周波数変調型モード同期 Cr:ZnS レーザー

Frequency-Modulation Mode-Locked Cr:ZnS Laser

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In this research, we for the first time demonstrate a mid-infrared (MIR), frequency-modulation (FM) mode-locked Cr:ZnS laser using an electro-optic phase modulator (EOPM). CW mode-locking with a repetition rate of 103 MHz and a narrow linewidth of ~0.1 nm centered at 2.2 μm is achieved.

Mode-locked MIR lasers are promising for applications in molecular spectroscopy, remote sensing, material processing, higher order harmonic generation, etc. Although passive mode-locking is commonly utilized for shorter pulse generation, active mode-locking provides alternative possibilities of much narrower linewidth and controllable repetition rate. The active mode-locking may be achieved by amplitude modulation (AM) [1], but there are few high-speed intensity modulators in the MIR range longer than 2 μm. On the other hand, MIR phase modulators up to 20 GHz are commercially available, which fulfills the requirement for high-repetition-rate frequency modulation (FM) mode-locking.

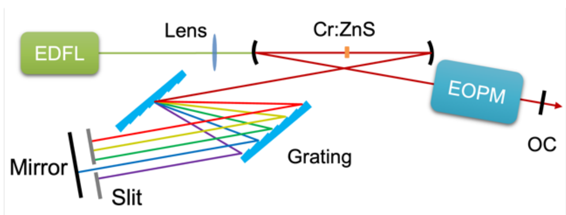

Fig. 1. Setup of the FM mode-locked laser.

The setup of the FM mode-locked laser is shown in Fig. 1. The Cr:ZnS crystal with AR coating is used as the gain medium to provide a broadband gain from 1.9 μm to 2.7 μm. The grating pair provides a chromatic dispersion of approximately -2 ps^2 for dispersion management. A slit is placed in front of the HR mirror for wavelength filtering and tuning. The total cavity length is about 1.456 m, which corresponds to a free spectral range (FSR) of 103 MHz. The EOPM is utilized to provide a periodic phase modulation at the frequency of FSR. The optical sidebands are generated by the EOPM and constrained by a band-pass filter to form a mode-locked pulse train [2].

The mode-locked pulse train is shown in Fig. 2(a), the interval of pulses is 9.7 ns, which has a good agreement with the modulation frequency of 103 MHz. As shown in Fig. 2(b), the optical spectrum of the laser is as narrow as ~0.1 nm, which, to our best knowledge, is the narrowest linewidth achieved by MIR mode-locked tunable lasers. Assuming the time-bandwidth product of 0.5, the pulse duration is estimated to be ~70 ps. Fig. 2(c) and (d) show the RF spectra of the laser, which indicate that the repetition rate of the CW mode-locking is determined by the modulation frequency.

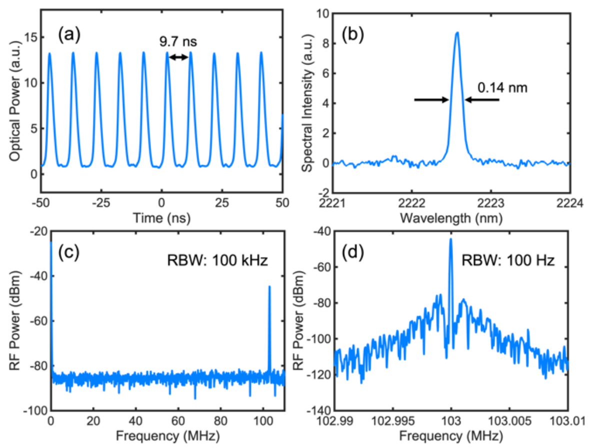

Fig. 2. (a) Pulse train, (b) optical spectrum and (c, d) RF spectra of the FM mode-locked laser.

The demonstrated FM mode-locked technique would be useful for the MIR pulse generation with high and/or tunable repetition rate and for applications where narrow spectral linewidth is important, such as high-precision vibrational spectroscopy.

References

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[2] D. Kuizenga, and A. Siegman, "FM and AM mode locking of the homogeneous laser-Part I: Theory," IEEE J. Quant. Electron. 6, 694-708 (1970).