Simulation of injection seeding of an integrated passively modelocked ring laser

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We have simulated an integrated injection seeded modelocked unidirectional ring laser with a fundamental repetition rate of 40GHz. The model is based on the transmission of a pulse through a semiconductor amplifier, an absorber and a passive waveguide. The amplifier and the absorber are described using rate equations. The ring is segmented in parts in which a uniform carrier and photon density in the active regions is assumed. A digital filter simulates the bandwidth limitation. Reshaping effects of the laser pulse and clock recovery were observed. This model will be used to analyse the behaviour of the mode-locked lasers we are currently producing.

Introduction

MODELOCKED LASERS are keys components for high bit rate telecommunication. In recent years Wavelength Division Multiplexing (WDM) has considerably increased the bit rate per fibre. Lately multi-terabit WDM transmission systems based on a channel rate of 40 Gbit/s have been reported [1]. A further increase in channel rate to 160 Gbit/s or higher will reduce the number of optical sources required and thus reduce costs and simplify the network configuration. As electronic multiplexing is expected to be limited to 40 Gbit/s for the coming years, Optical Time Domain Multiplexing (OTDM) is a solution to increase the rate per WDM channel. The application of OTDM requires clock recovery for demultiplexing the signals. In our project we are developing an All Optical Clock Recovery (AOCR) based on an injection seeded integrated passively modelocked ring laser. In this paper we present a simulation of such device with a fundamental repetition rate of 40GHz.

Modelocked laser device

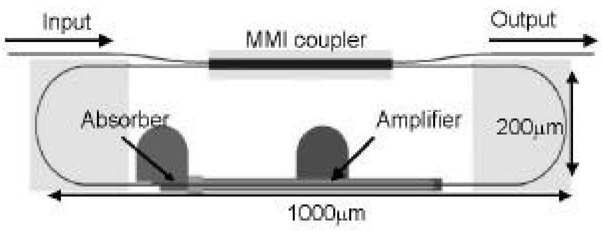

Fig.1 Layout of the MLL layer simulated.

The device that we designed and want to simulate will be realised in InP/InGaAsP material system with active-passive integration. The layout of the laser is showed in figure 1. The input and output waveguides of the ring laser are connected to an intra-cavity Multi-Mode Interferometer (MMI). Light entering at one input of the MMI is distributed evenly over its two output waveguides. Opposite to the MMI an active region is a bulk Semiconductor Optical Amplifier (SOA) integrated in the passive cavity. The SOA is separated in two sections. The first section is a 450µm long forward biased amplifier. The second is a 50µm long reverse biased saturable absorber. The length of the cavity corresponds to a Free Spectral Range (FSR) of 40 GHz. The laser will be injection seeded which will make it go unidirectionally.

Modelling

In order to simulate our device under injection seeding, a numerical unidirectional model has been developed. The amplifier and the absorber are described using rate equations. The ring is divided in segments that are equal in optical length (Fig.2). Uniform photon and carrier densities are assumed in the active region segments. A digital filter simulates the bandwidth limitation.

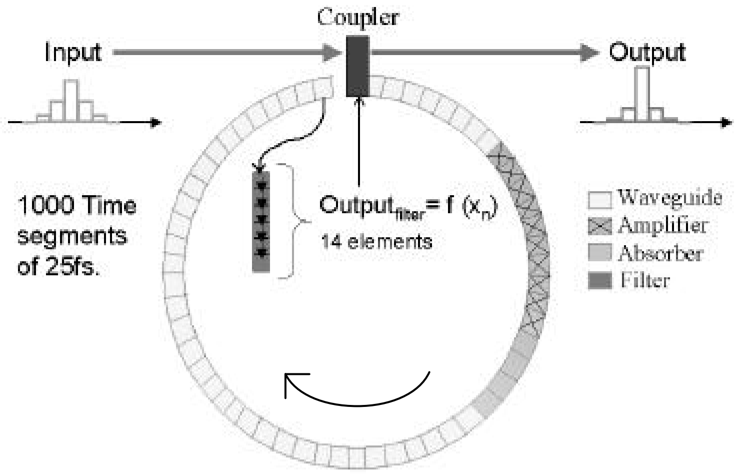

Fig.2 Structure of the MLL modelled.

Every 25fs the photon and carrier densities are calculated for all segments. Then the photon densities are transferred to the next segment and the carrier density values are saved in active segments for the next step. A 1000 segments in the ring form the 40GHz FSR laser cavity. The input light field is given as a series of intensity values, one for each 25fs segments.

