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Versatile high power pulse-laser source for pico- and nanosecond optical pulses

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Abstract

This paper presents a pulse-laser source for the generation of ps and ns laser pulses with more than 50 W peak output power. The final stages of the drivers use GaN transistors and are capable of switching currents of 0.8 A with 200 ps minimum pulse width and 50 A with 3 ns minimum pulse width. The pulses can be externally triggered by ECL logic. Both single-pulse and pulse train modes are possible.

1. Introduction

There is an increasing demand for semiconductor-based sources which emit laser pulses in the nanosecond and picosecond ranges with peak powers from several Watts up to more than 100 W. Shorter pulses in the time range from 20 ps down to 1 ps or less are needed, e.g., for applications in micromachining systems, for precision measurements [1], THz-imaging [2], THz spectroscopy systems and THz-time domain spectroscopy systems [3]. So far, such short pulses cannot be achieved by switching the current through the laser diode itself since this would require switching currents in the order of 10 A in time intervals below 20 ps.

Rather, so-called mode-locked lasers can be applied, which emit very short pulses but only in form of a train with repetition rates in the GHz range.

On the other hand, for some applications the ps pulses are too short, due to their low pulse energy. Instead, pulses in the ns range are of interest, which is true for applications in LiDAR systems.

Hence, it is advantageous to realize a gating system which can select single ps-pulses from a mode-locked optical GHz pulse train as well as generate short optical ps- and ns-pulses from a cw single-mode laser through gating. In both cases, an optical gate must be switched transparent and non-transparent by a suitable electrical driver, associated with an optical gate section.

This should be monolithically integrated with a semiconductor optical amplifier. The challenge in realizing such a ps pulse laser source is the development of fast electronic circuits capable of switching current pulses from 200 ps to 2 ns length with 0.8 A amplitude for gating. Moreover, in order to increase the optical pulse power, the final-stage optical amplifier should be switched, which demands a 50 A driver with 3–5 ns pulse width.

Common pulse gating techniques are based on Pockels cells, acousto-optical modulators, electro-optical modulators or integrated optical Mach–Zehnder modulators using optical fibers [4]. The disadvantages of these systems are the relatively large size, high cost, and the limitation in modulation frequency to pick out the pulses with a precise pulse selection.

There are only a few publications so far addressing microwave controllers like the one needed here. In [5–7], a pulse system with fixed pulse width, with synchronous triggering and active mode locking is described. However, this system cannot be triggered externally. Moreover, the active mode locking used there is not as stable as passive mode locking because of the necessary thermal tracking of two oscillators.

This paper presents an improved electronic driver based on GaN transistors which combines various functionalities. It enables realization of a compact short-pulse laser source where the working mode can be switched between mode locking and pulse gating operation. The generation of 3–20 ps optical pulses with a pulse power $>$ 50 W in mode-locking regime as well as optical pulses from 200 ps—2 ns with a pulse peak

