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Kerr-lens mode-locked, diode-pumped Yb,Gd:YAP laser generating 23 fs pulses

HAI-YU NIE,[1,2,3] PEIXIONG ZHANG,[4] PAVEL LOIKO,[5] ZHANG-LANG LIN,[1] HUANG-JUN ZENG,[1] GE ZHANG,[1] ZHEN LI,[4] XAVIER MATEOS,[6] HSING-CHIH LIANG,[7] VALENTIN PETROV,[8] ZHENQIANG CHEN,[4,9,10] AND WEIDONG CHEN[1,8,*]

[1] *State Key Laboratory of Functional Crystals and Devices, Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, 350002 Fuzhou, China*
[2] *College of Chemistry and Materials Science, Fujian Normal University, 350002 Fuzhou, China*
[3] *Fuijan College, University of Chinese Academy of Sciences, 350108 Fuzhou, China*
[4] *Guangdong Provincial Engineering Research Center of Crystal and Laser Technology, 510632 Guangzhou, China*
[5] *Centre de Recherche sur les Ions, les Matériaux et la Photonique (CIMAP), UMR 6252 CEA-CNRS-ENSICAEN, Université de Caen, 6 Boulevard Maréchal Juin, 14050 Caen Cedex 4, France*
[6] *Universitat Rovira i Virgili, URV, Física i Cristal·lografia de Materials, FiCMA, Marcel·lí Domingo 1, 43007 Tarragona, Spain*
[7] *Institute of Physics, National Yang Ming Chiao Tung University, 30010 Hsinchu, Taiwan*
[8] *Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2a, 12489 Berlin, Germany*
[9] *Guangdong Provincial Key Laboratory of Industrial Ultrashort Pulse Laser Technology, 518055 Shenzhen, China*
[10] *tzqchen@jnu.edu.cn*
[*] *chenweidong@fjirsm.ac.cn*

Abstract: We report on the generation of sub-30 fs pulses from a diode-pumped Yb,Gd:YAP laser. Using soft-aperture Kerr-lens mode-locking, soliton pulses as short as 23 fs were achieved at 1082.3 nm, with an average output power of 45 mW at a repetition rate of 67.25 MHz. The mode-locked laser also produced a maximum average output power of 101 mW at 1056.5 nm with a slightly longer pulse duration of 34 fs, corresponding to a peak power of 38.9 kW. To the best of our knowledge, this is the first demonstration of Kerr-lens mode-locked operation in a diode-pumped Yb,Gd:YAP laser, with the shortest pulses ever reported from any Yb^{3+}-doped perovskite-type crystal.

1. Introduction

Few-optical-cycle lasers operating in the 1-µm spectral range at high repetition rates are essential for applications such as time-resolved molecular spectroscopy, pump/seed sources for parametric frequency down-conversion, and seed sources for ultrafast regenerative laser amplifiers. The development of mode-locked (ML) solid-state lasers based on the ytterbium (Yb^{3+}) ion has greatly benefited from the rapid advancements in cost-effective, low-power, spatially single-mode InGaAs laser diodes operating near 980 nm, which were originally designed for Erbium-fiber amplifiers in telecommunications [1–8]. When these laser diodes are used as pump sources for ML Yb lasers, they provide maximum gain per watt of absorbed power compared to multi-transverse mode pumping, owing to their near-diffraction-limited beam quality. This feature helps in achieving the highest possible optical efficiency, minimizing thermo-optic effects and thermal stress caused by nonuniform temperature distribution in the laser gain medium, which could otherwise compromise the ML regime stability [9,10]. Laser diodes exhibiting a

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near-fundamental Gaussian mode spatial intensity distribution enable the use of a tight focusing pumping scheme, enhancing the Kerr-lens effect and supporting the generation of ultrashort pulses by soft-aperture Kerr-lens mode-locking (KLM) [11–17]. With a broadband Yb-doped gain medium, e.g., Yb:CALGO crystal, sub-20 fs pulses could be generated directly from such a diode-pumped KLM laser [18]. Moreover, using high-brightness laser diodes, the pulse repetition rate of femtosecond ML Yb lasers can easily reach the multi-gigahertz (GHz) range [19–23]. Additionally, the reduced thermal effects eliminate the need for active cooling of the laser gain medium, thereby simplifying the setup and making such ML lasers more compact. Consequently, misalignment-free, space-qualified, GHz repetition-rate, femtosecond Yb lasers and amplifiers with minimal size are now feasible [24,25]. These advances have also enabled the generation of low-noise, fully stabilized optical frequency combs with a minimized footprint [26,27]. Thus, for applications requiring compact femtosecond Yb lasers at ~1 µm, where high peak power, e.g., tens of kilowatts (kW), is prioritized over high average power, it is advantageous to use these low-power but spatially single-mode InGaAs laser diodes near 980 nm as pump sources [28–31].

