There are many ways to generate ultrafast laser operations. One can use real saturable absorbers, such as semiconductor saturable absorber mirror (SEASM) [SESAM mode-locked red praseodymium laser] or low-dimensional material-based saturable absorbers such as graphene [] and blablabla [], and solid-state laser media []. One can also exploit artificial saturable absorbers. The two most prominent artificial saturable absorber mode locking techniques are called Kerr-Lens Mode Locking (KLM) [1][2][3][4][5][6][7] early[8][9][10] and Additive Pulse Mode Locking (APM) [].

Kerr effect

The general principle behind Kerr-Lens Mode Locking is that a pulse that builds up in a laser cavity containing a gain medium and a Kerr medium experiences not only self-phase modulation but also self-focusing that is nonlinear lensing of the laser beam, due to the nonlinear refractive index of the Kerr medium. A spatial-temporal laser pulse propagating through the Kerr medium has a time dependent mode size as higher intensities acquire stronger focusing. If a hard aperture is placed at the right position

in the cavity, it strips of the wings of the pulse, leading to a shortening of the pulse. Such combined mechanism has the same effect as a saturable absorber. If the electronic Kerr effect with response time of a few femtoseconds or less is used, a fast saturable absorber has been created. Instead of a separate Kerr medium and a hard aperture, the gain medium can act both as a Kerr medium and as a soft aperture (i.e. increased gain instead of saturable absorption).

Schemes have been devised to initiate and sustain the pulse

formation mechanism.

The third-order nonlinear optical responses are closely related to the stimulated Raman

scattering (SRS) process and the Kerr-lensing effect [Nonlinear refractive indices of disordered NaT(XO4)2 T=Y, La, Gd, Lu and Bi, X=Mo, W femtosecond laser crystals].

Gaponenko et al. obtained a pulse width of 18 ps (FWHM) with SESAM mode-locking [SESAM mode locked red praseodymium laser].

Pr:YLF

The first Kerr-lens mode-locked Pr3+:YLiF4 visible lasers at 607 and 640 nm were realized utilizing the Kerr-lensing effect and initiated by saturable absorbers in 1995 by introducing argon-ion lasers as the pump source. [Kerr-lens mode-locked visible transitions of a Pr:YLF laser].

The first self-staring Kerr-lens mode locked Pr3+:YLiF4 laser was reported in 1996, which was also pumped by an argon-ion laser [Self-starting Kerr-lens mode-locked femtosecond Cr4+:YAG and picosecond Pr3+:YLF solid-state lasers].

In 2014, by using an intra-cavity frequency-doubled Optically Pumped InGaAs Semiconductor Laser (2ω-OPSL) as the pump source, Gaponenko et al. obtained the self-starting stable cw mode-locked Pr3+ ion visible laser at the wavelength of 639 nm with a pulse width of 18 ps (FWHM) with SESAM mode-locking

which was first reported with a SESAM as the saturable absorber [SESAM mode-locked red praseodymium laser].

In recent years, the self-mode-locking of Nd3- and Yb3-doped crystal lasers with GHz repetition rates and picosecond/femtosecond pulse widths has been widely reported based on simple two-mirror cavities [11–13]

Recently, using a SESAM, Gaponenko et al. successfully demonstrated a passively mode-locked Pr3+:YLF laser pumped by a frequency-doubled optically pumped semiconductor laser (2ω-OPSL) operating at the red wavelength [SESAM mode-locked red praseodymium laser]. The maximum averaged output power reached 16 mW at an incident pump power of 3.75 W with a mode-locked pulse width of 18 ps (FWHM). Due to the narrow gain bandwidth of the transition (3P0→3F2) in the Pr3+:YLF, generating mode-locked sub-picosecond pulses is challenging.

stable mode-locking of an InGaN laser-diode-pumped Pr3+:YLF laser with a pump power of 2.8 W using a semiconductor saturable absorption mirror. A maximum averaged output power of 65 mW was obtained with a 45-ps pulse width at a pulse repetition rate of 108 MHz. We also attempted Kerr-lens mode-locking by employing an SF57 glass in a cavity as a Kerr medium. [Pr3+:YLF mode-locked laser at 640 nm directly pumped by InGaN-diode lasers]

