Nearly transform-limited optical pulse from a passively mode-locked laser diode

Rongjian Du (杜荣建)[1,2], Wanghua Xiang (向望华)[1], and Guizhong Zhang (张贵忠)[1]

[1] *College of Precision Instrument and Opto-Electronics Engineering, Key Laboratory of Opto-Electronics Information Technical Science, EMC, Tianjin University, Tianjin 300072*

[2] *Department of Opto-Electronic Information and Electronic Engineering, Tianjin Institute of Technology, Tianjin 300191*

Received July 10, 2003

An optical ultra-short pulse train with a duration of 2.9 ps was successfully generated from a passively mode-locked laser diode. The time-bandwidth product was 0.43, and it was very close to the transform-limited value of a Gaussian waveform. The highest peak power of 10 mW in an InP-based passively mode-locked laser has been achieved. The laser is promisng as an optical source for an ultra-high-speed bit rate transmission system, especially for the optical time division multiplexing (OTDM) system.

OCIS codes: 140.5960, 140.7090, 140.4050.

Ultra-short optical pulse generation with laser diodes has been widely studied in the developing ultra-fast opto-electronic, photonic and communication systems. The laser diodes generate ultra-short optical pulses with high repetition rates exceeding several tens of gigahertz due to their wide gain bandwidth and short cavity. Among ways to obtain ultra-short optical pulses[1−3], mode-locked laser diodes (MLLDs) have attracted considerable interest due to their compactness, stability, low noise, low cost, and high reliability. These features make them attractive for applications in high-speed optical transmission systems in the picosecond and femtosecond ranges[4,5].

Passively MLLDs based on an intracavity saturable absorber (SA) have an advantage over other techniques because of the increased repetition rate with the short-cavity laser[6]. This technique requires no electrical modulation and suffers from no electrical limitations. In a passively MLLDs, a certain pulse is formed by the combined action of a SA section and gain section. In terms of pulse shortening, there should exist an optimum combination of gain and absorption characteristics[7]. However, to our knowledge, the study of MLLDs has not been reported so far in China.

In this letter, we present a new monolithic MLLDs, generating the nearly transform-limited value pulse at wavelength 1550 nm.

The basic laser diodes structure of the external MLLDs and the experimental setup are shown in Figs. 1 and 2.

The device was a double channel planner buried heterostructure (DC-PBH) laser diode with a graded index and a separate confinement heterostructure (GRIN-SCH) with InGaAsP/InP strained six quantum wells for the active layer. The MLLDs chip used in the external cavity MLLDs had a 460-μm-long gain section and 40-μm-long SA section. The facet on the SA section was cleaved and on the gain section was anti-reflection (AR) coated. An optimal AR coating was necessary to prevent the formation of unintentional secondary pulses. Here, when the gain section is forward-biased and absorber section is reverse-biased suitably, passive mode locking will occur. Threshold currents were in the range of 0 − 100 mA and lasing wavelengths were in the range of 1530 − 1570 nm, which agreed well with the cavity round-trip frequency estimated from the cavity length 500 μm.

Mode-locked semiconductor laser consists of a gain medium such as InGaP/InP and a SA, with the gain positively biased by a current source and the SA inversely biased by a voltage source. Due to the insertion of a thin layer of absorber in the cavity, a stronger light signal will sense less loss while a weaker light signal will be much damped albeit that their gains are almost the same. Thus, the same gain but different loss for these two kinds of pulses will result in a stable oscillation for the stronger pulse, and the originally weaker pulse is eventually damped out. Meanwhile, the leading and trailing