Recently, we demonstrated the potential of a Yb^{3+}-doped rare-earth orthoaluminate crystal with perovskite structure, namely $Yb:YAlO_3$ (abbreviated as Yb:YAP) for generating sub-30 fs pulses. Pumping by a high-power Yb fiber laser with near-diffraction-limited beam quality, a SEmiconductor Saturable Absorber Mirror (SESAM) ML Yb:YAP laser delivered 29 fs pulses at 1091 nm, with an average output power of 156 mW at a repetition rate of 85.1 MHz [32]. Yb:YAP is a structurally ordered laser crystal featuring excellent thermo-mechanical and spectroscopic properties. As an orthorhombic crystal, it exhibits anisotropic properties but this is weakly pronounced in the relatively high thermal conductivity ($\kappa_a = 7.1$, $\kappa_b = 8.3$ and $\kappa_c = 7.6$ $\mathrm{Wm^{-1}K^{-1}}$, *Pnma* notations used), measured for 5 at.% Yb^{3+} doping [33].

Adding an optically passive rare-earth ion to the YAP host (resulting in a solid-solution compound) can introduce inhomogeneous spectral line broadening due to compositional disorder. By partially substituting Y^{3+} with Gd^{3+} (up to about 10 at.%), we grew a compositionally disordered crystal with a stoichiometric formula of $Y_{0.8447}Gd_{0.0988}Yb_{0.0565}AlO_3$ (5.65 at.% Yb^{3+} doping), abbreviated as Yb,Gd:YAP. Continuous-wave (CW) and femtosecond ML laser operation of such Yb,Gd:YAP crystal were reported in our previous works [34,35]. Pumped by a single-transverse-mode, fiber-coupled InGaAs laser diode at 976 nm, the SESAM ML Yb,Gd:YAP laser generated 43 fs pulses at 1052.3 nm, with an average output power of 103 mW at 70.8 MHz, corresponding to a peak power of 29.8 kW [34]. Soliton pulses as short as 32 fs at 1067 nm were produced by a KLM Yb,Gd:YAP laser, pumped by a 10-W Yb fiber laser at 979 nm, achieving an average output power of 328 mW at 84.6 MHz [35].

Compared to using a high-power, single-transverse-mode Yb fiber laser as the pump source, low-power, spatially single-mode, fiber-coupled InGaAs laser diodes enable a much more compact, cost-effective, and passively cooled Yb laser design without the need for active cooling. The excellent mode-locking performance of the Yb,Gd:YAP crystal inspired us to explore sub-30 fs pulse generation with kW-level peak power by soft-aperture KLM.

2. Laser set-up

A schematic of the diode-pumped KLM Yb,Gd:YAP laser is depicted in Fig. 1. A 3-mm-thick uncoated laser element was cut along the crystallographic ***c***-axis (***c***-cut in *Pnma* notation) with an aperture of 4×4 $\mathrm{mm^2}$ and an Yb^{3+} doping level of 5.65 at.%. It was mounted in a copper holder without active cooling and positioned at Brewster's angle between two plane-concave mirrors, M_1 and M_2 (radius of curvature: RoC = -100 mm) in an X-folded astigmatically compensated linear cavity. The pump source was a low-power (1.39-W) fiber-coupled InGaAs laser diode delivering unpolarized CW output with a near diffraction-limited beam quality ($M^2 = 1.02$) at 976 nm. Its emission wavelength was stabilized by a fiber Bragg grating (FBG), ensuring a narrow spectral linewidth of 0.2 nm (full width at the half maximum, FWHM). The pump beam was collimated by

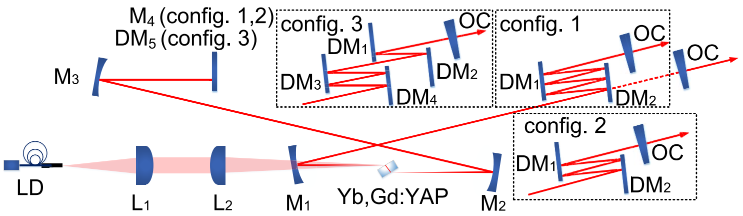

Fig. 1. Schematic of the diode-pumped KLM Yb,Gd:YAP laser. LD: fiber-coupled InGaAs laser diode; L_1: aspherical lens; L_2: spherical lens; M_1 - M_3: plane-concave mirrors; M_4: flat rear mirror; DM_1 – DM_5: flat dispersive mirrors; OC: output coupler.

