Ultrafast nonlinear optics in hollow-core photonic crystal fibers

- Introduction
- Self-phase modulation / Pulse propagation
- Objectives / Literature review
- Experimental setup / Equipment / Work plan
- Applications
Ultrashort pulse lasers are important experimental tools for investigating fast-evolving atomic and molecular dynamics in physics, chemistry and biology. Ultrashort pulses can be generated by extracavity compression techniques SPM(Self-phase modulation)+ODL(optical delay line). High energy pulse compression technique is based on hollow fibers or capillaries filled with noble gases. Hollow-core photonic crystal fibers are interesting medium for nonlinear spectral broadening and possible use for high energy pulse compression.
Self-phase modulation

\[
\vec{P} = \vec{P}^{(1)} + \vec{P}^{(2)} + \vec{P}^{(3)} + \ldots \\
\vec{P}^{(1)}(\omega) = \varepsilon_0 \chi^{(1)}(\omega) \vec{E}(\omega) \\
\vec{P}^{(2)}(\omega_1 + \omega_2) = \varepsilon_0 \chi^{(2)}(\omega_1, \omega_2) \vec{E}(\omega_1) \vec{E}(\omega_2) \\
\vec{P}^{(3)}(\omega_1 + \omega_2 + \omega_3) = \varepsilon_0 \chi^{(3)}(\omega_1, \omega_2, \omega_3) \vec{E}(\omega_1) \vec{E}(\omega_2) \vec{E}(\omega_3) \\
n(I) = n_0 + n_2 \cdot I
\]

\[
\omega(t) = \frac{d\phi(t)}{dt} = \omega_0 - \frac{2\pi L}{\lambda_0} \frac{dn(I)}{dt}.
\]

\[
I(t) = I_0 \exp \left( -\frac{t^2}{\tau^2} \right)
\]

\[
\omega(t) = \omega_0 + \frac{4\pi L n_2 I_0}{\lambda_0 \tau^2} \cdot t \cdot \exp \left( -\frac{t^2}{\tau^2} \right).
\]
Pulse propagation

Linear medium (anomalous dispersion)  Kerr nonlinear medium

Kerr medium + Linear medium
Objectives

Self-phase modulation due to nonlinear optical Kerr effect in gas-filled hollow-core photonic crystal fibers will be investigated and possible use for laser pulse shortening will be analyzed. Spectral broadening will be investigated in different gazes Ar, Kr... and liquids under various (pressure and temperature) conditions. Also linear, circular and elliptic polarizations cases will be probed.
3. Theoretical study of soliton-induced high-power supercontinuum generation by using kagome lattice HC-PCFs filled with a noble gas. [800nm 50fs 176 TW/cm²]

4. Spectral broadening in Ar [800nm 140fs 450nJ 1-150bar]

5. Pulse compression in Xe [1030nm 1ps-250fs 1μJ 8bar]

8. Compressing in inert gases [1053nm 1ps-100fs 1mJ 1-50bar]

9. Self-compression in Xe [1800nm 80fs-4.5fs 120μJ 4bar]

10. High energy ultrafast Ar [1030nm 740fs-88fs 18μJ 13bar]
Experimental setup

1030nm / 515nm
500fs 200μJ-1mJ
Ar gas 200bar

Laser

SHG
HS

PC

Autocorrelator

Spectrometer

Kagomé lattice hollow-core PCF

Step motor

Out

DAQ card

PM

CCD
## Equipment/Cost

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>PC</td>
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<tr>
<td>CCD</td>
<td></td>
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<tr>
<td>Power meter</td>
<td></td>
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<tr>
<td>Spectrometer</td>
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<tr>
<td>Autocorrelator</td>
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<td>Optical elements/mounts</td>
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<td>Second harmonic crystal</td>
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<tr>
<td>High pressure chamber</td>
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<tr>
<td>DAQ card /motors</td>
<td>~500$</td>
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<td>PC fiber /m</td>
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<tr>
<td>Diff. gratings pair</td>
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</tr>
<tr>
<td>10x Al mirrors</td>
<td>~200$</td>
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<tr>
<td>He, Ne, Ar, Kr, Xe, O₂, N₂</td>
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Work plan

1. Concept/Idea formation
2. Literature review
3. Simulation software
4. Small proof of concept experiment
5. Compression module assembly and testing
6. Main experiment (He, Ne, Ar, Kr, Xe, O$_2$, N$_2$ 1-100 bar)
7. Comparative analysis of results
8. Final pulse compression module assembly and testing
Applications

- Photonic-crystal fiber
- Ultrafast spectrometry
- Bright X-ray generation
- Multiphoton microscopy
- Particle acceleration
- Attoscience
2. US20100328658 A1 Abdel Fetah Benabid, Francois Yves Michel Denis Couny, Peter John Roberts University Of Bath (2010)
3. High-power soliton-induced supercontinuum generation and tunable sub-10-fs VUV pulses from kagome-lattice HC-PCFs Song-Jin Im, Anton Husakou, and Joachim Herrmann Optics Express, Vol. 18, Issue 6, pp. 5367-5374 (2010)
7. All fiber-based Yb-doped high energy, high power femtosecond fiber lasers Peng Wan, Lih-Mei Yang, Jian Liu (2013)
11.
12.