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40 GHz Actively Mode-Locked DBR Laser Diode Module with an Impedance Matching Circuit

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1. Introduction

Modelocked laser diode (MLLD) has attracted much attention as a short optical pulse source for RZ and CS-RZ format optical communication systems because of its compactness and robustness. MLLDs can be categorized into two: active MLLD and passive MLLD. An active MLLD essentially generates an optical pulse train synchronized to a given system clock with a low timing jitter, whereas the pulse generation from a passive MLLD is spontaneous and the timing jitter is often so large as an averaged pulse period due to lack of stable frequency reference source. Active modelocking using a semiconductor electroabsorption (EA) modulator [1], [2] is promising in pulse shortening due to large extinction ratio and high nonlinearity in absorption-to-reverse voltage characteristics of the EA modulator. Picosecond pulse generation was reported in the active MLLD integrated with the EA modulator.

Pulse width and locking range of the active MLLD strongly depend on modulation index achieved in the modelocker [3]. It is a key issue for the active modelocking at a repetition frequency exceeding several tens of GHz to make the modulation deep enough at such a high frequency. In this paper we report development of 40-GHz active MLLD module packaged together with a narrow band impedance-matching circuit of double open stubs [4] for efficient RF injection to the EA modulator section. 13 dB improvement of RF injection efficiency was obtained in comparison with a conventional 50-Ω termination system. Nearly transform-limited, picosecond (<3 ps) pulses were successfully generated. Wide locking bandwidth over 1.9 GHz (39 GHz-40.9 GHz) was also achieved remaining both the small variation of the pulse widths and the low RIN values less than –130 dB/Hz.

2. Module structure

The laser used was a monolithic multi-section MLLD consisting of an EA modulator section (100-μm length), a gain section (610 μm), a waveguide section (110 μm), and a DBR section (100 μm) [2]. The total cavity length was approximately 1050 μm. The active layer of the gain section consisted of a 6-well compressively strained InGaAsP/InGaAsP MQW structure, whereas the EA section, the waveguide section, and the DBR section consisted of a 1.465 μm bandgap-wavelength InGaAsP bulk layer. Butt-joint coupling was used as an optical coupling between the MQW active layer and the InGaAsP bulk layer. A ridge-waveguide structure was used to reduce parasitic capacitance. The DBR facet was anti-reflection (AR) coated by using Al_2O_3 thin film in order to simplify the DBR reflectivity profile by eliminating the effect of facet reflection. Typical threshold current and slope efficiency from the DBR facet were 35 mA and 0.1 W/A, respectively. Small signal response exhibited resonant peak at 39.9 GHz corresponding to a roundtrip frequency of the laser cavity.

Figure 1 schematically illustrates electrical circuits used in this study. We adopted a matching circuit of double open stubs using a 50-Ω microstrip line. DC reverse voltage and a sinusoidal-wave voltage were injected together to the EA section through a bias-T and the matching circuit. The lengths of the open stubs were trimmed with a laser cutter so as to minimise the electrical reflection at 40 GHz. The electrical reflection exhibited less than -30 dB after the trimming. The MLLD was packaged in a module consisting of a MLLD chip, lenses, an optical isolator, a pigtail fibre, a thermoelectric cooler, a thermistor, the matching circuit, and a package with a K connector.

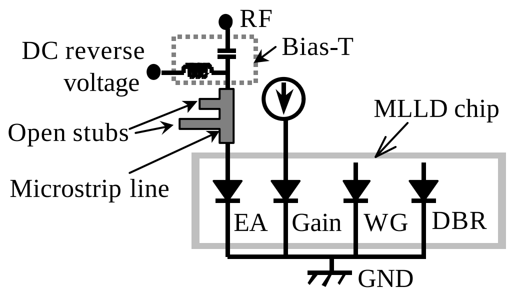

Fig. 1 Schematic of electrical circuit of 40 GHz actively mode-locked DBR laser diode module

3. Pulse characteristics

Figure 2 shows dependences of (a) pulse width and (b) spectral width and time-bandwidth product on the RF powers. Current in the gain section (I_{gain}) and reverse voltage to the EA section (V_{EA}) were 50 mA and 0 V, respectively. For comparison, results for a conventional 50-Ω terminated MLLD were also shown (open circles and open triangles).

The pulse width decreased and the spectral width broadened when the RF power increased. In a conventional active modelocking theory [3], the pulse width of the active modelocking is proportional to $M^{-1/4}$, where M the modulation index. In a linear approximation, M is proportional to RF voltage and therefore,

$$\Delta t \propto \left(P_{RF}\right)^{-1/8}$$

where P_{RF} the applied RF power.