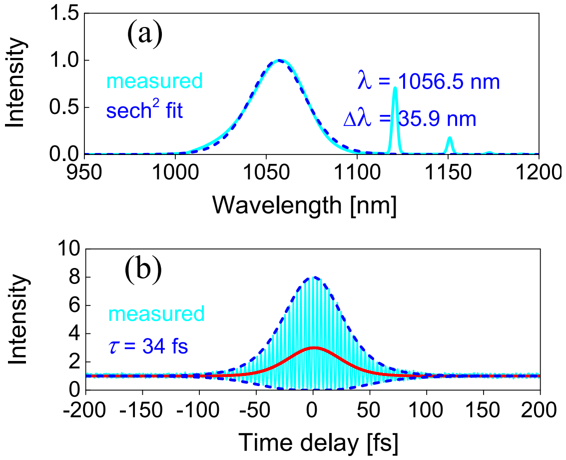

Fig. 2. Diode-pumped KLM Yb,Gd:YAP laser with a 2.5% OC. (a) Optical spectrum; (b) Interferometric autocorrelation trace. The red curve in (b) corresponds to the intensity autocorrelation profile.

an aspherical lens L_1 (focal length: $f = 25.4$ mm), and focused in the crystal with a spherical lens L_2 ($f = 75$ mm) through the pump mirror M_1, resulting in beam waist radii of 15 µm and 30.4 µm in the sagittal and tangential planes, respectively. For KLM operation, flat dispersive mirrors (DMs) with negative group delay dispersion (GDD) were employed, compensating for material dispersion and balancing the self-phase modulation (SPM) induced by the Kerr nonlinearity of the laser crystal. The laser polarization was selected to be $\boldsymbol{E} \parallel \boldsymbol{b}$ by the orientation of the crystal. The physical cavity length of the KLM Yb,Gd:YAP laser was ~2.23 m, corresponding to a pulse repetition rate of ~67 MHz.

3. Kerr-lens mode-locked laser performance

Initially, the KLM performance of the diode-pumped Yb,Gd:YAP laser was studied using a 2.5% output coupler (OC) and two flat DMs, DM_1 and DM_2, each of GDD = -150 fs^2 per bounce, see Fig. 1 (config. 1). By applying three bounces on each DM, the total round-trip negative GDD amounted to -1800 fs^2. To enable KLM operation, the laser cavity was aligned near the edge of the stability region by incrementally translating the folding mirror M_2 away from the pump mirror M_1. This adjustment resulted in a notable reduction of the CW output power. After precise cavity alignment, KLM operation was initiated by gently tapping the OC or slightly translating the flat rear mirror M_4.

Upon mode-locking, the Yb,Gd:YAP laser exhibited an abrupt increase in output power from 71 mW (CW) to 101 mW (KLM). The optical spectrum of the laser pulses, shown in Fig. 2(a), revealed a bandwidth of 35.9 nm (FWHM), with emission centered at 1056.5 nm, assuming a sech^2 spectral shape. The recorded second-harmonic-generation (SHG) interferometric autocorrelation trace, displayed in Fig. 2(b), was fitted with a sech^2-pulse duration (FWHM) of 34 fs. The corresponding time-bandwidth product (TBP) was 0.328, slightly exceeding the Fourier-transform limit for soliton pulses (0.315). These results were achieved at an absorbed pump power of 1.07 W, corresponding to an optical efficiency of 9.4%. The calculated peak output power reached 38.9 kW.

