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Citation: Review of Scientific Instruments **75**, 1369 (2004); doi: 10.1063/1.1711146
View online: http://dx.doi.org/10.1063/1.1711146
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REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 75, NUMBER 5 MAY 2004

Photoconductive generation of short electrical pulses of variable duration using a coplanar waveguide with capacitively coupled ground termination

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(Received 18 September 2003; accepted 23 February 2004; published 27 April 2004)

Short electrical pulses with variable duration are generated by optically exciting a coplanar waveguide that is capacitively connected to a ground termination. The underlying concept is based on the superposition of the original pulse and the reflected one with an opposite sign and a variable round trip delay. By sliding the pump beam along the coplanar waveguide, generation of short electrical pulses with different peak voltages, widths, and signs are demonstrated in a laser-diode-based system. © *2004 American Institute of Physics.* [DOI: 10.1063/1.1711146]

Photoconductive switches excited by short optical pulses have been widely used for generations of short electrical pulses.[1] These pulses are useful in a variety of applications, for example, the characterization of high-speed or high-frequency devices and circuits.[2,3] Electrical pulses generated by these switches usually exhibit fast rise and an extended tail that is mainly determined by the carrier recombination time. The photoconductive switches are thus fabricated on materials with a short carrier lifetime, such as low-temperature-grown GaAs (Ref. 4) or radiation-damaged materials.[5] Nonetheless, the preparation of these materials requires additional processes that may not be compatible with the fabrication of standard devices or circuits. Moreover, short carrier lifetime almost always implies low mobility and correspondingly low photoconductive gain. Short electrical pulses can also be generated by nonuniform illumination[6–8] of a charged coplanar transmission line or by pulse forming circuits,[9] both on materials with a long carrier lifetime. The pulse forms generated by this approach, however, are generally difficult to reproduce. Alternatively, one can suppress the slow components by using two optical pump beams to generate two steplike electrical transients with an opposite sign and then superimposing the signals. Electrical pulses from 450 fs to 3 ps have been generated on coplanar strip lines and coplanar waveguides, fabricated on a semi-insulating GaAs substrate.[10]

Here, we report a single-pump-beam method to produce short electrical pulses of variable duration on photoconductive switches also fabricated on a semi-insulating GaAs substrate. This method is based on the superposition of an incident and reflected electrical pulse. The coplanar waveguide is optically excited by a sliding contact scheme. The electrical pulse so generated is capacitively coupled to a ground termination, which generates a reflected electrical pulse with an opposite sign as well as a variable round trip delay. In this way, we not only shorten the fall time of the electrical pulse but also vary its duration.

To generate a reflected electrical pulse with an opposite sign and at the same time preserve the bias, the original pulse, after propagating a length ℓ along the coplanar waveguide, is coupled to a ground termination (GT) through a capacitor (C). The reflected pulse, after undergoing a time delay $t_d=2(\ell/v_w+d/v_c)$, is superimposed onto the original one. Here, d is the effective length from the waveguide through the bonding wire, coaxial cable (CC), and the C to the GT, and v_w and v_c are the wave velocity on the coplanar waveguide and CC, respectively. In general, the time delay can be expressed as $t_d=Nt_p+\Delta t$, where N is a positive integer, t_p is the repetition period of the pump pulse train, and Δt is the delay of the reflected pulse relative to the adjacent original pulse. When $N=0$, $t_d=\Delta t$, the time delay and hence the propagation loss and dispersion for the reflected pulse are minimized, and the shortest pulse may be achieved. To effectively eliminate the long tail of the original pulse without significantly reducing its amplitude, the time delay Δt needs be adjusted to a value which is related to the rise time of the original pulse. On the other hand, for $N>0$, an additional delay must be introduced and this inevitably causes additional loss and dispersion for the reflected pulse. In addition, Δt is negative if the reflected pulse is in front of the original pulse and vice versa. By changing the photoexcitation position and, consequently, the time delay, we can obtain short electrical pulses with different peak voltages, widths, and signs.

A laser-diode (LD)-based system is used to demonstrate the proposed technique. We carry out an experiment as shown in Fig. 1. A coplanar waveguide fabricated on a semi-insulating GaAs substrate is used as a sliding photoconductive switch (PCS). The waveguide is terminated on one end by connecting a CC via a dc block or C to the GT. In this

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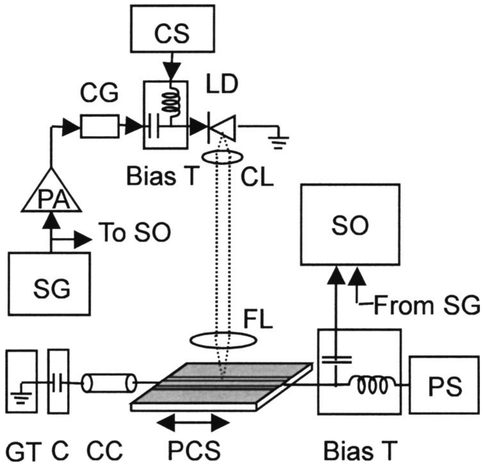

FIG. 1. Schematic diagram of the experimental setup.

