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Generating shaped femtosecond pulses in the far infrared using a spatial light modulator and difference frequency generation

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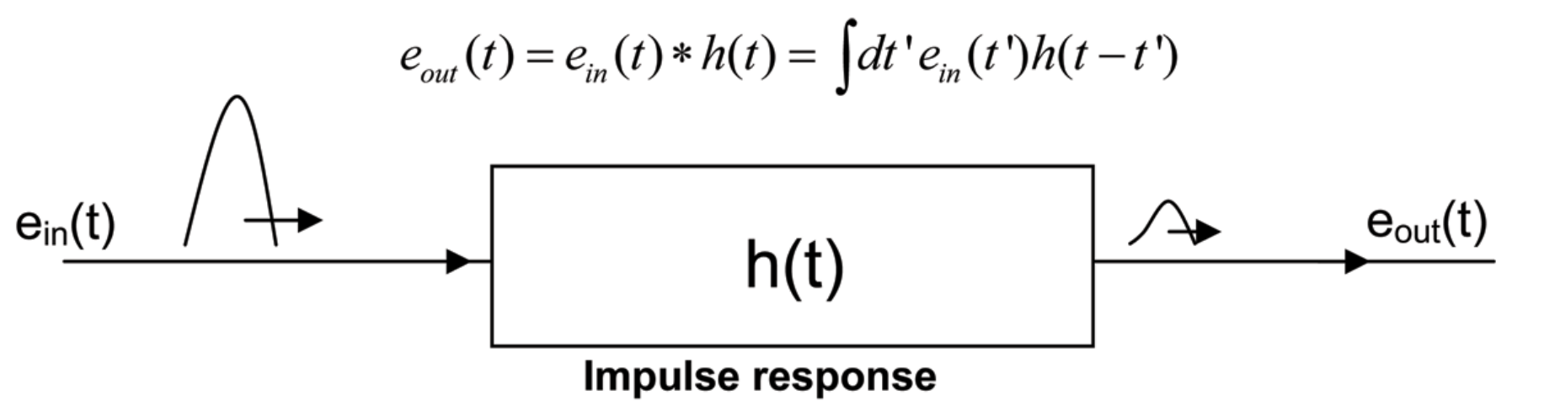
INTRODUCTION

Femtosecond pulse shaping can be done by different kinds of pulse shapers, such as liquid crystal spatial light modulators (LC SLM), acousto optic modulators (AOM) and deformable and movable mirrors. A few applications where pulse shaping is implemented are coherent control of molecules, communication systems, encoding and decoding and biomedical imaging.

THEORY OF PULSE SHAPING

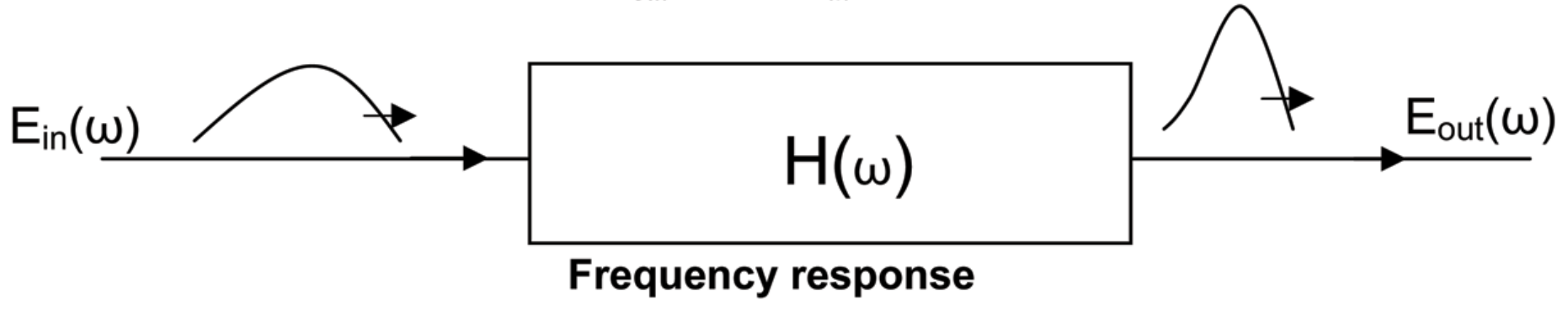
In the time domain, the output of the filter (shaper) is eout(t), and the input is ein(t). h(t) represents the input response function[1].

