Control of Light in Complex Aperiodic and Random Photonic Lattices

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Abstract— Engineering photonic systems is ideal for investigating wave phenomena and to control light in random or artificially fabricated deterministic aperiodic photonic lattices. Disorder in photonic systems fosters weak and strong light localization, known as Anderson localization and coherent backscattering, respectively, evolving from multiple scattering on randomly distributed scattering centers. On the other hand, tailored light propagation by designing distinctive band gap properties of deterministic aperiodic structures, such as golden-angle Vogel spirals, and Fibonacci lattices, is highly appealing. We present paradigm-shifting techniques for the optical realization of these functional structures and investigate light control by these engineered material modifications.

Recent developments in photonics shift investigations from periodic lattices to random structures [1] and deterministic aperiodic order [2] to investigate light control in these tailored scattering or band structure designed media.

In order to study light localization phenomena as pure wave effects in random potentials, photonic systems are ideal [1] due to the lack of secondary effects such as matter-matter interactions.Still, the principle is universal: Time-reversed pairs of scattering paths owing zero phase difference result in a constructive wavelet interference contribution that survives among statistical background which average out in an extensively large ensemble. Established classifications characterize localization in distinctive regimes: Strong localization, formally known as Anderson localization [1, 3], originates from closed scattering paths and localization consequently occurs around the input position. Weak localization in contrast, describes the inversion of an incoming wave vector to its negative direction, as it is called coherent backscattering [4].

Designing the optical properties of materials by tailoring their band structures is an active field of research. Nowadays, particular interest turned towards deterministic aperiodic structures showing distinctive band gap and Fourier spectrum properties [2]. These aperiodic structures offer highly isotropic band diagrams due to the lack of rotational and translational symmetry [2]. In particular, the golden-angle Vogel spiral has attracted much attention since its topology remarkably differs from many other lattices, implying effects like optical angular momentum-bearing discrete diffraction [5].

In this contribution, we describe the preparation of ensembles of random photonic potential landscapes in order to experimentally investigate light localization [3, 4]. We established an elaborate platform to examine transverse scattering effects in an ensemble of optically induced disordered photonic structures. Owing to the peculiar power spectrum,we not only examine both weak and strong light localization separately but in particular their mutual transition from Anderson localization to coherent backscattering [4].

Expanding photonic lattices to aperiodic structures, we present a new holographic fabrication technique for the pixel-wise optical induction of prominent aperiodic structures [5, 6], based on Bessel beams as fundamental single-site entities. We accomplished this by means of optical induction which allows to realize a huge class of two-dimensional photo refractive index landscapes, including our demonstrations of deterministic aperiodic golden-angle Vogel spirals as well as Fibonacci lattices [5, 6].

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