fluorescence output is shown with one shot and 40 shots accumulated. A large increase in signal-to-noise ratio is observed. The single-shot data is virtually unintelligible, whereas the averaged data has fairly good signal-to-noise ratio.

The use of a simple room-temperature DC-biased photoconductive switch has been shown to increase the performance of a streak camera in timing stability (±0.8 psec jitter), sweep speed (~½ speed of light) and ease of operation (no pulsed-bias, vacuum, liquid nitrogen, etc.). Voltage fluctuations (sweep speed fluctuations) were controlled to less than ± 0.1%, resulting in exceptional stability and reliability, and the system has no short- or long-term drift. This permits averaging experiments to extend over long periods of time to gain timing accuracy into the femtosecond domain and large signal-to-noise ratios for detailed fluorescence studies. Single-shot averaging has many advantages over repetitively scanned systems.

It is emphasized that with this technique in many cases the complex, unreliable, and cumbersome electronics commonly used with streak cameras can be replaced with an inexpensive, simple, and highly accurate device capable of increasing the usefulness of the streak camera tremendously.

The addition of a wedged short-cavity dye laser provides short pulses of numerous wavelengths across the visible spectrum for use in time-resolved emission studies.

It should be mentioned that the performance of this system in terms of timing accuracy scales with the laser pulsewidth used to excite the GaAs. With the use of a gigawatt subpicosecond source currently under construction at LLE, the expected timing accuracy is less than 0.1 ps.

3.B Picosecond Microwave Pulse-generation

Short optical pulses have been used in the past, in conjunction with bulk semiconductors to switch[55,56] and phase shift [57] microwave signals. Here 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[58] 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-

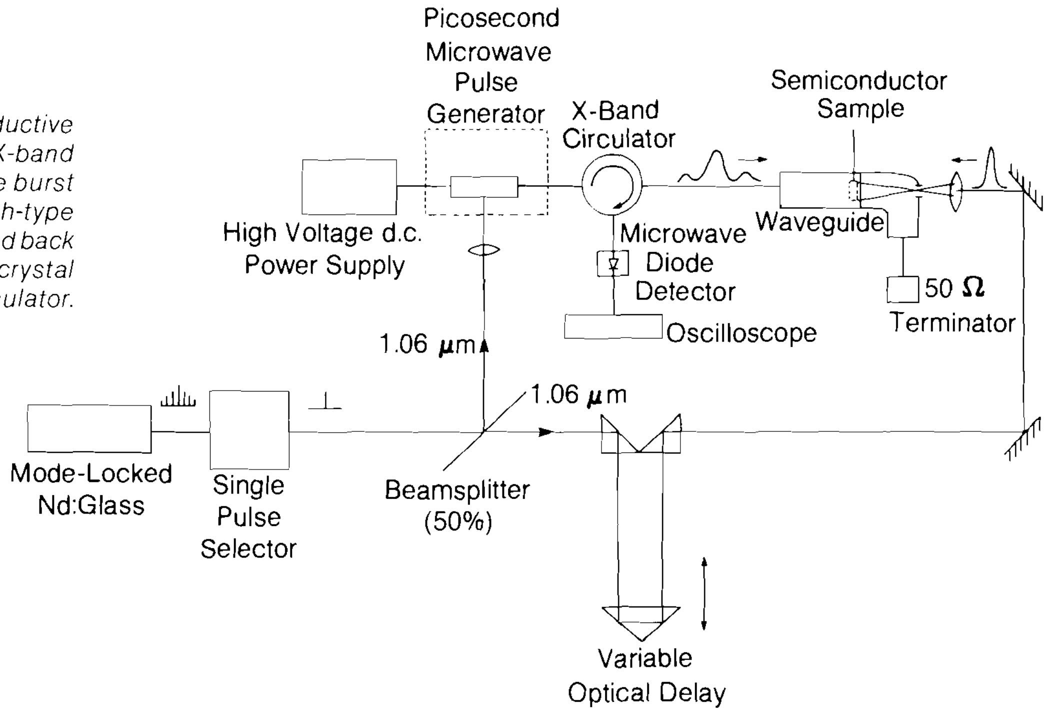


Figure 46

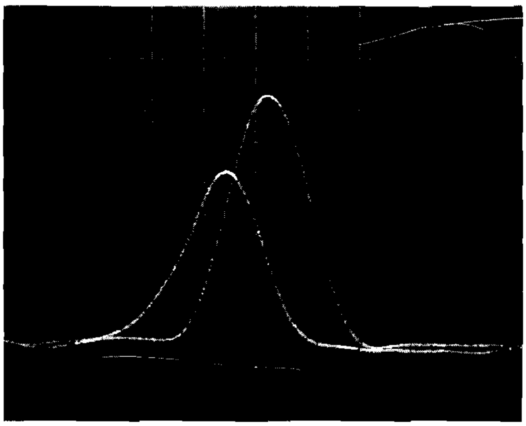
A laser-induced photoconductive switch is coupled to an X-band waveguide. The microwave burst is sent to an X-band dish-type antenna. The signal reflected back from the target is fed to a crystal detector by means of a circulator.

