PHOTONIC BANDS AND TUNNELING

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1 INTRODUCTION

Photonics is the electromagnetic analogy to electronics. In photonics the propagation of electromagnetic wave packets is studied in periodic dielectric structures. The whole theory of electrons in a periodic potential applies directly to the problem of electromagnetic waves. As a matter of fact this result is general and independent of the special physical meaning of the waves considered, and it must be the same for elastic, electromagnetic, and Schrödinger waves.

In a periodic dielectric structure there are photonic bands separated by forbidden gaps, as well as defect levels as we are used to from the elctronic states in a semiconductor crystal. Figure 1 illustrates a hypothetical combination of an electronic and a photonic band-gap in one crystal. The electron wave vector is scaled by a factor of 10^{-3} taking into consideration the larger wavelength of a photon and the correspondingly smaller photonic Brillouin zone. In this fictitious crystal the radiative electron-hole recombination would be inhibited, as the photonic band is opened at the relevant photon energy [1]. Such a crystal would extraordinarily improve the specifications of several optoelectronic devices.

Also tunneling which represents another important field of wave mechanics can be studied in photonic structures. The propagation of so-called evanescent electromagnetic waves is analogous to particle tunneling. Evanescent modes are the purely imaginary solutions of the Helmholtz equation, they correspond to the tunnel solutions of the Schrödinger equation. Accordingly, investigations with electromagnetic wave packets do promise to obtain general informations on the tunneling process. Particularly the tunneling time is very difficult to be measured in the case of electrons, this appears to be somewhat easier for evanescent electromagnetic wave packets.

In this lecture we shall introduce in the first part some basic features of one- and three-dimensional photonic bands and defect levels. The second part is devoted to photonic tunneling experiments and the interpretation of observed zero tunneling time.

Advances in Quantum Phenomena, Edited by E.G. Beltrametti
and J.-M. Lévy-Leblond, Plenum Press, New York, 1995

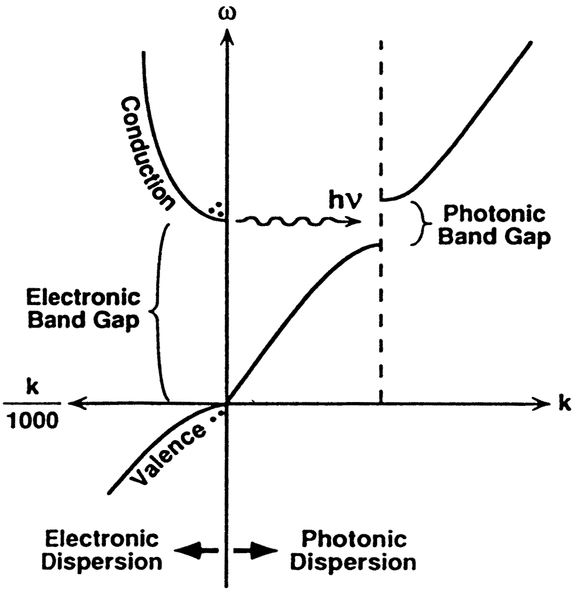

Figure 1. On the right is the electromagnetic dispersion, with a forbidden gap at the wavevector of the dielectric periodicity. On the left is the electron wave dispersion of a semiconductor. Since the photonic band gap straddles the electronic band edge, electron-hole recombination via photon emission is inhibited.

2 BANDSTRUCTURE

2.1 One-dimensional lattice

A simple one-dimensional lattice is obtained by the periodic arrangement of two types of dielectric layers as shown in the insert of Fig. 2. Their refractive indices are given by n_1 and n_2, respectively. The transmission of this structure is shown in the same figure [2]. There is a forbidden photonic band in the displayed frequency range, i.e. a stopping band where the transmission is reduced up to four orders of magnitude and the electromagnetic wave becomes evanescent modes. In principle this band structure could be calculated from the Kronig-Penney model [3].

2.2 Three-dimensional lattice

A gap in the energy dispersion relation is always opened at the Brillouin zone of a crystal. If this gap is narrow and the Brillouin zone deviates strongly from a sphere, there is no overlap of the individual gaps in the various directions of the reciprocal lattice, i.e. in momentum space. Therefore it was suggested, to investigate a priori only face centred cubic lattice structures (FCC), which have a Brillouin zone deviating least from a sphere compared with other common Brillouin zones [1, 4]. The Brillouin zones of the two most important crystal structures are displayed in Fig. 3. The Brillouin zone of the body-centred cubic (BCC) deviates much more from a sphere than the FCC one, thus for instance at the symmetry points L and X the forbidden gaps do not overlap.

However, it was figured out soon, that even the FCC structure does not ensure an overlap of the frequency gaps for all possible directions in reciprocal space. There was still a degeneracy of two bands for electromagnetic waves of different polarization at the