Finite-size scaling of the density of states in a 3D photonic band gap

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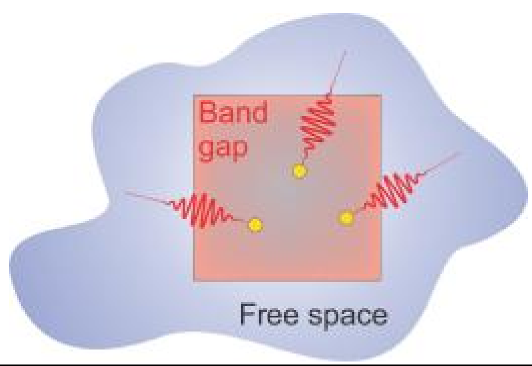
The central concept of a bandgap – both electronic or photonic - pertains to infinite systems ($L \rightarrow \infty$) only. In contrast, experiments and applications are obviously made with real and finite crystals [1,2], which begs the question: How fast does the density of states (DOS) in the band gap of a finite-crystal approach the infinite-crystal limit? In other words: what is the scaling behavior of the DOS?



Scheme of how to probe the DOS in the band gap of a finite crystal by local probes. Quantum light emitters (yellow spheres) embedded in a finite photonic band gap crystal (square) experience the local density of states (LDOS) as the density of vacuum fluctuations (red wavelets). By averaging over many emitters throughout the crystal, we probe an average LDOS that represents the DOS of the finite crystal.

We exploit a well-known effect in cavity quantum electrodynamics (QED): the density of photonic states plays an essential role in spontaneous emission of a quantum emitter. We study the scaling behavior of the photonic density of states for a sample that has a full 3D bandgap. We probe a position averaged local density of states that represents the DOS of the finite crystal and converges to the infinite-crystal limit of the DOS. We support our observations by a new theory that introduces finite-size effects into the DOS of an infinite system. Our study provides a first ever design rule for the usage of vanishing density of states, to cavity QED, quantum information processing, and notably to Anderson localization. This puts in a position to explore novel "Nanophotonic phase transitions of light", analogues to phase transitions in matter, such as metal-insulator transitions [3]. As an aside, we recently observed a curious inversion effect of a photonic gap on atomic dispersion [4].

References

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