

# Ultrafast optical signal pulse descending time controlling with deformable mirror and spatial light modulators

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**Abstract.** A programmable ultrafast optical signal pulse descending time controlling apparatus is demonstrated based on micro-machined deformable mirrors (MDM) and liquid crystal spatial light modulators (LCSLM), which can smoothly modulate the phase and amplitude of the optical pulse frequency component linearly or nonlinearly.

## 1. Introduction

Femtosecond pulse shaping, which allows for generating specified temporal optical waveforms by parallel manipulation of the complex optical spectrum, has advanced dramatically since the advent of reliable generation of laser pulses below 100 fs in duration in 1981 with the invention of the colliding pulse mode locked (CPM) ring dye laser [1]. The temporal femtosecond pulse shaping technology has been widely adopted in various applications such as harmonic generation [2], coherent control [3], generation of two-dimension electronic spectra and temporal solutions [4], high-energy isolated attosecond pulse generating [5], compression of optical pulses [6], single cycle pulse generation [7], radio-frequency waveform generation [8], and optical communications [9]. Recently, the application has been further expanded. For example, in 2013, Ferreira P H D and his coworkers used shaped 30 fs pulses to accomplish the enhancement of laser induced Au nano-particle formation [10] and Yi Cai used carrier-envelope phase stabilization techniques to obtain a 1kHz, 90fs, 0.4mJ femtosecond pulse train with a total gain of  $2 \times 10^6$  [11]. Bagayev S N obtained super-intense femtosecond multichannel laser system using parametric amplifier to overcome the phase distortions, which may be solved by Femtosecond pulse shaping techniques [12].

In this manuscript, a programmable femtosecond pulse shaping apparatus is designed based on MDM and LCSLM, which changes the phase and the amplitude of the frequency component of the pulse respectively. According to the fact that the time domain signal and its corresponding frequency



domain signal are Fourier transform pair, the pulse can be delayed or advanced by using the phase only MDM that just imposes a linear phase change onto its spectrum.

## 2. Theory analysis

Ultrafast optical signal pulse descending time controlling with deformable mirror and spatial light modulators refers two key factors which are temporal and spatial controlling.

### 2.1. Temporal controlling

In the time domain, the incident pulse electric field is denoted by  $E_{in}(t)$  and the output pulse electric field is denoted by  $E_{out}(t)$ , so the output of a linear filter can be simply given by the following convolution product:

$$E_{out}(t) = R(t) * E_{in}(t) \quad (1)$$

where  $R(t)$  is the impulse response of the pulse shaper. However, for femtosecond pulses, direct shaping in time is quite a hard task and most of the devices operate in the frequency domain and the output pulse can be written as following.

$$\tilde{E}_{out}(\omega) = H(\omega) \tilde{E}_{in}(\omega) \quad (2)$$

According to the formula (2), the temporal shaping can be accomplished through the spectral phase and amplitude controlling.

### 2.2. Spatial controlling

Fourier lens and LC-SLM constitute a conventional folded 4f zero-dispersion setup. The frequency components after being phase modulated by the LC-SLM were reflected back through the Fourier lens and recombined into a beam at the diffraction grating, which was anti-parallel by symmetry, and then a beam splitter separated out the retro-reflected beam. Hereto, the temporal shaping is accomplished.

According to the treatment of Kreuzer, the surface distribution of the two aspheric lenses in the Galilean shaping system can be represented as following [13].

$$\begin{aligned} z(r) &= \int_0^r \left\{ (n^2 - 1) + \left[ \frac{(n-1)d}{h(x) - x} \right]^2 \right\}^{-1/2} dx \\ Z(R) &= \int_0^R \left\{ (n^2 - 1) + \left[ \frac{(n-1)d}{h^{-1}(x) - x} \right]^2 \right\}^{-1/2} dx \end{aligned} \quad (3)$$

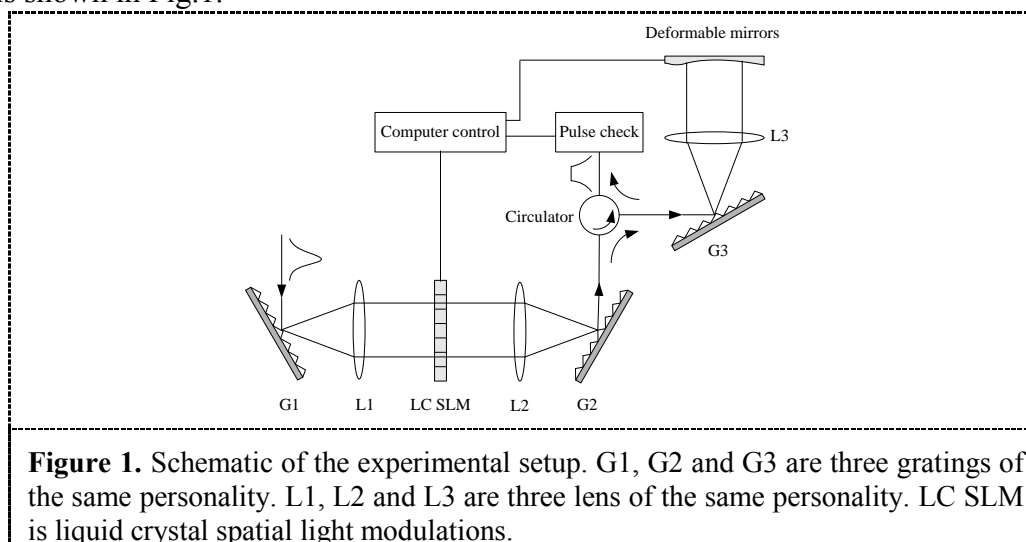
The relationship between the surface and phase distribution of the first aspheric lens in Galilean shaping system can be expressed as following [14].

