GENERATION OF SUBPICOSECOND OPTICAL PULSES BY MODE-LOCKING SEMICONDUCTOR LASERS WITH MILLIMETER-WAVE SOURCES

Y. K. Chen, M. C. Wu, T. Tanbun-Ek, R. A. Logan and M. A. Chin

AT&T Bell Laboratories, Murray Hill, NJ 07974

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ABSTRACT

Subpicosecond transform-limited optical pulses are generated from monolithic colliding pulse mode-locked multiple quantum well lasers at 1.5-um wavelength. The 0.95 ps optical pulses are synchronized with a millimeter-wave oscillator up to 40 GHz and have a modulation depth greater than 95%. Using a passive mode-locking technique, 610-femtosecond optical pulses are also generated at a repetition rate as high as 350 GHz without any synchronization sources. This is the highest pulse repetition rate ever reported by semiconductor optoelectronic sources.

INTRODUCTION

The generation of ultra-short optical pulses and their synchronization with electronic oscillators are of great interests to many optoelectronic applications which require the transmission of millimeter-wave signals through an alternative low-loss medium such as silica optical fibers. The generation of these short optical pulses at 1.55-um wavelength is also very important for high bit-rate time-division multiplexed communication systems because of the minimum fiber loss. The minimum pulse width that can be generated for a prescribed spectral bandwidth is limited by the Fourier theorem. A transform-limited optical pulse have very small frequency chirp and very little amplitude substructures and can propagate a long distance in dispersive mediums such as fibers. Traditionally, ultra-short subpicosecond optical pulses were generated using semiconductor lasers with external cavities [1]. However, this approach suffered from the multiple-pulse generation from the non-perfect anti-reflection coating and its repetition rate is limited by the bulk optical components. Here, we report on the generation of the short optical pulses at 1.5-μm wavelength by a single-chip colliding-pulse mode-locked semiconductor laser without external cavity.

EXPERIMENTS

A colliding pulse mode-locked (CPM) scheme [2] is incorporated into the multiple quantum well laser to produce subpicosecond transform-limited pulses. Figure 1 shows the schematic diagram of this monolithic CPM quantum well laser. The top contact stripe of the multiple quantum well laser is divided into five sections: a saturable absorber in the center, two modulator sections near the cleaved Fabry-Perot mirrors, and active waveguide sections linking the modulators and the saturable absorber [3]. Integrated microstrip transmission lines are used on the top of a semi-insulating iron-doped InP epitaxial regrowth layer to distribute the millimeter-wave synchronization signal to the two modulators in phase. The saturable absorber is reverse-biased, while the rest of the laser sections are forward-biased to provide gain.

Figure 2 shows the measurement setup for this mode-locking experiment. A millimeter-wave network analyzer and a traveling-wave tube (TWT) millimeter-wave amplifier are used to drive the semiconductor CPM laser up to 40GHz. The characteristics of optical pulses are analyzed simultaneously by an optical spectrum analyzer for optical spectral behaviors and a non-collinear second harmonic generation (SHG) auto-correlator for measuring the sub-picosecond pulse width. First, the small signal microwave modulation response of the CPM laser is characterized from 1 GHz to 40 GHz by the network analyzer and a high speed PIN photodiode. After the cavity resonance frequency is

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located from the microwave response, the network analyzer is locked to a CW frequency which is the resonance frequency of the CPM laser. By optimizing the voltage applied to the saturable absorber, synchronized mode-locked optical pulses are produced.

Figure 3 shows the measured SHG autocorrelation curve. By de-convoluting the measured traces, a pulse width as short as 950 femtoseconds is obtained assuming a hyperbolic secant square pulse shape. The calculated curve (solid line) fits very well to the measured data (dots) in Fig. 3, and near 100% optical modulation is obtained with very low RF power of 15 dBm at 40 GHz for a 2.1 mm-long laser. From the 2.61nm full-width-at-half-maximum (FWHM) spectral width of the mode-locked spectrum, the time-bandwidth product is 0.32, which is very closed to the theoretical limit of 0.314 for the hyperbolic secant pulse shape. Because the waveguide is composed of the active medium, the mode-locking operation can be obtained over a broad range of driving frequency. Figure 4 shows the measured second-harmonic generated auto-correlation pulsewidth for different driving frequencies. Short mode-locked optical pulses can be synchronized over 5% of the resonance frequency of the semiconductor CPM laser.

