Laser Diode Pumping with a Transmission Line Transformer

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Abstract—**A semiconductor laser was fed by a high-frequency transmission line transformer in an impedance matched circuit. The laser threshold for short duration electrical pulses is showed to be significantly lower than with conventional 50 Ω transmission line arrangements. This set-up can be used to increase the overall efficiency of laser diode systems.**

IN order to exploit fully the potential of optical communications, it is necessary to make use of high-speed light sources. In particular, systems have been described where semiconductor lasers were modulated at frequencies above 15 GHz [1], [2], and picosecond and subpicosecond optical pulse generation with laser diodes has been reported by several groups [3], [5]. A key factor in most systems is pumping the laser diode with an electrical pulse of short duration, in order to quickly raise it above lasing threshold. Comb generators, avalanche transistor circuits or direct RF modulation circuits can all provide the necessary current levels required with adequate pulse durations, in spite of the poor impedance matching that exists between the transmission line normally used (50 Ω) and the laser characteristic impedance (< 5Ω). In order to minimize spurious reflections, it is common practice to introduce a ~ 47 Ω resistor physically close and in series with the laser, matching the impedance of the load but dissipating most of the available electrical power. Clearly, it should be very advantageous to drive the laser in an impedance matched circuit and make full use of the electrical power available, but little attention has been payed in the literature to this important problem. A microstrip Chebyshev transformer, using a hybrid combination of lumped elements and transmission lines was proposed theoretically. The calculated centre frequency of this bandpass coupler is 10.5 GHz [6]. Recently, a high-pass transmission line transformer (TLT) without lumped elements was reported [7], which matches with large bandwidth 50 Ω transmission lines with low impedance components such as laser diodes and PIN photodiodes. In this letter, we demonstrate a significative reduction in the electrical pulse amplitude required to take the laser above threshold with the TLT, as compared to conventional arrangements.

A d.h. GaAs/AlGaAs laser (λ = 0.83 μm, Ith = 118 mA) was used in the experiments. A more detailed description of the TLT is given elsewhere [7], but here it was constructed on a 0.254 mm thick alumina substrate ($\epsilon_r = 10$), and designed to have 50 Ω impedance at one end and 5 Ω at the other end. Its length was 5 cm, it had a ground plane on the lower surface of the substrate and a centre line widening linearly from 250 μm to 1.2 mm along the structure, while the gap to the coplanar earthed semi-planes on either side of the line varied exponentially from 1.24 cm to 10 μm. Finally, a ground plane approached the top surface of the substrate along the structure (from 8 mm to 50 μm). The diode laser was wire bonded to the low impedance port and an SMA connector to the 50 Ω port. Time domain reflectometry (TDR) tests using the laser biased with dc above threshold through the TLT showed that the impedance gradually reduced along the structure, reaching the laser impedance (~ 5 Ω) at its end. A sharp peak of inductive nature was observed between the TLT and the laser, and was ascribed to the thin connecting bond wires between the TLT, submount and laser. A very similar peak was also observed when a TDR trace was made with a conventional 50 Ω transmission line arrangement to feed the laser.

The optical response of the laser diode fed by the TLT was compared with the response of the same laser, obtained by conventional coupling methods under fast pulse excitation. The experimental set-up is illustrated in Fig. 1. By using appropriate networks, a dc bias current and short electrical pulses were applied to the laser diode through the TLT (as shown) or alternatively trough a 50 Ω microstrip transmission line. The electrical pulses were obtained from a InP photoconducting switch activated by the picosecond laser pulse train of a CW *Q*-switched and mode-locked Nd:YAG laser, in conjunction with a picosecond electrical pulse shaper (PEPS) [8]. The pulsewidth of the frequency-doubled light from the Nd:YAG laser was approximately 70 ps, and this set the lower limit to the duration of the electrical pulses produced. Longer electrical pulses (100 ps) were generated by replacing the length of the branches used in the PEPS. The peak amplitude of the voltage pulses available was 10 V, and this level could be reduced by adjusting the dc bias to the InP switch. The optical pulses produced by the laser diode under pulsed excitation (plus dc bias) were monitored with a fast Ge photodiode (Optoelectronics PD-40) and a 75-ps resolution sampling oscilloscope.

Fig. 2 illustrates the experimental results obtained with the

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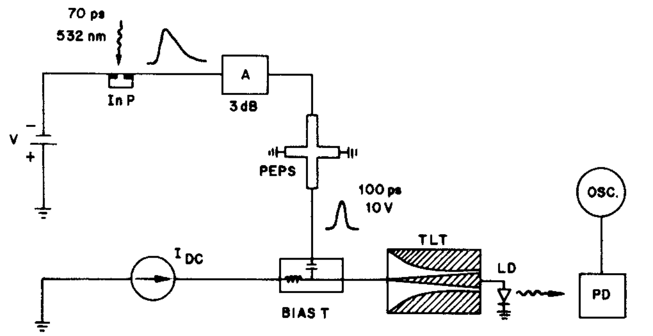

Fig. 1. Experimental set-up to characterize the coupling efficiency of TLT as compared to a conventional 50 Ω arrangement.

