Pulse re-shaping by using a liquid crystal spatial light modulator and deflector for producing a specific waveform

Jun Kang (康 俊), Wei Zhang (张 伟), Hui Wei (韦 辉),
Shaohe Chen (陈绍和), and Jianqiang Zhu (朱健强)

Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800

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A new shaping method for producing nanosecond pulses with specific shape is introduced. When a Gaussian laser pulse passes through an electro-optic deflector, it has been scanned as a line on the focal plane according to time precedence. Through controlling the intensity of transmitted light on each pixel of the liquid crystal spatial light modulator (LCSLM), various complicated pulses can be easily produced. Using this method, various specific shaped pulses with pulse duration varying from 750 ps to 5 ns are achieved.

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As a main method to generate ultra-short, ultra-high-power laser pulses, optical parametric chirped pulse amplification (OPCPA) has been widely adopted in many areas recently[1−4]. To optimize the OPCPA conversion efficiency, stability, pulse contrast and beam quality, the following conditions of pump need to be satisfied: 1) the pulse duration in nanosecond range, 2) square pulse, 3) high stability, 4) high intensity of the order of gigawatts per square centimeter. The pump to signal conversion efficiency can be greatly improved by carefully tailoring the pumping laser's spatial and temporal profiles[2]. According to the results of Bagnoud *et al.*[3] the output of oscillator is temporarily shaped with an aperture-coupled stripline pulse-shaping system[4] and the temporal shaped pulse is subsequently amplified in a regenerative amplifier. The 20th-order, super-Gaussian temporal and spatial profiles can be generated. In this condition, the pump-to-signal efficiency can achieve 34% with the root mean square (RMS) energy variation of 1% over 100 shots. But the pump setup about temporal shaped pulse is complicated and expensive and the output power is weak (of the order of picojoules)[4].

In this paper, we introduce a new method to produce specific shaped pulses with the help of electro-optic deflector and liquid crystal spatial light modulator (LCSLM). In the experiment, we successfully produced various complicated pulses by controlling the light transmission intensity of every pixel on LCSLM. It is well proved that this transforming system is capable of producing shaped pulses, and above all, it can be programmed and controlled by a computer. Besides, compared with the aperture-coupled stripline pulse-shaping system, this system is simple and the output energy which is limited by damage threshold of fiber is high.

The deflector is made of magnesium-doped lithium niobate (MgO:LiNbO$_3$) which has a high damage threshold. The deflector employs the quadrupole electrode structure as shown in Fig. 1 in order to make use of the largest electro-optic coefficient, i.e., the r_{33} coefficient[5,6].

The crystal was cut at 45° to the x and z axes and used with the beam propagating in the y direction. The four electrodes are cylindrical and a uniform field gradient can be produced in the z direction. In this configuration, an incoming beam with its electric vector in the z direction is deflected in the xy plane through an angle θ_{def}[6,7],

$$\theta_{\mathrm{def}} = -\frac{C_{\mathrm{s}}}{2} n_{\mathrm{e}}^3 r_{33} V \frac{L}{D^2}, \tag{1}$$

where n_{e} is the extraordinary refractive index of crystal, r_{33} is electro-optic coefficient, V is the voltage applied to the deflector, L is the effective length of the deflector, D is the maximum aperture of light transmission, and the structure coefficient C_{s} is related to the parameter of the electro-optic deflector structure, and

$$C_{\mathrm{s}} = \frac{D^2}{V} \frac{\mathrm{d}E_{\mathrm{z}}(x)}{\mathrm{d}x}, \tag{2}$$

with $\frac{\mathrm{d}E_{\mathrm{z}}(x)}{\mathrm{d}x}$ being the gradient of electrical field. Theoretically the deflection angle θ_{def} is in direct proportion to the voltage applied to the crystal.

During the course of applying the high voltage to the deflector, the voltage on the deflector varies linearly so the gradient of electrical field in the electro-optic deflector gradually increases as time goes on. Thus, as indicated in Eq. (1), beam transferring through the deflector will have its deflection angle enlarged successively.

Figure 2 indicates the layout of pulse shaping system based on the new method. The effective diameter of the deflector is 4 mm and the effective length is 30 mm, and the focal lengths of lenses L$_1$—L$_4$ are all 1 m. The incident pulses with duration of about 85 ns at a wavelength

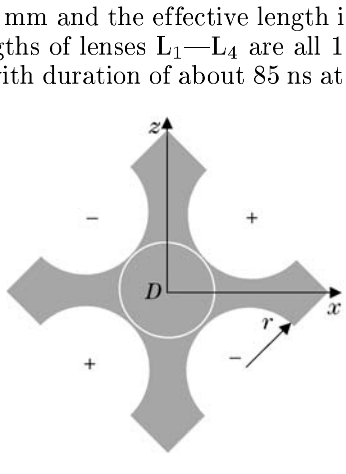

Fig. 1. Cross section of LiNbO$_3$.

of 1.053 μm and repetition rate of 1 Hz were obtained from a single-mode Q-switched Nd:YLF master oscillator, the oscilloscope trace of which is shown in Fig. 3(a). The optical beam from laser was directed to a beam splitter (BS) which can reflect lights partially, and split into a reflected beam and a transmitted beam. The reflected beam was received by positive-intrinsic-negative photodiode (PIN), which transformed it to an electrical signal to trigger the high voltage circuit that drives the deflector through metal oxide semiconductor (MOS) circuit. The transmitted beam, after propagating through a $4f$ system (including lenses L_1, L_2, and an aperture) to improve the beam quality, was directed onto the deflector located at the front focal plane of lens L_3.

