

Dispersion management in passively modelocked integrated semiconductor lasers

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We report on the development of integrated femtosecond modelocked ring lasers that can serve as optical clocks in future all-optical THz rate data processing. The chirp of the pulses in these lasers is investigated and the dispersion of the integrated laser cavity is analysed.

To compensate for this dispersion and to compress the chirped pulse in the time domain towards the femtosecond regime an integrated dispersion compensating element is necessary. For this we propose and investigate the use of an Arrayed Waveguide Grating (AWG) pair

Introduction

State of the art passively modelocked semiconductor laser devices at 1.5 μm are able to produce pulses with a width of 1-2ps (e.g. [1]). Self-phase modulation (SPM) of the light in the semiconductor optical amplifier (SOA) and absorber and the dispersion of the laser cavity prevent the formation of shorter pulses.

To obtain well-defined sub-picosecond pulses an intracavity dispersive element is necessary to compensate the phase distortion. Mach-Zehnder interferometers [2] have been used as optical dispersion compensators but these can only compensate over a relatively narrow bandwidth (14GHz). In [3] an Arrayed Waveguide Grating (AWG) pair is proposed, but this particular design is not fully integrated and not suitable for integration in an active-passive semiconductor circuit.

In this paper we report on the investigation of the phase of the pulses in an InP/InGaAsP ring laser to gain insight in the spectral characteristics of the pulse and the possibilities for pulse compression. Thereafter the use of an AWG-pair as a fully integrated dispersion-compensating element for intracavity dispersion compensation and pulse compression is discussed.

Dispersion modeling

To model the dispersive effect of the laser elements a phase filter in the frequency domain is used. This approach is preferred over the use of time domain filters as it allows for the description of more complex dispersive elements. To this end the electric field of the pulse in the time domain is converted to the frequency domain using a Fourier transform. The electric field of the pulse is described by the following equation:

$$\begin{aligned} E(t) &= \sqrt{P(t)} e^{i\omega_0 t - i\varphi(t)} \\ \omega(t) &= \omega_0 - \frac{d\varphi(t)}{dt} \end{aligned} \quad (1)$$

in which $P(t)$ is the pulse power, ω_0 the optical carrier frequency and $\varphi(t)$ the chirp. The pulse is described with the parameter t in a time frame moving along with the pulse. The

instantaneous frequency is denoted by $\omega(t)$. This field is converted to the frequency domain using a Fast Fourier Transform algorithm over a 25ps time slot. This is done to be able to apply a frequency dependent filter function to the field. We intend to model a ring laser cavity with a pulse repetition rate of 40GHz (a period of 25ps). The distance between the frequency components in the Fourier domain corresponds to the separation between the laser modes of the ring laser structure ($\Delta\lambda=0.3\text{nm}$). The 2nd order dispersion in the frequency domain can then be modeled using the parabolic phase filter [3]:

$$H(\omega) = \exp\left[-\frac{i}{2}k''_{\text{tot}}(\omega - \omega_0)^2\right] \quad (2)$$

in which k''_{tot} is the total dispersion in $[\text{s}^2]$. In this paper we restrict ourselves to the analysis of 2nd order dispersion compensation.

Pulse compression

To gain insight in the spectral and temporal characteristics of the pulse from a passively modelocked bulk InP/InGaAsP laser the model presented in [4] is used along with the fit parameters defined therein. This model takes carrier heating, spectral hole-burning and two-photon absorption into account as well as ultrafast nonlinear refraction. As a first approach only the SOA section is taken into account, as this section is much longer than the absorber section and will dominate the nonlinear behavior. The chirp profile after one pass of the (unchirped) pulse through the SOA section is given in Fig. 1. The input pulse has a width of 1ps and a peak power of 0.1W. This corresponds to an input power of 4-5mW at 40GHz. As can be seen the pulse is linearly chirped (positive chirp) over the pulse center, which allows for compression by choosing the proper cavity dispersion.

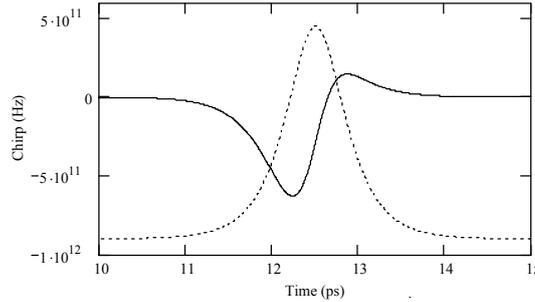


Fig 1. Characterization of the chirp (solid) of the pulse (dotted) after passing through the SOA, simulated using the model and parameters presented in [4]. The input pulse peak power is 0.1W and the pulse width is 1ps.

This pulse can be compressed with a maximum compression ratio of 10% at a dispersion value of $k''_{\text{tot}}=-0.08\text{ps}^2$. This is in agreement with the theory in [5], which predicts a maximum compression ratio of 1.085-1.11 for the pulse above assuming the chirp extends linearly over the whole pulse.

