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Published in:
2002 IEEE/LEOS Annual Meeting Conference Proceedings

Publication date:
2002

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Yvind, K., Jørgensen, T., Birkedal, D., Skovgaard, P. M. W., & Hanberg, J. (2002). Tunable mode-locked semiconductor laser with Bragg mirror external cavity. In 2002 IEEE/LEOS Annual Meeting Conference Proceedings (Vol. 2, pp. 789-790). IEEE.

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Tunable mode-locked semiconductor laser with Bragg mirror external cavity

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Abstract *We present a simplified design for a wavelength tunable external cavity mode-locked laser by employing a wedged GaAs/AlGaAs Bragg mirror. The device emits 4-6 ps pulses at 10 GHz and is tunable over 15 nm.*

Introduction

Tunable external cavity mode-locked semiconductor lasers have been shown to be very versatile and able to produce pulses suitable for optical signal processing in future optical communication systems [1-3]. Wavelength tuning has previously been achieved either by a diffraction grating [1] or an etalon/mirror combination [2]. Here we present an alternative solution based on a wedged Bragg mirror allowing a simplified cavity design and the possibility to tailor the reflectivity with respect to bandwidth and chirp [4].

Device structure

A schematic of the external cavity laser is shown in Fig. 1. The semiconductor chip consists of two sections; a 32 µm absorber section and a 630 µm gain section separated by a 5 µm wide trench etched through the contact layers for electrical isolation. The end facet of the gain section is AR-coated (R ~ 10^{-4}) with a two-layer $TiO_{1.7}/SiO_2$ coating and the light is coupled to an external cavity using a plano-convex 0.6 NA GRIN lens to collimate or focus the light. The external cavity length can be varied to achieve repetition rates in the range of less than a GHz to above 10 GHz.

The laser chip is a ridge wave-guide device with a 3 µm wide ridge formed by combined dry and wet etching, using BCB planarization, thinning to 100 µm and standard Ti/Pt/Au p- and Ni/Ge/Au n-contact metallization. The epitaxial material is MOCVD grown InGaAsP on InP, with an active region employing two 28nm Q(1.13) separate confinement heterostructure layers and 10 quantum wells: 8nm compressive (1%) strained wells and 8.8 nm tensile (0.9%) strained barriers. The uncoated threshold current (both sections forward biased) is approximately 30 mA and the peak lasing wavelength is 1530nm.

The Bragg mirror is composed of 40 periods of λ/4 layers $GaAs/Al_{0.2}Ga_{0.8}As$ grown by MBE on a GaAs substrate. The wafer was not rotated during growth and due to the geometrical layout of the growth chamber, it therefore has a thickness and composition gradient across the wafer, which we use for tuning the laser.

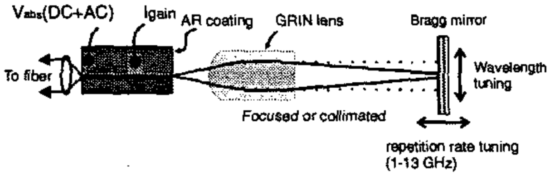

Figure 1: Schematic of mode-locked laser

Bragg mirror

The reflectivity of the Bragg mirror was measured using a white light source and referenced to a gold mirror. Fig. 2 shows a plot of the measured reflectivity in three different points on the mirror along a direction where the gradient is largest.

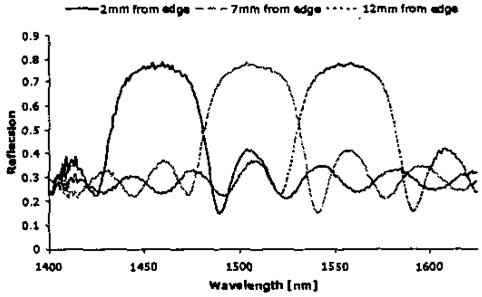

Figure 2: Reflection measurements across the center axis of the Bragg mirror.

The plot shows how the reflectivity peak moves as the position of the mirror is changed. The gradient is found to be 9 nm/mm. The bandwidth (FWHM) of the mirror is approximately 50nm and the peak reflectivity is approximately 78%.