The experimental data were well fitted with eq. (1) (solid and dashed curves in Fig. 2 (a)). These results indicate that the pulse width can be easily tuned by the RF power. When the RF power exceeded 17 dBm, the pulse width was further shortened deviating from eq. (1). The pulse envelope became close to a sech^2 shape, whereas it was close to a Gaussian shape at low RF power levels. This is due to nonlinearity of absorption-to-reverse voltage characteristics of the EA modulator.

The pulse width of the impedance-matched MLLD was reduced by 13-dB lower RF power in comparison with that of the conventional 50-Ω terminated MLLD. This implies that RF injection efficiency was improved by 13 dB in the impedance-matching structure.

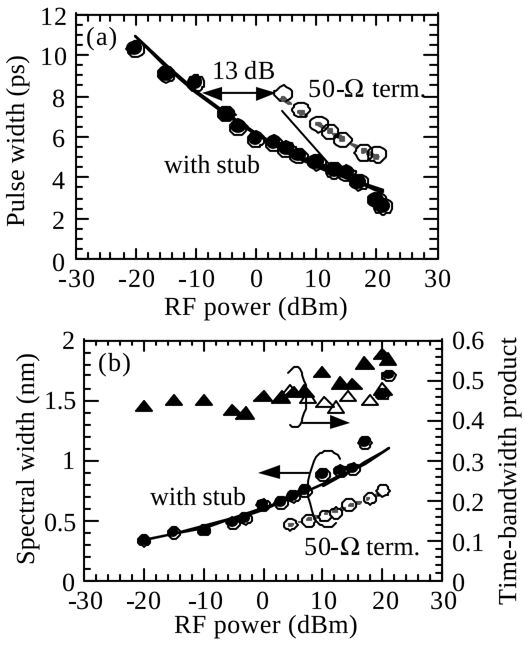

Fig.2 Dependence of (a) pulse width and (b) spectral width and time-bandwidth product on RF power

The spectral widths were in reverse well fitted in proportion to $P_{RF}^{1/8}$ (solid and dashed curves in Fig. 2 (b)). The time-bandwidth products were less than 0.55. This implies that almost transform-limited conditions were satisfied. The timing jitters were around 0.15 ps in all the experimental results, almost equal to that of the RF driver.

Figure 3 shows locking characteristics of the 40-GHz MLLD module when I_{gain}=90 mA, V_{EA}=-1.25 V, and P_{RF}=21 dBm. Changes in the pulse widths were less than 0.2 ps (2.8 ps-3 ps) from 38.7 GHz to 41.2 GHz and the timing jitter was constant at 0.15 ps over measured frequency region. The locking range was rather dominated by the degradation of RIN value at low frequency region around 5 GHz. When we define the locking range as a frequency region in which the degradation of RIN value was within 6 dB (corresponding to doubling of amplitude noise), it was from 39 GHz to 40.9 GHz. Such a wide locking bandwidth over 1.9 GHz is very promising for cost effective device fabrication because it is enough to cover an error in cavity length in the cavity cleaving process (typically 20 μm).

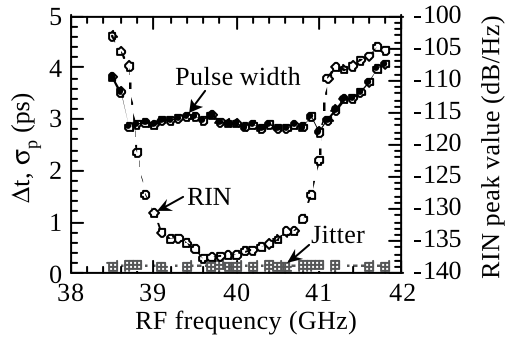

Fig.3 Locking characteristics of the 40 GHz MLLD module. Δt: pulse width, σ_p: timing jitter

4. Conclusions

In summary, we have developed a 40 GHz active MLLD module packaged together with a narrow-band impedance matching circuit of double open stubs. A wide locking bandwidth of 1.9 GHz has been achieved remaining short pulse widths (<3 ps) and low RIN values (<-130 dB/Hz). Such a wide locking range could fully cover an error in cavity length in the cleaving process and is very promising for cost effective device fabrication. This LD is promising as a short optical pulse source for 40-Gbit/s and higher bit-rate optical communication networks.

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