3-D Lattices with a Twist: Next Generation Photonic Structures

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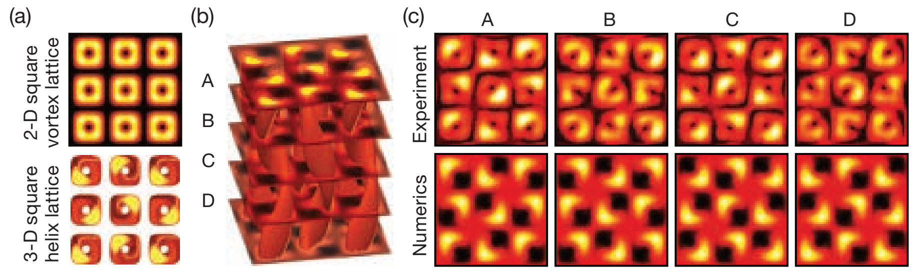
The investigation of artificial dielectric structures in order to engineer, guide or store light is driven by the increasing requirements for digital information transmission and processing bandwidth.[1] Materials that change their properties due to light (whereupon light itself reacts on the changed material) provide the missing link to controlling light with light itself. Photorefractive crystals are promising examples. The illumination of such a material with structured lattice-writing light waves yields fascinating reconfigurable nonlinear photonic lattices.[2]

In recent years, this technique has led to photonic structures that are optically induced with the help of so-called discrete non-diffracting beams. These nifty plane wave interference patterns possess an intensity distribution modulated in both transverse dimensions but invariant in the direction of propagation. This allows for the optical induction of corresponding photonic lattices, which pioneered the demonstration of fundamental effects such as discrete solitons, Zener tunneling and Bloch oscillations, as well as Anderson localization. However, we see that the full potential of this technique has not yet been explored. In particular, vortex fields and their three-dimensional counterparts—helical lattices—have been a closed book in singular optics, despite their enormous potential.

We presented several novel strategies for overcoming the rather simple lattice geometries studied so far and head towards a new structural variety of non-diffracting wave fields including vorticity.[3] One of our ideas—to control the phase relation of different components in the spatial spectrum of discrete non-diffracting beams—led to the demonstration of non-diffracting kagome[4] and graphene lattices.[3] Extending this strategy, we developed an approach to constructing all three fundamental vortex lattices.[5] These non-diffracting beams represent unique periodic patterns of triangular, square or hexagonal vortices and are particularly interesting due to the inherent connection between optical vortices and the orbital angular momentum of light.

In the same way, the creation of three-dimensional helical lattices was a big challenge for discrete photonics until we found an ingenious modification to our approach and used the two-dimensional vortex lattices as a basis for the first construction of helix lattice waves.



(a) Comparison between the intensity distributions of the two-dimensional square vortex lattice and the top view of the corresponding three-dimensional helix lattice. (b) Plot of the isointensity surfaces of the square helix lattice at 60 percent of the maximum intensity. (c) Comparison of experimental (top row) and numerical (bottom row) images for the planes A–D marked in (b). Three-dimensional data of all fundamental helix lattices can be accessed online as multimedia components to this article.

The figure illustrates the square vortex and square helix lattice, and the analysis of different planes in the direction of propagation clearly verifies the helical structure of the three-dimensional intensity distribution.

These recent developments enable the optical preparation of an unequaled versatility of novel two- and three-dimensional photonic structures, providing forward-looking contributions to our vision of controlling light with light. Moreover, our approach can easily be transferred to other fields. An adaption to different photosensitive media allows for the realization of complex photonic bandgap materials or advanced artificial material structures such as photonic crystals or metamaterials. In addition, the creation of chiral optical traps in atom optics and the field of cold gases is now feasible due to our technique. ▲

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