1.55-μm Optical Short Pulse Generation at 10-GHz Repetition Rate, Using a Mode-Locked Hybrid Distributed Bragg Reflector (ML-HDBR) Laser Source

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***Abstract*—In the present paper we report the realization of a mode-locked hybrid distributed Bragg reflector (HDBR) laser for picosecond optical pulse generation at 10-GHz repetition rate. 12.7-ps 2-mW optical pulses, with 400-MHz locking bandwidth have been obtained by using a saturated (95% of peak reflectivity) Gaussian Bragg grating. Linear phase gratings have shown even better results in terms of stability and output power (7 mW), whereas so far 15 ps of pulsewidth has been achieved, mainly limited by the spectral bandwidth of the grating. Key features of this realization are the intrinsic simplicity and the compactness of the laser source.**

***Index Terms*—Gratings, high-speed devices, optical pulses, quantum-well lasers, semiconductor lasers.**

I. Introduction

In RECENT YEARS, several examples of short optical pulse sources using active mode locking have been proposed. This method provides low timing jitter picosecond pulses, locked to an external electrical reference frequency, for high-speed optical communication systems. Monolithic mode-locked lasers [1] have been proposed as multifunctional sources in OTDM systems, demonstrating short pulse generation and optical clock recovery. Femtosecond optical pulses at 10-GHz repetition rate have been obtained using external cavity lasers [2], [3].

A hybrid distributed Bragg reflector (HDBR) laser, also called a fiber-grating (FG) laser, much more compact and simple in respect to the previous examples, has been demonstrated in mode-locking regime at 2.5 GHz [4] and 10 GHz [5]. An interesting feature of these devices is the extremely wide operating frequency range, which can be enhanced by using chirped gratings, as reported in [4].

In this letter, we report the realization of a mode-locked HDBR laser for picosecond optical pulse generation at 10-GHz repetition rate, showing a comparison of the short pulses obtained by using different Bragg gratings. 12.7-ps Gaussian-shaped pulses, with 400 MHz locking bandwidth have been obtained using a saturated (95% of peak reflectivity) Bragg grating, unchirped, assuring 2 mW of peak power. Linear phase gratings have been also investigated, showing a significant improvement in terms of pulse power (7 mW), extinction ratio and emission stability, together with a pulse width of 15 ps. This source seems therefore to be suitable for optical pulse generation in transmission and demultiplexing OTDM systems.

A key aspect of this work is that we have obtained these results using a simple, compact and potentially low cost structure, similar to the realization already demonstrated for WDM application [6].

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II. Device Realization

The HDBR laser is based on a fast Fabry–Perot laser diode, AR (antireflection) coated on the output facet, leaving the other laser facet as cleaved. The facet residual reflectivity is close to 10^{-4}; this value has been recognized by several authors [7] as the minimum requirement for stable pulse generation.

The laser is a semi-insulating buried heterostructure (SI-BH), with a 1.55-μm InGaAsP MQW active layer, made by 9 (80 Å thick) compressive strained (+0.9%) wells and 8 (90 Å thick) tensile strained (−0.5%) barriers, grown by metal–organic chemical vapor deposition (MOCVD). Before the AR coating, the device exhibited 7 mA of threshold current. After the AR coating the threshold current was increased (at about 25 mA, consistent with the facet reflectivity reduction), and the quantum efficiency was increased as well. Typical maximum bandwidth achieved with these devices is between 12–15 GHz.

The HDBR laser is mounted on an optical bench, and the bias current and the RF signal as well are provided by a RF probe, designed for our chip geometry, including a 45-Ω matching resistor.

The chip is temperature-controlled by a thermistor and a Peltier cell, with an accuracy estimated in 1 °C in the whole bias current range. The output beam is coupled, by using a micromovement, into a standard single-mode fiber (SMF), with an UV-written grating centered around 1552 nm.

