Amplitude noise and RF response analysis of 1 GHz mode-locked pulses from an InP-based laser chip at 1550 nm

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***Abstract*—In this work, we investigate a 1 GHz InP-based hybrid mode-locked laser chip and find an amplitude noise of 0.036 percent. An RF response simulation of its custom-designed mounting PCB is performed providing power transmission between 86 and 92 percent.**

***Keywords*—mode-locking, monolithic chip, amplitude noise, RF response**

I. Introduction

Over the past decades, semiconductor mode-locked lasers (MLLs) have become promising candidates for ultrashort pulse generation. In addition to compactness, their emission wavelength can be easily tailored during manufacturing. Thus, they are excellent devices for applications such as optical frequency comb generation [1]. For such an application, the longer the comb spacing is, the more suitable the system for single wavelength selection becomes. To achieve this goal, low repetition-rate (RR), up to 1 GHz, and highly timing stable system is demanded. External cavity diode lasers are typically utilized to obtain low RR pulses [2]. However, they feature a drawback of mechanical complexity leading to less stability of the system. In contrast, to meet the high stability need, monolithic MLL chips are typically the utilized sources. Due to the short optical waveguide of these chips, their pulse repetition-rate is consequently higher than 10 GHz. To overcome these drawbacks, the longest optical on-chip resonator was reported by Guzmán [3]. The chip is InP based which features RR of 1 GHz. In this work, we investigate the amplitude noise of an identical chip to that in the work of Guzmán [3] based on hybrid mode-locked operation. Furthermore, a custom-designed PCB is utilized to mount the chip. The PCB's transmission lines which guide the RF signals are designed to match the 50 Ω impedance demanded by the electronic spectrum analyzer (ESA). Moreover, a simulation of the RF response of the entire PCB is performed.

II. Laser Chip and Experimental Schematic

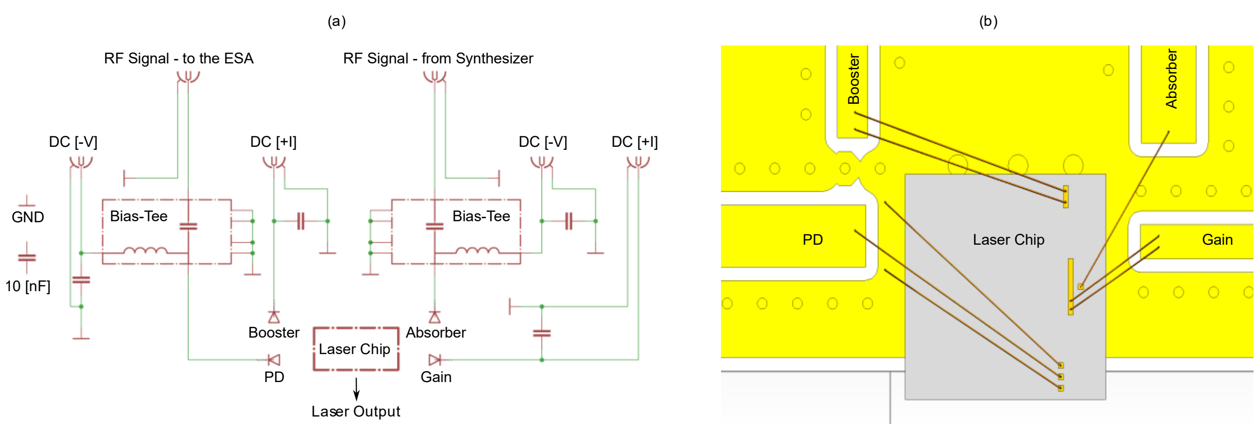

Fig. 1. (a) Schematic illustration of the chip with the custom-designed PCB. (b) Zoomed illustration of the chip, PCB and bond-wires.

Figure 1(a) shows an illustrative image of the chip along with the driving schematic. Four pads are introduced on the top layer of the chip allowing to operate the chip in the demanded regime. The laser resonator is defined between two multi-mode interference reflectors which are partially transparent to couple out part of the laser light. While one of the reflectors features laser output of the chip, the output from the other is boosted and fed directly in an on-chip photo

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diode (PD). The hybrid mode-locking scheme is realized by applying forward current to the gain section and a modulated voltage to the absorber section. The modulating RF signal is generated from an electronic synthesizer and combined with the DC voltage by utilizing a surface mounted Bias-Tee. Another Bias-Tee is introduced to enable applying a reversed bias voltage into the PD and realize an RF output signal which can be investigated with an ESA. Zoomed illustration of the chip and its related PCB's tracked as well as bond-wires are depicted in Figure 1(b). The PCB is simulated for determining the RF response. The RF transmission lines are realized as grounded coplanar waveguides with a linewidth of 1.1 mm and a gap of 0.24 mm on a FR4 substrate with 1mm height. With these parameters an impedance of 50 is achieved.

