Einblicke in die
Forschungsarbeit

MASTER THESIS

"Full Electric Field Characterization of Soliton-effect Self-compressed Few-cycle Laser Pulses by Optical Field-induced Electric Currents in a Dielectric Microjunction"

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University of Nürnberg-Erlangen, January 2020

Why we need to characterise ultrashort laser pulses feet

Ultrashort laser pulses are important to many ultrafast optical experiments. Depending on their duration, they allow for measurements with a temporal resolution down to the attosecond regime (10-18 seconds). In the attosecond regime, scientists can even study the dynamics of electron movement. Before those ultrashort pulses can be applied to any kind of experiment, however, their properties need to be identified using a pulse characterisation technique. Knowing what the pulse looks like before an experiment allows information to be extracted on how the pulse was changed by the experiment.

The aim of my master’s project was to experimentally implement a full electric field characterisation technique known as nonlinear photoconductive sampling. I completed my master’s thesis at the Max Planck Institute for the Science of Light in Erlangen under the supervision of Dr Francesco Tani and Professor Philip Russell. My master’s project can essentially be divided into two parts, the first related to compressing laser pulses by soliton-effect self-compression in a photonic crystal fibre (PCF) and the second related to characterising pulses via nonlinear photoconductive sampling.

Generation of ultrashort laser pulses

The process I used to generate the ultrashort pulses relies on the formation of optical temporal solitons. The interplay of dispersion and nonlinear effects broadens the spectrum and shifts the phase of the individual spectral components such that the laser pulse becomes compressed in time. Generally, a broader spectrum can support shorter pulses. I influenced the extent to which the pulse becomes compressed or, to put it more generally, what the pulse looks like after it exits the fibre, by choosing the design of the fibre, the type and pressure of the noble gas filling the fibre and the pulse energy at the input of the fibre. In an iterative process based on running simulations, using a spectrometer to measure the bandwidth of the generated spectrum and a measurement technique called dispersion scan, and continuously adapting the compression parameters, I was eventually able to generate pulses that we suspect to be a few cycles long. There are many advantages to pulse compression in a PCF via the soliton effect. One example is the wide range of pulse energies supported, which can be as low as 100 nJ.

Setting up the nonlinear photoconductive sampling measurement technique

Firstly, I want to briefly explain how nonlinear photoconductive sampling can characterise the full electric field of a laser pulse. The amplitude and phase of each spectral component comprising the pulse can be determined as well as its carrier-envelope phase. The carrier envelope phase is the relative phase between the envelope of a laser pulse and the carrier wave. Photoconductive sampling essentially means that an electric circuit is closed by shining light on a photoconductive medium; in the present case, this closing mechanism will be highly nonlinear. The field dependence that enables us to retrieve information about the carrier wave comes from this highly nonlinear process, which is the optical induction of a current in a dielectric microjunction.

A pump-probe setup is installed for the current induction and thus for the characterization process. The pump pulse serves as a temporal gate and determines the resolution of the overall measurement. It is temporally overlapped with the probe pulse, which will eventually be characterised. The very intense pump pulse injects carriers into the dielectric, a probing pulse drives the carriers towards electrodes connected to the dielectric, and the combination of both processes allows an electric current to be detected. The imminent field strength of the probe pulse at the temporal overlap with the pump pulse can be deduced from the voltage of the measured current. Collecting a series of data points by changing the point of temporal overlap reconstructs the full electric field of the probe pulse. The crux of this technique is that sub-fs resolution can be achieved without the need for an equivalently short pump pulse, avoiding an overly complex experimental set-up. As the electric field needs to bridge the wide bandgap of the dielectric in order to inject carriers, in our case it is sufficient for the peak electric field to be just a fraction of the laser pulse.

By the end of my master's project, I was able to generate pulses in the order of a few cycles and validated them using several established techniques. I have advanced our experimental nonlinear photoconductive sampling set-up, including alignment for different variations of the technique and the conduction of several intermediate and test measurements. Ultimately, I gained experience of working with PCFs and aligning various free space optics while deepening my knowledge of nonlinear fibre optics and gaining insights into many other topics related to scientific work in the field of optics and laser technology.

More on "Advanced Optical Technologies":

https:// www.elitenetzwerk.bayern.de

More on the Russell division at the Max Planck Institute for the Science of Light:

https://mpl.mpg.de/divisions/russell-division/