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Invited

Ultrafast Optical Pulse Generation Using Semiconductor Devices

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Abstract

Nearly transform-limited optical pulses with duration of 2.3 ps were generated from monolithically fabricated mode-locked semiconductor lasers at high repetition rate of 48 GHz, and optical pulses with low timing jitter of 0.41 ps were generated by electroabsoption (EA) modulator. Furthermore, the timing jitter of the mode-locked pulse train was reduced with the injection of optical pulses from EA modulator.

1. Introduction

Ultrafast optical pulse generation using semiconductor devices is of great interest for many applications, such as optical communication systems [1], micro-wave/millimeter-wave communication with optical fiber, data processing systems, optical detection systems, and so on. In such systems, optical pulse sources with high repetition rate, short pulse width, and low timing jitter are required. Passive mode-locked semiconductor lasers [2,3] have advantage of high repetition rate over 100 GHz. A problem of passive mode-locking is comparably large timing jitter. On the other hand, an EA modulator can generate optical pulse with low timing jitter [4], but repetition rate and pulse width are limited by the electrical response of the device.

In this paper, we report on optical pulse generation using mode-locked semiconductor lasers and EA modulators. Furthermore, we describe on a subharmonic synchronous mode-locking for ultrafast optical pulse generation with low timing jitter by combining these techniques

2. Mode-locked semiconductor lasers

Figure 1 shows the schematic structure of the mode-locked semiconductor laser used in this study. The laser has two sections corresponding to a saturable absorber

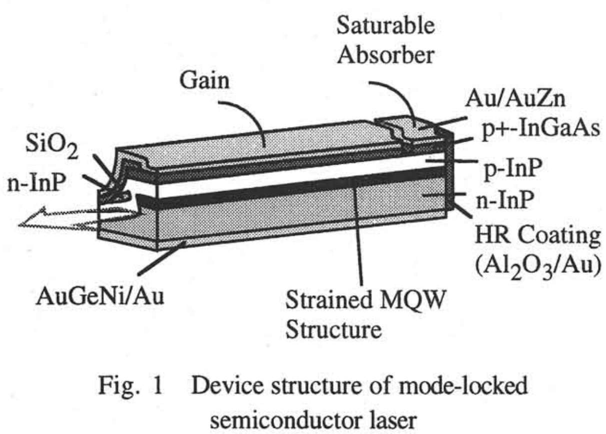

Fig. 1 Device structure of mode-locked semiconductor laser

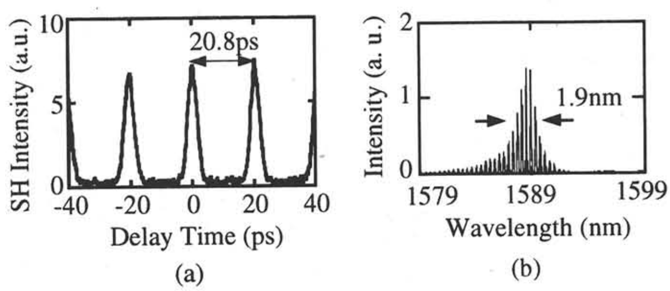

Fig. 2 SHG correlation trace (a) and time averaged optical spectrum (b)

section and a gain section. Both the gain and the absorber sections consist of eight compressively strained InGaAsP quantum wells separated by InGaAlAs barriers. The absorber facet is high-reflection (~90%) coated, leading to a self-colliding pulse mode-locking operation. The gain facet is as-cleaved. The output from the gain facet was measured by an autocorrelator and an optical spectrum analyzer.

Figure 2 shows the SHG correlation trace (a) and the optical spectrum (b) of the output of the mode-locked laser with 50 μm saturable absorber section. The repetition rate was 48 GHz, which coincided with the round-trip frequency estimated from the cavity length of 850 μm. The correlation trace and the envelope of the spectrum were in good agreement with a $Sech^2$ waveform. The actual pulse width was estimated to be 2.3 ps and the time-bandwidth product was 0.52, close to the transform limited value for $Sech^2$ pulses.

3. EA modulator

Figure 3 shows a schematic device structure of the EA modulator used for short pulse generation. Absorption layer is strained multiple quantum well consisted of seven 10 nm-thick InGaAsP wells (0.3% tensile strain) and six 8 nm-thick InGaAsP barriers (0.2% compressive strain). Ridge waveguide structures were formed by a combination of reactive