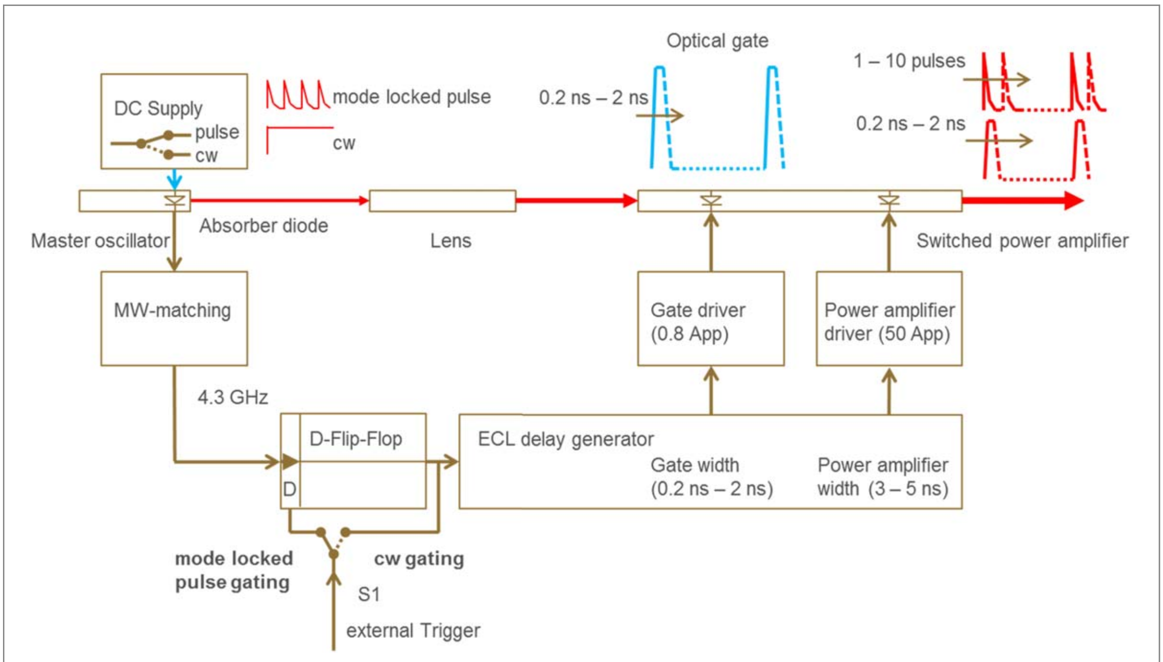


Figure 1. Block diagram of compact short pulse laser system.

power $>$ 10 W in pulse gating regime are demonstrated, using this driver together with a fast microwave controller. This system can be easily triggered externally with low jitter. The paper is organized as follows: section 2 explains the pulsed laser source, its key components and the principle of operation. Section 3 presents the system realized and the measurement data, while section 4 adds the conclusions.

2. The compact short pulse laser system

2.1. Complete system

The block diagram of the complete system is shown in figure 1. It comprises a compact optical 1030 nm picosecond light module and newly developed electronic circuits with high-speed drivers.

The short-pulse laser module (see figure 1) consists of a 10 mm long multi-section distributed Bragg reflector (DBR) laser acting as master oscillator (MO), an ultrafast multi-section optical gate and a flared power amplifier (PA), mounted together with the high-frequency electronics and the optical elements on a 5 $\times$ 4 cm micro bench. The 10 mm long five-section ridge waveguide (RW) DBR laser consists of a 200 μm long saturable absorber, a 1500 μm long gain section, an 8000 μm long cavity, a 200 μm long DBR and 100 μm long monitor sections.

The 2 mm long multi-section optical gate (OG) and the 4 mm long gain-guided tapered power amplifier (TPA) are monolithically integrated. Both the MO and the TPA with optical gate were grown by low-pressure metal organic vapor phase epitaxy (MOVPE) and have active InGaAs double quantum well's (DQW's).

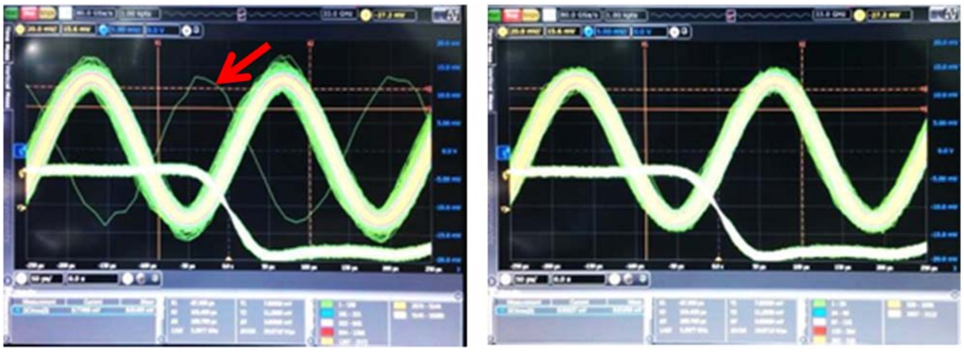
The output signal generated by the MO is coupled by a GRIN-rod lens into the input of the OG. For collimating the output beam from the amplifier, a three lens system is used. The optical path of the module is indicated in figure 1 by the red arrows.

The light source can be switched between pulse gating and passive mode locking operation. For pulse gating all sections of the MO (except of the DBR and monitor sections) are forward biased and driven by a constant current. For mode locking the output section of the MO is used as an absorber and biased with a reverse voltage.

The repetition rate of the laser in mode-locking regime can be calculated by

$$f_r = \frac{c}{2l * n} \qquad \begin{array}{l} f_r - \text{Round trip frequency} \\ l - \text{Cavity length} \\ c - \text{Light velocity} \\ n - \text{Refraction index(square root of relative dielectric constant)} \end{array}$$

with f_r denoting the round trip frequency of the optical cavity. The 10 mm length of the MO corresponds to an operating frequency of about 4.3 GHz. For most of the applications, repetition rates in this range are too high and one should be able to adjust them from single shot to 50 MHz. This can be achieved with the optical gate.



