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Femtosecond Cr:LiSAF laser pumped by a single diode laser

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Abstract

Using a single diode laser to pump a Kerr-lens mode-locked Cr:LiSAF laser, we demonstrate the generation of Fourier-transform limited 26-fs pulses with spectral bandwidth of 34 nm. A novel cavity design for the mode-locked laser was used to focus tightly the pump beam. We have pointed out that the prism edge near the folding mirrors in the laser cavity plays a role of the hard aperture for Kerr-lens mode-locking.

Keywords: Cr:LiSAF; Kerr-lens mode-locking; Tight focusing; Single diode laser; Hard aperture; Fourier-transform limited

Kerr-lens mode-locked (KLM) Cr:LiSAF lasers are attractive femtosecond (fs)-pulse sources which can directly be pumped by compact diode lasers. As well as KLM Cr:LiSAF lasers pumped by Kr or Ar ion lasers [1–3], those pumped by diode lasers have been demonstrated by several authors [4–8], and the shortest 18-fs pulses were recently produced [5]. In these studies, multiple diode lasers have been used to produce sub-50-fs pulses [4–7]. This is due to the fact that the laser diode output having a poor beam quality is very difficult to be tightly focused to achieve an intracavity laser power large enough for pulse shortening in a KLM Cr:LiSAF laser. In the conventional Z- or X-fold-cavity configuration, one meets some technical problems in using a short focal-length lens for tight focusing of a pump beam, because the numerical aperture of the pump beam is usually limited by both of the diameter and the radius-of-curvature of the folding mirror used in the cavity. If the multiple diode lasers can be replaced by a single diode laser, the mode-locked Cr:LiSAF laser certainly becomes much more compact due to the simple configuration.

Recently, several authors have tried to use tight focusing geometry to achieve a low-threshold Ar-ion laser pumped mode-locked Ti:sapphire laser [9] and a low-threshold diode-pumped mode-locked Cr:LiSAF laser [8]. In each case, both the radii-of-curvature of the two folding mirrors used in the cavity were reduced. With decreasing radius of curvature, the cw-oscillation stability range of the folding-mirror separation becomes smaller, and the alignments for cw and KLM oscillations become more difficult. One can alleviate this difficulty by reducing each arm length between the folding mirror and the output coupler, but in this case a different technical problem arises in that the prism-pair separation cannot be kept large enough for dispersion compensation.

In order to avoid these problems, we have developed a novel tight focusing geometry which can be pumped by *a single diode laser*. In our tight focusing geometry, only the radius-of-curvature of *one* folding mirror is reduced. At the same time, we reduce the length of *one* arm which does not contain the prism pair, so that the alignments for cw and KLM oscillation become easier. In this communication we report on a new cavity geometry for a stable KLM femtosecond Cr:LiSAF laser. The mode-locked laser produces Fourier-transform limited 26-fs pulses with spectral bandwidth of 34 nm. To our knowledge, this pulse width is the shortest in the *single-diode-pumped* solid-state lasers produced so far.

The schematic diagram of the KLM Cr:LiSAF laser is shown in Fig. 1. The Z-fold laser cavity is composed of two folding mirrors and two flat output couplers. The radius-of-curvature R of one of the folding mirrors is 50 mm, and the other is $R = 100$ mm. All mirrors are highly reflecting at 810–920 nm. The laser medium is a 1.5%-doped 5-mm-long Brewster-cut Cr:LiSAF crystal (Lightning Optical), which temperature is stabilized at 15.0°C. The two intracavity fused-silica prisms for dispersion compensation are separated by 500 mm. In order to cancel out

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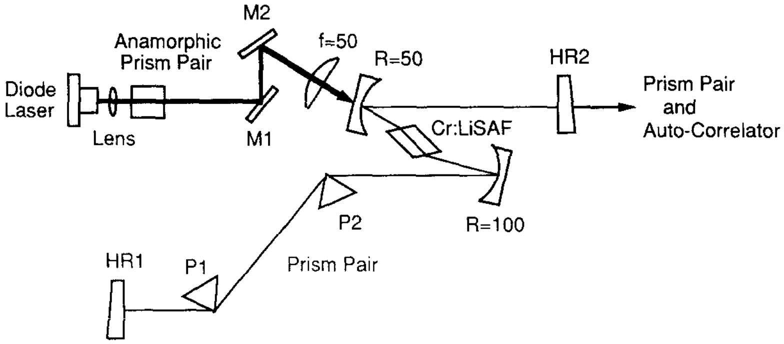

Fig. 1. Schematic diagram of the Kerr-lens-mode-locked Cr:LiSAF laser pumped by a single diode laser.

the astigmatism of the intracavity mode that arises from the Brewster-cut Cr:LiSAF crystal and the two folding mirrors, the folding mirrors are tilted at the angles of 12 and 8 degrees for the $R = 50$ and 100 mm mirrors, respectively [10]. The high-power diode laser (Applied Optronics) used is capable of producing the maximum output power of 800 mW from a 200-μm wide stripe. The pump beam is focused by a 50-mm focal-length lens through the folding mirror of $R = 50$ mm. The focused beam size was measured to be 70 μm × 45 μm.

Considering an equivalent two-mirror resonator [11], one can find the position and the diameter of the intracavity mode waist located between the folding mirrors. The reduction of radius-of-curvature of one of the folding mirrors usually results in shortening the cw-oscillation stability range of the distance z between the two folding mirrors. In order to avoid this effect, we increased the cw-oscillation stability range by reducing the arm length between the folding mirror of $R = 50$ mm and the output coupler HR2 to 210 mm, while the other arm length was fixed to be 926 mm. This made it easy to find out the Kerr-lens mode-locking condition for the cavity configuration concerned.