The amplifier

The SOA is described using the two standard rate equations:

$$\begin{cases} \dfrac{d f(x,t)}{dt} = f(x,t)\cdot\left[(\mathrm{N}(x,t)-\mathrm{N0})\cdot\left(Vg\cdot a_{amp}\cdot\Gamma\right) - \dfrac{Loss_{seg}(x)}{t_{seg}} \right] + \mathrm{B}\cdot\Gamma\cdot\mathrm{N}(x,t)^2\cdot b \\ \dfrac{d\mathrm{N(x,\ t)}}{dt} = -Vg\cdot a_{amp}\cdot f(x,t)\left[\mathrm{N}(x,t)-\mathrm{N0}\right] - \dfrac{\mathrm{N}}{t_{carAmp}}\mathrm{B} - \mathrm{N}(x,t)^2 - C\cdot\mathrm{N}(x,t)^3 + W(t) \end{cases}$$

Here ϕ is the photon density, N is the active region carrier density, W(t) is the carrier density generated by the injection current, N_0 is the carrier transparency density, Vg is the group velocity, α is the linear gain coefficient, τ_{carAmp} is the carrier lifetime, B is the bimolecular recombination coefficient, C is the Auger recombination coefficient, Γ is the confinement factor, $Loss_{seg}$ are the losses for one segment, τ_{seg} is the time segment and β is the spontaneous emission coupling factor. The material parameters used have been obtained from the Apollo Photonics ALDS software. Using these parameters in a simple laser model, we have been able to fit a set of PI curves that were recorded from integrated extended cavity Fabry-Pérot lasers with varying amplifier length.

The saturable absorber

The absorber is a short SOA that is reverse biased, it is described with the same rate equation as the amplifier but with different values for several parameters. The reverse bias current through the SOA structure is negligible, so the pump rate is set to zero. In this mode, the carrier transparency density is two times smaller and the linear gain coefficient is four times bigger [2]. The field inside the SOA structure pulls out the carriers; the direct consequence is a decrease of the carrier lifetime. We used 30ps as a value in the absorber instead of 600ps in the amplifier.

The bandwidth limitation

The gain in the amplifier is wavelength independent in the model. To simulate the 50nm bandwidth of the amplifier ($400 \cdot 10^{12}$ rad/s) we implemented an external bandwidth limitation in the form of a digital Bessel filter (14th order). The filter transmission spectrum is close to the measured gain spectrum of an InGaAsP bulk amplifier (fig.3) and it is numerically stable. The coefficients are calculated using the MathCAD signal processing extension.

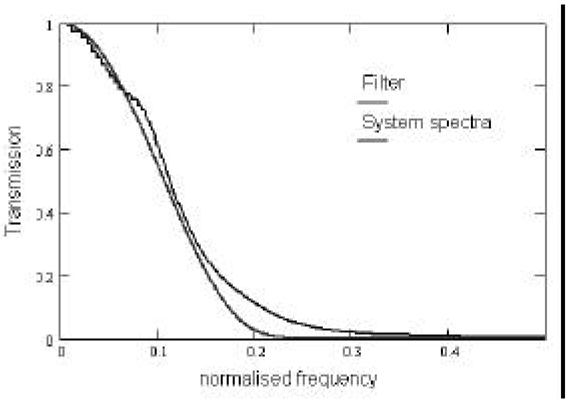

Fig.3 Spectra of the amplifier and transmission of the digital Bessel filter.

Simulation of an injection seeding

First the behaviour of the model is analysed when one pulse is injected into the cavity. The output of the laser with a pulse injected is shown in figure 4. The Full Width at Half Maximum (FWHM) of the input pulse is 3.0ps. The system shows relaxations for the first 30 roundtrips. During this time the carrier densities in the amplifier and the absorber are stabilising. Finally the energy of the pulse becomes constant but reshaping effects decrease the FWHM and increase the peak power to reach 1.0ps FWHM and 0.47W peak power.

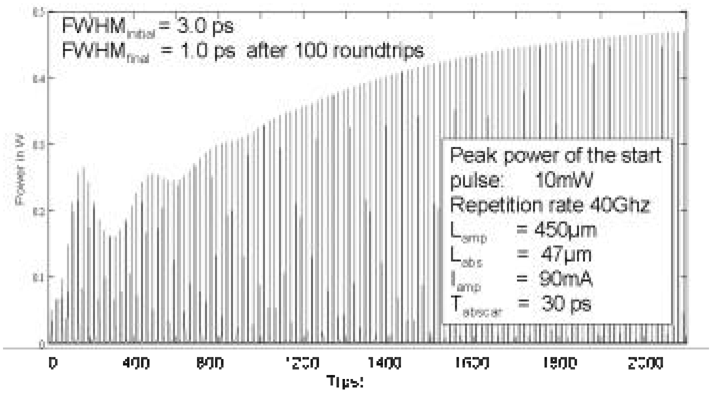

Fig.4 Output power vs. time initialised with a 3.0ps wide and 10mW peak power pulse (100 roundtrips).