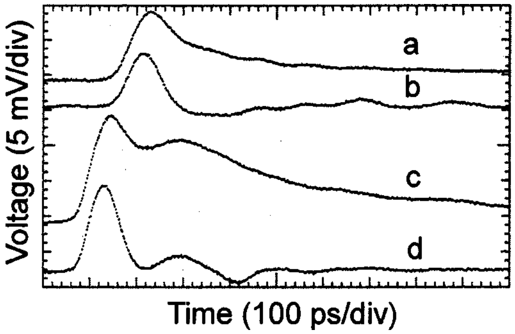

FIG. 3. Short electrical pulses generated by optical excitation of the coplanar waveguide with impedance match [(a) and (c)] and GT [(b) and (d)] using a normal-biased [(a) and (b)] and an overbiased [(c) and (d)] gain-switched LD. For clarity, different offsets are added.

preliminary experiment, the C and the GT are not integrated into the available switch, but are externally integrated to the coplanar waveguide. This results in a longer time delay and gives rise to $N>0$. The length of the CC is chosen to satisfy the relation $t_d=t_p+\Delta t$, that is $N=1$. One may choose a larger N by using a longer CC, but this can introduce additional loss and dispersion for the reflected pulse and degrade the pulse-shaping effect. The light source used in the experiment is a gain switched LD system. The gain switched LD system consists of a signal generator, a power amplifier, a comb generator, a bias network, a current source, and a LD. By applying a bias current of 10 mA and a 90-ps-wide electrical pulse with peak current of 110 mA into the LD, we can generate optical pulses with widths of about 40 ps at a repetition frequency of 520 MHz and an average power of 2.3 mW ($\lambda=865$ nm). The output of the gain switched LD is collimated by a 40× objective lens and then focused on the PCS via a 10× objective lens. We observe the output of the PCS using a 35-GHz-sampling oscilloscope through an 18-GHz-bias network. A power supply provides the required bias voltage to the PCS via the dc port of the bias network.

The electrical signal generated from the output of the PCS with a 50 Ω (impedance matched) termination is shown in the top trace of Fig. 2. The trace has a fast rise and an extended tail. When a GT is connected in place of the 50 Ω termination, a reflected pulse with an opposite sign and a time delay is generated as shown in the second trace in Fig. 2. By adjusting the time delay, we can tune the reflected pulse to a desired overlap with the original pulse and obtain electrical pulses with different signs, widths, and peak voltages. The third to fifth traces in Fig. 2 correspond to electrical pulses generated with a relative delay of $\Delta t=-100$ ps, 0 ps, and +100 ps. By properly adjusting the time delay, the long tail can be reduced significantly. The shortest pulse width that can be achieved with this system is limited by the pulse width of the light source, rise time of the PCS, and the finite bandwidth and loss introduced by the coplanar waveguide, bonding wire, SubMiniature version A connector, CC, C, and the GT. These limitations can partially be removed or improved by using an ultrashort pulse light source, higher pumping power, and integrating the C and GT into the coplanar waveguide. By adjusting the time delay, the pulse width can be continuously changed from 70 ps to 300 ps. The longest attainable pulse width is limited by the length of the coplanar waveguide and by the fall time of the PCS.

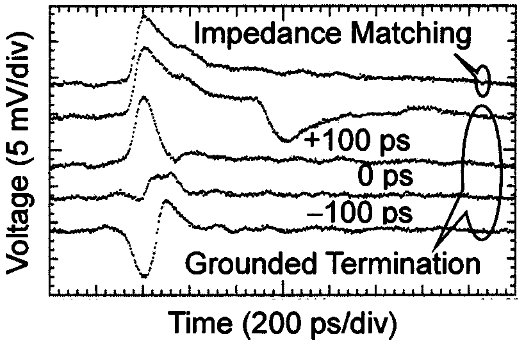

FIG. 2. Short electrical pulses generated by optical excitation of the coplanar waveguide with impedance match (top trace) and GT (lower traces). The relative delay between the reflected and original pulses is shown next to the curves. For clarity, different offsets are added.

It is worth mentioning that, in principle, the extreme pulse width reduction of our method is only dependent on the rise time of the original pulse and independent of its fall time, width, or even profile. This is especially of advantage to some systems, for example, a gain-switched LD. In this system, the LD generates the shortest pulse by injection of a current pulse and a proper bias current (usually below threshold). By increasing the bias current, however, we can obtain higher peak power with the penalty of broader pulse width or even multiple pulses. Because the short electrical pulses generated by our method are independent of the fall time, width, or profile of the original pulse, we can take advantage of a higher bias current in gain-switched LDs to obtain a higher peak voltage and still shorten the pulse width. Moreover, higher optical power can give rise to a larger photoconductance and, hence, higher pulse amplitude and faster rise time.

In Fig. 3, we show the output wave forms of the PCS with the same operating conditions as in Fig. 2 except that the bias current for the gain-switched LD, I_{bias} is 10 mA for the two upper traces and 20 mA for the two lower traces. For $I_{\text{bias}}=10$ mA, we obtain electrical pulses (trace a) with a fast rise of about 49 ps, an extended tail of about 313 ps, a pulse width of about 116 ps, and a peak voltage of 10 mV. Trace b is the electrical pulse obtained with the GT. The rise time of this pulse is 50 ps, its fall time decreases to 51 ps, the pulse width shortens to about 77 ps, and the peak voltage is 7.5 mV. When the bias current increases to 20 mA, the rise time is 41 ps, the fall time extends to 490 ps, the peak voltage increases to 15 mV but the pulse width also broadens to 288 ps as shown in trace c of Fig. 3. With a GT (trace d of Fig. 3), the rise time is still 40 ps, the fall time reduces to 50 ps, the pulse width again shortens to 72 ps, and the peak voltage now increases to 12 mV. This experiment demonstrates that our method can be applied to a variety of short pulse laser systems to photoconductively generate electrical pulses with different widths.

This research was partially supported by the National Science Council of the Republic of China under Grant Nos. NSC85-2221-E-029-003 and NSC90-2115-E-009-054. One of the authors (C.-L. P.) was also sponsored by the Ministry of Education under the Pursuit of Academic Excellence Program.

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