(a) D-Flip-flop with failure (b) D-Flip-flop with double buffering

Figure 2. (a) D-Flip-flop with failure. (b) D-Flip-flop with double buffering.

Since many applications require external triggering, one has to combine the external trigger with the mode-locked laser pulse clock for controlling the optical gate.

Basically, such a controller is a key component for all short pulse systems working in the high power range. The main challenges in realizing it are (i) to have fast-switching transistors with the appropriate current capabilities as well (ii) to combine an external trigger with the optical ps pulses with low jitter. As regards the first item, the high peak currents are needed to drive the short current pulses properly through the parasitic board and laser inductances into the laser diode, which, to a first order, represents a low-impedance ohmic resistor in parallel with a high parasitic capacitance of some nF.

The electronic signal detecting the round trip frequency in the GHz range can be taken from the absorber diode, one of five sections of the master oscillator (MO). In our case, we have 4.3 GHz. This diode has a further function: Varying the reverse voltage changes the quality factor of the internal cavity and hence the pulse width. In this case, a range of 3–20 ps is covered.

Due to the nonlinear characteristics one can also synchronize the internal MO repetition pulse frequency with an external electronical reference source by feeding a signal with nearly the same frequency as the repetition frequency of the MO, i.e., one can perform active mode locking. This possibility is not used here.

2.2. Trigger stability

An external asynchronous trigger signal, e.g., from a micromachining system, is synchronized with the repetition frequency of the laser pulses by a microwave D-type flip-flop. Since the trigger signal is asynchronous, occasional violations of set and hold times occur and the flip-flop can assume metastability [6, 8].

The following equation describes how the mean time between failures (MTBF) depends on the clock and trigger frequencies and technological based timing data of the used flip-flop:

$$MTBF = \frac{e^{t_{MET}/c_2}}{c_1 \cdot f_{CLK} \cdot f_{DATA}}$$

MTBF – Meantime between failures
t_{MET} – Metastability settling time
f_{CLK} – Clock frequency
f_{DATA} – Data(trigger)frequency
c_1, c_2 – Device time constants

A reduction of t_{MET} leads to an exponential improvement of MTBF. t_{MET} can be reduced by a synchronization chain of several flip-flops and by employing the proper statistical rules. Using two flip-flops only reduces the failure to an acceptable level already.

Figure 2 shows the round trip signal (4.3 GHz) triggered by the resulting falling edge from the output of the D-type flip-flop. As can be seen, a trigger error may lead to a failure in the round trip signal. This is documented in figure 2(a), where only one D-type flip-flop is used. With double buffering using two flip-flops no error is detected within the observation period any more (see figure 2(b)).

2.3. Output driver stages

Digitally controllable analog ECL-delay-generators deliver the delayed pulses for the final driver stages (see figure 1).

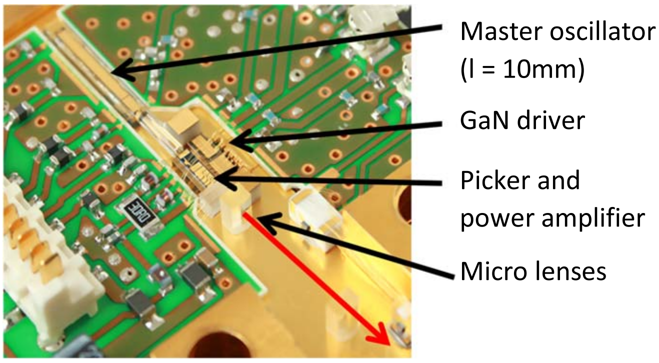


Figure 3. Realized module.

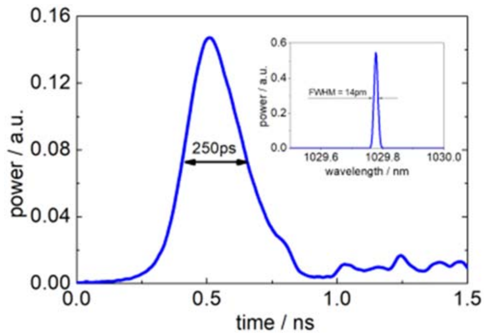


Figure 4. Pulse with 0.25 ns pulse width, generated by cw-pulse gating.

In the optical path, an optical gate separates the laser pulses. The driver for this gate can switch up to 0.8 App with current pulse widths down to 200 ps. It uses GaN transistors placed directly at this section of the laser diode. A second power section acts as an amplifier to boost optical output power. The respective driver uses GaN-transistors as well, generating 50 App pulses of 3–5 ns width.

