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Novel design of low-jitter 10 GHz all-active monolithic mode-locked lasers

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Abstract: Using a novel design, we have fabricated 10 GHz all-active monolithic mode-locked semiconductor lasers that generate 1.4 ps pulses with record-low timing jitter. The dynamical properties of lasers with 1 and 2 QWs are compared.

OCIS codes: (060.4510) Optical communications; (140.4050) Mode-locked lasers; (140.5960) Semiconductor lasers

Mode-locked lasers are attractive components for pulse generation and all-optical clock-recovery in high-speed optical time-division multiplexed systems and for high-speed optical sampling systems. The requirements on stability, compactness and easy integration, favour monolithic semiconductor devices. While several good results have been obtained with monolithic lasers operating at 40 GHz, the long 10 GHz all-active lasers were predicted to have poor performance [1]. We show, however, that the use of a novel all-active design makes it possible to achieve jitter and time-bandwidth product performance that compare favourably with the best results, known to us, obtained for any monolithic structure and [2] even for external-cavity mode-locked lasers [3].

High-frequency timing jitter originates from amplified spontaneous emission noise, and chirp originates from the dynamic refractive index changes incurred during a cavity roundtrip. These can be minimized using a design that lowers the loss during mode-locking, leading to low threshold current and low gain saturation [4, 5]. This reduces the dynamic changes and increases the output power without pulse broadening. We choose to use a single growth step for the gain and absorber sections in a simple two-contact self-colliding mode-locked laser. The use of only a few quantum wells (1 and 2 are tested here) is important in order to decrease the degree of gain saturation by achieving high inversion and low optical confinement factor.

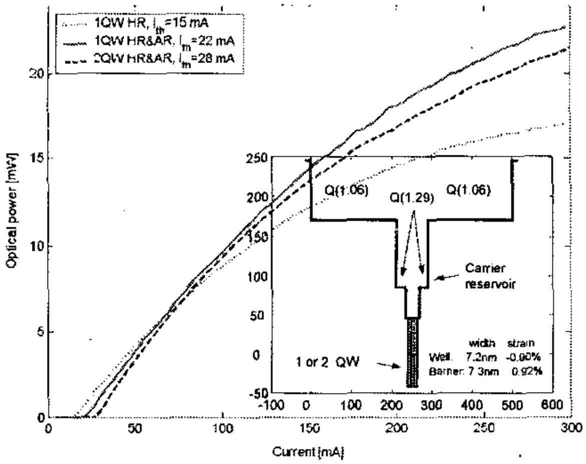

Fig. 1. Measured LI-characteristics showing high differential quantum efficiency and low threshold, indicating low loss.

The laser chips are ridge structures made from MOCVD-grown InGaAsP on InP cf. inset in figure 1. Chips, ~4250 μm long, are soldered to a microwave substrate and the absorber section is bonded to a co-planar transmission line that is contacted with a high-frequency probe for hybrid mode-locking. No 50 Ω termination was employed. After mounting, an HR and a 5% AR coating was applied to the absorber and gain facet respectively.

The output is coupled into a lensed fibre with 3-dB coupling loss; measured static LI-characteristics are shown in figure 1. The jitter is extracted from an absolute phase noise measurement [6]. The appropriate frequency range for noise integration depends on the application; for telecom applications at 10 GHz, ITU-T specifies the range to be from 20 kHz to 80 MHz, with special emphasis on the high frequency part [7]. The lower graph of figure 2 presents the influence of the upper integration limit. The measured jitter is record-low for all the devices and is actually determined mainly by the synthesizer rather than the intrinsic spontaneous emission noise. Since the phase-noise plateau is record-low [3], further improvements may be expected using homodyne mixing techniques.

