INTRODUCTION

Quantum control using femtosecond laser pulses has recently induced a revolution in photochemistry. Not only the nuclear motion within a molecule can be observed time resolved, but it can be controlled. The necessary pulse shaping techniques, however, have mainly restricted this control so far to visible and near IR absorptions. Fundamental compounds of organic chemistry and biochemistry such as aromatic rings, usually excited in the 250-400 nm region could therefore not be directly addressed by quantum control experiments. Shaping ultrashort X-Rays or XUV laser pulses is another hot topic, especially in the context of high harmonics generation (HHG) and attosecond research.

UV-Pulse shaper using MEMS

We decided to develop a dedicated pulse shaper for the UV and soft X-Rays based on micro-mirror arrays (MEMS = Micro Electro Mechanical Systems) together with the University Neuchatel. For this, the UV femtosecond laser pulse is dispersed by a diffraction grating so that each spectral component can be modulated in phase and amplitude by the reflective micro-mirror array (up to 512 elements). The shaped spectral components are then recombined by retracing back their track on the grating. The main application of this UV-pulse shaper is the coherent excitation of biological molecules, in the context of bacteria identification and cancer research.

RESEARCH OBJECTIVES

Construction of 100 and 512 elements MEMS prototypes

A first prototype of a 100 elements MEMS will be manufactured using the unique facility of the University Neuchatel (mask lithography, ion etching,…). Aluminium coating will then be applied to the mirrors in order to provide a very broad reflectivity in the UV range. The 8 x 100 contacts will then be bonded and enclosed in a package socket that fits in the driving electronics.

In a second phase, the design will be evaluated, upgraded, and extended to a 512 micro-mirrors MEMS array. The number of elements is important in order to cover a broad spectral range at high resolution (which defines the maximum duration of the shaped pulse).

Driving electronics and software

The 100 x 2 (tilt and stroke) electronic driver has been developed at the University Geneva and will be tested using the 100 elements prototype MEMS. Each driver is encoded in 14 bits allowing a maximal theoretical resolution on the stroke (phase shift) of about 0.2 nm. Each channel drives an amplifier delivering 100 V. An extension of the electronics for driving 512 elements will then be implemented as well, which should not be a major problem because of the flexible architecture that was chosen so far.

A dedicated driving software will be developed in order to allow the use of the prototype as a femtosecond laser pulse shaper. In particular, time sequence and synchronization with an external trigger and acquisition electronics will be developed. A calibration procedure with a feedback loop using an external analyzer (FROG, SPIDER) will be developed as well.

MEMS-based UV Pulse shaper prototype

A rugged optical layout based on a folded 4f dispersion free line has been designed for both the 100 and the 512 elements prototype (only the diffraction grating has to be adapted). Simulation of the 512 elements prototype characteristics leads to the following specifications:

- Spectral range: 250-300 nm
- Spectral resolution: 0.1 nm
- Max. shaped pulse duration: 5 ps
- Max. phase modulation: 4π
- Throughput: limited by grating reflection efficiency

The spectral range chosen for these prototypes targets the excitation of the aromatic rings of organic and biological molecules, in particular amino-acids (tryptophan, tyrosine) within proteins and DNA bases.
Test of the prototype on a simple pulse shaping experiment

A test experiment of the device performance will be performed using a difference frequency mixing cross-correlator, in order to analyse the temporal characteristics of the shaped pulse and a UV spectrometer to control the function of amplitude shaping. By adding a piece of fused silica in the UV laser path, dispersion will be introduced. A first test of dispersion correction using an adaptive algorithm on the DFM signal will demonstrate the operation of our prototype.

APPLICATION PERSPECTIVES

Biological application of the UV-pulse shaper:

Discrimination of quasi-identical biomolecules

We recently demonstrated that pump-probe experiments and Optical Dynamic Discrimination (ODD) can discriminate between molecules having similar structures or even between complex systems such as bacteria versus traffic related organic particles. The goal is now to use broadband coherent control in the UV to discriminate nearly identical biomolecules, such as Riboflavin and its phosphated homologue FMN (Flavin Mononucleotide). These two molecules exhibit identical linear excitation and fluorescence spectra, and are thus indistinguishable with traditional LIF techniques. A pump-probe depletion spectroscopic scheme using shaped UV pulse and a delayed 800 nm pulse will be applied to the discrimination of RbF and FMN. Both flavin samples will be excited by the femtosecond pulse sequence, and the resulting fluorescence signals will be compared such that fluorescence of one molecule will be maximized against the other. A very efficient genetic algorithm was recently developed in Geneva and is optimally suited for this task.

Applications are numerous, both in proteomics and pharmacology and in medical diagnostics (early detection of cancer cells)

Applications in the XUV range and HHG for attosecond pulse shaping

We recently verified that similar MEMS micromirror arrays based on the same technology can be operated under vacuum and in a cryogenic environment (T=100K). This opens unprecedented perspectives for pulse shaping high harmonics. For this, we plan to produce a second MEMS device with an optimized coating in the 2-80 nm range, without protective window. Optimally each harmonic would be driven by a single micro-mirror, modulated both in phase and amplitude. This experiment requires a careful design of the soft X-ray optics with toroidal gratings. First tests could be done using the HELVETERA platform, but also in cooperation with other groups involved in the NCCR-QP. A major challenge will be the required flatness and stroke resolution of the device at these short wavelengths.

Contact:
Prof. Jean-Pierre Wolf (University of Geneva)
Prof. Nico de Rooij (University of Neuchâtel)
http://www.gap.unige.ch/biophotonics