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40 GHz Pulse Generation by Passively Mode-locked Semiconductor Laser with Distributed Bragg Reflector for Oscillating Mode Selection

Tetsuya Nishimura, Yoshinori Nomura, Koichi Akiyama,
Nobuyuki Tomita and Toshiro Isu

Advanced Technology R&D Center, Mitsubishi Electric Corporation
8-1-1, Tsukaguchi-Honmachi, Amagasaki, Hyogo 661-8661, Japan
Phone:+81-6-6497-7081, Fax:+81-6-6497-7294,
E-mail: Nishimura.Tetsuya@wrc.melco.co.jp

1. Introduction

Optical pulse generation at a several tens GHz repetition rate from semiconductor lasers is useful for high bit-rate optical fiber communication systems. Recently, the necessity of 40 GHz pulse generation is grown up.

Mode-locked lasers are suitable for the applications to signal generation, clock recovery and so on. A 40 GHz mode-locked laser integrated with a saturable absorber has been reported [1]. On the other hand, it has been demonstrated that Fabry-Pérot (FP) semiconductor lasers without any saturable absorbers was capable of generating passively mode-locked pulses over 60 GHz repetition rate under constant current injection [2,3], or by the aid of an injected continuous wave light [4]. In addition, 35 and 56 GHz pulse generations using a subharmonic optical injection technique [5] were reported.

To realize a 40 GHz repetition rate in FP lasers, a cavity length should be elongated upto 1000 μm which corresponds with the mode separation. The phase differences between oscillating modes become larger due to the dispersions in such a long semiconductor cavity, and that causes an out-of-phase mode locking. We have proposed a structure to reduce the phase differences [3], and demonstrated a passively mode-locked pulse generation [6]. However, in Ref [6], spectral widths were not yet optimized for optical communication.

In order to obtain well-defined mode-locked pulses, the mode spectrum should be controlled in addition to the phase differences. In this paper, we demonstrate almost transform-limited pulse generation by mode-locked semiconductor lasers with distributed Bragg reflectors (DBRs) for oscillating mode selection.

2. Passively Mode-locked DBR Laser

In Fig. 1, the calculated phase differences for several cavity structures are plotted. This figure shows that as the cavity is longer for FP lasers, the phase differences become larger. However, it turns out that if gain region is restricted to a half part of the cavity, phase differences are reduced as indicated for the 1100 μm cavity in Fig. 1. We adopt this structure in this work. The proposed laser consists of four sections as shown in Fig. 2, a front passive waveguide section (260 μm), a gain section (520 μm) at the middle of cavity, a rear passive waveguide (83.8 μm), a DBR section (291 μm). The overall cavity length was chosen so that a 40 GHz repetition rate would be obtained. The laser was made of the InGaAsP/InP material system and designed to emit light in a 1550 nm band. The passive waveguides have a bandgap of 1325 nm. The DBR was designed to select three or more modes of the longitudinal modes. No saturable absorber sections were implemented in the cavity.

3. Mode-locking Operation

The threshold current of the sample was 13 mA, and the output intensity was 10 dBm for a 130 mA injection current into the gain section (I_{gain}) at 25 ℃, while the DBR section and two passive waveguide sections were electrically open-circuited.

Mode-locked pulses were observed under constant current injection into the gain and the DBR section. The spectra and the waveforms of mode-locked pulses were measured by the setup as shown in Fig. 3. The experimental results in Fig. 4 were obtained at I_{gain} = 130 mA and the DBR current (I_{DBR}) = 3.66 mA. The spectrum indicated a selection of three modes within -20 dB as shown in Fig. 4(a). The repetition rate estimated from the observed pulse separation was 40.4 GHz, and the pulse width, assuming that the waveform is to be sech^2, was 8.8 ps as shown in Fig. 4(b). The extinction ratio of second harmonic intensity was not so high probably due to the inequality of the oscillating mode intensities.

By varying I_{DBR} upto 22.5 mA, the center wavelength of mode-locked pulses was changed over 5 nm by virtue of the plasma effects, as shown in Fig. 5.

4. Conclusions

Passively mode-locked pulse generations at a 40 GHz repetition rate were demonstrated without any saturable absorbers. The DBR implemented in the cavity acted as an oscillating mode selector for getting clear mode-locked pulses. The DBR also worked for reducing the spectral width to the three mode separation. By varying the DBR current, the center wavelength of mode-locked pulses was changed over 5 nm. All those characteristics reveal that the mode-locked semiconductor lasers with the DBR are promising light sources in various scenes of optical communication.