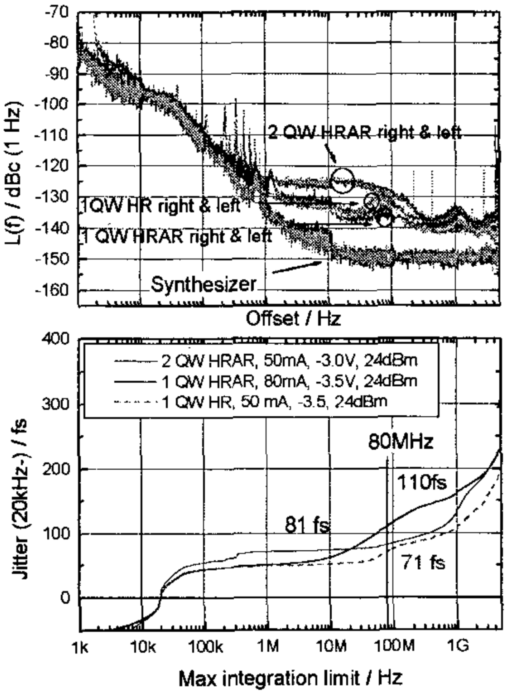

Fig. 2. Top: Single side-band phase noise spectra of 1 and 2 QW devices and HP8673C RF synthesizer. Bottom: Integrated absolute rms jitter from 20 kHz to the upper integration limit. Legend: # QWs, coating, gain current, absorber bias, RF-power.

The dynamic characteristics of the lasers corresponding to the operating conditions in figure 2 are summarised in Table 1.

Table 1. Summary of the devices investigated. $\Delta\tau_{compr}$ is the pulse width after compression in an optimal length of fibre, L_{opt}.

#QW	Coat	L_{abs} µm	f_{rep} GHz	λ µm	T °C	$\Delta\tau_{laser}$ ps	$\Delta\tau_{compr}$ ps	L_{opt} m	$\Delta\lambda$ nm	$\Delta\tau_{compr}\Delta\nu$	P_{out} mW
1	hr	100	9.93	1531	20	6.6	1.8	135	1.8	0.42	0.5
1	hr & ar	100	9.93	1526	24	-	2.3	120	1.8	0.54	4.0
2	hr & ar	55	9.97	1556	20	2.4	1.4	40	3.3	0.58	1.5

Figure 3 shows the measured shape and spectrum of the pulses from the 2-QW device, which gives the minimum time-bandwidth product directly out of the laser. The pulse width is strongly dependent on the RF-power, indicating predominately active mode-locking. This observation together with the higher confinement factor in the absorber section for the 2-QW device compared to the 1-QW device could explain the stronger pulse shaping.

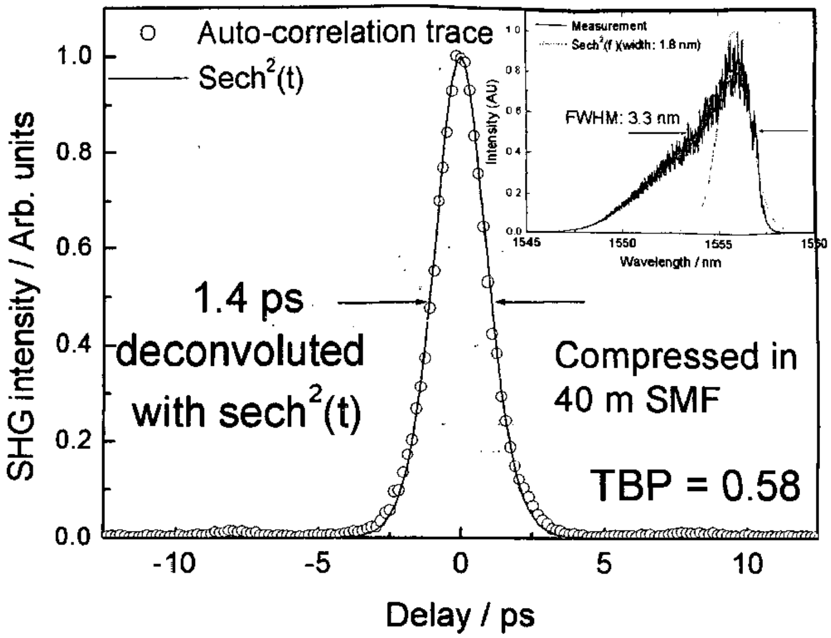

Fig. 3. Pulse autocorrelation and spectrum for the 2-QW device corresponding to the measurement conditions in figure 2 and table 1. There is excellent agreement between autocorrelation data and fit.

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