GaN is the material of choice here, because it has the best ratio between output current per input capacitance among the common semiconductor materials. Essential is that one has higher output currents than other semiconductor materials due to the high 2D electron density [7, 9].

If the D-type flip-flop is bypassed with switch S1 (see figure 1) and the MO is switched to cw-mode by using suitable bias points, which reduce the quality factor of the laser cavity, the laser pulses can now be cut from the cw signal with the optical gate driven by the GaN driver. In this case, the resulting optical pulse width can be controlled by the electrical pulse. The minimum width is determined by the driver's and optical gate's switching speed.

Using these two operation modes, one can generate both ps-pulses (3–20 ps) or gated ns-pulses (0.2–2 ns) with just one setup and an external trigger, from single pulses to a pulse train with 40 MHz repetition rate.

3. Realization and measurement results

Figure 3 shows the realized module with the different optical and electronical parts. Realized module.

Figure 4 presents an example of a 250 ps optical pulse with a MHz linewidth, generated by pulse gating from a cw signal and measured with a real-time oscilloscope, while in figure 5 two examples for picked mode-locking pulses with different ps pulse width are plotted. The pulse widths were adjusted with the absorber voltage U_a and measured by an autocorrelator. The inset in figure 4 shows the single mode optical spectrum.

Figure 6 demonstrates the pulse selection in the mode-locking regime of the laser module. The external trigger frequency is approx. 1 MHz. The measurements are performed with a real-time scope. The fluctuations of the amplitude of the measured laser pulses are the result of the asynchronous relationship between the clock of the mode-locked laser oscillator and the reference clock of the scope.

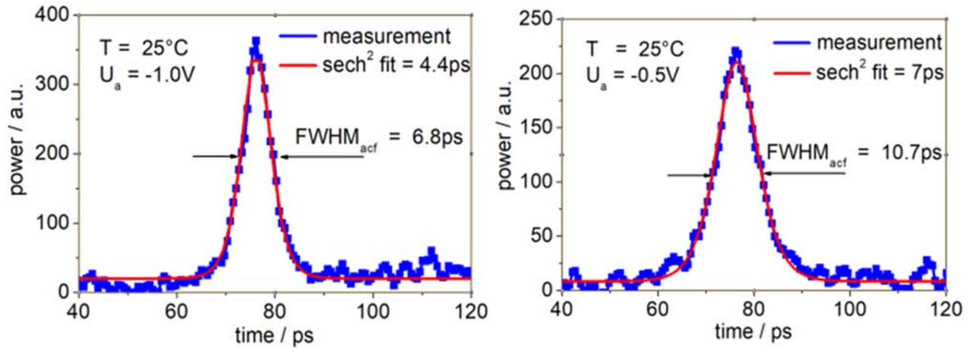


Figure 5. Pulse generated in mode-locking operation, for two different absorber voltages of −1 V (left) and −0.5 B (right).

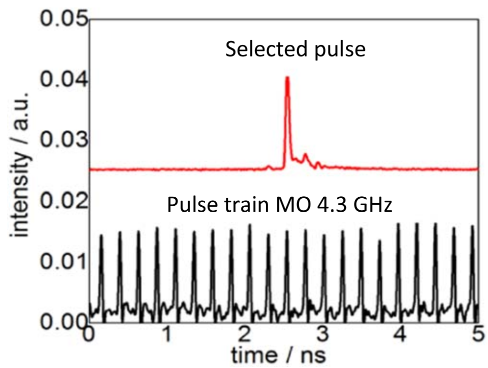


Figure 6. Pulse selection from a 4.3 GHz pulse train.

Table 1. Comparison of different laser sources.

	Solid state laser	Fiber laser	Mach–Zehnder modulator	This semiconductor laser module
Flexibility wrt pulse width	-	-	+	++
Flexibility wrt repetition rate	-	-	+	++
Flexibility wrt wavelength	-	-	+	+
Functionality	+	+	-	+
Compactness	-	+	+	++
Output power	++	++	+	+
Cost	-	-	+	++

4. Conclusion

Using a new high-current high-speed GaN microwave controller we realized a pulse-laser source with unprecedented performance: it can generate optical pulses of variable width and high power in both the ps-range (3–20 ps with 50 W) and the ns-range (0.2–2 ns with 10 W). The resulting module is of small size and mechanically very robust. Table 1 illustrates its benefits compared to the types of laser sources. Particularly, the cost advantage is to be mentioned, which is due to the cost-efficiency of semiconductor wafer processing in high-volume series production.

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