Figure 5 shows the output repetition rate, pulse width and energy of the system, all as a function of time, when 60 pulses are seeded at 39.92GHz. First a pulse is inserted in the cavity to stabilise it (zone1). Then after 10 roundtrips the injection seeding at 39.92Ghz starts (zone 2). Two pulses are travelling in the cavity; a new pulse is growing up from the seeding and the initial one starts to disappear. After 10 others roundtrips this new pulse has more energy than the initial one (indicated by an arrow in the energy plot). The repetition rate corresponds to the signal seeded with a delay of

0.5ps. In the main time the pulse width of pulses are increasing. When 33 pulses are seeded the initial pulse disappears. The new one has the repetition rate of the seeding (zone3), the final FWHM is 1.57ps and the energy 0.8pJ. Finally the seeding is stopped (zone4). The system starts immediately to operate at 40Ghz. The energy decrease causes a minor relaxation oscillation, and the pulse width decreases to 900fs in 20 roundtrips. Similar results are obtained at 40.08Ghz.

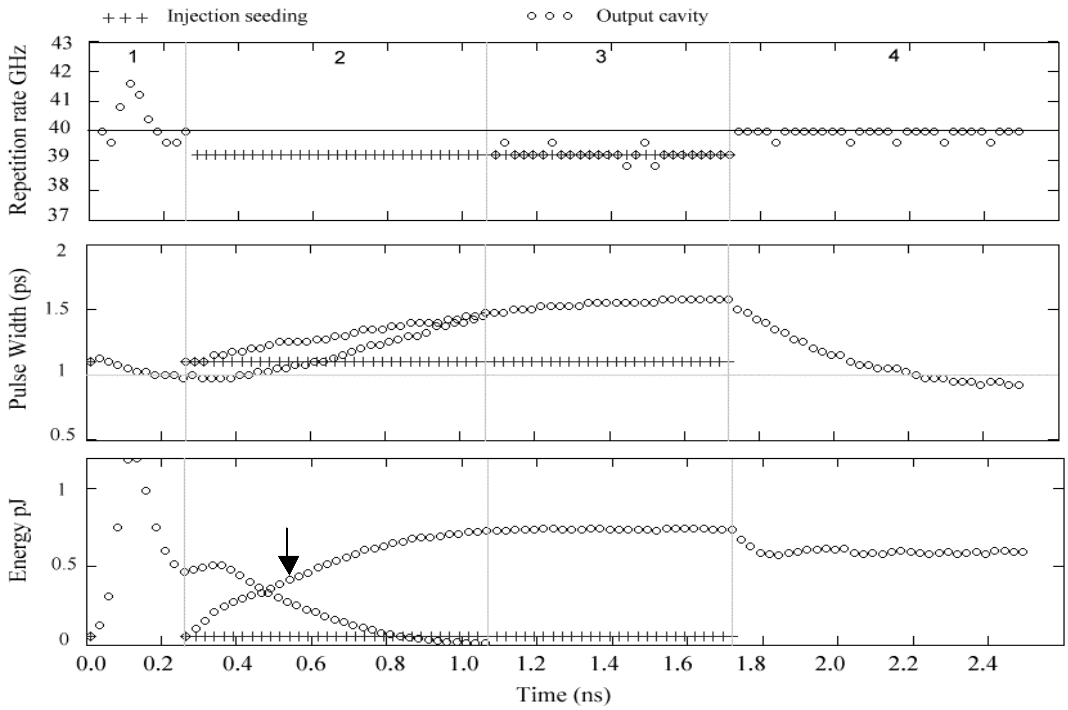

Fig.5 : Output repetition rate, pulse width and energy versus time of the laser when 60 pulses are seeded at 39.92GHz after an initialisation.

Conclusion

We have simulated an integrated injection seeded modelocked unidirectional ring laser with a fundamental repetition rate of 40GHz. 10 roundtrips are necessary to lock the system to an injected 40GHz pulse train. The range of locking was simulated at ±80MHz with an increase of 0.5ps of the FWHM and a delay of 0.5ps or ±40MHz with an increase of only 0.1ps of the FWHM and a delay of 0.4ps. Future developments will be a 160GHz injection seeding to 40GHz clock recovery and an extension to bi-directional operation. The model will be used to analyse measurements on the devices we are currently fabricating.

Acknowledgment

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References

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