References

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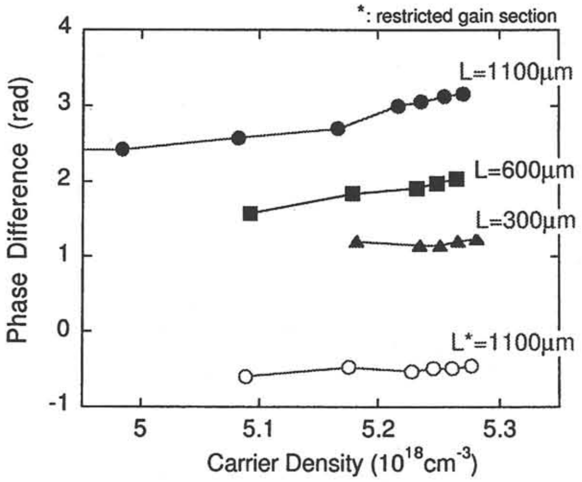

Fig. 1 Calculated phase differences of oscillating modes in Fabry-Pérot lasers of 300μm, 600μm, 1100μm cavity length, and in the structure of 1100 μm cavity length with restricted gain section (open circles).

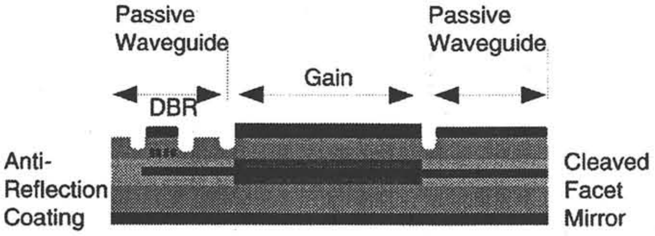

Fig. 2 Schematic cavity structure of proposed mode-locked laser.

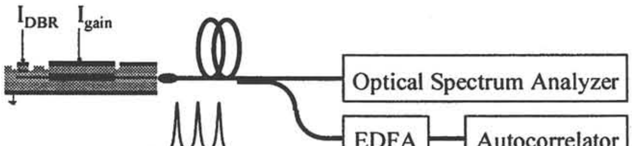

Fig. 3 Experimental setup.

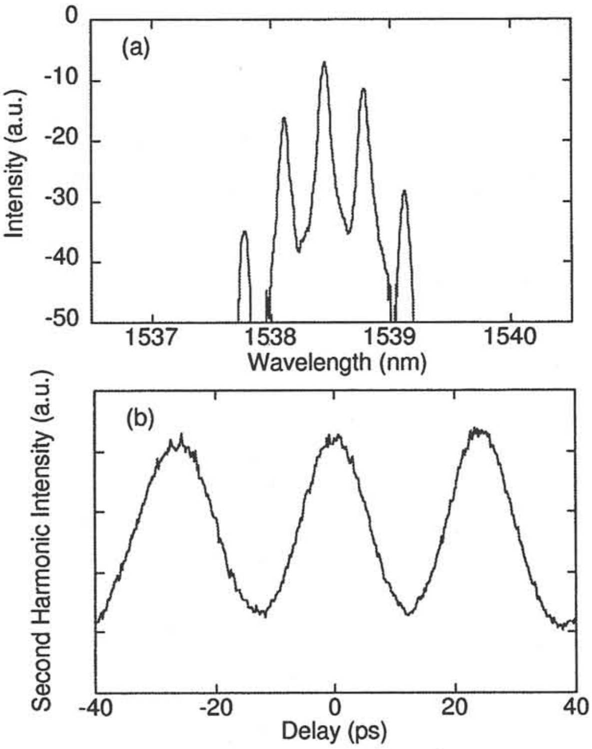

Fig. 4 (a) Measured optical spectrum and (b) autocorrelation trace at I_{gain}=130mA, I_{DBR}=3.66mA. Wavelength resolution is 0.1nm.

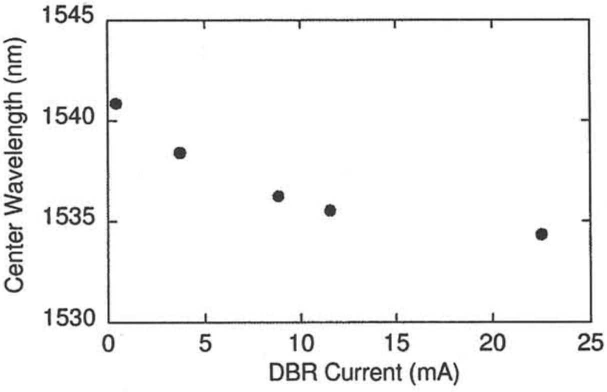

Fig. 5 Wavelength tuning characteristics at I_{gain}=130mA.