Experiment

In this report we concentrate on passive mode locking of the laser at a repetition rate of 10 GHz using a focused beam on the mirror. Fig. 3 shows the autocorrelation trace and the spectrum of the pulse train at 10 GHz. The data were obtained with a current injection of 84 mA and at a reverse bias to the absorber of –0.638V. Furthermore, 20 m of standard single mode fiber were added to compress the pulse. The pulse was

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amplified in an EDFA and filtered using an external filter with a bandwidth of 2.7 nm. This results in a sech^2 pulse width of 3.79 ps and a spectral width of 1.81 nm, which is 2.72 times the transform limit.

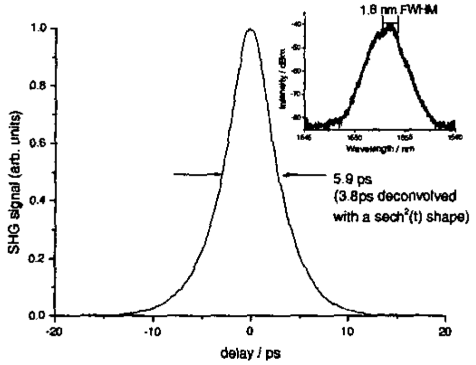

Figure 3: Autocorrelation of a 10 GHz pulse train using the Bragg mirror. Inset: optical spectrum.

The reason for the large residual chirp is that the laser chip length was chosen to be fairly long in order to reduce the magnitude of trailing pulses for a given epitaxial design and AR coating [3] (in the present case >20dB). This however, combined with the large confinement factor in the gain section, makes it possible for the pulses to strongly saturate the gain with additional chirp as a result. This effect is not related to the new cavity design and can be reduced either using a shorter chip or changed epitaxial design.

In the following we investigate the tunability of the laser when translating the Bragg mirror. The laser operating conditions have been optimized at each point and the results are summarized in Fig. 4. While the pulse width is seen to narrow for increasing wavelength the time-bandwidth product is nearly unaffected.

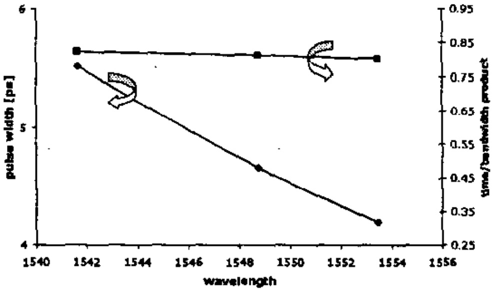

Figure 4: Pulse width and time bandwidth product (transform limit for sech^2: 0.315)

With the present mirror design the tuning range is limited to 1540 nm – 1555 nm. We speculate that the limited tuning range is due to satellite mirror peaks outside the stop band of the Bragg mirror. To support this we show in Fig. 5 the laser spectrum for two positions on the mirror. When tuned to 1550 nm a small shoulder is seen in the spectrum at 1530 nm corresponding to the first satellite peak of the Bragg mirror on the short wavelength side. Even though the reflectivity of this satellite peak is smaller than that of the stop band, the laser can overcome this due to larger gain at 1535 nm.

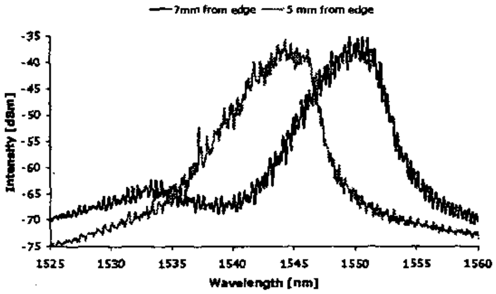

Figure 5: Optical spectra (unfiltered)

A straightforward way of reducing the side-peaks in the spectra is by applying an (uncritical) AR-coating on the Bragg mirror and use it as output coupler. This will reduce the peak/sidepeak ratio from around 3dB to 10dB, but also reduce the reflectivity by 25%.

Conclusions

We have demonstrated the use of a semiconductor Bragg mirror as the wavelength tunable element in a mode-locked external cavity semiconductor laser. In the present configuration tunability is limited to 15 nm, however, we have shown the potential of a tuning range above 100 nm in a single mechanical stable device.

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