Short mode-locked optical pulses can also be generated by the passive mode-locking of this semiconductor CPM quantum well laser. Using this technique, free-running optical pulses can be generated without any synchronizing sources. The repetition rate is then only determined by the effective cavity length of the monolithic semiconductor lasers. By reducing the length of the laser to 250 μm and optimizing the semiconductor layer structure, optical pulses as short as 610 femtoseconds are obtained at a rate as high as 350 GHz (Fig. 5). These high speed short optical pulses may serve as effective means to generate millimeter-wave or sub-millimeter-wave electrical signal up to multi-hundred giga-hertz regime which is difficult to achieve with conventional electronic devices.

SUMMARY

In summary, we have generated 950 fs optical pulses with a time-bandwidth product of 0.32 at a repetition rate of 40 GHz from an monolithic active colliding pulse mode-locked semiconductor laser. Nearly transform-limited optical pulse width of 610 fs at 350 GHz are also produced with passive mode-locked CPM quantum well lasers with a time-bandwidth product of 0.34. These CPM lasers are very useful for millimeter-wave optoelectronic systems.

REFERENCE

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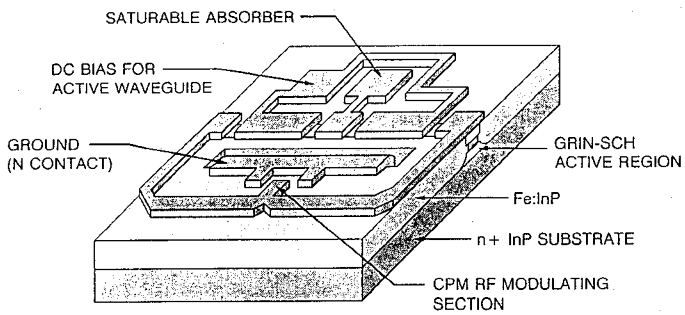

Fig. 1 Schematic diagram of a integrated colliding-pulse mode-locked quantum well laser on a single chip.

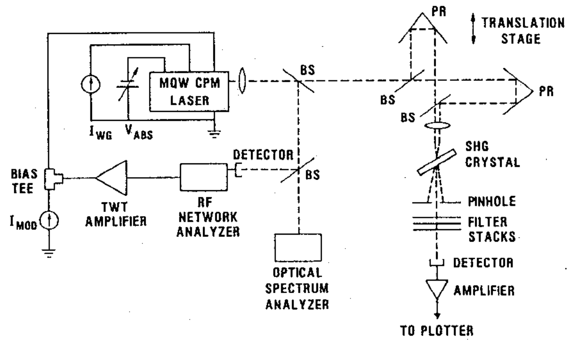

Fig. 2 Schematic diagram of the experimental setup.

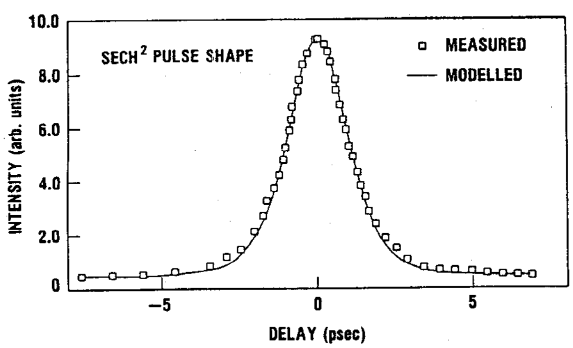

Fig. 3 Measured and modeled second harmonic autocorrelation trace of a CPM MQW laser at 40 GHz with a FWHM pulse width of 0.95 ps.

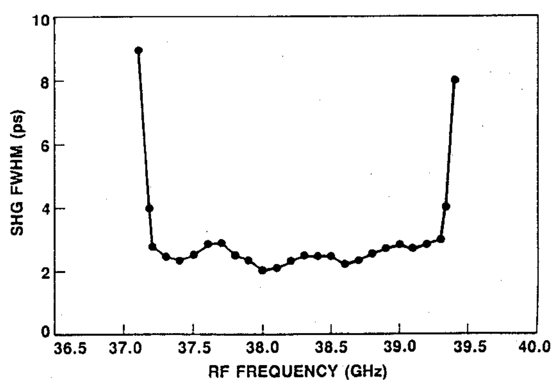

Fig. 4 Broad frequency tuning range of an active mode-locked CPM laser.