$$e_{out}(t) = e_{in}(t) * h(t) = \int dt' e_{in}(t') h(t-t')$$



In the frequency domain, the filter is characterised by its frequency response H(ω). The output of the linear filter $E_{out}(\omega)$ is the product of the input signal and response function[1].

$$E_{out}(\omega) = E_{in}(\omega) H(\omega)$$



$e_{out}(t)$, $e_{in}(t)$, h(t) and $E_{out}(\omega)$, $E_{in}(\omega)$, H(ω) respectively are Fourier transforms of each other.

$$H(\omega) = \int dt h(t) e^{i\omega t}, \quad h(t) = \frac{1}{2\pi} \int d\omega H(\omega) e^{i\omega t}$$

LIQUID CRYSTAL SPATIAL LIGHT MODULATOR (LC SLM)

One of the most popular pulse shapers the liquid crystal spatial light modulator (**Figure 1**).

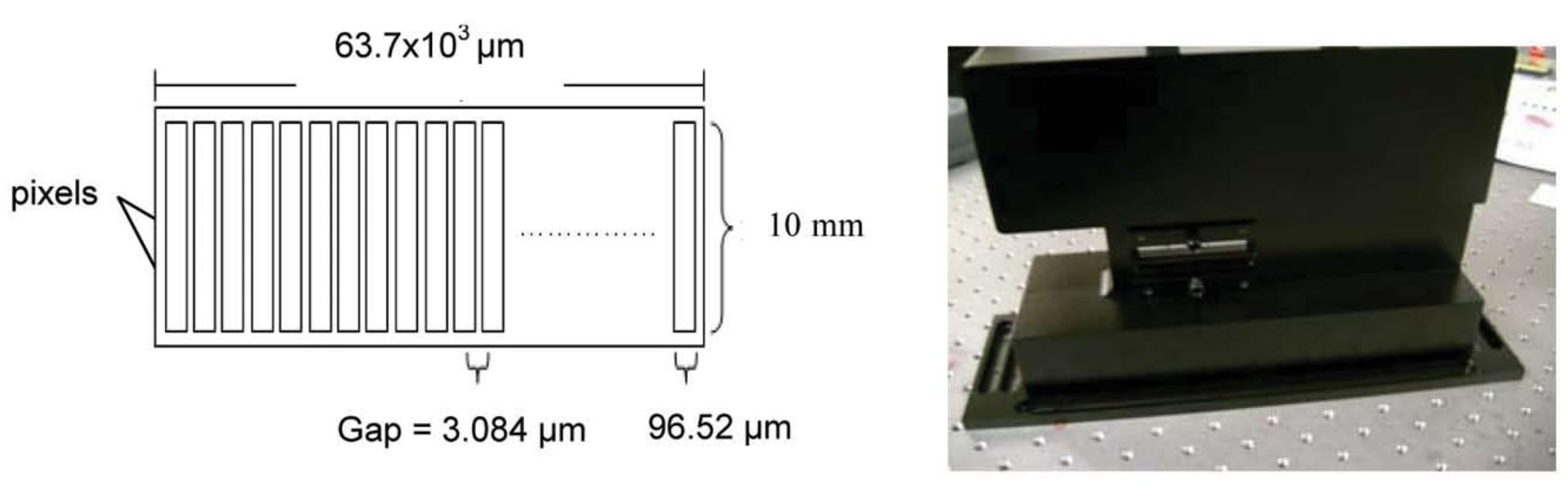


Figure 1

PULSE SHAPER SETUP DESIGN

The 4f design (**Figure 2**) is the most commonly used setup for pulse shaping.

