SUB-PICOSECOND OPTICAL PULSE GENERATION AT 350 GHz IN MONOLITHIC PASSIVE CPM MQW LASERS

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ABSTRACT

Sub-picosecond optical pulses have been successfully generated using a novel monolithic passive colliding pulse mode-locked (CPM)[1] semiconductor multiple quantum-well (MQW) laser. Transform-limited pulse width of 830 femto-seconds is achieved at a wavelength of 1.5μm and a repetition rate of 80 GHz. The measured time-bandwidth product is 0.31. A record high repetition rate of 350 GHz is also demonstrated with 900 femto-seconds pulse width.

INTRODUCTION

Generation of short optical pulses using monolithic mode-locked semiconductor lasers has attracted a great deal of attention recently.[2-8] In active mode-locking case, the phases of the longitudinal modes are locked together by an external microwave source. Passive mode-locking requires the saturable absorber cross-section to be larger than the gain cross-section.[9] Multiple quantum well (MQW) material is ideal to realize monolithic passive mode-locked lasers because this criterion can be satisfied by operating the same quantum well materials under different bias conditions.[10] Other properties of MQW such as low dispersion, broad gain spectrum, and fast saturation and recovery time further improve the performance of the monolithic mode-locked lasers.[10-12]

Previously, we have incorporated the colliding pulse mode-locking (CPM) technique into a monolithic *active* mode-locked quantum-well laser.[7,8] An RF source was used to synchronize two counter-propagating optical pulses to collide in a center saturable absorber. In this paper, we report a *passive* monolithic CPM laser that generates continuous and stable sub-picosecond optical pulses without using any synchronization sources. The two counter-propagating pulses time themselves to collide in the center saturable absorber because of minimum energy loss. Shorter pulse can be obtained with the enhanced effectiveness of the saturable absorber.[1] The transient grating formed by the two pulses at the saturable absorber helps to generate pulses with transform-limited width. Optical pulses with transform-limited widths of 830 femto-seconds are achieved. This is the first time that tranform-limited pulses with sub-picosecond widths are generated with any monolithic mode-locked semiconductor lasers.

DEVICE STRUCTURE

The schematic diagram of the monolithic passive CPM laser is shown in Fig. 1. A graded-index separate-confinement heterostructure (GRIN-SCH) strained MQW laser was used in the experiment.[13] The active region consists of 5 $In_{0.48}Ga_{0.52}As$ strained quantum wells and 6 InGaAsP (λ=1.25μm) barriers. The detailed layer structure is shown in Fig. 2. Iron-doped InP is then selectively regrown around the active stripe to form a buried heterostructure. Both growths were done by organo-metallic vapor phase epitaxy (OMVPE). The growth conditions and device performance of the MQW lasers were reported in Ref. 13. The laser is then patterned into various sections using segmented top p-contacts. The same quantum wells are used for both the gain and the saturable absorber sections. A linear optical cavity is used for this monolithic CPM laser: a 50-μm-long saturable absorber is located in the symmetry center of the cavity, the remaining active cavity is connected together and forward-biased as the gain section. The heavily doped cap layer between the gain and

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the absorber sections is removed by chemical etching.

MEASUREMENT RESULTS

The light-versus-current (L-I) characteristics of a 2.1-mm-long CPM laser is shown in Fig. 3 by the solid lines. Linear L-I curve is obtained with uniform current injection, and the laser threshold current is 54 mA. When the center saturable absorber is reverse-biased, nonlinear L-I curves are observed, which shows the effect of saturable absorption. The photocurrent from the absorber is also shown in Fig. 3 by the dotted lines. Mode-locking is observed over a wide range of bias conditions. Figure 4 shows the bias range of the gain-section current (I_G) and the saturable absorber voltage (V_{abs}) to obtain pulses of widths < 1.5ps. The bias range for active mode-locking condition with 14 dBm of RF power is also shown for comparison. Less reverse bias on the saturable absorber is required for the active CPM laser.

