Picosecond microwave pulse generation

Gerard Mourou
The Laboratory for Laser Energetics, University of Rochester, Rochester, New York 14623
Charles V. Stancampiano
Department of Electrical Engineering, University of Rochester, Rochester, New York 14627
Daniel Blumenthal
The Laboratory for Laser Energetics, University of Rochester, Rochester, New York 14623

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Picosecond duration X-band microwave pulses have been generated using a laser-activated photoconductive switch. These pulses have been used to observe the microwave reflection from optically excited germanium. The reflection measurements indicate that the microwave pulse has a full width at half-maximum of 50 ps and is synchronized with picosecond precision to the laser pulse. A high-resolution radar experiment is also reported.

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Short optical pulses have been used in the past, in conjunction with bulk semiconductors, to switch[1–2] and phase-shift[3] microwave signals. In this letter we report the generation of picosecond microwave bursts inherently synchronized with an optical trigger pulse by shock excitation of an X-band waveguide. The excitation is generated by a high-voltage photoconductive switch driven by a picosecond optical pulse. This fast switching technique[4] provides a means of generating a high-voltage pulse in picosecond synchronism with the optical driving pulse. This high-voltage switching technique, developed and implemented in the laser-driven fusion area,[5–7] now finds a new application in picosecond microwave pulse generation. A measured microwave pulse duration of 50 ps, corresponding to the optical excitation pulse width, has been obtained. We expect that shorter pulses may be generated by using picosecond or subpicosecond optical excitation.

The concept of producing electromagnetic radiation by means of "shock" excitation of a transmission line is not new.[8–9] In the past, microwave pulses have been created in the subnanosecond time domain by electrically driven spark gaps. Because this switching mechanism relies on avalanche multiplication, this technique is limited to lower microwave frequencies and is affected by switching-time fluctuations. Laser-activated photoconductive switching has been used in a frozen-wave generator to generate rf pulses.[10] However, microwave frequencies were not attained owing to the long laser pulse width. The present effort combines some of the features of these previously reported results. The microwave pulsewidth has been determined by a gating technique based on the change of reflectivity induced in a slab of Ge by the short optical pulse. The microwave pulse duration has been found to be less than 50 ps, in good agreement with the laser pulse width. The peak microwave power in the burst has been estimated to be on the order of 100 mW and is sufficient to allow a high-resolution radar experiment to be performed.

A schematic representation of the microwave generator is shown in Fig. 1. A piece of semi-insulating Cr-doped GaAs interrupts the center conductor of a coaxial line and is biased by a high-voltage dc power supply.[5,11] The switching action is initiated by laser-induced photoconductivity in the semiconductor crystal. The optical driving pulse is generated by a Nd^{+++}:YAG laser, actively and passively mode locked. The laser wavelength is centered around 1.064 μm and the pulse duration is 35 ± 5 ps. For a bias voltage of a few hundred volts, 10 μJ of absorbed optical energy is required to achieve good switching efficiency. In a wide-band geometry the electrical pulse exhibits a rise time dictated by the laser pulse width, i.e., 35 ± 5 ps. The fall time is determined by the charge-line length (in Fig. 1, the distance between the resistor and the GaAs switch) and by the carrier recovery time, which is Cr-concentration dependent. The switch drives an X-band coaxial-line-to-waveguide transition. The transition is modified by removal of the rear wall. This nearly eliminates the microwave reflection from the end of the waveguide and aids in reducing the microwave pulse width. Upon laser action, the charge stored in the charge line is dumped into the transition resulting in an rf emission. The microwave burst is guided via WR-90 waveguide to a 20-dB broadband ferrite circulator and then to an X-band dish-type antenna. The signal reflected from a target is received by the same antenna and circulated back to a standard microwave crystal detector located on the third port of the circulator. The crystal detector has a response time FWHM of 500 ps. The target is a flat aluminum plate located about 4 m from the antenna. Figure 2 shows two echoes separated by about 500 ps obtained for two target positions differing by 8 cm. The spatial resolution is ultimately limited by the oscilliscope trace width and corresponds here to a few millimeters.

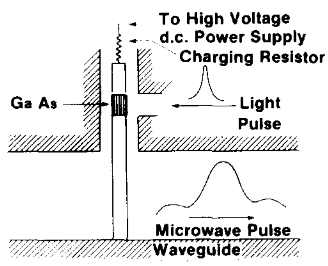

FIG. 1. Schematic of the microwave generator. A laser-triggered photoconductive switch is coupled to an X-band waveguide.

