Physics Colloquium

Thursday, 8 December 2022 | 17:00 – 18:00, Seminar Room 3rd floor, and online

Shaping waves to penetrate deep inside forbidden gaps

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ABSTRACT

It is well known that waves with frequencies within a forbidden gap – a band gap – enter a limited depth into a crystal before being reflected by Bragg interference. This holds for photons in photonic band gap crystals and for electrons in semiconductor crystals alike [1], and leads to an intriguing position dependence of the local density of states (LDOS) [2]. Here, we investigate how to seemingly defy the notion above, by sending waves deep into band gap crystals with optical wavefront shaping and tailored nanostructures. We fabricate silicon photonic band gap crystals by CMOS-compatible deep-reactive etching, including 3D superlattices of coupled cavities that resonate within the band gap. As metrology of the fabricated nanostructures, we employ non-destructive synchrotron X-ray imaging methods. These appear to be powerful tools to determine the material density, including embedded quantum dots, with up to 20-50 nm spatial resolution [3]. By spatially shaping the incident optical wave fronts [4], the internal energy density appears to be enhanced at a tunable distance away from the front surface. The energy density is enhanced up to 100× compared to plane or random incident wavefronts, much brighter than expected from Bragg interference of Bloch modes, and which is successfully understood with an extended mesoscopic model [5]. When neighboring cavities in a 3D cavity superlattices are sufficiently closely spaced, we observe that their resonances hybridize and form a new band within the gap. Our observations agree with a theory where photons hop between cavities in Cartesian high-symmetry directions, hence the new optical state is called Cartesian light [6]. Furthermore, we derive a scaling method to classify all possible dimensionalities of classical and quantum Cartesian waves – light, sound, electrons, spins, and so forth – that propagate through any superlattice [7]. Cartesian light has application potential, for example, in 3D classical and quantum photonic networks, 3D Anderson localization of light, and further in future to exotic photonic states.

References

[1] E.N. Economou, *The Physics of Solids* (Springer, Berlin, 2010)
[2] C.M. Mavidis, A.C. Tasolamprou, S.B. Hasan, T. Koschny, E.N. Economou, M. Kafesaki, C.M. Soukoulis, and W.L. Vos, Phys. Rev. B **101** (2020) 235309
[3] A.S. Schulz, *et al.*, ACS Nano **16** (2022) 3674; D.A. Grishina, *et al.*, ACS Nano **13** (2019) 13932
[4] I.M. Vellekoop and A.P. Mosk, Opt. Lett. **32** (2007) 2309; A.P. Mosk, A. Lagendijk, G. Lerosey, and M. Fink, Nat. Photonics **6** (2012) 283; S. Rotter and S. Gigan, Rev. Mod. Phys. **89** (2017) 015005
[5] R. Uppu, M. Adhikary, C.A.M. Harteveld, and W.L. Vos, Phys. Rev. Lett. **126** (2021) 177402
[6] S.A. Hack, J.J.W. van der Vegt, and W.L. Vos, Phys. Rev. B **99**, 115308 (2019)
[7] M. Kozoň, A. Lagendijk, M. Schlottbom, J.J.W. van der Vegt, and W.L. Vos, Phys. Rev. Lett. **129** (2022) 176401