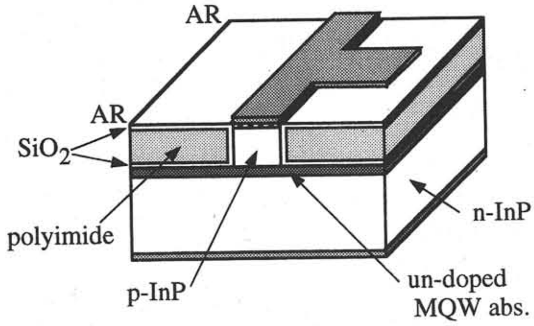

Fig. 3 Device structure of EA modulator

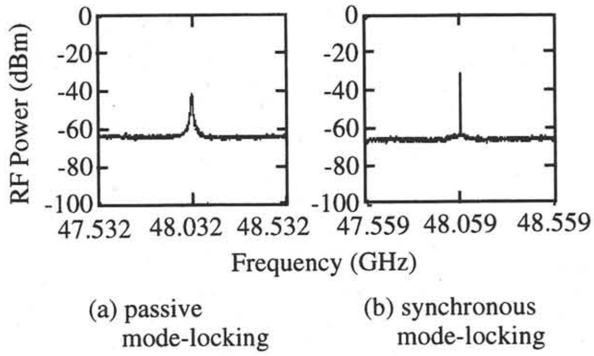

Fig. 5 RF spectra of mode-locked laser

ion etching and wet chemical etching. Low capacitance pads were formed on 2 μm thick polyimide to reduce the parasitic capacitance. Both facets were AR coated by SiO_x films.

The length of the EA modulator used in the experiment of optical pulse generation was 200 μm and the extinction efficiency was about 20 dB/V. Light from a DFB laser emitting at 1559 nm was coupled into the EA modulator driven by sinusoidal signals. We observed stable optical pulse train, when DC bias voltage, RF power, and RF frequency were 3.5 V, 23.6 dBm, and 12 GHz, respectively. The pulse width was 11.2 ps, assuming Gaussian waveform, and the timing jitter was 0.41 ps estimated by integrating the single side band (SSB) noise from 100 Hz to 10 MHz [5].

4. Synchronous mode-locking

Figure 4 shows the experimental setup for optical synchronous mode-locking [6-8]. Low jitter optical pulses from EA modulator were amplified by an Er^{+3}-doped fiber amplifier, and then they were coupled to the mode-locked laser at the gain facet through a circulator. The output of the mode-locked laser was detected by a p-i-n photodiode and measured by a microwave spectrum analyzer.

Figure 5 shows RF spectra of the mode-locked laser with (a) and without (b) optical injection. The injected signal frequency was set around 4th subharmonic of that of the mode-locked laser. In passive mode-locked operation, the RF spectrum was rather broad, indicating large timing jitter. The timing jitter was estimated about 7.3 ps from the SSB noise measurement. When the optical signal of 4 mW was injected to the mode-locked laser, the timing jitter was reduced to 0.53 ps, close to that of injection signal.

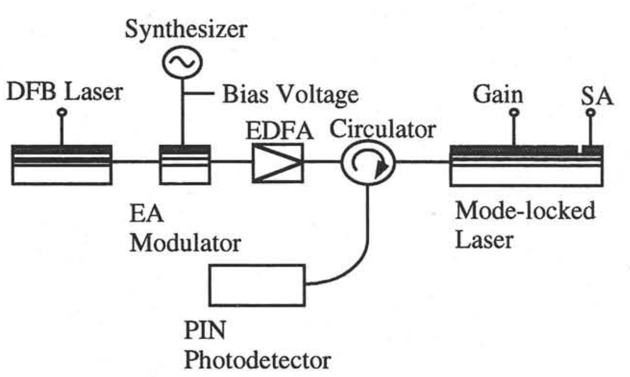

Fig. 4 Experimental set-up for synchronous mode-locking

5. Conclusions

In conclusion, we have fabricated monolithic mode-locked semiconductor lasers and EA modulators. A train of transform-limited optical pulses with a duration of 2.3 ps has been generated from the mode-locked laser at a high repetition rate of 48 GHz. Also we have observed optical pulses with low timing jitter at repetition rate of 12 GHz using EA modulator. Furthermore, the timing jitter of the mode-locked laser is reduced to less than 1 ps by optical signal injection techniques.

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References

[1] T.Kataoka, A. Sano, H.Tsuda, A.Hirano, K.Hagimoto, and K.Sato, Tech. Digest of OFC'96, TuD4, 17(1996).
[2] Y.K.Chen, M.C.Wu, T. Tanbun-Ek, R.A.Logan, and M.A.Chin, Appl. Phys. Lett. **58**, 1253 (1991).
[3] S.Arahira, Y.Matsui, T.Kunii, S.Oshiba, and Y.Ogawa, IEEE Photon. Technol. Lett. **5**, 1362 (1993).
[4] S.Oshiba, K.Nakamura, and H.Horikawa, Tech. Digest of MWP'96, TH1-3, 253(1996).
[5] D.von der Linde, Appl. Phys. **B39**, 201(1986)
[6] X.Wang, H.Yokoyama, and T.Shimizu, IEEE Photon. Technol. Lett. **8**, 617(1996).
[7] Y.Ogawa and S.Arahira, Tech. Digest of MWP'96, TH1-1, 245(1996).
[8] Z.Ahmed, H.F.Liu, D.Novak, Y.Ogawa, M.D.Pelusi, and D.Y.Kim, IEEE Photon. Technol. Lett. **8**, 37(1996).