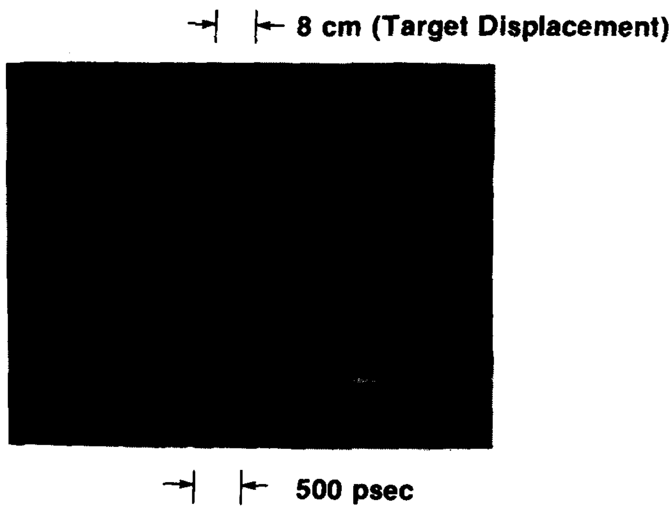

FIG. 2. High-resolution radar echoes. Oscilloscope display showing the detector output for two target positions 8 cm apart from a target located 4 m away from the microwave dish.

The electronic system, consisting of the oscilloscope and detector, has a combined bandwidth on the order of 1 GHz and is inadequate to time-resolve the microwave burst. This difficulty was overcome by using a gating technique illustrated in Fig. 3 and taking advantage of the synchronism between the microwave and optical pulses. The microwave burst is reflected by a laser-induced electron-hole plasma in a thin wafer of intrinsic germanium mounted across the waveguide. The wafer is made thin (50 μm) to reduce microwave reflections due to intrinsic carriers and dielectric mismatch but is still substantially thicker than the optical penetration depth of about 2 μm in order to maximize optical carrier generation and provide mechanical support. The time delay between the illumination of the Ge sample and the microwave burst can be varied over several hundreds of picoseconds by means of an adjustable optical delay line. In the absence of illumination, the Ge is nearly transparent to microwaves and reflects only 1% of the incident wave. The transmitted pulse is absorbed in a matched load. If the microwave burst arrives at the semiconductor sample shortly after illumination, the microwave pulse is readily reflected by the laser-induced electron-hole plasma. For an incident optical energy of 500 μJ absorbed in the thin slab and spread over 1 cm^2, roughly 30% of the incident microwave power is reflected. The reflected signal is integrated by the detection system (detector-oscilloscope). The detector output pulse height, as observed on the oscilloscope, is plotted as a function of the time delay between the microwave and optical bursts and is illustrated in Fig. 4. Owing to the relatively long carrier lifetime in Ge (on the order of microseconds) the plasma reflectivity is sustained long after the illumination ceases. Therefore the resulting microwave reflection is a microwave burst modulated by the step function of the Ge reflectivity, and the oscilloscope output represents the time integral of the signal. From a knowledge of the laser pulse duration, a FWHM of less than 50 ps can be determined for the microwave burst. This result is in good agreement with the laser pulse width and the waveguide cutoff frequency of 6.56 GHz, which establish, respectively, the upper and lower frequency bounds of the microwave spectrum generated.

In conclusion, we have shown that microwave bursts in picosecond synchronism with an optical pulse may be generated using a laser-activated photoconductive switch coupled to an X-band waveguide. A 50-ps microwave pulse was generated using a 35 ± 5-ps optical trigger pulse. Further efforts to determine the microwave power as well as the spectral content are underway. Current efforts also involve extension of this technique to the millimeter wave range by using pico-

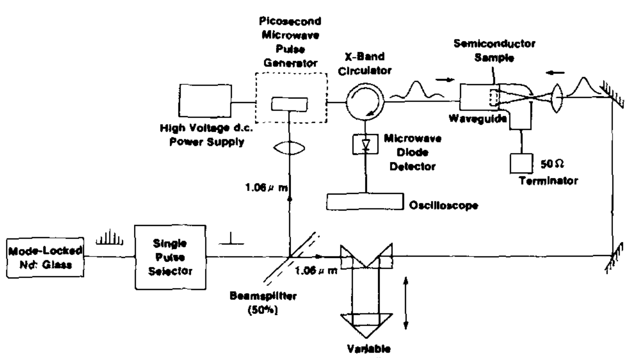

FIG. 3. Picosecond microwave pulse measurement. The microwave burst generated by a GaAs switch activated by a 30-ps, 1.06-μm optical pulse coming from Nd:YAG mode-locked laser is gated by laser-induced reflectivity in a Ge wafer. The microwave reflectivity of the Ge is measured as a function of the time delay between the microwave and the optical bursts. The carrier recovery time in Ge is several microseconds so the time integral of the microwave burst can be generated.

