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DBR based passively mode-locked 1.5µm semiconductor laser with 9 nm tuning range

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We present the first tuneable DBR based extended cavity integrated passively mode-locked laser realized in an anti-colliding design. The laser is realized as an InP based photonic integrated circuit. A detailed study of the laser performance under various operating conditions is presented. Tuning of the laser over 9nm using the DBR grating was achieved. We demonstrate that tuning of the optical spectrum towards increased absorption of the saturable absorber leads to an improvement of the mode-locked laser performance. A reduction of the fundamental RF linewidth and a reduction of the pulse length down to the Fourier-limit were observed.

Introduction

A semiconductor passively mode-locked laser (PML) is an attractive compact source for the generation of short optical pulses and coherent frequency combs. Especially an integrated semiconductor PML is of particular interest. It is a robust and small source which does not require either optical pumping or an RF source for producing periodic short pulses. Usually to achieve mode-locking a saturable absorber (SA) and semiconductor optical amplifier (SOA) should be combined in the laser cavity. In the case of an integrated PML the SA can be formed by reverse biasing a small section of the SOA. The SOA provides the optical gain which can be saturated when light of high intensity propagates through. Similarly the high intensity signal saturates the SA which recovers in the order of several ten of picoseconds. The combination of these two saturation processes leads to the appearance of a short time window of positive net gain, which causes pulsed operation of the laser.

To obtain short optical pulses in a semiconductor laser an optimal spectral detuning between the SA and SOA spectra should be achieved. Both gain and absorption spectra vary with the operating conditions, which leads to the spectral variation of the output signal of a PML. Operating at different wavelength also influences the recovery processes in the SOA and SA. This also makes it difficult to accurately predict the operating wavelength. In order to solve this issue a distributed Bragg reflectors (DBR) can be used as a mirror in the linear PML. The use of a DBR grating in a PML allows for tuning of the optical spectrum by injecting current into DBR section. In this paper we present an integrated tuneable extended cavity PML operating at 1.55 µm. Moreover, we demonstrate an improvement of the performance in terms of RF linewidth and pulse duration when the PML is being tuned towards shorter wavelength.

Device geometry

The laser was designed using a library of predefined building blocks and layerstack in a multiproject wafer run of the Oclaro foundry for photonic integration. A DBR section of 50 % reflection centered at 1550 nm was used as an output coupler. A multimode interference reflector (MIR) served as an end mirror. The MIR was designed to provide 100 % reflection however fabrication imperfections cause a loss of less than 1 dB [1].

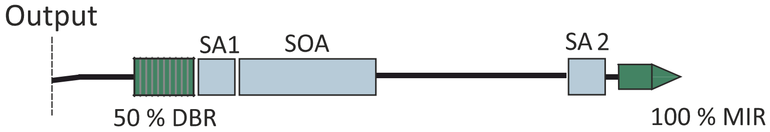

Fig. 1. Sketch of the layout of the PML.

As shown in Fig. 1 the cavity also includes three active sections (100 μm long SA1, 100 μm long SA2 and 2 mm long SOA) and 3 mm passive waveguide. The total length of the cavity is 5.5 mm. The laser configuration allows for repositioning of the SA either to the output coupler or to the end mirror depending on the bias applied on the SA1 and SA2. If the SA1 is reversely biased and SA2 is forward biased, the SA is placed next to the output coupler. Alternatively the SA is placed at the MIR by reversely biasing the SA2 and forwards biasing SA1. In both cases the long active section (SOA) has to be forward biased. Previously in [2] we used a laser layout very similar to the one presented here to show that positioning of the SA next to the low reflectance mirror leads to an improvement of the PML performance in terms of output power, stability and pulse duration. For this reason in this paper we will investigate the configuration where the SA is placed next to the DBR section.

Tuneable mode-locked laser performance

The chip with the PML was mounted on a copper chuck. Its temperature was stabilized at 18° C. Before going to the instruments the light was collected with an AR coated lensed fiber after which it went through an optical isolator. First, the DBR reflection spectrum was measured. It was obtained from measurements of the power of the signal from a tunable laser reflected from the DBR grating in the PML while SA1 and SOA were reversely biased. The reflection curve is shown in Fig. 2 (a). The maximum is scaled to 0.5. The DBR section was not contacted during this measurement. The reflection band is 4 nm wide and it is centered at 1551 nm, which is 1 nm higher than the design value. Even though the facet of the chip was AR coated, the raw experimental data had ripples with the period associated with the distance between the DBR and the facet at the end of the output waveguide. To obtain the reflection spectrum which is shown in Fig. 2 (a) the ripples were filtered out.