Resolution:
$$\frac{\lambda\, spread}{length\ of\ SLM} = \frac{44\,\text{nm}}{63.7 \times 10^3 \mu\text{m}}$$
$$= 0.000691\ nm/\mu m$$
$$0.000691 \times length\ of\ pixel$$
$$= 0.0667\, nm/pixel$$

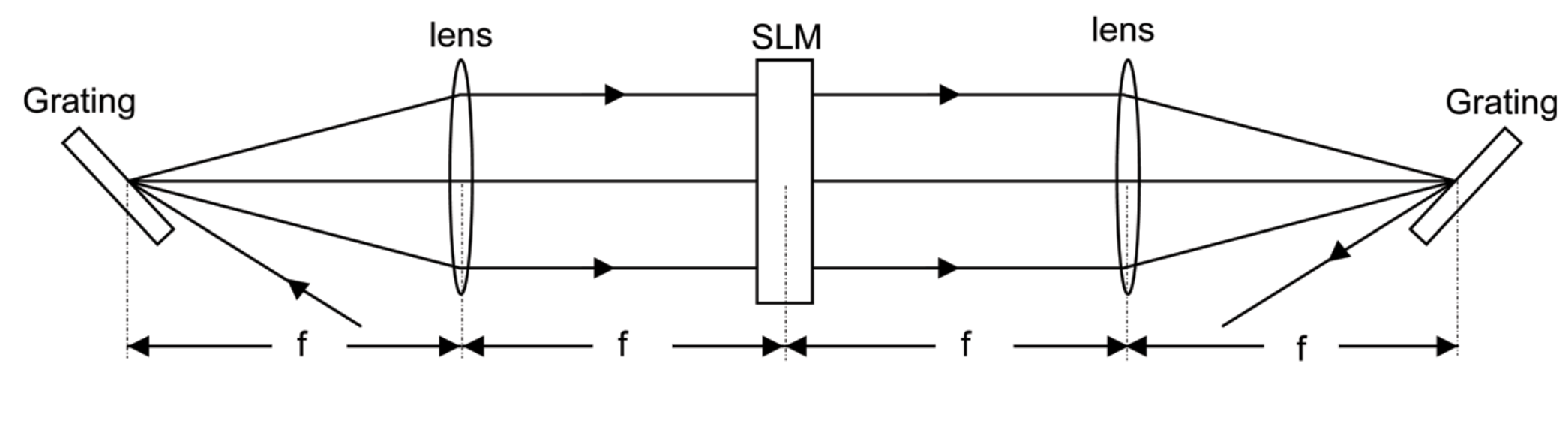


Figure 2

There are different variations of the 4f setup of which some are more compact[2] (**Figure 3**). Replacing the lenses with cylindrical mirrors also insures less temporal and spatial reconstruction errors.

