

## Passively modelocked 15, 20 and 40 Ghz bulk InGaAsP lasers

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## **Passively Modelocked 15, 20 and 40GHz Bulk InGaAsP Lasers**

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*Passively modelocked linear lasers have been fabricated using bulk InGaAsP/InP material. Modelocking in 20 GHz self colliding pulse modelocked lasers and 40 GHz colliding pulse lasers has been demonstrated and the devices have been characterized. Pulse lengths down to 1.6 ps have been observed from a linear device at 20GHz. 15GHz modelocked ring lasers have been fabricated as well. In order to avoid internal reflections in the ring, the design employs successfully adiabatic bends and a directional coupler. Measurements with a 50GHz RF analyzer showed more stable operation than the linear devices, but pulses are highly chirped. The layer stack used for these lasers is compatible with our active-passive integration scheme.*

### **Introduction**

In this paper we report on three types of passively modelocked lasers using a 120 nm thick bulk 1.5  $\mu\text{m}$  InGaAsP gain region. Modelocking is achieved using a short reversely biased section of the ridge waveguide as a saturable absorber. The bulk InGaAsP active material is the same used in our active-passive integration technology with very low butt-joint loss and reflections [1]. We demonstrated 20 GHz Fabry-Pérot self colliding pulse modelocked lasers as well as 40GHz Fabry-Pérot colliding pulse lasers using such active bulk material. Pulse lengths down to 1.6 ps have been observed from the 20GHz device. 15GHz modelocking from a ring laser has been demonstrated as well. Measurements showed more stable operation than the linear devices. Furthermore the resulting 4.5 nm bandwidth obtained from the highly chirped pulses is a great source of interest for OCDMA applications [2].

### **20GHz SCPM laser design and performances**

The figure 1 shows the Self Colliding Pulse Modelocked (SCPM) lasers fabricated with different saturable absorber (SA) lengths at one side of the chip. A 2  $\mu\text{m}$  wide and 1985  $\mu\text{m}$  long straight ridge waveguide defines laser channel. The electrical isolation between SA and the amplifier is realized by a 15  $\mu\text{m}$  long section where 500nm of the top cladding have been etched ( $R = 150\text{k}\Omega$ ).

The largest operating range of modelocking has been obtained for the shortest saturable absorbers (10 $\mu\text{m}$  long). The range of modelocking is continuously reduced with the increase in absorber length. The SCPM with the 37 $\mu\text{m}$  long absorber did not modelock. The different lasing regimes of the SCPM with the 10 $\mu\text{m}$  SA are plotted in figure 2. Modelocking is achieved for a continuous range of reverse voltages on the SA between 0.9 and 2.4 V and a range of amplifier currents between 110 and 125 mA. For higher current self pulsation is observed in the RF spectrum. Short pulses down to 1.6 ps have been measured from this device. The corresponding RF spectrum is plotted in figure 3. A 10 MHz wide peak at -20 dB is visible at 19.65 GHz. The relaxation oscillation peaks at 1GHz are 40 dB lower. The autocorrelator trace and the optical spectrum are

plotted in figure 5. The optical spectrum shows some extra components at the lower wavelengths. The time bandwidth product is 0.76 which means the pulses are chirped. For larger pulses widths (2-3 ps) the spectrum is symmetric and the time-bandwidth product is 0.65. Depending of the settings the MLL frequency is between 39.73 and 39.78 GHz. We have observed a decrease of 50MHz in the repetition rate between the non modelocked state and the modelocked state.

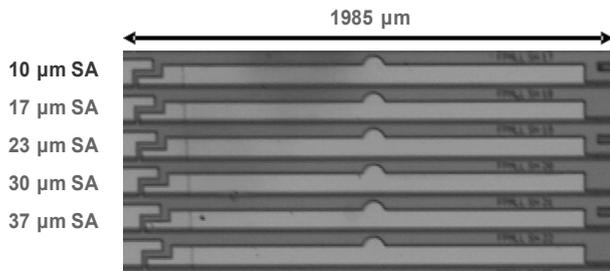


Figure 1: Top view picture of the 20GHz FP MLL

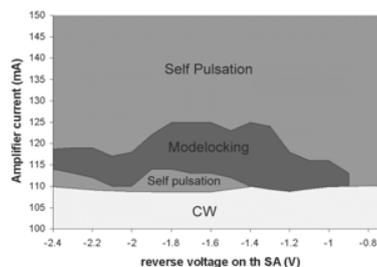


Figure 2: Modelocking regimes versus amplifier current and SA reverse voltage.