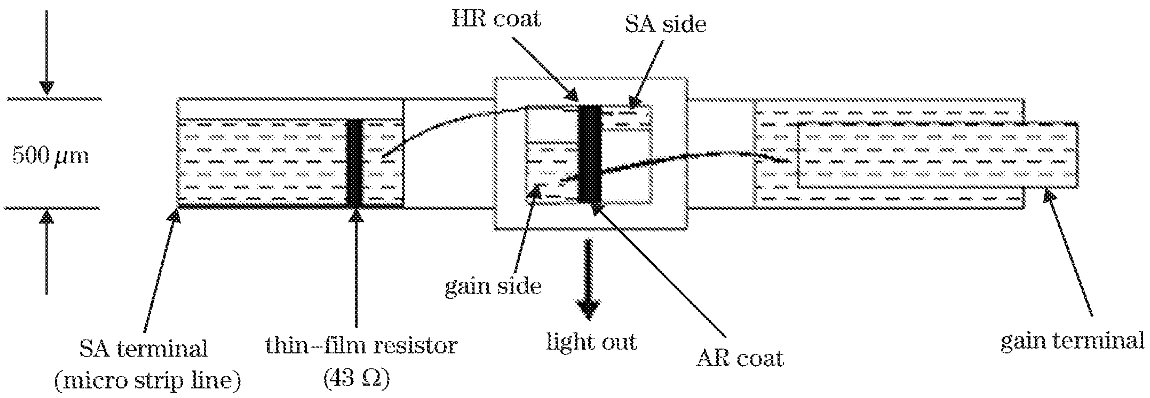

Fig. 1. Schematic illustration of a MLLDs structure.

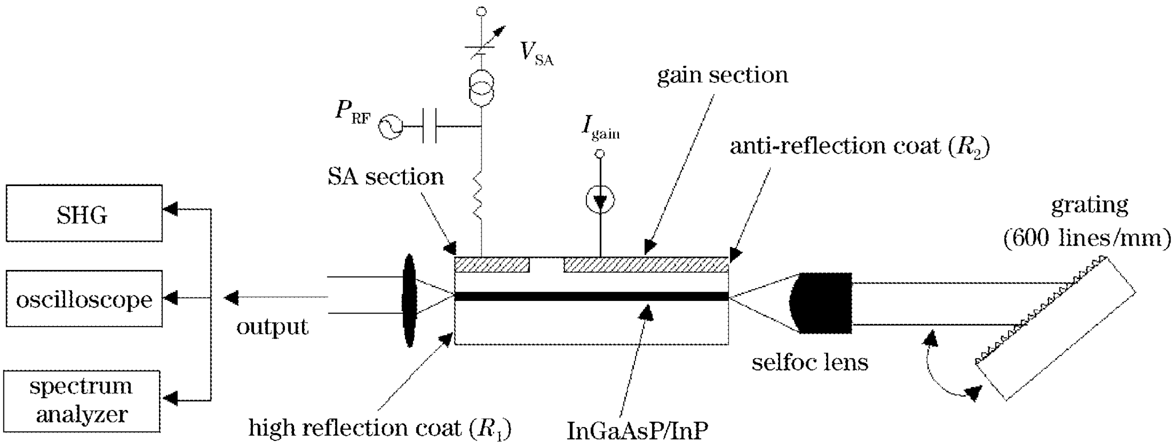

Fig. 2. Experimental setup for the external cavity passively MLLDs.

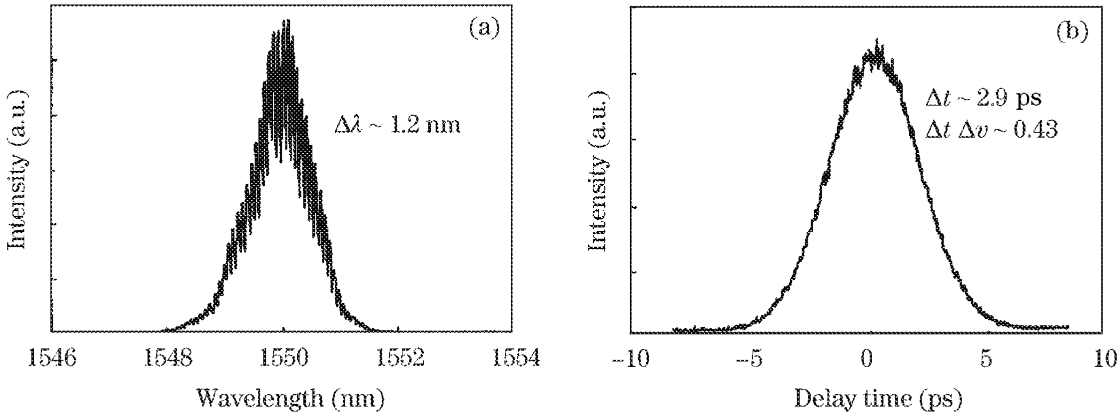

Fig. 3. Characteristics of optical pulses generated from a passively mode-locked external cavity MLLDs. (a) Optical spectrum; (b) SHG autocorrelation trace (1550 nm).