The pulse duration could be further shortened by decreasing the transmittance of the OC and reducing the overall amount of intracavity negative GDD. Sub-30 fs pulses were directly generated by employing a 1.6% OC and applying two bounces on each DM (DM$_1$ and DM$_2$), resulting in a total round-trip negative GDD of -1200 fs^2, see Fig. 1(conFig. 2). The optical spectrum of the KLM Yb,Gd:YAP laser was centered at 1073.6 nm with a sech^2-shape spectral width of 47.6 nm (FWHM), as shown in Fig. 3(a). The envelope of the interferometric autocorrelation trace, recorded in Fig. 3(b), could be again well fitted using a sech^2-shape temporal profile, yielding a deconvolved pulse duration of 27 fs, equivalent to 8.4 optical cycles. The resulting TBP was 0.334, indicating a slight residual chirp. Under these conditions, the ML laser produced an average output power of 57 mW at an absorbed pump power of 1.03 W, corresponding to an optical efficiency of 5.5% and a calculated peak power of 27.8 kW.

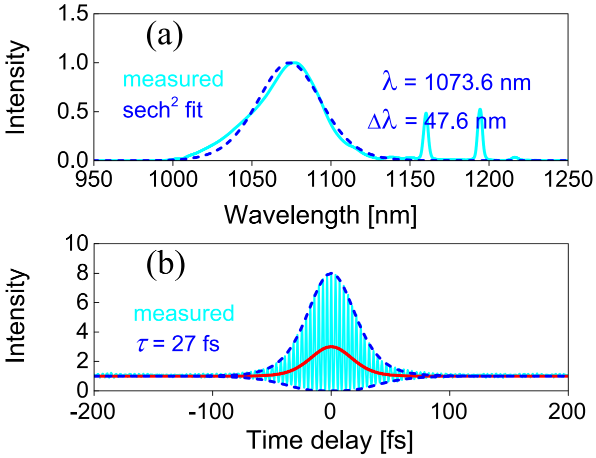

Fig. 3. Diode-pumped KLM Yb,Gd:YAP laser with a 1.6% OC. (a) Optical spectrum; (b) Interferometric autocorrelation trace. The red curve in (b) corresponds to the intensity autocorrelation profile.

The shortest pulses with ultimate stability were achieved using the same 1.6% OC further reducing the cavity negative GDD. Three additional flat DMs (DM$_3$ -DM$_5$) with GDD = -50 fs^2 per bounce were incorporated into the laser cavity. By applying one bounce on each of DM$_1$ and DM$_2$, two bounces on each of DM$_3$ and DM$_4$, and replacing M$_4$ by DM$_5$, the total round-trip negative GDD of the KLM Yb,Gd:YAP laser was reduced to -1050 fs^2, see Fig. 1(conFig. 3). The measured laser spectrum, shown in Fig. 4(a), exhibited a broader bandwidth of 54.8 nm, with emission centered at 1082.3 nm, assuming a sech^2-shaped spectral profile. The satellite peak observed above 1150 nm arises from the uncontrollable intracavity GDD at the long-wave spectral wing and the non-optimized spectral reflectivity of the cavity mirrors. The sech^2-shape pulse duration, estimated from the recorded interferometric autocorrelation trace, was as short as 23 fs (~6.4 optical cycles). The corresponding TBP was 0.323, slightly above the Fourier-transform-limit value. The inset in Fig. 4(b) displays the SHG-based background-free intensity autocorrelation trace over a 50-ps time span, confirming single-pulse steady state ML operation free of multiple pulse instabilities. The average output power for the shortest pulses was 45 mW at an absorbed pump power of 1.02 W, corresponding to an optical efficiency of 4.4% and a calculated peak power of 25.6 kW.

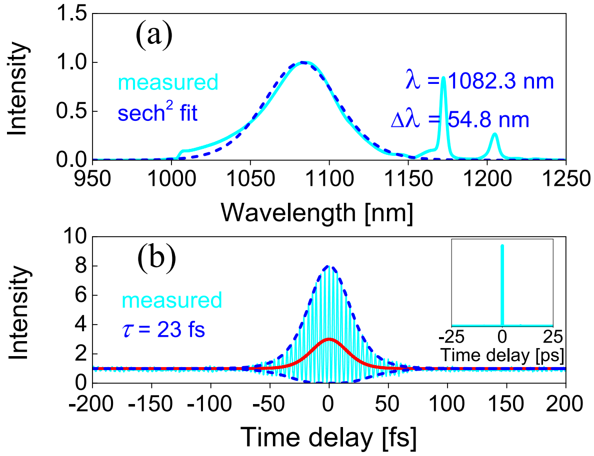

Fig. 4. Shortest pulses from the diode-pumped KLM Yb,Gd:YAP laser. (a) Optical spectrum; (b) Interferometric autocorrelation trace. The red curve in (b) corresponds to the intensity autocorrelation profile. *Inset*: intensity autocorrelation trace measured on a time span of 50 ps.