In this paper, to the best of our knowledge we reported the first SESAM mode-locked Pr3:YLF laser that is directly pumped by InGaN LDs. Stable mode-locked operation started from absorbed pump power of 2.8 W. At absorbed pump power of 3.8 W, a maximum averaged output power of 65 mW was obtained with a pulse width of 45 ps (FWHM) at a pulse repetition rate of 108 MHz. By employing a SF57 glass as a Kerr medium, we also tried LD-pumped Kerr-lens modelocking. In this approach, however, we could not achieve self-sustained CW mode-locking and only obtained a Q-switch

mode-locked pulse train whose pulse repetition rate was doubled. The laser operation only switched to CW modelocking immediately after we tapped an end mirror. Our

model calculations predicted that a stable mode-locking cavity condition could be found with larger Kerr effects at high-power laser oscillation.

might be restricted to great extent by

might result from the fact that

contribute to

facilitate

shows the absence of

**References**

[Nonlinear refractive indices of disordered NaT(XO4)2 T=Y, La, Gd, Lu and Bi, X=Mo, W femtosecond laser crystals]. A. García-Cortés, M. D. Serrano, C. Zaldo, C. Cascales, G. Strömqvist, and V. Pasiskevicius, “Nonlinear refractive indices of disordered NaT(XO4)2 T=Y, La, Gd, Lu and Bi, X=Mo, W femtosecond laser crystals,” Appl. Phys. B 91, 507-510 (2008).

[Novel self-mode-locking mechanism in narrow-band lasers]. Y. Bai, S. Chen, Z. Wang, and G. Zhang, Appl. Phys. Lett. 63, 2597 (1993).

[SESAM mode locked red praseodymium laser]. M. Gaponenko, P. W. Metz, A. Härkönen, A. Heuer, T. Leinonen, M. Guina, T. Südmeyer, G. Huber, and C. Kränkel, “SESAM modelocked red praseodymium laser,” Opt. Lett. 39, 6939–6941 (2014).

[Red-luminescence analysis of Pr3+ doped fluoride crystals] S. Khiari, M. Velazquez, R. Moncorge, J.L. Doualan, P. Camy, A. Ferrier, M. Diaf, J. Alloys Compd. 451 (2008) 128–131

[Pump-to-mode size ratio dependence of thermal loading in diode-end-pumped solid-state lasers]. Y. F. Chen, “Pump-to-mode size ratio dependence of thermal loading in diode-end-pumped solid-state lasers,” J. Opt. Soc. Am. B 17(2000) 1835.

[Theory of passive additive-pulse mode locking].

[Additive pulse mode locking]. E. P. Ippen, H. A. Haus, and L. Y Liu, “Additive pulse mode locking,” J. Opt. Soc. Am. B 6, 1736 (1989).

[SESAM mode-locked red praseodymium laser]. Maxim Gaponenko, Philip Werner Metz, Antti Härkönen, Alexander Heuer, Tomi Leinonen, Mircea Guina, Thomas Südmeyer, Günter Huber, and Christian Kränkel, “SESAM mode-locked red praseodymium laser,” Opt. Lett. 39(24), 6939 (2014)

[Kerr-lens mode-locked visible transitions of a Pr:YLF laser]. S. Ruan, B. H. T. Chai, J. M. Sutherland, P. M. W. French, and J. R. Taylor, “Kerr-lens mode-locked visible transitions of a Pr:YLF laser,” Opt. Lett. 20, 1041–1043 (1995).

[Self-starting Kerr-lens mode-locked femtosecond Cr4+:YAG and picosecond Pr3+:YLF solid-state lasers]. Y. P. Tong, A. V. Shestakov, B. H. T. Chai, J. M. Sutherland, P. M. W. French, and J. R. Taylor, “Self-starting Kerr-lens mode-locked femtosecond Cr4+:YAG and picosecond Pr3+:YLF solid-state lasers,” Opt. Lett. 21, 644–646 (1996).

[Pr3+:YLF mode-locked laser at 640 nm directly pumped by InGaN-diode lasers]. KODAI IIJIMA, RYOSUKE KARIYAMA, HIROKI TANAKA, AND FUMIHIKO KANNARI, “Pr3+:YLF mode-locked laser at 640 nm directly pumped by InGaN-diode lasers,” Applied Optics 55(28), 7782 (2016)