In the present experiment, the cw-oscillation stability ranges were 76.43 mm $< z <$ 79.28 mm and 79.81 mm $< z <$ 82.66 mm. For the Kerr-lens mode locking, we set the distance z near the upper stability limit of ~ 79.28 mm in the former range [12,13], and then the laser cavity and the focused pump beam were optimized for maximum cw laser power. For the purpose of mode matching between the intracavity and the pump beam, the laser crystal had to be shifted a little toward the focusing lens from the intracavity node between the folding mirrors. This shift enhances the loss variation caused by an intracavity-mode change in the Kerr-lens mode locking [12,13]. Here the distance between the folding mirror of $R = 50$ mm and the laser-crystal surface was 23 mm. Next, we translated the prism P2 so that the intracavity laser beam was cut a little by the edge, and the intracavity dispersion was compensated by adjusting the prism P1. The movement of P1 initiated Kerr-lens mode locking. We sometimes adjusted again the separation z of the two folding mirrors to optimize the mode-locked operation.

A typical autocorrelation trace observed is shown in Fig. 2. The pulse width (FWHM) is 26 fs, assuming a sech^2 pulse shape. The corresponding spectral profile with bandwidth (FWHM) of 34 nm is shown in Fig. 3. The time–bandwidth product is 0.32 and very close to the Fourier-transform-limited value of 0.315 for a sech^2 pulse. The mode-locked laser power was 6.2 mW at the absorbed pump power of 520 mW.

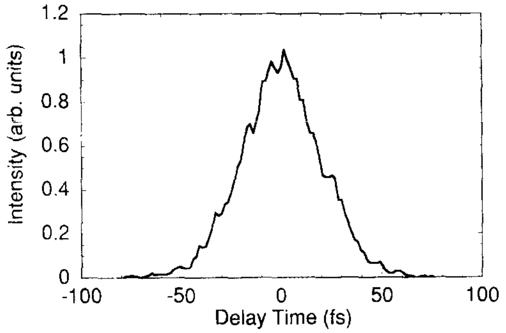

Fig. 2. Typical autocorrelation trace of fs pulses produced by the Kerr-lens-mode-locked Cr:LiSAF laser. The pulse width (FWHM) is 26 fs, assuming a sech^2 pulse shape.

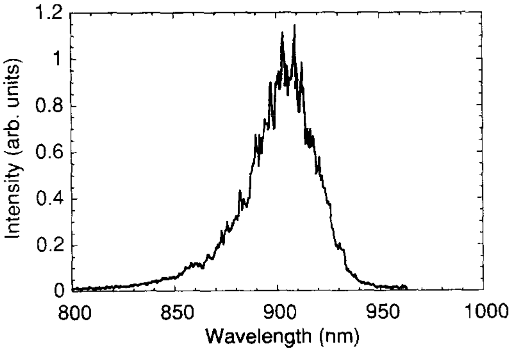

Fig. 3. Corresponding spectrum profile of the fs pulses. The spectral bandwidth (FWHM) is 34 nm.

The stable KLM operation was obtained with no slit. Because the waist diameter of the intracavity mode between the folding mirrors was estimated to be 50 μm and almost the same as that of the pump beam, as mentioned above, the KLM was not sustained by the soft-aperturing effect of the focused pump beam. In the experiment, we found that the amount of insertion of the prism P2 was sensitive for stabilizing the mode-locking, and that the prism edge was always required to partially cut the intracavity laser beam for the KLM. These facts suggest that the edge of the prism P2 is working as a hard aperture for the KLM.

To confirm this, we calculated the strength Δ of Kerr-lens mode-locking which is defined as $\Delta = -\delta = -\{(\mathrm{d}w/\mathrm{d}p)/w\}_{p=0}$ (δ was introduced in Ref. [13]). Here w is the beam radius at the aperture, and p is the normalized intracavity laser power. The variations of Δ for three values of z are shown in Fig. 4 as a function of the distance between the mirror HR1 and the aperture of the laser cavity. In Fig. 4, the position of P2 is indicated by an arrow at 635 mm. The calculated value of $\Delta > 0$ at P2 indicates that the prism edge is working as a hard aperture for the Kerr-lens mode locking. The KLM strength Δ increases as the position of the aperture becomes closer to the folding mirror ($R = 100$). Fig. 4 also demonstrates that the strength Δ increases as z approaches the upper cw-stability limit ($z = 79.28$ mm).

In summary, we have successfully produced Fourier-transform limited 26-fs pulses from a KLM Cr:LiSAF laser pumped by a single diode laser. We designed a novel cavity configuration including a folding mirror, which radius of curvature was reduced to 50 mm. This cavity configuration can keep a prism-pair separation large enough for dispersion compensation. We have also pointed out that the prism edge near the folding mirrors in the laser cavity plays the role of a hard aperture for Kerr-lens mode-locking.

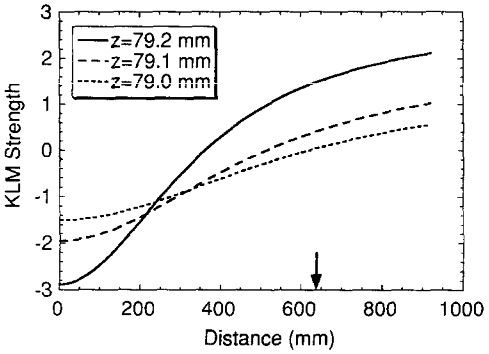

Fig. 4. The strength of Kerr-lens mode locking for various values of the distance z between two folding mirrors as a function of the distance between the output coupler HR1 and the aperture in the laser cavity. The arrow indicates the position of the prism P2.

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