The PML performance was characterized for a range of the SOA currents between 60 to 140 mA and applied voltages on the SA from -0.5 to -2.1 V. Fig. 2 (b) shows an optical spectrum of the PML measured using a 20 MHz spectrum analyzer at I_{SOA} = 90 mA and U_{SA}=-1.3 V. The spectrum shows a frequency comb centered at 1554 nm with a mode separation of 7.4 GHz. It must be noted that the optical spectrum is asymmetrically shaped and its central wavelength is shifted from the top of the DBR reflection band towards longer wavelengths by 2.5 nm. We assume that a red shift of the PML optical spectrum is caused to the gain and absorption spectral dependency.

Despite the fact, that the optical spectrum to a large extent is determined by the gain and absorption profile, tuning of the optical spectrum with the injecting current into DBR grating was achieved.

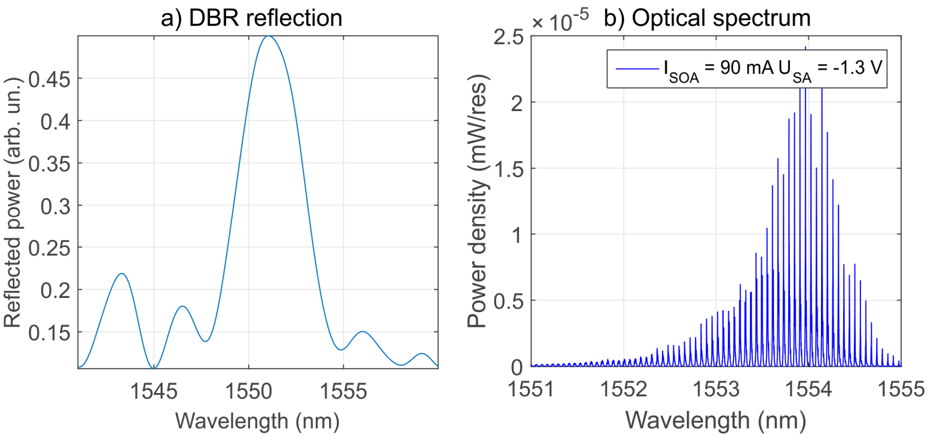

Fig. 2. a) DBR reflection spectrum at $I_{DBR} = 0$. b) Optical spectrum of the PML measured at $I_{SOA} = 90$ mA and $U_{SA} = -1.3$ V.

The tuning was investigated when the SOA current was set at 80 mA and a voltage of -1.1 V was applied on the SA. The performance of the PML under the tuning was evaluated through the measurements of output power, optical spectrum, beating signal generated in a fast photodetector and recording of autocorrelation traces. Since the laser output power was low, the signal was first amplified by a low noise erbium doped fiber amplifier (EDFA) and then sent through the polarization controller (PC) to the autocorrelator. Measurements of the output power showed that tuning of the DBR reflection band to shorter wavelength causes a decrease of the output power. The decrease of the output power can be explained by the increased small signal absorption in the SA at shorter wavelength. The change of the energy in SA and SOA section as well as spectral tuning are causing significant changes in PML performance. Fig. 3 shows the RF spectrum (a) and optical spectrum (b) for I_{DBR} from 0 to 15 mA. As it can be noticed from these figures the current injection in the DBR section leads to a variation of the fundamental frequency in the order of 100 MHz and a 9 nm red shift of the optical spectrum. Fig. 3 (c) shows the dependency on I_{DBR} of the wavelength of the maximum of optical spectrum. Moreover, an improvement of the PML performance was observed while the DBR was tuned. Fig. 3 (d) shows a decrease of the 10 dB RF linewidth down to 200 kHz, which is lower than the minimum RF linewidth value (290 kHz) observed without applying current in the DBR. The tuning of the optical spectrum also leads to the narrowing of the AC trace width from 10 ps to 3.95 ps. The narrowest AC trace measured at $I_{DBR} = 19$ mA and together with a fit to a Gaussian function is shown in Fig. 3 (f). The optical spectrum which corresponds to this AC trace is shown in Fig. 3 (g). At these conditions the pulse width is 2.55 ps and optical spectrum has a width of 1.7 nm. It means that a time bandwidth product of 0.46 is achieved. This improvement in the PML performance can be explained by a wavelength dependency of the dynamics of the absorption. When shifting towards the higher energy side the SA absorber exhibits higher absorption and a faster recovery time. This leads to the decrease of the temporal window of positive gain and reduces the noise at the trailing edge of the pulse.