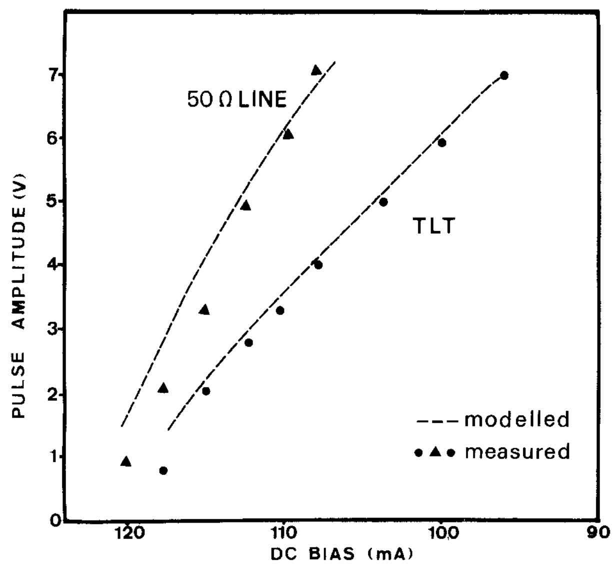

Fig. 2. Performance of TLT as compared to 50 Ω microstrip line. The amplitude of the 100 ps electrical pulses needed to take the laser above threshold (plus dc bias) is approximately halved.

laser diode fed by the TLT or alternatively by a 50 Ω transmission line (without matching resistor). A plot is shown of the peak voltage of the electrical pulse (V_p) versus the minimum level of dc bias current (I_0) simultaneously required for the semiconductor laser to produce short optical pulses. The comparison is shown for an electrical pulse duration 100 ps (FWHM). For a given dc bias level (e.g., 110 mA), the amplitude of the 100 ps voltage pulses needed to take the laser above threshold (3 V) with the TLT is much less than with the conventional 50 Ω line (6 V). The improvement in the short electrical pulse coupling efficiency was even more marked when the pulsewidth was reduced from 100 ps to 70 ps (~3 times lower voltage pulses needed) confirming the good performance of the transmission line transformer for higher frequencies. It should be noted that in the case when the laser was fed through the 50 Ω transmission line with a 50 Ω matching resistor, no optical pulses were produced with either 70 ps or 100 ps electrical pulse pumping showing that most of the power available is dissipated.

The experimental results of Fig. 2 were also compared with theoretical predictions. A SPICE program (version 2G.6) was employed to simulate the response of the laser diode, and

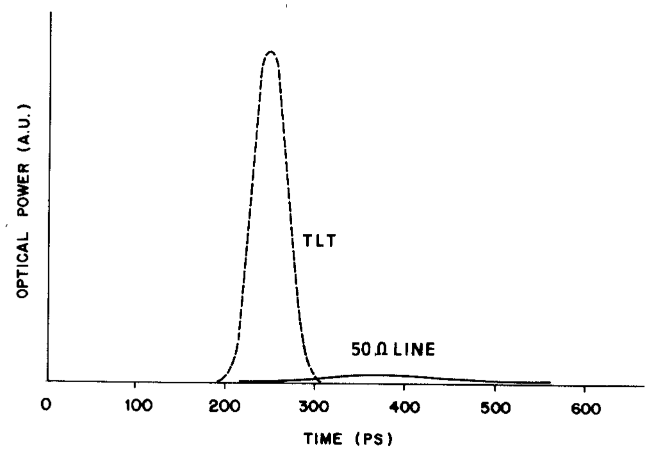

Fig. 3. Calculated response of laser diode in the regime of gain saturation coupled with the TLT or with a 50 Ω transmission line.

the model used is described in greater detail elsewhere [9]. In this simulation the laser was fed by a dc current source and a voltage source producing a short triangular pulse (100 ps FWHM) capacitively isolated from the dc supply. The TLT was simulated by a series of 10 small steps where the impedance is gradually altered from 50 Ω to 5 Ω. Alternatively, the coupling was assumed to be through a 50 Ω transmission line connected directly to the laser or through a matching resistor. The *P-N* junction was described by an ideal diode, the parasitic capacitance was taken to be 10 pF, the series resistance 5 Ω and the inductance of the bond wire 2 nH. It was possible to predict with an error $<5\%$ the dc bias level that should be added to the short electrical pulses to reach lasing threshold. Knowing that the behavior of the laser could be well described by the model, we extended the calculations to evaluate the effect of gain saturation. Fig. 3 shows the calculated response of a laser coupled through the TLT and through a 50 Ω line to a pulse of amplitude 30 V and duration 200 ps. The higher coupling efficiency results in higher optical power and consequently greater gain saturation, so that the pulsewidth is significantly shortened. The time delay for laser action to start is also reduced, as shown in Fig. 3.

Other simulations showed that even when the mechanism of gain saturation is negligible, the response time of the laser diode to rapidly varying electrical signals is faster (1.5 times) when the laser is fed through the TLT. The reason for this is that the stray capacitance of the laser, that normally discharges solely through the laser diode itself, now can discharge through the feeding line also, since its impedance is low. A similar increase in bandwidth has been experimentally observed when a TLT replaced a 50 Ω transmission line in a PIN photodiode circuit [7]. Therefore, the use of the TLT is expected to improve considerably the overall bandwidth of laser diode arrangements also, with potentially important consequences in optical telecommunication systems.

In conclusion, the use of the transmission line transformer, which acts as an impedance-matching coupler is shown to bring about improvements in the efficiency and should also increase the bandwidth of semiconductor laser systems. Its use is advantageous in high-speed laser diode applications and it should make it possible to drive semiconductor lasers with fast electronic components such as tunnel diodes that otherwise switch electrical signals with insufficient amplitude.

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