A good coupling efficiency is achieved using a tapered fiber (coupling loss of 2 dB), and the residual cavity effects are eliminated by an antireflection coating (10^{-5}–10^{-6}) on the fiber taper itself. In the present realization, this fiber assures both the

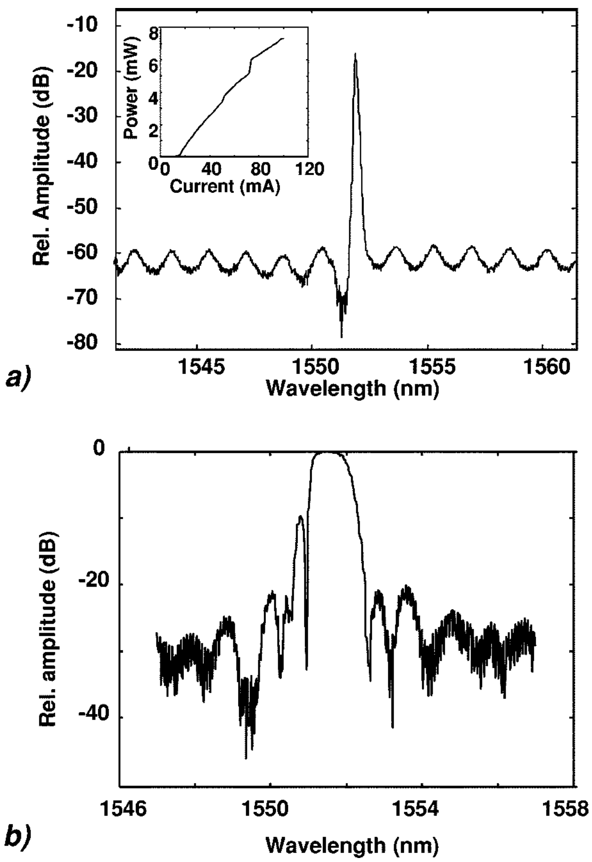

Fig. 1. (a) Typical spectral emission of the HDBR laser, and (inset) power-current characteristics, showing the 15 mA of threshold current, and the mode-hopping at various bias current. (b) Spectral reflectivity of the 95% saturated fiber grating.

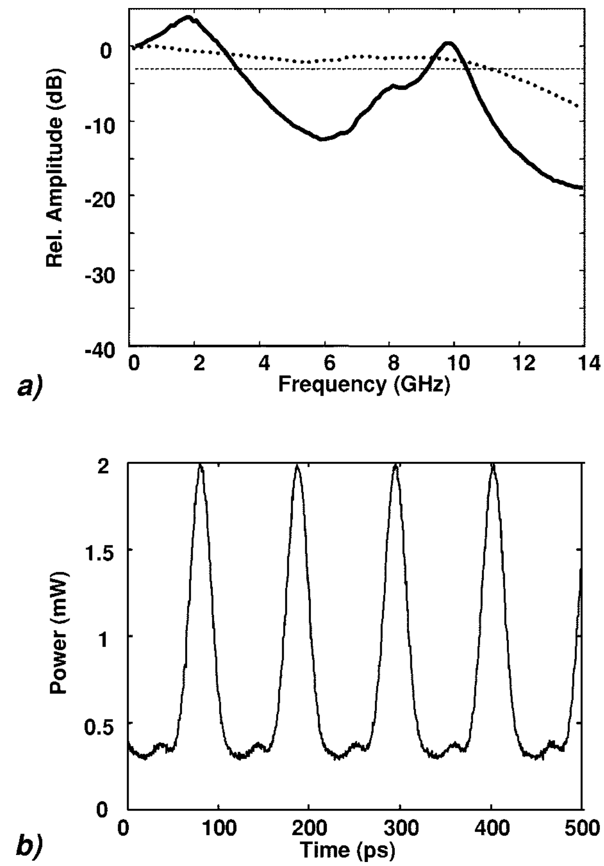

Fig. 2. (a) Comparison of small signal modulation response of the original Fabry–Perot laser (••) and the HDBR laser (—), at 60 mA of bias current. It is clearly visible the strong resonance peak, close to 10 GHz thanks to the properly designed external cavity. (b) Optical pulse train detected by a fast photodiode; the actual pulsewidth, evaluated by an autocorrelation measurement, was 12.7 ps.

output coupling and the external cavity. The alignment tolerances are quite critical, since a standard edge-emitting (not spot size converted) laser has been used: therefore, the transversal position of the fiber should be maintained in a range of ± 1 μm.