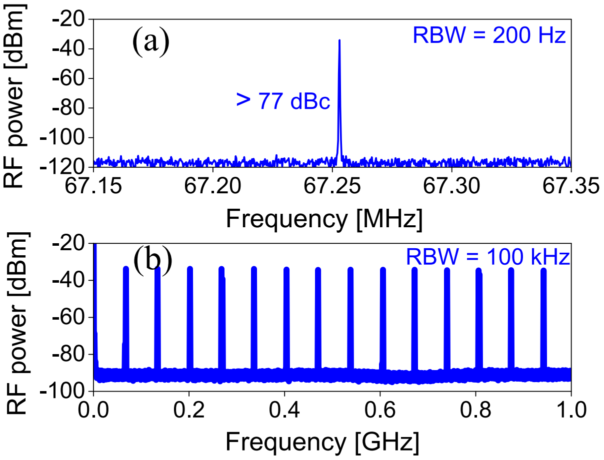

Fig. 5. RF spectra of the diode-pumped KLM Yb,Gd:YAP laser with 1.6% OC: (a) Fundamental beat note at 67.25 MHz recorded with a resolution bandwidth (RBW) of 200 Hz, and (b) harmonics on a 1-GHz frequency span recorded with a RBW of 100 kHz.

To confirm the ultimate stability of the ML operation across different frequency span ranges, the radio-frequency (RF) spectra of the shortest pulses were recorded, as shown in Fig. 5. The fundamental beat note located at 67.25 MHz exhibited a high extinction ratio exceeding 77 dBc above the carrier, as shown in Fig. 5(a). Additionally, the harmonics displayed uniformity over a

1-GHz frequency span, as illustrated in Fig. 5(b). These results indicate excellent single-pulse stability without any signs of Q-switching modulations or multiple-pulse operation, further validating the robustness of the KLM mechanism. The measured beam propagation factor (M^2) for the shortest pulses was 1.02.

The observed beam shrinking is a direct manifestation of the Kerr nonlinearity in the laser crystal, where the intensity-dependent refractive index modifies the intracavity mode. This effect enhances the mode overlap with the pump beam and facilitates self-focusing, a key mechanism in achieving and stabilizing soliton pulses. This phenomenon was verified by observing the far-field beam profiles in both CW and KLM regimes with the shortest pulses. An infrared (IR) camera was positioned approximately 0.6 m from the 1.6% OC to record the beam profiles. The transition from CW to dominating soft-aperture KLM regime was marked by a notable reduction in the beam diameter, from 3.39 mm (x) × 1.70 mm (y) in the CW regime to 2.17 mm (x) × 1.68 mm (y) in the KLM regime, as shown in Fig. 6.

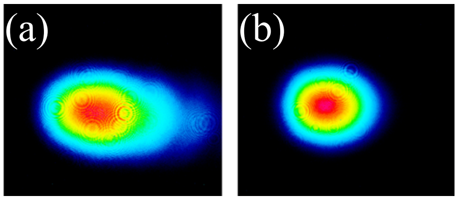

Fig. 6. Measured far-field beam profiles of the diode-pumped KLM Yb,Gd:YAP laser with a 1.6% OC: (a) CW and (b) KLM regimes of operation.

4. Conclusion

In summary, we demonstrated the first sub-30 fs diode-pumped mode-locked Yb laser using a "mixed" rare-earth orthoaluminate crystal with perovskite structure as the gain medium. By employing a low-power, spatially single-mode, fiber-coupled InGaAs laser diode at 976 nm as the pump source, soliton pulses as short as 23 fs were directly generated from the Yb,Gd:YAP laser at 1082.3 nm via soft-aperture Kerr-lens mode-locking, with an average output power of 45 mW. Utilizing an output coupler with higher transmission, the average output power increased to 101 mW at the cost of a slightly longer pulse duration (34 fs), corresponding to a peak power of 38.9 kW. To the best of our knowledge, these results represent the shortest pulses ever reported from any Yb^{3+}-doped perovskite-type crystal.

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Data availability. Data underlying the results presented in this paper are not publicly available at this time but may be obtained from the authors upon reasonable request.