edges of the strong spike pulse will be gradually chopped off when passing the absorber so that a train of ultrashort light pulses with period of $T = 2L/c$ are formed. This is a passive modelocking process without the need of any external modulation signal, which is ideal for semiconductor integration.

We used the selfoc lens with a large numerical aperture (NA~0.6) and an optical plane grating as the wavelength selector. We can also avoid notable changes in the effective-cavity-length during the wavelength tuning procedure. The optical pulse repetition frequency was adjusted to the one desired simply by changing the position of the grating on the durable rotating stage. The device chip was mounted on a thermoelectric cooler and the entire cavity module equipped with an optical fiber output port. The present external cavity MLLDs have higher stability over long hours of operation than other actively mode-locked lasers.

The coherent optical pulses were obtained from this passively MLLDs. Figure 3 shows the characteristics at a wavelength of 1550 nm controlled precisely.

The generated optical pulse with a pulse width of 2.9 ps, a spectral width of 1.2 nm and time-bandwidth product of 0.43 is shown in Fig. 3. The pulse width was evaluated from intensity correlation traces by non-collinear second harmonic generation (SHG) correlation measurement assuming a sech^2 pulse shape. In the SHG intensity correlation trace shown in Fig. 3(b), slight secondary-pulse-components can be recognized at a delay time of ±12 ps. Although this secondary pulse was due to residual reflectivity at the device facet, the intensity was less than −17 dB of the main pulse and was negligible in the following optical signal processing experiments. Lastly, we obtained nearly transform-limited ($\Delta t \Delta \nu \sim 0.43$) optical pulses of 2.9 ps width with a wavelength tuning range of over 40 nm at an average optical power of about 3.5 dBm.

In conclusion, we have showed that an external cavity MLLDs module generated ultra-short optical pulses with good coherence, precisely controlled wavelength and low timing jitter in ultra-fast optical time division multiplexing (OTDM) systems. A nearly transform-limited optical short pulse train with the duration of 2.9 ps was successfully generated from the monolithic passively MLLDs. The highest peak power of 10 dBm in MLLDs was achieved. This MLLDs are promising as an optical source for high-bit rate and long-haul optical communication transmission systems.

We are grateful to Ryosuke Kuribayashi and Hiroyuki Yokoyama of NEC corporation for their support in fabricating laser diodes chip. This work was supported by the National Natural Sicence Foundation of China (No. 69978015 and 69987002) and the Tianjin Educational Committee Foundation of China (No. 020623). W. Xiang's e-mail address is whxiang@tju.edu.cn.

References

1. K. Sato, A. Hirano, M. Asobe, and H. Ishii, Electron. Lett. **34,** 1944 (1998).
2. F. N. Timofeev, I. A. Kostko, P. Bayvel, O. Berger, R. Wyatt, R. Kashyap, I. F. Lealan, and G. D. Maxwell, Electron. Lett. **35,** 1737 (1999).
3. T. Schrans, R. A. Salvatore, S. Sanders, and A. Yariv, Electron. Lett. **28,** 1480 (1992).
4. T. R. Clark, T. F. Carruthers, T. F. Carruthers, P. J. Matthews, and I. N. Duling III, Electron. Lett. **35,** 720 (1999).
5. H. Bissessur, A. Vuong, C. Graver, O. Le Gouezigou, G. Michaud, and A. Pinquier, Electron. Lett. **36,** 139 (2000).
6. M. Ibsen, E. Ronnekleiv, G. J. Cowle, M. N. Iervas, and R. I. Laming, Electron. Lett. **36,** 143 (2000).
7. C. Bornholdt, B. Sartorius, S. Schelhase, M. Möhrle, and S. Bauer, Electron. Lett. **36,** 327 (2000).