In summary, the first tuneable integrated passively mode-locked laser realized in anti-colliding pulse mode-locking configuration was demonstrated. A tuning range of 9 nm was achieved, which to our knowledge the largest tuning range is observed in an integrated PML. A significant improvement of the PML performance in terms of pulse width and RF linewidth was observed when tuning the optical spectrum towards shorter wavelength.

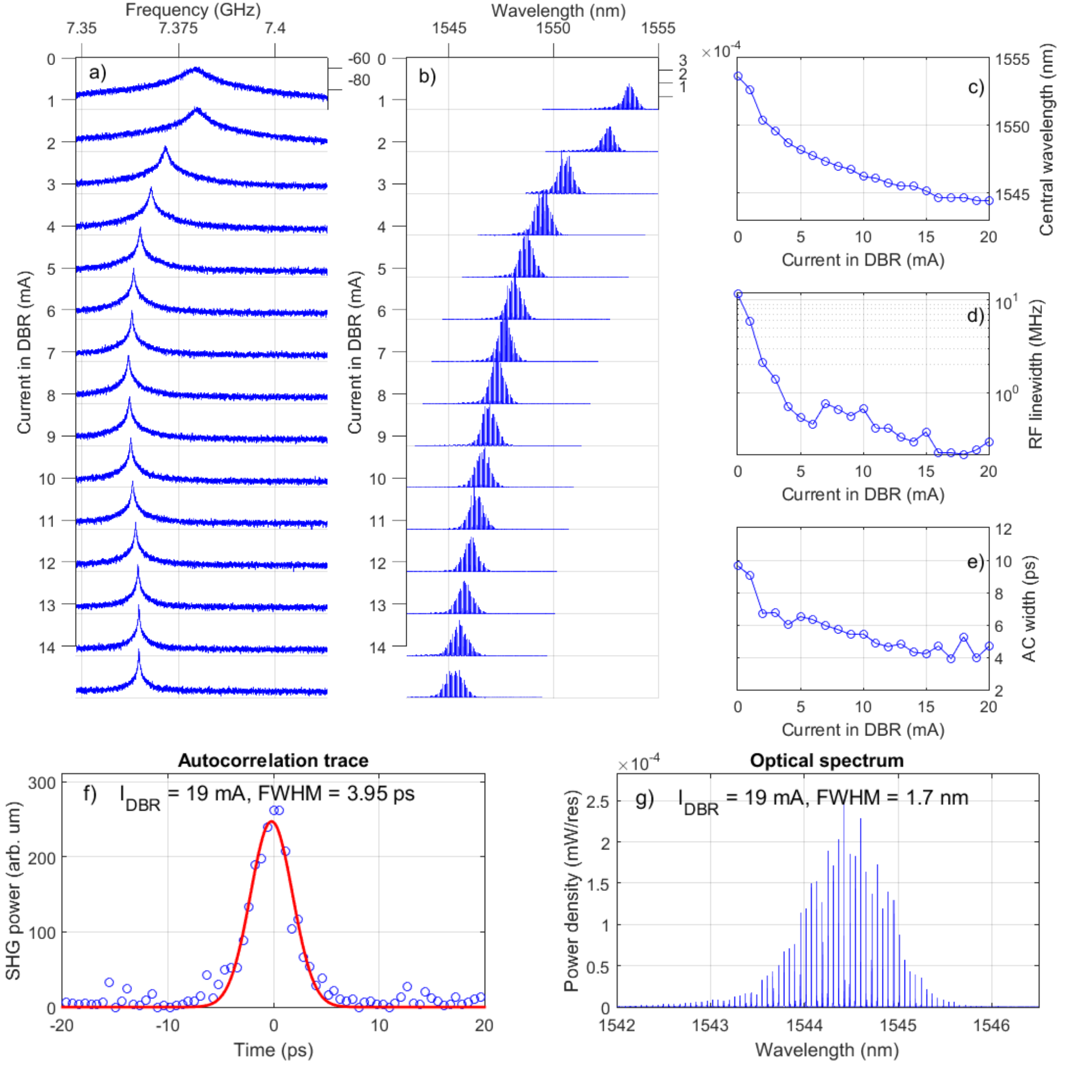

Fig. 3. a) RF spectra and b) optical spectra recorded for the range of I_{DBR} from 0 to 15 mA. c) Dependency of the wavelength of optical spectrum maximum on I_{DBR}. RF linewidth (d) and AC width (e) as a function of I_{DBR}. f) AC trace fitted measured at I_{DBR} =19 mA. The experimental data (blue circles) fitted by sech^2 (red line). g) Optical spectrum recorded at I_{DBR} =19 mA. All the results were obtained at I_{SOA} = 80 mA and U_{SA} = -1.1 V.

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