Dispersion compensation using an AWG-pair

To realize such dispersion compensation in a photonic integrated circuit, an AWG-pair setup such as depicted in Fig. 2 is considered. The first AWG separates the different wavelength components in the input pulse over its output waveguides (delay lines). The separate spectral components are then individually delayed in these delay lines to create chromatic dispersion. For this phase modulators can be used to make the setup tunable. Hereafter the second AWG combines the separate components back to the compressed pulse.

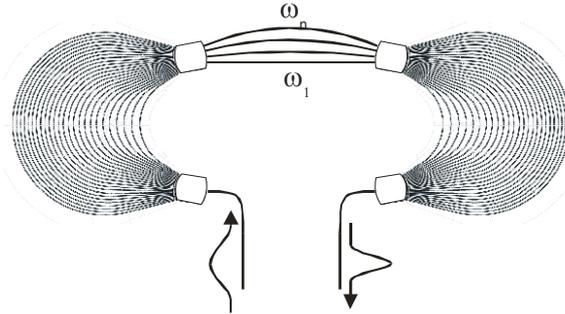


Fig. 2. The first AWG is used to convert the (chirped) pulse to the frequency domain, where the separate frequency components are separately delayed to compress the pulse. Then the second AWG recombines the frequency components to a shorter pulse.

We have selected an AWG channel spacing of 1.6nm (200GHz) to simulate the dispersive behavior. The phase filter to create a dispersion of -0.08ps^2 is depicted in Fig. 3. It represents the setting of the phase modulators or length of the delay lines between the two AWGs. This phase filter describing the dispersion is not smooth as the width of the delay lines is finite. It turns out this has no significant impact on the pulse shaping effect. Approximately 12-13 delay lines are necessary for this setup to have a good pulse shaping effect.

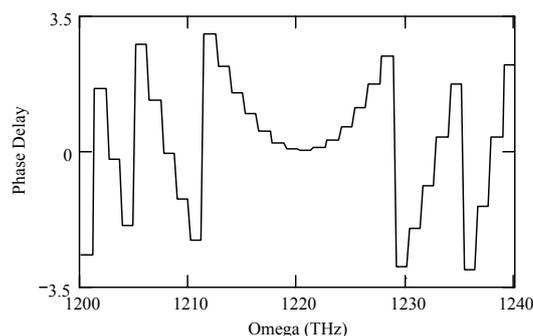


Fig. 3. Discrete phase filter for simulation of an AWG-pair with a channel spacing of 1.6nm.

Also the non-flat transmission of the AWG channels is simulated using a periodical sinusoid transmission in the filter function. This means that different laser modes (mode spacing 0.3nm) within one delay line get attenuated differently. This results in the formation of satellite pulses or, in the limit that only one mode is transmitted per channel, the multiplication of the pulse repetition rate (Fig. 4). The pulse compression is

still 10%, as the total bandwidth (the number of lines between the AWGs) is not influenced. The next step is to simulate the incorporation of such a dispersion compensating device in a laser model to check the intended intracavity function.

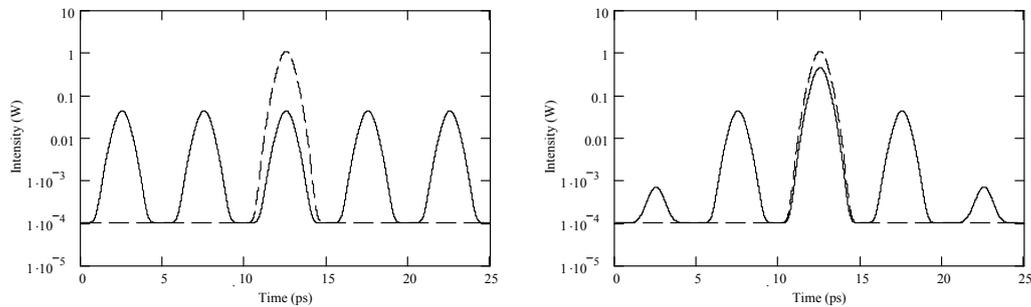


Fig. 4. Formation of satellite pulses for non-flat transmission of the five modes in a channel (solid, left) and transmission of only one of the five modes (solid, right). The pulse shape for flat transmission is given for reference (dotted).

Conclusion

We propose the use of an AWG-pair for dispersion compensation and pulse compression in a fully integrated laser structure. We have used a model from the literature to gain insight in the shape and magnitude of the chirp over the pulse after amplification by a SOA and the possibilities for pulse compression. This analysis shows that the pulse can be compressed by 10% after one pass through the SOA.

We have analyzed the effect of an AWG-pair on the chirped pulse. A model for the AWG-pair is presented. Based on this simulation it is shown that the AWG-pair is a practical solution that can be used as an integrated dispersion compensating and pulse-compressing element.

More extensive simulation with multiple roundtrips through a laser structure with a dispersion-compensating element has to be done to gain insight in the tuning parameters and maximum pulse compression.

Acknowledgements

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