Exploiting aperiodic order in photonic devices

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During the last few years a growing number of papers considering the role of deterministic aperiodic order in the optical response of different physical systems has progressively appeared in the literature [1]. Most of these works address the fundamental question concerning whether the specific aperiodic order present in the considered devices results in a better performance than that obtained for more usual periodic arrangements in some specific applications. The inspiring basic principle at work can be easily grasped by considering a layered structure consisting of a number of films aperiodically stacked. In this way, two kinds of order are introduced in the same sample at different length scales. At the atomic level we have the usual periodic order determined by the crystalline arrangement of atoms in each layer, whereas at longer scales we have the quasiperiodic order determined by the sequential deposition of the different layers. This long-range aperiodic order is artificially imposed during the growth process and can be precisely controlled. Since different physical phenomena have their own relevant physical scales, by properly matching the characteristic length scales we can efficiently exploit the aperiodic order we have introduced in the system. Thus, the possibility of growing devices based on an aperiodic stacking of different layers introduces an additional degree of freedom, related to the presence of two different kinds of order in the same sample at different length scales, hence opening new avenues for technological innovation [2]. For instance, one can use sandwiched arrays of aperiodic dielectric multilayers to design optical microcavities [3-5], omnidirectional mirrors [6], multi-stop band filters [7,8], photonic bandgaps [9-12], waveguide structures [13] and many other optical systems of practical interest.

In the case of nonlinear optics, quasiperiodic multilayers can provide more reciprocal vectors to the quasi-phase-matching optical process, and this ultimately results in a more plentiful spectrum structure than that of a periodic multilayer [14,15]. On this basis, the possibility of designing aperiodic structures able to simultaneously phase matching any two nonlinear interactions by properly introducing an aperiodic modulation of the nonlinear coefficient in ferroelectric devices has been proposed in one [16] and two dimensions [17]. The nonlinear properties of optical heterostructures can also be used to fabricate compact-sized compressors for laser pulse. This compression is physically determined by the group velocity dispersion in the material, so that one can expect that by adding more layers to a periodic multilayer one should obtain narrower optical bands and the compression effect will be increased. However, this is inevitably accompanied by an increase of the total thickness of the structure, which is undesirable. In this context, the recourse to aperiodic structures, exhibiting a significantly larger fragmentation of their optical spectrum for similar system sizes, appears as a natural choice.

New approaches in order to obtain innovative optical systems are also based on the construction of modular devices composed of both periodically and aperiodically arranged multilayers Such devices can be viewed as hybrid order systems made of two different kinds of subunits, each one exhibiting a different kind of topological ordering [18]. The introduction of these subunits endows the system with an additional design parameter, bridging the gap between the atomic level characteristic of the microstructural domain of each layer and the mesoscale level associated to the long-range order of the entire device as a whole [19-21].

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