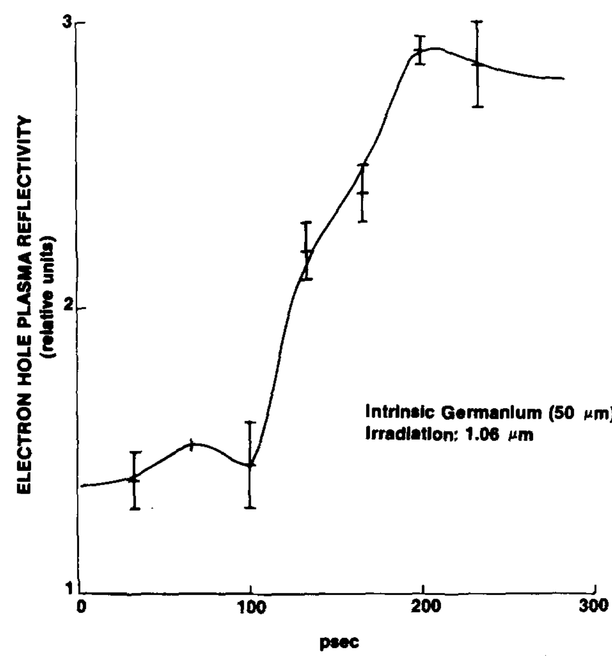

FIG. 4. The time integral of the microwave burst. The derivative of the signal unfolded with the laser pulse width leads to an upper limit of the microwave pulse width of 50 ps.

second or subpicosecond optical pulses. An application of a short microwave pulse is illustrated in this letter with a high-resolution radar experiment. Potential applications of these bursts are many and include studies pertaining to electron-hole plasma kinetics, plasmas associated with laser-driven fusion, temporal investigation of the surface properties of semiconductors undergoing laser annealing, and light-matter interactions such as in biological materials or photographic emulsions.

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Pyroelectric behavior of $LiNbO_3$ at low temperatures

S. Vieira

Departamento de Física Fundamental, Universidad Autónoma de Madrid, C-III-602, Canto Blanco, Madrid 34, Spain.

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A large enhancement of the ratio between the proelectric coefficient π and the heat capacity C is obtained for $LiNbO_3$ for $T < 10\ K$. This suggests that this material could be a good infrared detector at low temperatures.

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Glass and Lines[1] have suggested the convenience of using the ferroelectric $LiNbO_3$ as an infrared detector at temperatures close to 30 K, where a maximum appears in the ratio π/C, π being the total pyroelectric coefficient and C being the heat capacity. As indicated by these authors, in the neighborhood of the π/C maximum, the response is greater than at room temperature, and the thermal noise is decreased. These authors have also observed in $LiTaO_3$, and for temperatures lower than 7 K, a small increase in π/C.

In Fig. 1 in this letter I present results of π/C for $LiNbO_3$ for the temperature range $2.2 < T < 45\ K$. The pyroelectric coefficient Π was obtained from measurements of the spontaneous polarization Ps between 2.2 and 50 K, using a charge integration technique. Details of my measure technique have been published elsewhere.[2] In this experiment, I measure the charge released ($\Delta Q > 0$) by the sample surface perpendicular to the C-axis when the temperature is changed by ΔT. In this way

$$\pi = \Delta Ps/\Delta T = -\Delta Q/A\Delta T,$$

where A is the surface area. At lower T temperature changes were $\Delta T \simeq 0.2$ K.

The sample used in this work was cut from a large, single-crystal growth from congruent melt by the pulling method of L. Arizmendi. After polishing, the sample was polarized, i.e., forced into a monodomain state, in O_2 atmo-

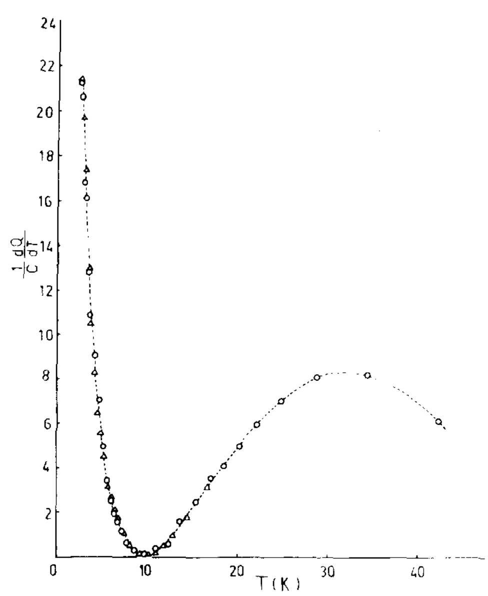

FIG. 1. Ratio of dQ/dT in $10^{-16}\ C/K$ to specific heat in erg/grad$K$ vs T.