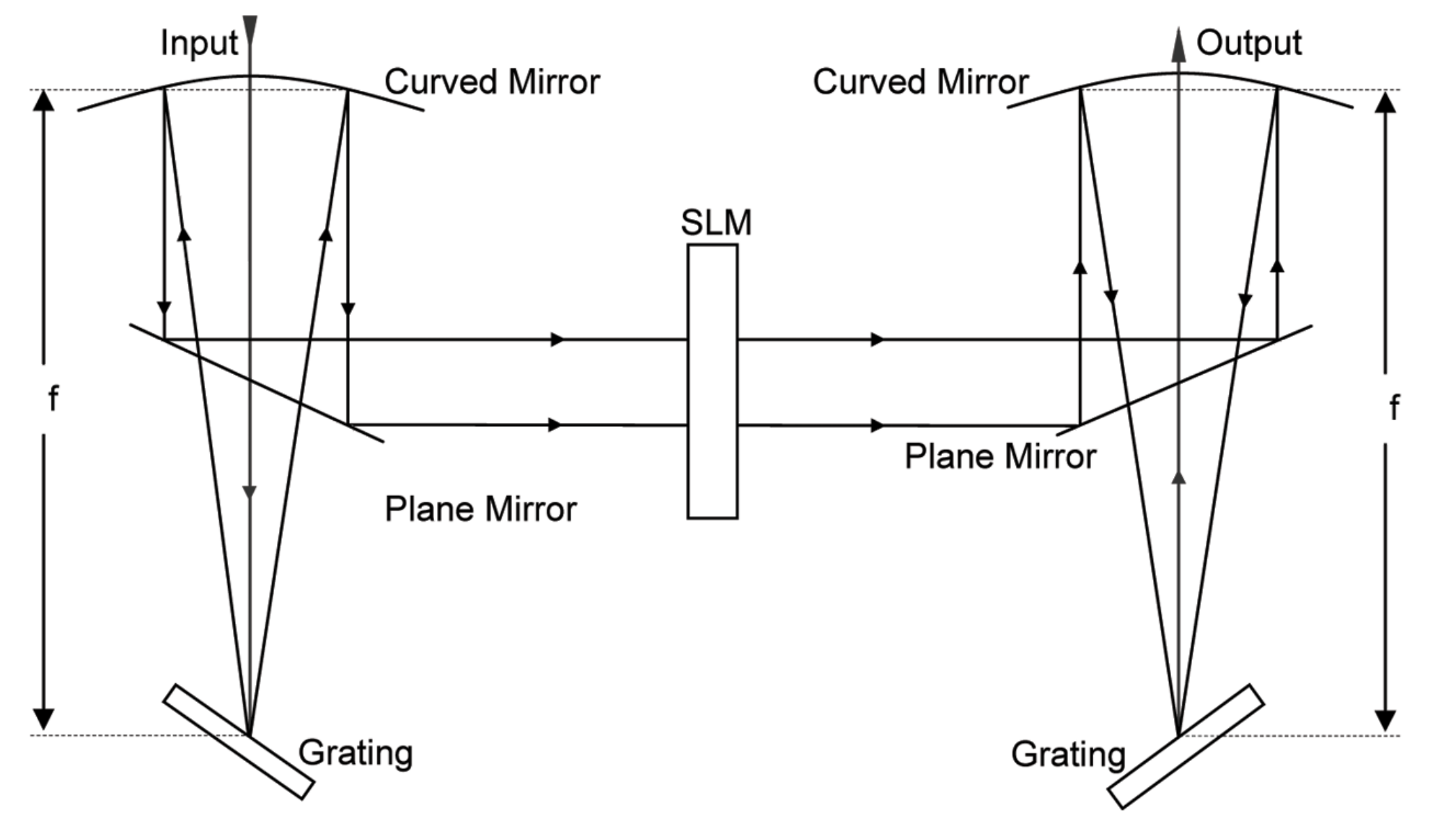
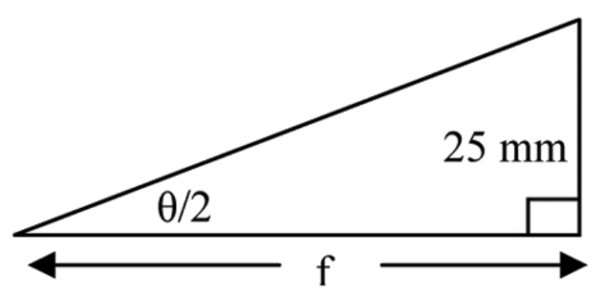


Figure 3

Focus length necessary for a sufficient angular dispersion to illuminate the whole SLM:

$$\frac{d\lambda}{d\theta} = \frac{nm}{\cos\theta}$$
$$\int \cos\theta\, d\theta = \int nm\, d\lambda$$
$$\sin\theta = nm\,\Delta\lambda = (1200 \times 10^3)(44 \times 10^{-9})$$
$$\theta = 3.03$$
$$f = \frac{25mm}{\tan(\theta/2)} = 945.26\, mm$$



MEASUREMENT OF PULSES

Due to the fact that femtosecond pulses are so short, current electronics cannot measure the pulse shapes and duration. An intensity autocorrelator (**Figure 4**)
can be used for the measurement of femtosecond pulse durations. More information can be extracted using frequency-resolved optical grating (FROG) or Multiphoton intrapulse interference phase scan (MIPS). Replacing the Photodiode detector with a spectrometer the intensity autocorrelator becomes a FROG.