References

1. A. Agnesi, A. Greborio, F. Pirzio, *et al.*, "40-fs Yb^{3+}:$CaGdAlO_4$ laser pumped by a single-mode 350-mW laser diode," Opt. Express **20**(9), 10077–10082 (2012).
2. A. Agnesi, A. Greborio, F. Pirzio, *et al.*, "Diode-pumped passively mode-locked tunable Yb:CALGO solid-state laser," J. Opt. Soc. Am. B **30**(6), 1513–1516 (2013).
3. F. Pirzio, S. D. D. D. Cafiso, M. Kemnitzer, *et al.*, "Sub-50-fs widely tunable Yb:$CaYAlO_4$ laser pumped by 400-mW single-mode fiber-coupled laser diode," Opt. Express **23**(8), 9790–9795 (2015).
4. F. Pirzio, L. Fregnani, A. Volpi, *et al.*, "87 fs pulse generation in a diode-pumped semiconductor saturable absorber mirror mode-locked Yb:YLF laser," Appl. Opt. **55**(16), 4414–4417 (2016).

5. H. Lin, G. Zhang, L. Zhang, *et al.*, "Continuous-wave and SESAM mode-locked femtosecond operation of a Yb:$MgWO_4$ laser," Opt. Express **25**(10), 11827–11832 (2017).
6. H. Lin, G. Zhang, L. Zhang, *et al.*, "SESAM mode-locked Yb:GdYCOB femtosecond laser," Opt. Mater. Express **7**(10), 3791–3795 (2017).
7. M. Kowalczyk, X. Zhang, V. Petrov, *et al.*, "Self-frequency-doubling Yb:CNGS lasers operating in the femtosecond regime," J. Opt. Soc. Am. B **37**(10), 2822–2829 (2020).
8. F. Pirzio, M. Kemnitzer, A. Guandalini, *et al.*, "Ultrafast, solid-state oscillators based on broadband, multisite Yb-doped crystals," Opt. Express **24**(11), 11782–11792 (2016).
9. F. Pirzio, S. D. Di Dio Cafiso, M. Kemnitzer, *et al.*, "65-fs Yb:CaF_2 laser mode-locked by semiconductor saturable absorber mirror," J. Opt. Soc. Am. B **32**(11), 2321–2325 (2015).
10. M. Kowalczyk, J. Sotor, and K. M. Abramski, "59 fs mode-locked Yb:KGW oscillator pumped by a single-mode laser diode," Laser Phys. Lett. **13**(3), 035801 (2016).
11. A. A. Lagatsky, C. T. A. Brown, and W. Sibbett, "Highly efficient and low threshold diode-pumped Kerr-lens mode-locked Yb:KYW laser," Opt. Express **12**(17), 3928–3933 (2004).
12. A. A. Lagatsky, A. R. Sarmani, C. T. A. Brown, *et al.*, "Yb^{3+}-doped YVO_4 crystal for efficient Kerr-lens mode locking in solid-state lasers," Opt. Lett. **30**(23), 3234–3236 (2005).
13. H. Zeng, H. Lin, Z. Lin, *et al.*, "Diode-pumped sub-50-fs Kerr-lens mode-locked Yb:GdYCOB laser," Opt. Express **29**(9), 13496–13503 (2021).
14. X. Su, Y. Wang, G. Li, *et al.*, "Sub-60-fs ultralow threshold and efficient Kerr-lens mode-locked Yb,Gd:$CaSrF_2$ laser," Opt. Lett. **47**(9), 2362–2365 (2022).
15. Y. Yu, Y. Chen, W. Tian, *et al.*, "A 54-fs diode-pumped Kerr-lens mode-locked Yb:$LuYSiO_5$ laser," Chin. Phys. B **32**(6), 064204 (2023).
16. Z. Q. Li, Z. L. Lin, P. Loiko, *et al.*, "Kerr-Lens Mode-Locked Yb:BaF_2 Laser," Photonics **11**(4), 322 (2024).
17. Z. Q. Li, Z. L. Lin, H. J. Zeng, *et al.*, "Diode-pumped Kerr-lens mode-locked ytterbium-doped compositional mixed calcium aluminate laser," Opt. Express **32**(23), 40507–40513 (2024).
18. Y. Wang, X. Su, Y. Xie, *et al.*, "17.8 fs broadband Kerr-lens mode-locked Yb:CALGO oscillator," Opt. Lett. **46**(8), 1892–1895 (2021).