III. EXPERIMENTAL RESULTS

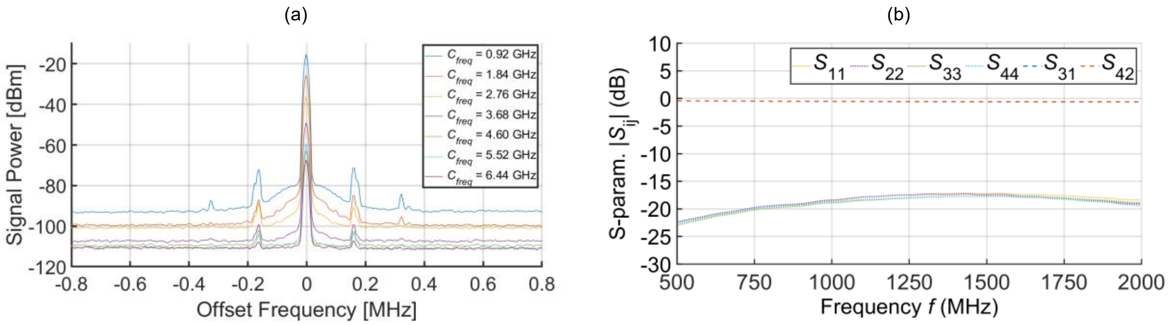

Fig. 2. (a) Low resolution spectra of the hybrid mode-locking laser. (b) S-parameters for frequencies 500MHz < f < 2000MHz of the entire PCB.

The chip is operated by applying 143 mA and -5.8 V into gain and absorber sections, respectively. A modulating signal with a power of 25 dBm from a synthesizer is applied into the absorber section to realize hybrid mode-locking scheme. The amplitude noise is investigated following the defined approach in [4]. The best amplitude noise stability is achieved by locking to 920 MHz modulation frequency. Figure 2(a) represents the first seven harmonics of this frequency, acquired at low resolution span and low resolution bandwidth of the ESA. Pronounced sideband spurs with a spacing of 165 kHz originates from the synthesizer can be also recognized. However, their contribution is negligible compared to the main mode due to the large power variation. The resultant relative amplitude noise is 0.036% from a high frequency contribution.

To verify the RF response of the PCB, we applied 3D electromagnetic simulations using CST Microwave Studio®. The 3D simulation model includes the PCB with bottom metal layer, FR4 substrate and the top metal structures as well as the blocking capacitors. Furthermore, the Bias-Tees and connectors are included by a netlist-based post simulation with the corresponding s-parameters of the single components with a reference impedance of 50 Ω. The resulting s-parameters for frequencies 500 MHz < f < 2000 MHz of the entire PCB including all components are depicted in Figure 2(b). Hence, the desired transmission of the PD and modulating RF signal $S_{3,1}$ and $S_{4,2}$, respectively, are between -0.63 dB and -0.36 dB. This corresponds to a power transmission between 86% and 92%. The reflection coefficients $S_{1,1}$, $S_{2,2}$, $S_{3,3}$ and $S_{4,4}$ are well below -16 dB, corresponding to a reflected power of less than 2.5%. The simulated isolations are below -67 dB and we conclude not to have them depicted for clarity of the figure. However, the real scattering parameters of the setup are typically influenced by the bond-wires, in particular the input impedance of the laser chip itself. This will be investigated in future work.

IV. CONCLUSION AND OUTLOOK

In this work, we present an investigation of the amplitude noise performance of a 1 GHz InP on-chip hybrid mode-locked laser at 1550 nm wavelength. The measured relative amplitude noise is 0.036% from a high frequency contribution. The RF response of the entire hosting PCB is analyzed resulting in a power transmission between 86% and 92%. In the future, we will investigate the input matching impedance circuit of the laser chip as well as the optical spectrum.

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