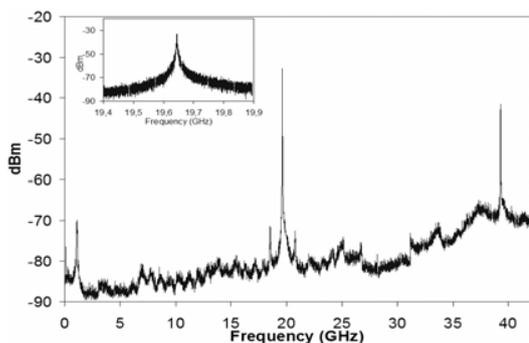


Figure 3: RF spectrum of a 20GHz 10μm long SA modelocked laser ( $I = 121.7 \text{ mA}$ ,  $V = -1.9\text{V}$ )

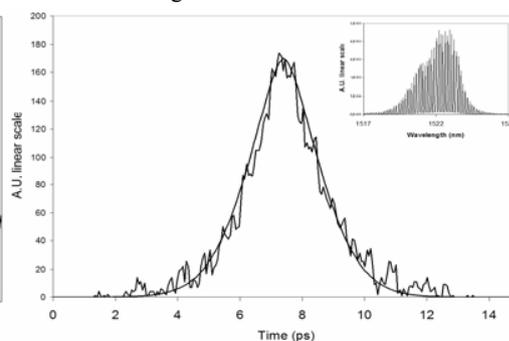


Fig 4 Autocorrelator trace of a 1.6ps pulse from a 10μm long SA modelocked laser ( $I = 121.7\text{mA}$ ,  $V = -1.9\text{V}$ ) with its corresponding optical spectrum.

### 40GHz CPM laser design and performances

Colliding pulse modelocked (CPM) lasers were fabricated on the same chip. The saturable absorbers are 20 or 40μm long and positioned in the center. From device to device the position of the SA is shifting by steps of 10μm; it guarantees that we have one laser with a well centered SA. The two amplifiers have the same electrical contact and are optically coupled through the SA. The symmetry of the device is very important in order to obtain large range of modelocking in CPM lasers. Modelocking has not been achieved with the series of devices with the 20μm long SA. But it has been achieved with the most symmetric device with the 40μm long SA. A longer SA could compensate the asymmetry, but still the modelocking range is limited. For high reverse voltage the MLL shows high dynamics dominated by the relaxation frequency of the amplifier. The dynamics of the asymmetric devices are currently under investigation. The operating range for the modelocked device has been found with reverse voltages between 0.6 and 1.1 V and pulses of 2.4 ps have been measured. On the 42GHz RF spectrum only a narrow peak at 39.75GHz is visible (figure 5). In detail there are two 5MHz wide peaks spaced by 10MHz. We conclude the laser operates with an overall intensity modulation

at 10 MHz. The autocorrelator trace shows well defined peaks spaced by 25ps without background (figure 6). Pulses down to 2.0 ps have also been measured with a higher reverse voltage on the absorber ( $V_{abs} = -1.1V$ ) however with some background.

### 15 GHz mode-locked ring laser design and performances

A picture one of the device 15 GHz mode-locked ring laser is plotted in figure 7. In

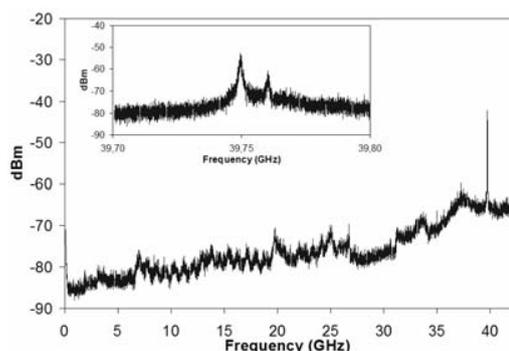


Figure 5: RF spectrum from a 40GHz CPMLL with 40 $\mu$ m long SA ( $I = 175.7$  mA  $V = -0.7V$ ).

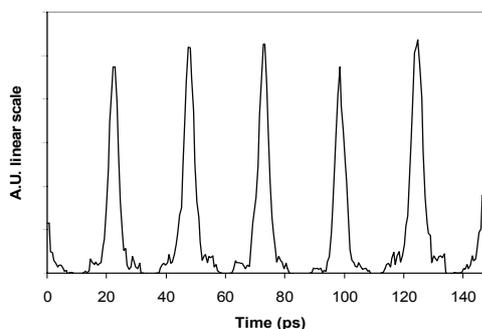


Figure 6: Autocorrelator trace of 2.4ps pulses from a 40GHz CPMLL (Labs=40 $\mu$ m  $I=175.7$  mA  $V=-0.7V$ ).

order to avoid any reflection, adiabatic bends and a 200 $\mu$ m long directional coupler are used. The coupler has the same electric contact as the amplifier. The two output waveguides have their own electrical contact and facet reflectivity is reduced using angled facets at 7° and AR-coating. The SA is 50 $\mu$ m long; its separate electrical contact is visible at the bottom of the ring. Every isolation section is 15  $\mu$ m long and under a 45 degrees angle with the waveguide.