19. M. Endo, A. Ozawa, and Y. Kobayashi, "Kerr-lens mode-locked Yb:KYW laser at 4.6-GHz repetition rate," Opt. Express **20**(11), 12191–12197 (2012).
20. M. Endo, A. Ozawa, and Y. Kobayashi, "6-GHz, Kerr-lens mode-locked Yb:Lu_2O_3 ceramic laser for comb-resolved broadband spectroscopy," Opt. Lett. **38**(21), 4502–4505 (2013).
21. M. Endo, I. Ito, and Y. Kobayashi, "Direct 15-GHz mode-spacing optical frequency comb with a Kerr-lens mode-locked Yb:Y_2O_3 ceramic laser," Opt. Express **23**(2), 1276–1282 (2015).
22. S. Kimura, S. Tani, and Y. Kobayashi, "Raman-assisted broadband mode-locked laser," Sci. Rep. **9**(1), 3738 (2019).
23. S. Kimura, S. Tani, and Y. Kobayashi, "Kerr-lens mode locking above a 20 GHz repetition rate," Optica **6**(5), 532–533 (2019).
24. Y. Feng, T. P. Lamour, H. Ostapenko, *et al.*, "Towards a space-qualified Kerr-lens mode-locked laser," Opt. Lett. **46**(21), 5429–5432 (2021).
25. H. Ostapenko, Y. Feng, T. Lamour, *et al.*, "Misalignment-free, Kerr-lens-modelocked Yb:Y_2O_3 2.2-GHz oscillator, amplified by a semiconductor optical amplifier," Opt. Express **31**(2), 3249–3257 (2023).
26. M. Mitaki, K. Sugiyama, and M. Kitano, "Octave-spanning optical frequency comb based on a laser-diode pumped Kerr-lens mode-locked Yb:KYW laser for optical frequency measurement," Appl. Opt. **57**(18), 5150–5160 (2018).
27. L. M. Molteni, F. Canella, F. Pirzio, *et al.*, "Low-noise Yb:CALGO optical frequency comb," Opt. Express **29**(13), 19495–19505 (2021).
28. M. Kowalczyk, T. Martynkien, P. Mergo, *et al.*, "Ultrabroadband wavelength-swept source based on total mode-locking of an Yb:CaF_2 laser," Photonics Res. **7**(2), 182–186 (2019).
29. M. Kowalczyk, A. Hudzikowski, M. Porębski, *et al.*, "Low-noise carrier-envelope-offset-stabilized Yb:CaF_2 oscillator," IEEE Photonic.Tech. L. **32**(13), 823–826 (2020).
30. M. Kowalczyk, A. Major, and J. Sotor, "High peak power ultrafast Yb:CaF_2 oscillator pumped by a single-mode fiber-coupled laser diode," Opt. Express **25**(21), 26289–26295 (2017).
31. L. Marta Molteni, F. Pirzio, C. Manzoni, *et al.*, "Few-optical-cycle pulse generation based on a non-linear fiber compressor pumped by a low-energy Yb:CALGO ultrafast laser," Opt. Express **28**(9), 13714–13720 (2020).
32. Z. L. Lin, W. Z. Xue, H. J. Zeng, *et al.*, "Semiconductor saturable absorber mirror mode-locked Yb:YAP laser," Opt. Express **30**(18), 31986–31997 (2022).
33. R. Aggarwal, D. Ripin, J. Ochoa, *et al.*, "Measurement of thermo-optic properties of $Y_3Al_5O_{12}$, $Lu_3Al_5O_{12}$, $YAIO_3$, $LiYF_4$, $LiLuF_4$, BaY_2F_8, $KGd(WO_4)_2$, and $KY(WO_4)_2$ laser crystals in the 80–300 K temperature range," J. Appl. Phys. **98**(10), 103514 (2005).
34. W. Z. Xue, Z. L. Lin, H. J. Zeng, *et al.*, "Diode-pumped SESAM mode-locked Yb:(Y,Gd)AlO_3 laser," Opt. Express **30**(7), 11825–11832 (2022).
35. Z. L. Lin, W. Z. Xue, H. J. Zeng, *et al.*, "Kerr-lens mode-locked ytterbium-activated orthoaluminate laser," Opt. Lett. **47**(12), 3027–3030 (2022).