The pulse width of the monolithic CPM laser is measured with a second-harmonic generating (SHG) autocorrelator. Figure 5(a) shows the autocorrelation trace of a 1-mm-long CPM laser, which has a repetition rate of 80 GHz. The experimental data is very well fitted by a sech^2 pulse shape with a full-width-at-half-maximum (FWHM) pulse width of 830 femto-seconds. The time-averaged optical spectrum (Fig. 5(b)) is very symmetric and the spectral width is 2.89 nm. The measured time-bandwidth product is 0.31, indicating that the pulse width is transform-limited for sech^2 pulse shape.

Passive mode-locking at 350 GHz is performed with a similar CPM laser of 250 μm long. Figure 6(a) shows the measured and the fitted SHG autocorrelation traces. Very good fit with symmetric two-sided exponential pulse shape is obtained. The repetition period is only 2.87 ps, and a series of 5 pulses (5 periods) are observed during the 15-ps scan. Figure 6(b) shows the deconvoluted waveform, which has a pulse width of 900 femto-seconds. and a dc level of 5%. The spectrum in Fig. 6(c) has a FWHM of 7 nm, which is about six times of the transform limit.

CONCLUSION

A novel monolithic passive colliding pulse mode-locked laser is demonstrated for the first time. Transform-limited pulse with 0.83 ps duration is demonstrated at a repetition rate of 80 GHz. A record high repetition of 350 GHz is also achieved with sub-picosecond pulse width.

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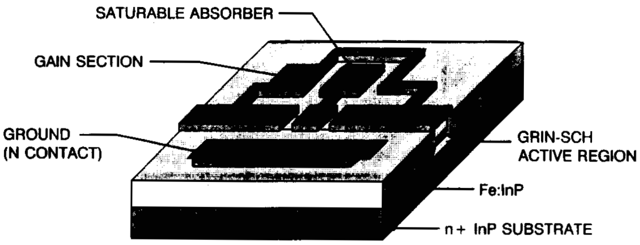


Fig.1 The schematic diagram of the monolithic passive CPM quantum well laser.

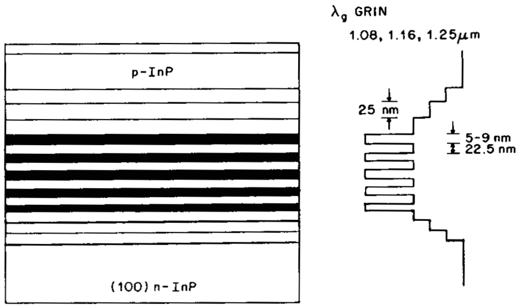


Fig.2 The layer structure of the InGaAs/InGaAsP GRIN-SCH strained MQW laser.

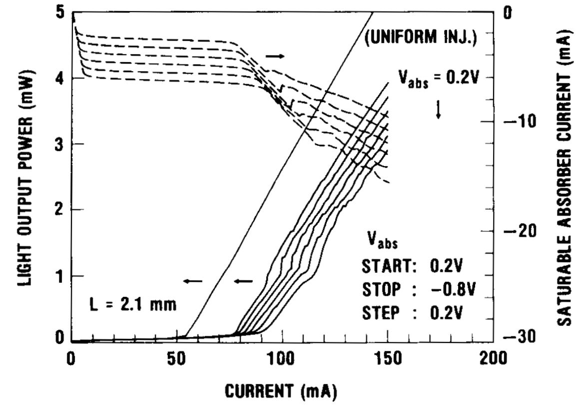


Fig.3 The L-I characteristics (solid lines) and the photocurrent of saturable absorber (dotted lines).

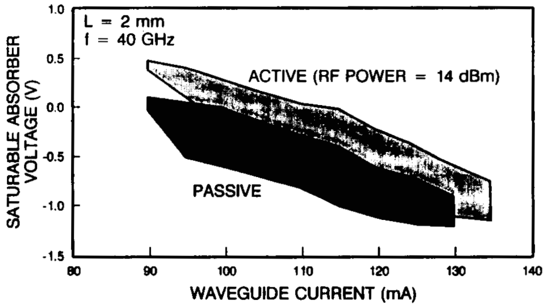


Fig.4 The bias range of I_G and V_{sat} to obtain pulse width $<$ 1.5 ps for both passive CPM and active CPM lasers.