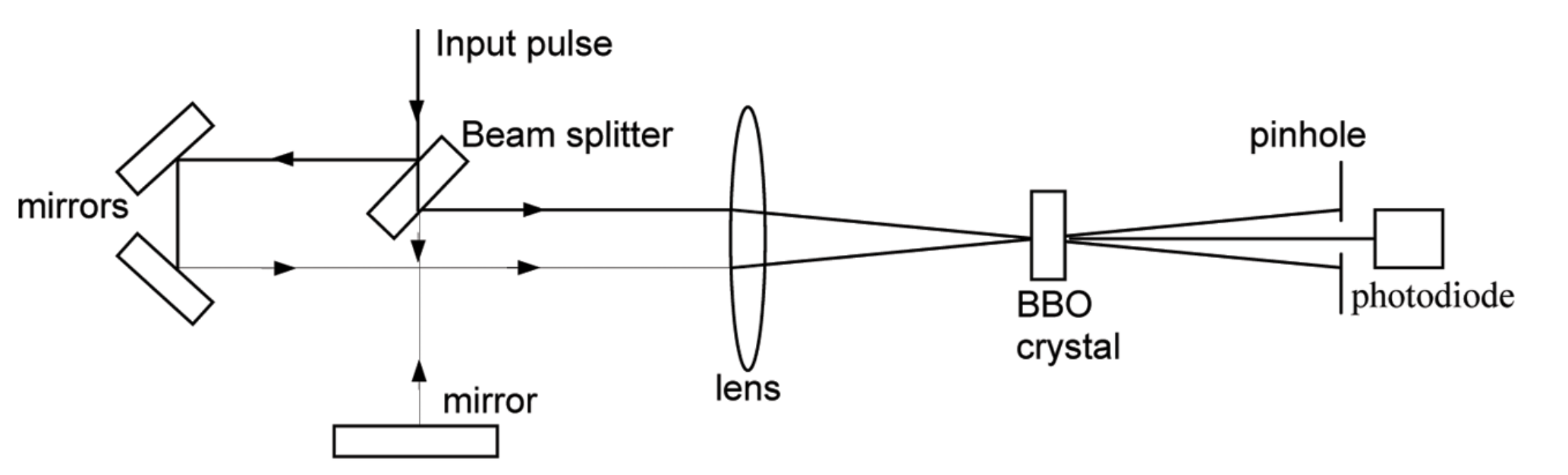


Figure 4

INFRA-RED PULSE SHAPING

Infra-red pulse shaping can be done directly, when a pulse already in the infra-red regime is shaped or it can be done indirectly, when a pulse is shaped in the visible regime and the shaped pulse then transferred to infra-red by frequency mixing. Using the equations below[3] difference frequency mixing of a shaped pulse in a crystal can be simulated.

$$\frac{\partial E_s}{\partial u} = \frac{i\omega_s \chi_{eff}^{(2)}}{2n_s c} E_p E_i^*$$
$$\frac{\partial E_i}{\partial u} + \left(\nu_i^{-1} - \nu_s^{-1}\right) \frac{\partial E_i}{\partial t} = \frac{i\omega_i \chi_{eff}^{(2)}}{2n_i c} E_p E_s^*$$
$$\frac{\partial E_p}{\partial u} + \left(\nu_p^{-1} - \nu_s^{-1}\right) \frac{\partial E_p}{\partial t} = \frac{i\omega_p \chi_{eff}^{(2)}}{2n_p c} E_s E_i^*$$

