Slow light, Anderson localisation and routes to Purcell Enhancement in photonic crystal waveguides

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In this work we have studied GaAs based linear defect photonic crystal waveguides (PCWs), demonstrate the role waveguide losses play in the propagation of photons as the group velocity is reduced when operating close to the PCW band edge and show that Anderson localisation of photons occurs very close to the band edge. We also investigate modified waveguide geometries to reduce group index dispersion and aid the coupling of quantum dots (QDs) to slow light modes.

Photonic crystal waveguides (PCWs) are a promising technology for photon transfer in on-chip integrated quantum optical circuits. Using III-V based materials systems allows the incorporation of QD single photon sources and large optical non-linearities. A significant advantage of PCWs over competing technologies, such as ridge waveguides, is their unique dispersion characteristics, which modify the local density of states and produce broad band slow light within the waveguide mode that can be engineered to exhibit low dispersion. There are advantages of working in the slow light regime for manipulating photons with enhanced non-linearity. However two key concerns are dispersion and scattering losses which can compromise these advantages through pulse broadening and excessive losses.

PCWs of varying lengths incorporating a single layer of InAs QDs are studied using a spatially selective photoluminescence (PL) technique. This provides independent control over the regions of the sample from which PL is excited and collected allowing us to simultaneously study in plane propagation and surface losses.

Fabry-Perot (FP) resonances observed with PL collected from vertical-couplers at the waveguide ends are used to map the dispersion within the waveguide mode, with values of group velocity, v_g, up to $c/30$ measured. By studying the finesse of the observed modes the out-coupler facet reflectivity and waveguide losses as a function of vg in the different length PCWs are measured. We find the waveguide losses in the slow light region of $v_g > c/12$ limit photon propagation lengths to tens of micrometers.

In addition, Anderson localised modes are observed vertically from the PCWs and occur in a spectral window between the final visible FP resonance and the slow light mode at the band edge. This provides further evidence that enhanced scattering in PCWs (without intentional disorder) contributes to waveguide losses as the band edge is approached. This has significant implications for the use of PCWs in integrated quantum optics where photon propagation lengths many times those observed in our structures will be required.

The potential of engineered flat band slow light is also investigated in modified waveguides where the two innermost rows of holes are shifted. An electromagnetic eigenmode solver technique is used to determine shifts that produce local minima in the group index with a constant index-bandwidth product of 0.3, facilitating low dispersion propagation away from the band edge. Another interesting property of these regions is that they offer Purcell enhancements of up to 10 for QDs located at field antinodes. This coupling regime offers enhanced collection efficiency of the QD emission compared to cavity-enhanced emission with the additional benefit of a large coupling bandwidth. This is especially important for integrated quantum optics, where the random energies of QD growth can be problematic when coupling to high-Q cavity modes.