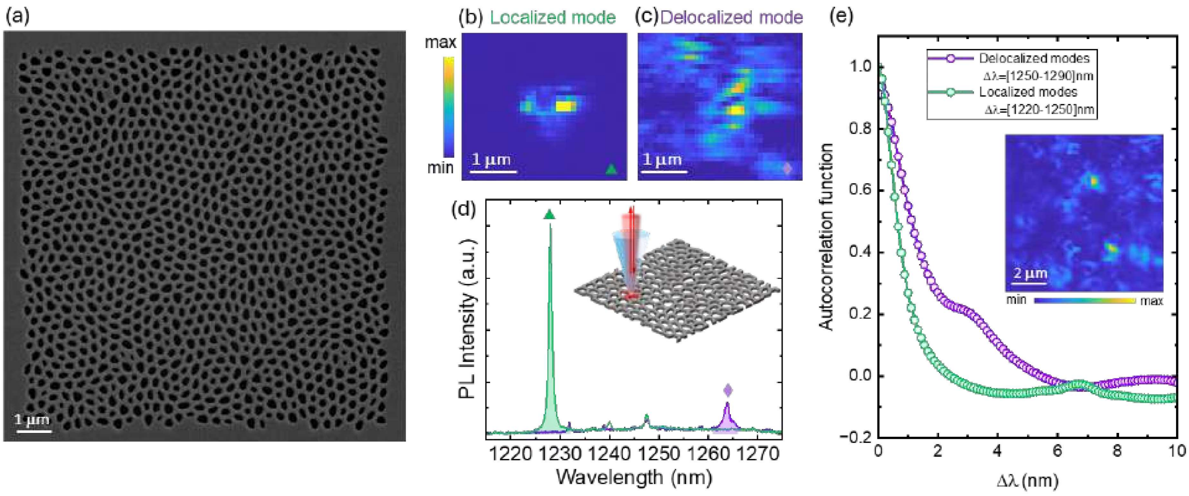
Recently, an experimental study has revealed the transition from light localization to diffusive transport in an optically active platform with a HuD design [2], showing that this type of correlated disorder system hosts Anderson-like modes very promising for fundamental studies but also for technological applications in the field of light-matter interactions. The presence of deterministically tailored localized and diffusive transport within the same photonic platform has raised novel and exciting questions.

Quantum mechanical level repulsion in complex and disordered quantum systems has first been modeled by Wigner and Dyson's random matrix theory [3], and thanks to the many experimental verifications in various branches of physics, became a most valuable criterion for the study of the Anderson transition [4,5].

Here, taking advantage of the Scanning Near-field Optical Microscopy (SNOM) technique, we present the first experimental evidence of level repulsion in HuD systems in a tailored diffusive regime.

The studied samples consist in 200nm thick GaAs slabs patterned with a HuD design (Fig.1a); embedded in the middle of the slab are InAs quantum dots that act as optically active medium. The room temperature SNOM, capable of subwavelength spatial resolution in the near-IR range, is employed in illumination/collection configuration, meaning that the sample is excited with light from a diode laser (785 nm) coupled into a chemically etched optical fiber. Photoluminescence (PL) spectra from the sample are collected at each tip position through the same probe. Fig.1b-d report the results of a SNOM measurement performed on the sample; the PL SNOM maps of a typical Anderson localized mode (b) and of a delocalized one (c), along with their relative spectra acquired in the positions of maximum intensity (d).

The method employed to detect the level repulsion phenomenon is based on the evaluation of the autocorrelation function [4,6], which allows for a statistical description of the systems in terms of energy level distribution of the optical modes sustained by the system. Within a single SNOM scan performed on the entire sample (as shown in the inset of Fig.1e) we have access to all the modes within a large spectral range. We selectively evaluate the autocorrelation function in the two spectral ranges corresponding to localized and delocalized modes, and the results are plotted in Fig.1e. The presence of a pronounced shoulder at short spectral distances in the purple curve is a clear indication of level repulsion between delocalized modes, differently, from what is observed in the autocorrelation function of localized modes. Moreover, through the evaluation of the spectral width of the autocorrelation peak, our spatially resolved spectroscopy technique gives direct insights on the typical hallmark of light localization regimes, like for example the smaller (larger) spectral width of localized (delocalized) modes.



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