The cavity length has to be precisely designed in order to give a mode-lock frequency close to 10 GHz. By using the equivalent mirror approximation of the Bragg grating [8], we were able to define precisely the actual length of the optical cavity, and therefore the position of the grating required for the 10 GHz mode-locking operation. For a 300-μm-long device, the equivalent mirror should be positioned 7.2 mm far from the taper edge. Moreover, the wide locking range obtained with this source has effectively reduced the requirements in terms of geometrical precision of the grating.

The grating reflectivity shape is also a key factor for picosecond pulse generation: to obtain short pulses, the reflectivity spectrum has to be wide enough to provide a large number of locked modes. In the present paper, we compare results obtained by using different Gaussian shaped fiber gratings, unchirped, with a peak reflectivity between 50%–95%, designed to provide a wide spectral reflectivity bandwidth [full-width at half-maximum (FWHM)].

III. Experimental Results

For all the different fiber grating mentioned above, the HDBR has shown a threshold current between 12–15 mA at 20 °C, as well as various mode-hopping caused by the wide FWHM of the gratings. The continuous-wave spectrum was centered around the fiber grating peak, showing more than 40 dB of suppression of the residual semiconductor laser cavity modes [Fig. 1(a)]. Different sets of bias currents and RF powers have been tested: best performances have been obtained with a bias current of 40–50 mA, and an RF signal between 20–25 dBm, depending on the reflectivity of the grating. The optical pulse train has been detected by a fast photodiode and a 50-GHz sampling oscilloscope (typically with 4–8 scope averages).

We originally tested the device with a 1.2 nm FWHM saturated (95% of peak reflectivity) grating, Gaussian shaped, 5 mm long [Fig. 1(b)]. The effect of the external cavity was initially evaluated by a small signal frequency measurement, identifying [Fig. 2(a)] clearly the resonance peak of the overall cavity close to the 10 GHz.

The pulse operation was obtained by pumping the device with a +20-dBm 10-GHz signal, achieving good quality of optical pulses, with a locking bandwidth of 400 MHz around the 10-GHz repetition rate, and a peak power of 2 mW [Fig. 2(b)]. The measured pulse width was limited by the photodiode rise time. The actual pulse duration (Gaussian shaped), evaluated by an autocorrelation measurement, was 12.7 ps. A time-band-

