2), originating from temporal gain narrowing in GaSe. Pulses of only ≈ 100 –200 fs duration are obtained for longer wavelengths, and from the bandwidths we anticipate even shorter pulse durations by subsequent pulse compression.

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CThK2

10:30 am

Generation of 1-GW, 1-kHz femtosecond mid-infrared laser pulses

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There have been several endeavors to generate high-power ultrafast infrared pulses with optical parametric amplifier (OPA). For example, 11 μJ of 200-fs pulses were generated in the 2.5–4.4- μm range in KTP by Gale *et al.*¹ In this study, we generate 140 pulses with as much as 120 μJ of energy per pulse in the 2.8 to 4.1 μm region, representing, to our knowledge, the highest IR pulse energy generated from a 1-kHz femtosecond laser system.

KTP and KTA are employed in our OPA system. They are cut for type II phase-matching. The femtosecond laser system used in pumping the OPA system consists of a femtosecond Ti:Sapphire regenerative amplifier generating 1 kHz, 3 mJ, and ca. 110-fs pulses. Figure 1 depicts a diagram of the OPA system. The OPA contains a white light generator to produce a seed signal beam, a two-pass and a one-pass amplification stages. The major portion of the first pump beam is split into two beams by a beamsplitter (BS2). The smaller reflected portion is made collinear with the white light seed beam and directed onto the first crystal (NOC1). The generated IR pho-

CThK2 Fig. 1. The layout of the OPA system. See text for the abbreviations.

CThK2 Fig. 2. The idler output power as a function of the wavelength.

CThK2 Fig. 3. The cross-correlation trace between the 800-nm beam and the idler beam of the OPA-KTP system at 3 μm . The inset shows the idler spectrum.

tons in this first stage, after reflection off a concave mirror (CM), pass again through NOC1. The reflected beam is combined with the larger portion of the first pump beam. The signal-idler beam is then directed onto the second crystal (NOC2), collinearly overlapped with the third pump beam. To tune the idler wavelength, both the crystal orientation and the three delay lines are adjusted simultaneously.

Figure 2 shows the wavelength dependence of the idler output power of both OPA systems. From 2.7 to 3.6 μm , the idler power of the OPA-KTP system drops continuously from 120 to 70 μJ . The idler power of the OPA-KTA system shows the similar behavior except that the cutoff wavelength is 4.1 μm . For both KTP and KTA, the first-pass gain is about 50, while the second-pass gain is about 10. The photon conversion efficiencies of both cases are about $\geq 12\%$. The energy fluctuation is about 5%. For OPA-KTP, Fig. 3 shows the idler spectrum and its cross-correlation trace of the OPA-KTP system at 3 μm .

We have succeeded in generating very intense pulses (up to 120 μJ) between 2.8 and 4.1 μm using a three-stage OPA with two KTP/KTA crystals. These intense IR pulses thus offer an unprecedented opportunity to perform time-resolved infrared spectroscopy.

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CThK3

10:45 am

Acousto-optic filter for femtosecond laser pulse shaping, gain narrowing and phase distortion compensation

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The acousto-optic programmable dispersive filter (AOPDF) recently proposed¹ creates an optical output $E_{\text{out}}(t)$ that is the convolution between an optical input $E_{\text{in}}(t)$ and a time scaled electrical signal $S(\alpha t)$.

$$E_{\text{out}}(t) = E_{\text{in}}(t) \otimes S(\alpha t)$$

The scaling factor $\alpha = \Delta n/v$ is the ratio of the speed of sound to the speed of light times the index difference between the ordinary and extraordinary wave in the birefringent material used. We thus synthesize a filter of impulse response $S(\alpha t)$, and because α is of order 10^{-7} we can manipulate an optical signal in the hundred-THz range with an electrical signal in the ten-MHz range. In our setup,² the $S(t)$ signal is applied to a piezoelectric transducer to generate an acoustic wave in a 2.5-cm-long TeO₂ crystal. The center frequency of $S(t)$ is 50 MHz. The bandwidth is larger than 20 MHz. This translates into an optical bandwidth of 150 THz around 375 THz. The associated time resolution is 6.7 fs yielding 450 resolution points in the 3-ps group delay allowed by the crystal length.

We report the use of this filter to precompensate for gain narrowing by amplitude shaping before amplification and to correct, independently and simultaneously, for phase errors arising from an imperfect matching of the dispersions of the stretcher and compressor. We also demonstrate programmed pulse shaping in the spectral and temporal domains. Experiments were conducted on a commercially available amplified femtosecond chain (Omega 1000; FemtoLasers GmbH), which delivers 1-mJ output pulses with 45-nm spectral bandwidth and 30-fs duration. The stretcher consisting of a 10-cm heavy flint glass block and the chirped mirrors used to precompensate for negative cubic phase errors were removed and replaced by the AOPDF to yield the simple set-up shown in Fig. 1.

To compensate for gain narrowing by amplitude shaping, we first used a transfer function $S(\alpha t)$ with a 200-nm FWHM Gaussian amplitude and a transmission minimum at 800 nm [Fig. 2(a)]. The width of the output amplitude spectrum was broadened from 45 nm to 80 nm as shown in Fig. 2(b). We then proceeded to adjust the spectral phase. A fourth-order polynomial was fitted to the spectral phase measured using the FROG tech-

CThK3 Fig. 1. Schematic of the CPA laser system used (Ref. 3) with the AOPDF replacing both the flint glass stretcher and the third-order chirped mirrors.