Theory of Gain Enhancement in Periodic Structures with Degenerate Band Edges

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The pursuit of unprecedented performance in amplifiers and oscillators has led to unveiling new class of periodic structures where the dispersion relation can be readily engineered and optimized for high gain and high efficiency. We propose a novel amplification paradigm in periodic structures comprising four electromagnetic modes that exhibit a special degeneracy condition called degenerate band edge (DBE). A DBE condition corresponds to an exceptional point in the dispersion diagram that causes a quartic power dependence at the band-edge of the Bloch wavenumber versus frequency, and is accompanied by significant reduction in the group velocity of waves and giant improvement in the local density of states. We show how to realize a DBE in coupled waveguide structures ranging from microwaves to optical frequencies; and we represent wave propagation in those realistic structures using an equivalent multi transmission line (MTL) model. We provide accurate basis for modeling the gain medium in many devices such as electron beam devices, RF solid state devices, lasers, etc; all based on a unified MTL theory. Giant gain improvement is reported compared to a conventional amplifier with the same parameters; attributed to the gigantic Fabry-Perot resonance. We demonstrate the application of such giant gain phenomena in many periodic structures with DBE in oscillations, and we report low threshold in oscillators operating based on DBE modes; that can be an order of magnitude lower than a conventional oscillator. We numerically examine and quantify those dynamics in FPCs supporting DBE using finite-different time-domain (FDTD). The results reported here also suggest potential application of DBE in other devices such as active filters, pulse compressors, or antennas.