A Novel Electrooptic Phase Modulator Featuring Lens Modulation for Ultrashort Optical Pulse Generation

Dae-Sik KIM and Testurou KOBAYASHI*

Venture Business Laboratory, Osaka University, Suita, Osaka 560 Japan
*Faculty of Engineering Science, Osaka University, Toyonaka, Osaka 560 Japan.
E-mail: kim@laser.ee.es.osaka-u.ac.jp

The electrooptic modulation method[1-3] for generation of ultrashort optical pulses is applicable to all kinds of lasers regardless of the linewidth. This method has advantages of controllability and stability. For example, the optical pulse position, width, shape and repetition rate can be controlled electrically. From a this point of view, we have developed a quasi-velocity-matched(QVM) electrooptic phase modulator of high frequency with periodic domain inversion[4,5] and succeeded in generating terahertz sidebands[3] which are sufficiently wide for forming femtosecond optical pulses. In the electrooptic chirping-compression method, the phase modulated light has frequency up-chirp and down-chirp within a modulation period. We have formed about *560*fs optical pulses using a grating pair as an anomalous dispersive circuit and using a dispersive optical fiber in the previous experiments[4]. However, in this method, a residual CW optical power and the sidelobes of the peak pulse after compression are not sufficiently small. These problems are effectively alleviated by using the novel electrooptic phase modulator being reported here.

We designed a novel phase modulator to have lens-shaped periodic domain inversion in order to perform lens modulation and make quasi-velocity-matching possible at a high frequency. Lens modulated optical pulse is formed as if being amplitude modulated by placing a slit with suitable aperture around the movement range of the optical focus. Therefore, it is possible to control the optical pulse shape in order to suit the frequency chirp by changing the position of the slit. In general, applying phase modulation to the electrooptic lens causes the sinusoidal movement of the optical focus point. When a CW laser of beam waist w is phase modulated by a sinusoidal function $M(t)=sin(2f_m t)$ in the electrooptic lens, through a Fourier transform lens and slit, the output light field is expressed as follows;

$$e(t)=\frac{\exp(-j\Delta\theta\sin 2\pi f_m t)}{\sqrt{1-j(w/D)^2(\theta_0+\Delta\theta\sin 2\pi f_m t)}}$$

where $\theta_0=kD^2/2f_1$, $\Delta\theta$ is modulation index, f_m is modulation frequency, D is width of electrooptic lens and k is wave number. Output pulses at the place of the slit are variable for $\Delta\theta$ and w/D due to change the instantaneous phase and optical frequency. A bulk type $LiTaO_3$ quasi-velocity-matched electrooptic phase modulator featuring lens modulation was fabricated with periodic domain inversion. As shown Figure 1, a microwave resonator[6] at *16.25*GHz is formed by an open-circuit terminated silver strip line on a $LiTaO_3$ crystal (thickness $t=0.5$mm, length $l=45$mm). For the microstrip linewidth $w=1.0$mm, the wavelength of light $\lambda=514.5$nm, the phase velocity of microwave $v_m=4.95\times10^7$m/s, the group velocity of light $v_0=1.24\times10^8$m/s, a period of the domain inversion is *2.62*mm. Each lens type domains has a radius of *5*mm and was inverted by applying a high DC voltage (*22*kV/mm on +z surface) in an insulating fluid at room temperature. Figure2 shows the experiment setup. Ar laser was used as a light source, and *16.25*GHz pulsed multi-kilowatt magnetron was used as a modulating microwave source. In order to apply the phase and amplitude modulation simultaneously, we fabricated quasi-velocity-matched electrooptic phase modulator featuring lens modulation. There are consist of a electrooptic phase modulator, a Fourier transform lens and a slit. After traveling pass the electrooptic modulator, the light is large-amplitude phase modulated and has lens modulation at the same time. And then the optical focus point is sinusoidally changed by use of the Fourier transform lens. Amplitude modulated optical pulses are formed by placing a slit with suitable aperture and non-compressed residual light is cut. Finally, the modulated light passes through the grating pair with the group delay dispersion of *18.1*fs/GHz to generate the efficient ultrashort optical pulses. As a result, residual non-compressed CW optical power is cut and the extinction ratio is improved.

In conclusion, we proposed a novel electrooptic phase modulator featuring lens modulation for pedestal free ultrashort optical pulse generation. In the experiments, transform-limited pulses of *550*fs with *16.25*GHz repetition rate are obtained from a continuous-wave Ar laser with improved extinction ratio.

References

[1] T. Kobayashi et. al.: IEEE J. Quantum Electron. 24 (1988) 382.
[2] B. H. Kolner: Appl. Phys. Lett. 52 (1988) 1122.
[3] D.-S. Kim et. al.: IEEE J. Select. Top. Quantum Electron. 2 (1996) 493.
[4] D.-S. Kim et. al.: Jpn. J. Appl. Phys. 8 (1997) 5125.
[5] M. Kiminori et. al.: Appl. Phys. Lett. 62 19 (1993) 1860.
[6] T. C. Edwards: *Foundations for Microstrip Circuit Design* (John Wiley and Sons, New York, 1981) Chap. 4.

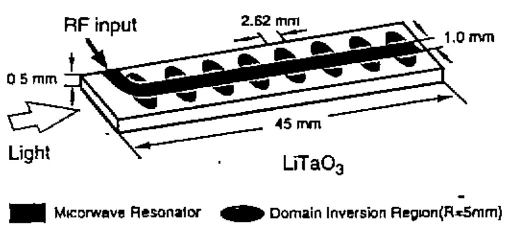

Fig1. A novel electrooptic phase modulator featuring lens modulation.

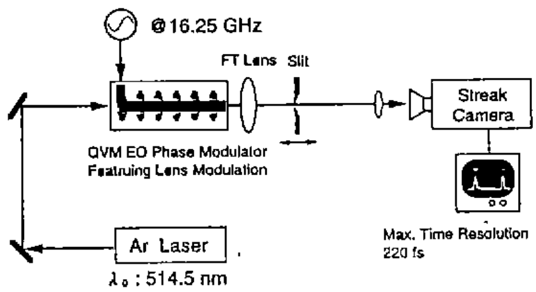

Fig2. Experiment setup for generation of pedestal free ultrashort optical pulses