INTRODUCTION

An exciting field known as “Coherent Control of Quantum Systems” emerged from previously unsuccessful attempts to employ lasers to steer chemical reactions. One of the main ideas is to use the phase coherences within a spectrally broad bandwidth laser pulse to drive quantum systems to a desired target state. In other words, we specify the initial and the final state of a quantum system and design the coherences within a laser pulse such that this goal is achieved with a maximum efficiency. Progress in this field is tightly linked to technological advances in pulse shaping, i.e. in tailoring the lasers’ spectral components, and has led to numerous achievements in communications, physics, chemistry, and life sciences. Especially, state-selective photochemistry has always been a driving force in this field, but recently many other fields have seen great impact of coherent or optimal control. In cases where the quantum system is too complicated and no predictions on the ideal laser waveform are available, self-learning algorithms are employed to circumvent this problem. The efficiency of the final quantum state population is monitored, and the algorithm optimizes the efficiency by adjusting the spectral coherences within the laser waveform. Often it is possible to extract useful information from the optimized waveform, therefore, gaining new and sometimes unexpected information on the underlying fundamental processes.

RESEARCH OBJECTIVES

Within our ongoing research we have started to merge the field of coherent control with the field of photonic bandgap fibers. The reason for doing so is to be able to control relatively large amounts of matter in a well defined environment. From the combination we anticipate a great number of fascinating both scientific and technological results. In the following we will first elaborate on the different enabling techniques, that is, on pulse shaping and photonic bandgap fibers, and finally describe some of our research goals. Although all initial experiments are performed with commercially available fibers, later stages will require custom made designs which can only be fabricated at our own facility.

Generation of user-defined optical waveforms

A pulse shaping apparatus, such as shown in figure 1, allows for spectral phase- and amplitude modulation of a typically 100nm broad laser pulse with a resolution of 640 pixel and, thus, to generate almost arbitrary user-defined optical waveforms.

Fig.1: A pulse shaper modifies the amplitude and phase of each spectral component within a broadband laser pulse. Each modification leads to a well defined temporal waveform. The whole setup is reminiscent to an electronic waveform generator. The inset shows a FROG trace of a pulse train.

Because the waveforms are too fast for any existing electronic detector, they have to be measured by some indirect technique. One out of a number of different techniques is a scanning frequency resolved optical gating setup (FROG). The measurement produces two dimensional time frequency distributions, such as the one shown in figure 1, from which the exact shape of the optical waveform can be deduced.

A few technological challenges remain to be solved, for example to fully control the vector nature of light.

Design and fabrication of photonic crystal fibers

Research in photonic bandgap structures was triggered in 1987 when E. Yablonovitch predicted the existence of a photonic band gap much akin to the electronic bandgap in semiconductor crystals. Many groups around the globe grasped the idea and a great number of exciting scientific contributions emerged, ranging from optical sources, amplifiers, devices, sensors, non-linear optics, metrology, et cetera. To the present day the field remains a vivid scientific area with ever-new avenues opening up.
The photonic crystal fiber (PCF) is one subgroup of photonic structures especially well suited for guiding light and alike. In contrast to fiber communications where most efforts concentrate on common standards, the many diverse scientific applications require a variety of different photonic structures. As the geometry of the PCFs' cross section next to the materials' properties determines the fiber characteristics, these needs can be served with unprecedented flexibility.

The fiber drawing facility at the University of Bern has recently been modified to allow for PCF fabrication. Currently, a novel production process is being implemented, which will greatly enhance our capabilities for PCF fabrication. Figure 2 shows one of the first microstructure fibers guiding light at 1064nm wavelength together with the simulated mode profile. Design and simulations are done via adapted public domain and commercially available software.

Controlling quantum systems in photonic bandgap fibers with tailored laser light

In our experiments the shaped laser waveforms are coupled into doped solid or filled hollow core photonic bandgap fibers. The hollow core fibers are ideally suited as a host for gases, liquids etc. So far we have been able to fill fibers with doped liquids or dispersed nanoparticles and quantum dots. Various feedback algorithms, such as simplex downhill, genetic algorithms or evolutionary algorithms have been implemented and successfully tested with model systems. In the future they will allow unveiling non-intuitive optical waveforms which are suitable to steer quantum systems into the desired direction.

On the theoretical side, we have implemented algorithms solving light propagation in PCFs containing various quantum systems. Atom/Ion-like n-level quantum systems are modelled in terms of density matrix formalism, molecular systems through their time dependent Schrödinger equation and in all cases they are coupled to Maxwell’s equations, i.e. accounting for PCF influence.

Our current investigations aim at controlling frequency conversion processes, selective state population, and chemical reactions.

APPLICATION PERSPECTIVES

Pulse shaping has many applications in optics and coherent control may some day become a tool for laser-assisted drug synthesis.

Fig.2: Solid large core, endlessly single mode fiber produced at the IAP and calculated mode profile.

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