JOINT RESEARCH ACTIVITIES POGRAM

JRA 1: Frontiers of Optical Science: Controlling Intense Light (FOSCIL)

Objectives and originality of JRA1

Recent progress in the control of coherent light has revolutionized femtosecond laser technology. In this field the European partners of the laser consortium are without any doubt world-leading. With femtosecond lasers based on Ti:Sapphire crystals now pulses can be generated comprising merely a few cycles of oscillations of the electromagnetic field with an evolution of the field precisely reproducible from one pulse to the next in the train of pulses emitted by the laser. The key to this new technical capability is the control of a previously inaccessible parameter, the carrier-envelope or "absolute" phase, which determines how the central wave cycle matches the peak of the light pulse. Mode-locked oscillators generating phase-stable few-cycle light pulses have been developed in the recent past and are now being commercialized by European companies. More recently phase-locked pulses have been demonstrated at the output of a kHz-rate amplifier at peak power levels (0.1 teraWatt) sufficiently high for opening the way to the generation of single vacuum and extreme ultraviolet (VUV,XUV) and soft-X-ray (SXR) pulses with sub-femtosecond duration as well as their measurement with 100 attosecond resolution.

In addition, polarization manipulation techniques are now maturing to a point where the time-dependent polarization state of ultrahigh-power (>1 teraWatt) laser pulses can be precisely controlled as well, allowing for the generation of high-energy XUV pulses of a few femtosecond in duration or possibly shorter. Whereas the former will allow time-resolved atomic spectroscopy with attosecond resolution, the latter may pave the way to XUV nonlinear optics and few-femtosecond-resolution XUV-pump/XUV-probe spectroscopy of molecular and atomic dynamics.

The periodicity of phase-controlled femtosecond light pulses also has important frequency-domain implications: the spectrum of this radiation consists of a "comb" of equidistant frequency spikes (harmonics of the pulse repetition rate). Hence, if this repetition rate or its integer multiple is locked to a microwave reference source, microwave frequency standards can be transferred into a broad range of the electro-magnetic spectrum, permitting the measurement of atomic and molecular transitions with unprecedented precision. With the development of sufficiently intense high-repetition-rate (MHz) sources of phase-controlled light the "frequency" ruler may be extended into regimes previously inaccessible (or hardly accessible) for precision metrology. The extension of the frequency ruler into the infrared and VUV-XUV domain is likely to break new grounds in this important sub-field of modern experimental physics. Phase-controlled (and consequently frequency-controlled) light will revolutionize metrology and control of the microcosm in both the frequency and the time domain.

This 4-year JRA project, which is at the forefront of laser and optics research, aims in a concerted action of leading European laboratories at the development of high-power (extending up to several teraWatts), ultra-short pulsed (reaching durations of less then 10 femtoseconds) sources with unprecedented control over the emitted light wave-packets. In addition to controlling both the spatial wave front and the temporal intensity profile, as well as the frequency sweep of the generated pulses by routine techniques (such as adaptive optics and frequency-domain pulse shaping respectively) now also the phase of the oscillating electric field with respect to the pulse peak (carrier-envelope or C-E phase) and the polarization state across the pulse will be governed by novel techniques pioneered recently in European laboratories. C-E-phase and/or polarization control possibly combined with wave front and pulse shape control offer the potential for *complete control of the electromagnetic fields of intense, ultra-short, pulsed light*. The mission of this JRA is to advance the state of the art of ultra-fast laser technology by improving control over ultra-short laser pulses and to use this controlled laser light for the development of advanced sources of coherent radiation based on optical parametric generation and low- as well as high-order harmonic generation. The resultant ultra-short-pulsed radiation will cover the spectral range all the way from tens of THz (near infrared, NIR) through visible (VIS) and ultraviolet (UV) to multi-PHz (XUV, SXR) frequencies and exhibit unprecedented characteristics including sub-femtosecond pulse durations and accurately known XUV frequencies. The emerging sources are expected to dramatically push the frontiers of time- and frequency-resolved spectroscopy and create fascinating new research opportunities for the European research community in these and several related sub-fields of experimental physics. The execution of this JRA will guarantee Europe's leading position in this field.

The applications of the new coherent laser-based sources will open a wide field of research in physics, chemistry and biology, in which many laboratories in the consortium will be involved, thereby greatly enhancing the quality of the access offered to users. Attosecond time-domain and XUV frequency-domain studies constitute exciting new frontiers of laser spectroscopy with far-reaching implications in basic science. Small and medium sized enterprises (SME's) will also be involved in these developments (Femtolaser GmbH, Vienna, Menlo-Systems GmbH, Munich).

Collaborating partners in the consortium

PIVUT	Photonics Institute, Vienna University of Technology	Austria
LCVU	Laser Centre, Vrije Universiteit, Amsterdam	Netherlands
CUSBO		Italy
LLC	Lund Laser Centre	Sweden
SLIC		France
CELIA		France
LOA	Laboratoire d'Optique Appliqué, Orsay	France
ULF-Forth	Ultraviolet Laser Facility, Heraklion	Greece, Crete
LENS	European Lab. Non-linear Spectroscopy, Florence	Italy
MPQ	Max Planck Institute for Quantum Optics, Garching	Germany
MBI	Max Born Institute, Berlin	Germany

The unique expertise of the various groups can be summarized as follows. PIVUT and MPQ are the pioneers in the field of phase-controlled femtosecond pulsed laser oscillators and the generation of frequency combs for metrological applications. These developments, with variations in the system build-up, are now also pursued at LCVU and LENS. PIVUT was the first to generate attosecond, isolated XUV (100 eV) pulses using these (amplified) phase-controlled pulses, thereby following the tradition in many of the laboratories within the laser consortium with a widespread and unique expertise in high-harmonic conversion. Some of the partners have expertise with high-power lasers (LLC, LOA, ULF-Forth, CELIA, SLIC, MBI), others developed more from the atomic and molecular laser spectroscopy point of view (PIVUT, LCVU, LENS, MPQ, CUSBO). There exists among all partners a great need in developing reliable and adequate diagnostic tools for characterizing VUV, XUV and SXR ultra-short pulses. In various groups activities have been taken up over the last few years with very promising results.

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