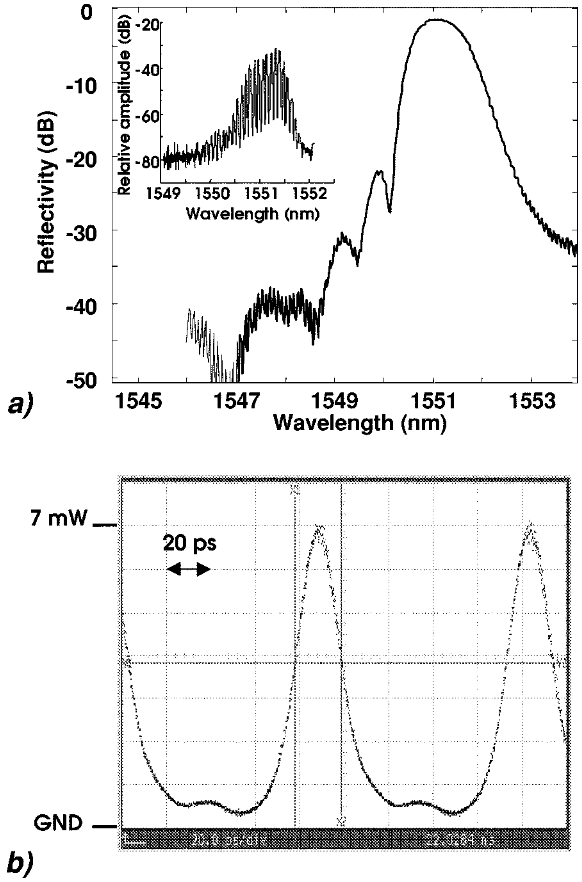

Fig. 3. (a) Linear phase grating, showing a FWHM of 1 nm, and a peak reflectivity of 72%; (inset) optical spectrum of the mode-locked laser realized using the above mentioned grating. (b) Optical pulses generated by the mode-locked laser, detected by a fast photodiode: a pulsewidth of 15 ps has been obtained, together with a significant improvement in terms of extinction ratio and pulse quality.

width product less than 0.6 was obtained in the whole mode-locking range, similar to the results reported in [4].

The device exhibited a critical behavior, being the pulse condition sensitive to the fiber alignment and to the operating temperature: this effect was limiting dramatically the packaging tolerances of the device. We identified the nonlinear phase of the grating (induced by the high value of the peak reflectivity) as a main cause of instability. To solve this problem, and to increase the peak power as well, we considered a different design of the grating. A FWHM of 1 nm has been obtained, with a peak reflectivity of 72% [Fig. 3(a)], by using a fiber with a shorter grating (40% less than the previous one). The grating simulation indicates that a practically linear phase has been obtained.

Fig. 3 reports also the optical pulses obtained at 50 mA of bias current, +20 dBm of RF signal, detected by a fast photodiode. The actual pulse duration has been evaluated as 15 ps, and the pulse train shows an improvement in terms of extinction ratio. The optical spectrum of the mode-locked laser is also shown in Fig. 3.

A peak power of 7 mW has been obtained in this configuration, with a locking range of 500 MHz. The peak power could be further improved by collecting the output power from the other facet of the laser chip, by using a standard tapered fiber.

By a Gaussian fitting of the optical spectrum, we have estimated the time-bandwidth product in 0.5, close to the bandwidth-limited value [7]. An absolute timing jitter of 1.06 ps has been measured by calculating the root-mean-squared (rms) jitter of the optical pulses [7], comparable with the jitter (0.92 ps) introduced by the RF source and the measurement set-up. Moreover, the absolute timing jitter was less than 1.2 ps in the whole (500 MHz) locking range.

Similar results have been obtained for different sets of bias current and RF power, and the device has shown no instability in any operating condition. This configuration seems therefore to be suitable to realize a packaged device, to be tested in a transmission experiments. Nevertheless, the pulse width, mainly limited by the spectral bandwidth of the grating, has to be further improved, to completely address the 40-Gb/s requirements.

IV. Conclusion

2-mW 12.7-ps optical pulses at about 10 GHz of repetition rate have been demonstrated, with a mode-locked hybrid distributed Bragg reflector (ML-HDBR) laser source, by using a saturated Bragg grating. Key features of this approach are the intrinsic simplicity and the compactness of the laser source, in fact the dimensions of the pulse source are practically the same of a conventional semiconductor laser. Furthermore wide locking bandwidth (400 MHz) has been demonstrated. Linear phase Bragg gratings have been also investigated, showing better results in terms of peak power, locking range (7 mW and 500 MHz, respectively) and pulse shape. Moreover, they have improved as well the stability of the pulse condition, key aspects for the packaged devices, whereas so far they are still less effective in terms of pulse width (15 ps).

The above results show that this device is, therefore, suitable for short pulse generation and optical clock recovery, in (4×10 Gb/s) OTDM systems.

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