The modelocking is achieved for a continuous range of reverse bias voltages on the SA between 0.9 and 2.2V and a range of amplifier currents between 410 and 460 mA (3.8kA/cm<sup>2</sup> and 4.4kA/cm<sup>2</sup>). Above 460mA the laser does not operate bi-directionally. The RF spectrum (figure 8) shows a 60 dB peak above the noise floor at the fundamental frequency. The linewidth is 5 times smaller than from the RF spectra of the linear devices. Furthermore, the optical spectrum is 4.5 nm wide (Figure 9). Pulses would be 600 fs long if transform limited but the autocorrelator reveals long pulses (4-5 ps) with sharper peaks on top. Those peaks are not coherence peaks but there are due to a partial compression of the pulse [3]. 7 ps pulses without sharp peaks are obtained by slicing the spectrum with a 1nm bandwidth filter. In order to better understand the results, we have performed simulations (unidirectional) using the model described in [4]. Results are a 3.3ps pulse wide (Figure 10) but very highly chirped (1.2 THz detuning). The spectrum obtained has the same width than the measured one. However as we could not compress the pulses using single mode fibers, the chirp over the pulse might not be linear due to the bi-directionality of the laser during MLL. Such laser with high bandwidth pulses and compatible with active-passive integration are a great source of interest for OCDMA applications [2] where information is coded in the spectrum.

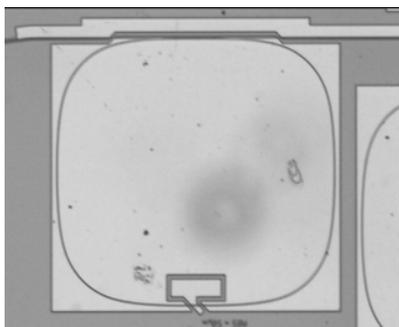


Figure 7 : Top Picture of the 15 GHz MLL Ring.

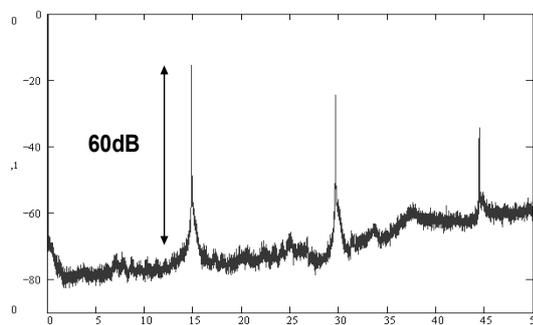


Figure 8: RF spectrum  $I=4.24\text{kA/cm}^2$   $V=-1.6\text{V}$

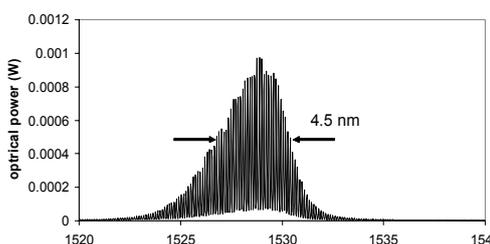


Figure 9: Optical spectrum  $I=4.24\text{kA/cm}^2$   $V=-1.6\text{V}$

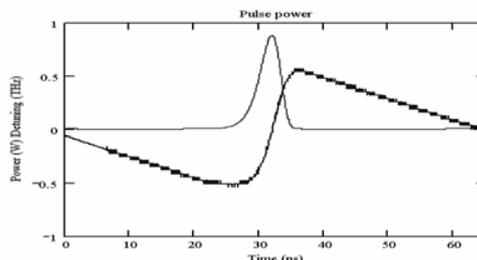


Figure 10: Simulation 3.3 ps pulse width 1.2THz detuning and thus 4.5nm BW

## Conclusion

Different passively modelocked lasers have been demonstrated using bulk InGaAsP/InP material which is compatible with our active-passive integration scheme. Pulses down to 1.6 ps have been demonstrated at 20GHz. High bandwidth pulses are of interest for OCDMA application have also been measured from 15GHz modelocked ring lasers. These results are very promising for future modelocked lasers using the benefits of the active-passive integration with very low butt-joint reflection.

## Acknowledgments

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