$$f_p(r) = \frac{2\pi(z_e - z(r) + nz(r))}{\lambda} \quad (4)$$

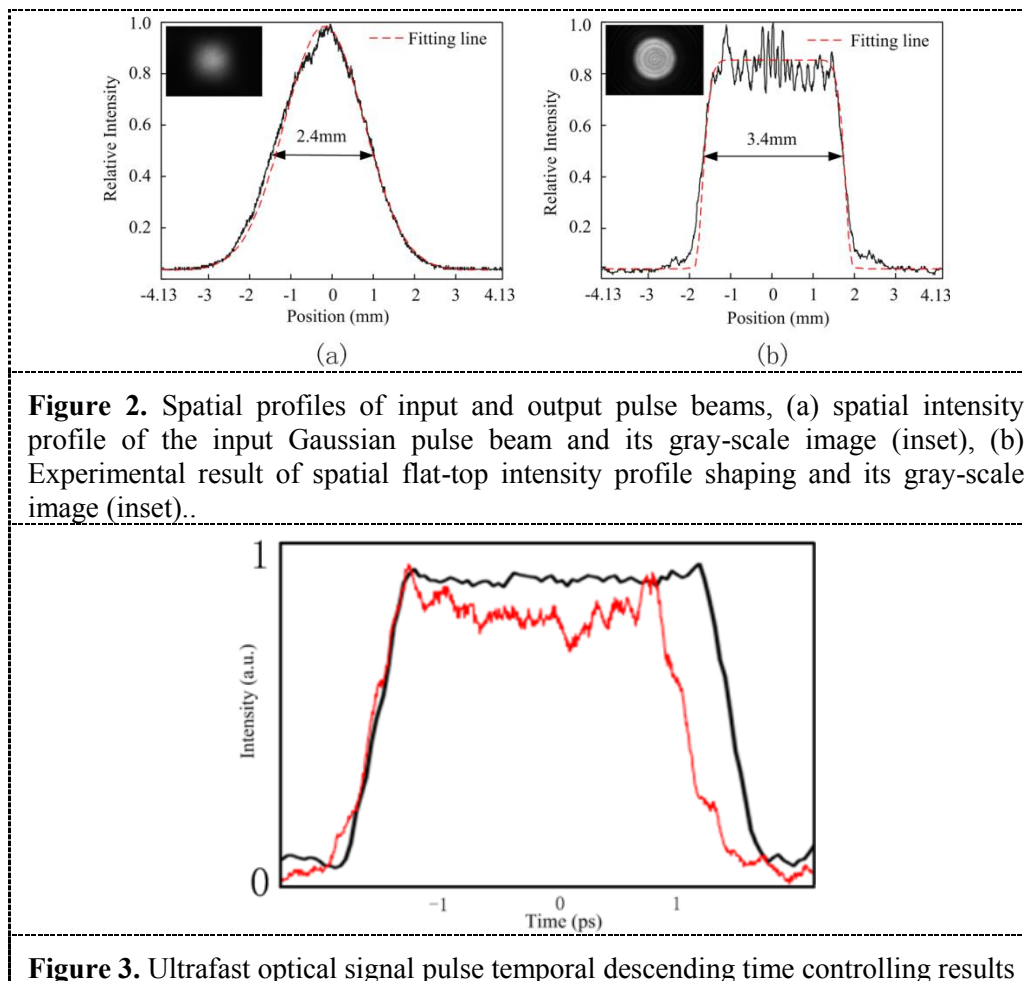
The LC-SLM imprints the phase distribution onto the input beam and the output beam with desired intensity distribution will be realized.

### 3. Experimental results

We concentrate our work on generating the flat-top profile femtosecond pulse beam in the target plane in the near field. The pulse beam used in all the measurements is generated by the Mai Tai HP Ti: sapphire laser with central wavelength at 707 nm. The beam waist radius after beam expander is 1.2 mm. The phase only LC-SLM with  $1920 \times 1080$ ,  $9 \mu\text{m} \times 9 \mu\text{m}$  pixels is a product of Holoeye Company. The phase level of each pixel is assigned between 0 and  $2\pi$ . The CCD camera which has  $1392 \times 1040$ ,  $6.45 \mu\text{m} \times 6.45 \mu\text{m}$  pixels is a Dolphin F-145B modal 12 bit product of AVT Company. After passing through the shaping setup, the intensity distribution of the output beam is captured by the CCD camera and tested by the pulse checking component by Second Harmonic Generation Frequency Resolved Optical Gating (SHG-FROG) method. FROG is simply a spectrally resolved autocorrelation, which allows the use of a phase-retrieval algorithm to retrieve the precise pulse intensity and phase vs. time. It can measure both very simple and very complex ultrashort laser pulses, and it has measured the most complex pulse ever measured without the use of a reference pulse. The experimental setup is shown in Fig.1.



In this manuscript, a programmable femtosecond pulse shaping apparatus is designed based on MDM and LCSLM, which changes the phase and the amplitude of the frequency component of the pulse respectively. According to the fact that the time domain signal and its corresponding frequency domain signal are Fourier transform pair, the pulse can be delayed or advanced by using the phase only MDM that just imposes a linear phase change onto its spectrum. The experimental results are shown in Fig. 2 and Fig.3.



**Figure 3.** Ultrafast optical signal pulse temporal descending time controlling results

The results above prove that this setup can not only controlling the spatial intensity profile but also the temporeal waveforms.

#### 4. Conclusions

Both theoretical and experimental results indicate that the ultrafast optical signal pulse descending time controlling with deformable mirrors and spatial light modulators demonstrated in this manuscript can controlling the descending time effectively. Moreover, optimization algorithms and deformable mirrors and spatial light modulators with better properties used can give better results.

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