Designing photonic crystal fibres for second-harmonic generation

Masters/midterm project
Supervisor Jesper Lægsgaard - jl@com.dtu.dk

Second-harmonic generation (SHG) in optical waveguides with second-order nonlinearity is of interest for using frequency upconversion to make light sources at wavelengths where good/cheap lasers are not available. The feasibility of inducing second-order nonlinearities in silica fibers by poling with internal wires was demonstrated long time ago. Recently, it has been shown that wires can be incorporated directly in the drawing process for both silica and polymer fibers. These findings raise the question whether optical fibres will be useful for second-harmonic generation. The advantage would be that long lengths of fibre are cheaply produced, so that very efficient SHG devices could be fabricated. The main challenge, apart from the poling, is to design fibres which can meet the rather challenging dispersion requirements. In this project, we will investigate the use of photonic crystal fibres (PCFs) to tackle the latter problem.

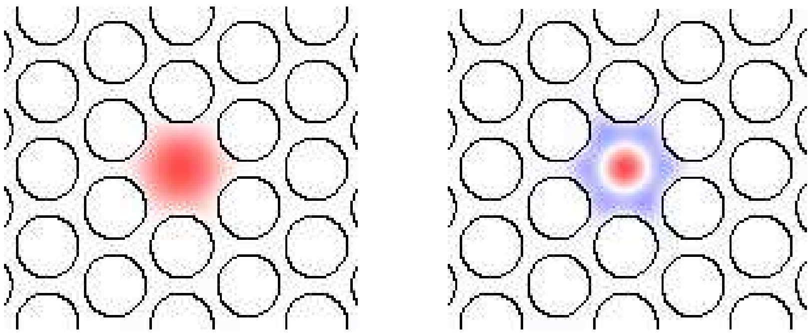

Figure 1: Fundamental (left) and LP_{02} like mode (right) of a photonic crystal fiber with large air-filling fraction.

Efficient SHG in a waveguide requires that the phase index of the fundamental mode and the mode in which the second-harmonic signal is generated have the same phase index. If both the fundamental and second-harmonic light are to propagate in the fundamental mode of the waveguide, this criterion cannot be met in a silica-based waveguide, since the material index of silica is a monotonically decreasing function of wavelength at optical frequencies. An additional requirement when using pulsed pump sources, is that the group velocity of the fundamental and second-harmonic modes should match, so that the generated SHG pulse keeps in step with the pump pulse.

Also this requirement is difficult to meet in standard optical fibres when going to SHG wavelengths shorter than $\sim 1\ \mu$m, due to the strongly negative material dispersion at these wavelengths.

It was recently shown by researchers from the FNO group at COM, that group velocity matching between fundamental modes at the pump and SHG frequency could be achieved using the strongly altered dispersion properties of photonic crystal fibres. However, to achieve phase index matching as well, it is necessary to consider SHG in a higher order mode. In this project we will attempt to design silica-based PCF waveguides having simultaneous phase- and group-velocity matching between the fundamental, LP_{01}-like, mode and the LP_{02}-like higher-order mode (see figure). Since both modes are circular symmetric the induced polarization field from the fundamental mode can be expected to have some overlap with the LP_{02} mode.

The dispersion properties of the fibers will be investigated using a freely available, full-vectorial modeling tool based on plane waves. To ease the treatment of material dispersion a perturbative approach developed at COM, will be utilized. The numerical codes needed for the project are already available, so the student will concentrate on understanding the methods and performing the calculations and data analysis.