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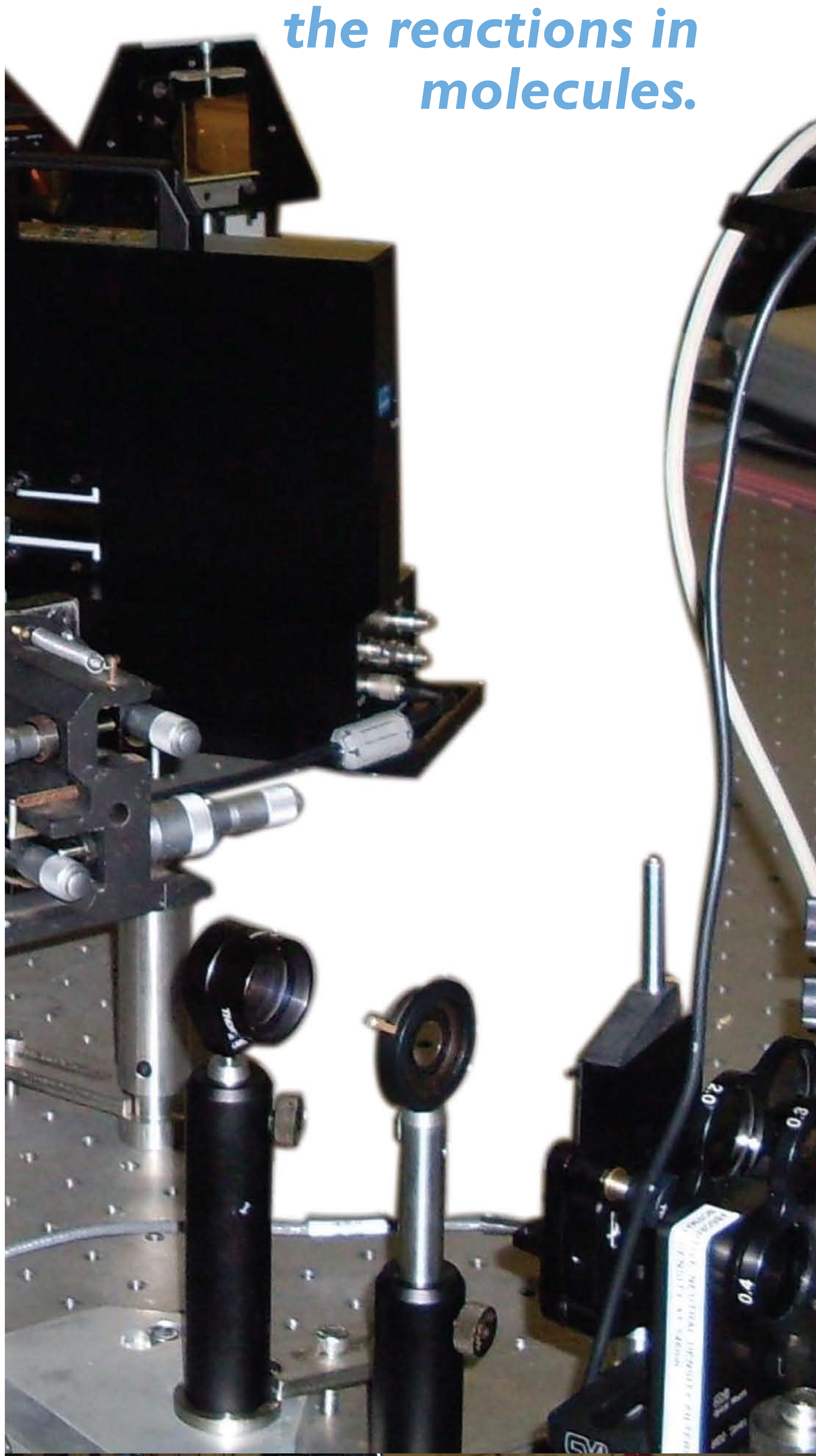
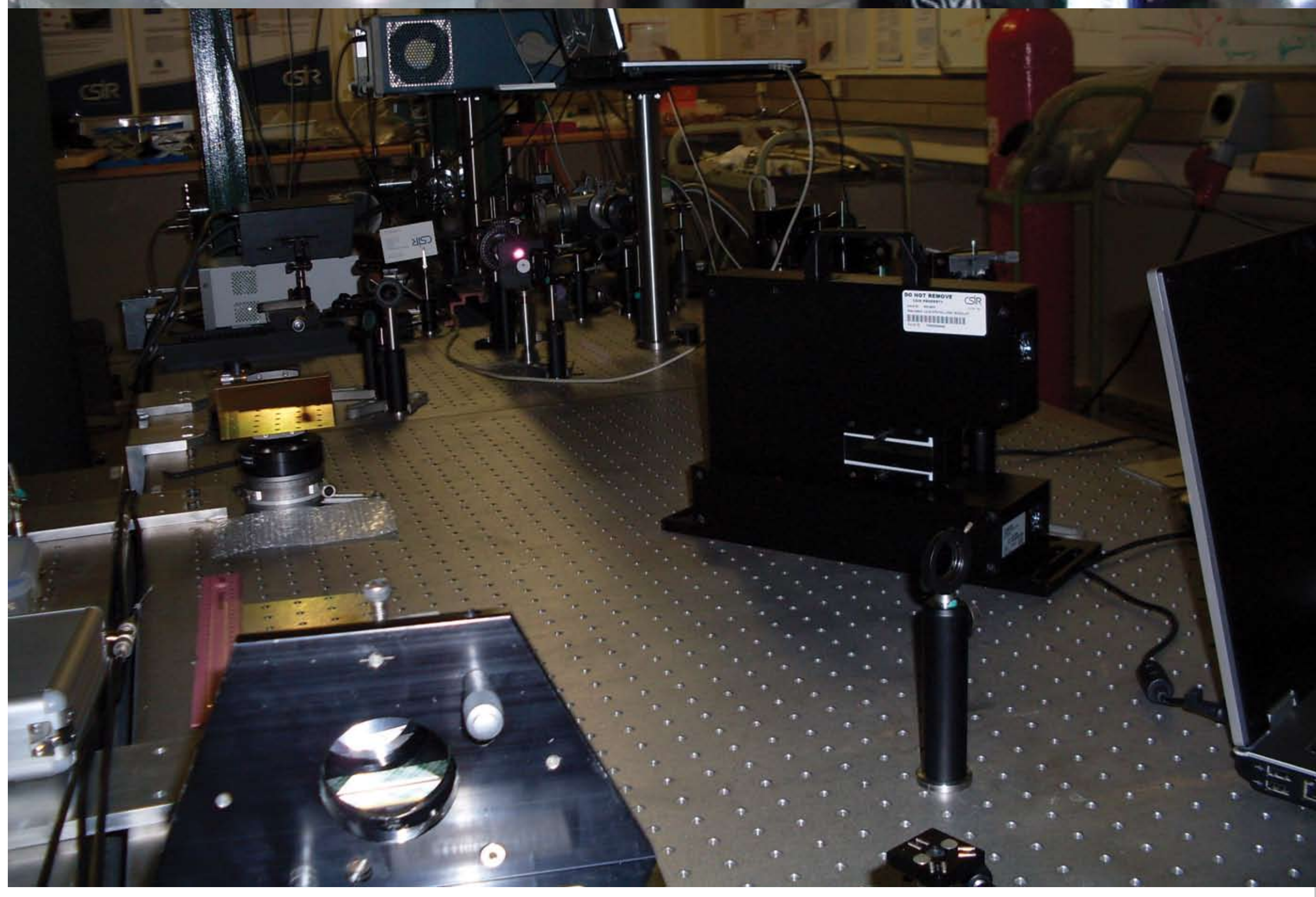
CSIR researchers shape femtosecond pulses in the mid-infrared wavelength regime to control the reactions in molecules.





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