Optical Analogue of Electronic Bloch Oscillations

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We report on the observation of Bloch oscillations in light transport through periodic dielectric systems (cover story of Phys. Rev. Lett. **91** [1]). By introducing a linear refractive index gradient $\Delta\delta$ along the propagation direction the optical equivalent of a Wannier-Stark ladder was obtained. Bloch oscillations were observed as time-resolved oscillations in transmission, in direct analogy to electronic Bloch oscillations in conducting crystals where the Wannier-Stark ladder is obtained via an external electric field. The observed oscillatory behaviour is in excellent agreement with transfer matrix calculations.

The phenomenon consists in the counter-intuitive effect that an electron propagating in a crystal can be brought into an oscillatory motion by a static electric field. This means that an AC current is generated by a DC field. The frequency domain counterpart of time-resolved Bloch oscillations is the formation of a Wannier-Stark ladder, equidistant energy levels in place of a continuous energy band, as shown in figure 1, in the photon analogue case.

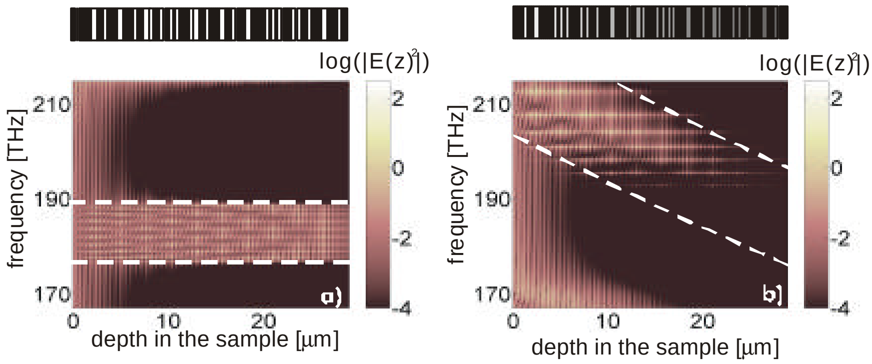

Figure 1. Scattering state calculation of the distribution of the energy spectrum inside an optical superlattice composed of 10 coupled microcavities. Panel a) flat band situation, $\Delta\delta = 0\%$. Panel b) tilted band situation $\Delta\delta = 14\%$. Above each panel the coupled microcavity structure is schematically shown (the darker the larger *n*, the refractive index).

Bloch-Zener controversial prediction dates back to 1928 [2], and it led to an enormous debate in literature that continued for over 60 years, until the advent of semiconductor superlattices [3], since researchers did not manage to agree if Bloch oscillations could exist or not. There exist fascinating analogies between electron transport and transport of optical waves in dielectric structures [4]. Ordered (periodic) dielectric systems are called photonic crystals and can exhibit a photonic bandgap in analogy with the electronic bandgap in semiconductors. There are many examples of wave phenomena where interference effects play a crucial role both in the optical and the electronic case. Often these processes are easier to study with light because the coherence time of an optical wave packet is usually much longer than that of an electronic wavepacket.

This observation of time-resolved optical Bloch oscillations was performed in time-resolved transmission experiments on optical superlattices made of chemically etched porous silicon. A linear gradient in the optical thickness was used to break translational invariance of the crystal, mimic the effect of an electric field and provide longitudinal confinement of the optical wave packet by tilting the photonic band structure, in direct analogy to the electron case.

REFERENCES

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3. See e.g. J. Feldman, et al., *Phys. Rev. B* **46**, 7252; (1992) K. Leo, et al., *Solid. State Comm.* **84**, 943 (1992).
4. See e.g. Ping Sheng, Introduction to Wave Scattering, Localization, and Mesoscopic Phenomena (Academic Press, New York, 1995).