The transmitted beam can be deflected by the deflector using the synchronous high voltage electrical pulse[6,7] shown in Fig. 3(b). As the voltage applied to the deflector varies, the transmitted beam is deflected in different angle, thus on the confocal plane of L_3 and L_4, the laser pulse is scanned as a line according to the time precedence. Through adjusting the delay time between the trigger electrical signal and transmitted beam signal carefully, the incident beam can be scanned during the time interval that the voltage of electrical pulses linearly vary rapidly. In this way, each section of the laser pulse in the time domain is transformed into corresponding section of the scanned line in the space domain; when the intensity distribution on the scanned line is modulated, the corresponding laser pulse shape will be produced also.

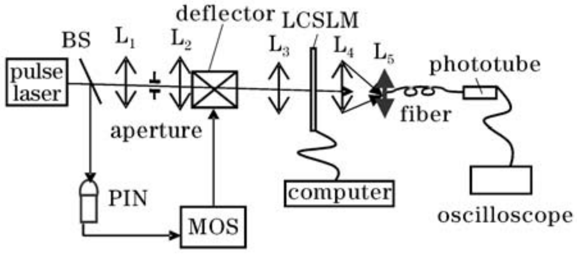

Fig. 2. Shaping system producing various waveforms with $LiNbO_3$ electro-optic deflector and LCSLM. L_5 is a 10× microscope objective.

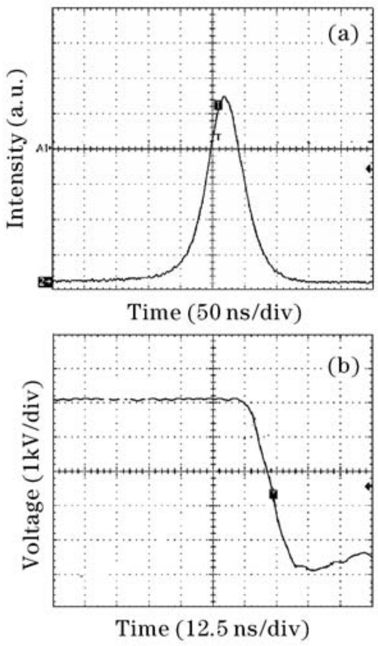

Fig. 3. (a) Oscilloscope trace of the laser pulse from oscillator; (b) electrical voltage waveform applied to the electro-optic deflector.

We inserted a LCSLM in the confocal plane between lenses L_3 and L_4, and the LCSLM gave an amplitude modulation to the intensity distribution on the scanned line. The light transmission intensity of every section on the scanned line will be controlled by computer through changing the modulating voltage on the pixels of LCSLM. In this way the temporal shaped pulse could be generated. By adjusting the focal position of a 10× microscope objective L_5 (numerical aperture (NA) 0.25), the laser pulses were coupled into a single-mode fiber about 3 m in length to restore the beam. The shaped pulses were received by a phototube. Figure 4 shows the traces of two shaped laser pulses.

In the experiment, Sharp LM64185P liquid crystal display (LCD) was used as LCSLM. For the 1.053-μm light, the maximum contrast ratio could overpass 30:1 through adjusting the orientation of polarizers. The information on the control of every pixel on the LCD could be written into driver integrated circuit (IC) to produce specific shaped pulses. An existing problem is that the LCSLM adopted in this experiment features a low pixel density of only about 4 pixels per millimeter, which limits the pulse-shaping capability.

Changing the light transmission intensity of every pixel, various specific shaped pulses with the pulse widths varying from 750 ps to 5 ns could be obtained. An oscillator (Tektronix TDS7404) and an O/E converter (MZ118A) were used to record the pulses (see Fig. 4).

The near field profile of shaped beam was measured with a charge-coupled device (CCD) camera (the CCD chip has 512×512 pixels and covers an area of 1.23×1.23 cm^2). From the profile shown in Fig. 5, we can see that the distribution of the output beam is smooth and symmetrical, and the shaped beam quality is good.

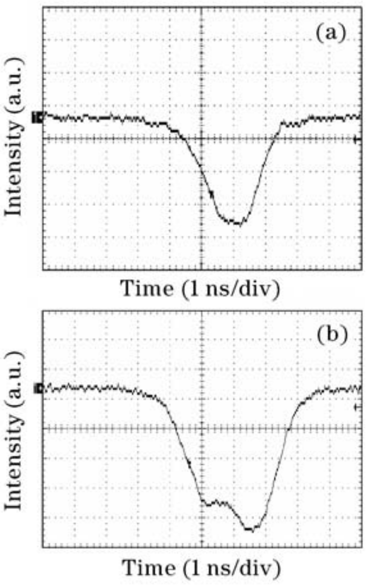

Fig. 4. Oscilloscope traces of shaped temporal pulses. (a) A square waveform; (b) an arbitrary shaped pulse.

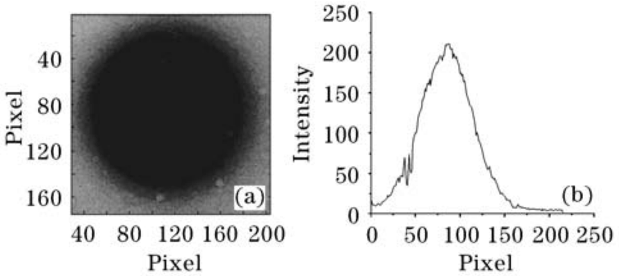

Fig. 5. Near field pattern of the output laser beam. (a) Two-dimensional intensity distribution; (b) one-dimensional scanning pattern.

In summary, we have demonstrated the temporarily shaping features of a new shaping system, in which arbitrary shaped pulses can be achieved by using LCSLM to control the light transmission intensity of every pixel.

J. Kang's e-mail address is kangjun@siom.ac.cn.

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