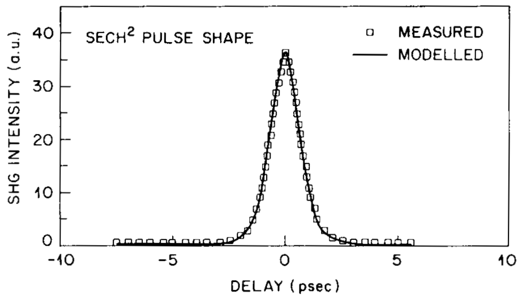


Fig.5 (a) The measured (□) and fitted (—, sech^2) SHG autocorrelation trace of 1-mm-long (80 GHz repetition rate) passive CPM laser.

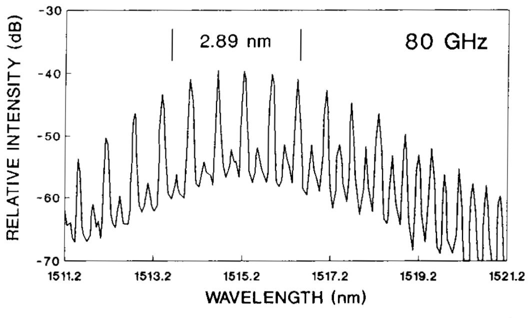


Fig.5 (b) The optical spectrum recorded simultaneously.

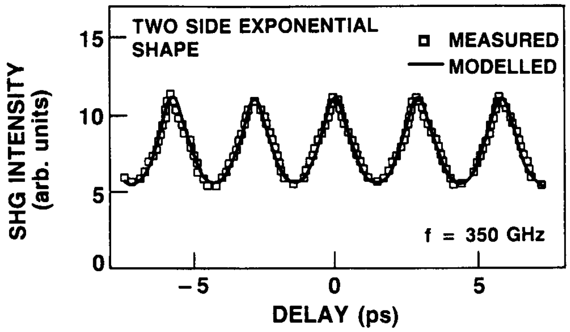
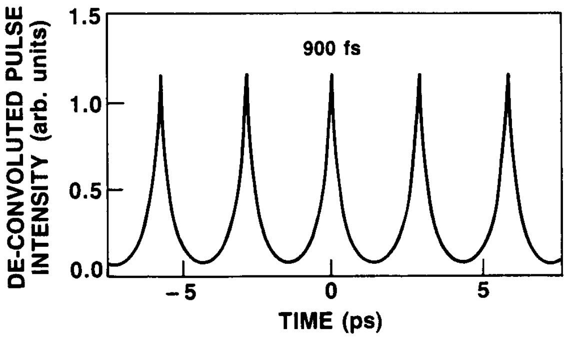
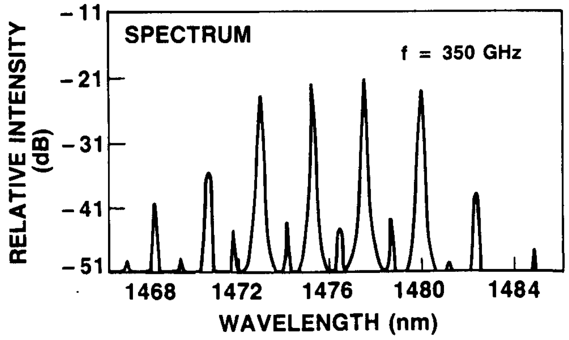


Fig.6 (a) The measured (□) and fitted (––, two-sided exponential) SHG autocorrelation trace of 250-μm-long (350 GHz repetition rate) passive CPM laser.



(b) The deconvoluted waveform.



(c) The optical spectrum.