driven fusion area[59,60,61] now finds a new application in picosecond microwave pulse generation. A measured pulse duration of 50 psec, corresponding to the optical excitation pulsewidth, has been obtained. Shorter pulses can be achieved by using picosecond or subpicosecond optical excitation.

The concept of producing microwave radiation by means of "shock" excitation of a transmission line is not new[62,63]. 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. In addition, laser-activated photoconductive switching has been used to generate rf pulses, for example, with the frozen-wave generator[64]. Microwave frequencies were not attained due to the long laser pulsewidth. 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 psec, in good agreement with the laser pulsewidth. 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 Figure 46. 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[59]. The switching action is initiated by laser-induced photoconductivity in the semiconductor crystal. The optical driving pulse is generated by a Nd^{+3}: YAG laser, actively and passively mode locked. The laser wavelength is centered around 1.064μm and the pulse duration is 35$\pm$ 5 psec. For a bias voltage of a few hundred volts, 10 μJ of absorbed optical energy is required to achieve good switching efficiency. In a wideband geometry the electrical pulse exhibits a risetime dictated by the laser pulse width, i.e. 35 $\pm$ 5 psec. The fall time is determined by charge line length 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 pulsewidth. The transition is then no longer matched, in the conventional sense, to the coaxial input. 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 psec. The target is a flat aluminum plate located about 4m from the antenna. Figure 47 shows two echoes separated by about 500 psec obtained for two target positions differing by 8 cm. The spatial resolution is ultimately limited by the oscilloscope trace width and corresponds here to a few millimeters.

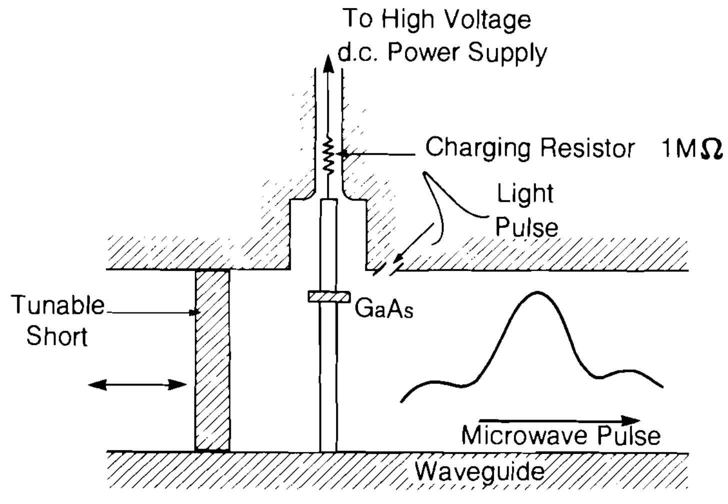
→| |← 8 cm (Target Displacement)



→| |← 500 psec

Figure 47

Oscilloscope display showing the detector output for two target positions 8 cm apart from a target located 4m away from the microwave dish.



CHARACTERISTICS
- Optically synchronized picosecond microwave burst
- 100 GHz obtainable with subpicosecond optical pulse

Figure 48
The microwave burst generated by a GaAs switch activated by a 30 psec, 1.06μm 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.

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 Figure 48 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 (50μm) to reduce microwave reflections due to intrinsic carriers and dielectric mismatch but is still substantially thicker than the optical penetration depth of about 2μm 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 Figure 49. Due 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 truncated by the step function of the Ge reflectivity and represents the time integral of the signal. From a knowledge of the laser pulse duration, a FWHM of less than 50 psec can be determined for the microwave burst. This result is in good agreement with the laser pulsewidth and the waveguide cut-off frequency of 6.56 GHz which establish, respectively, the upper and lower frequency boundaries of the microwave spectrum generated.

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 psec microwave pulse was generated using a 35 ± 5 psec 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 picosecond or subpicosecond optical pulses. An application of short microwave pulses is illustrated in this section 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.

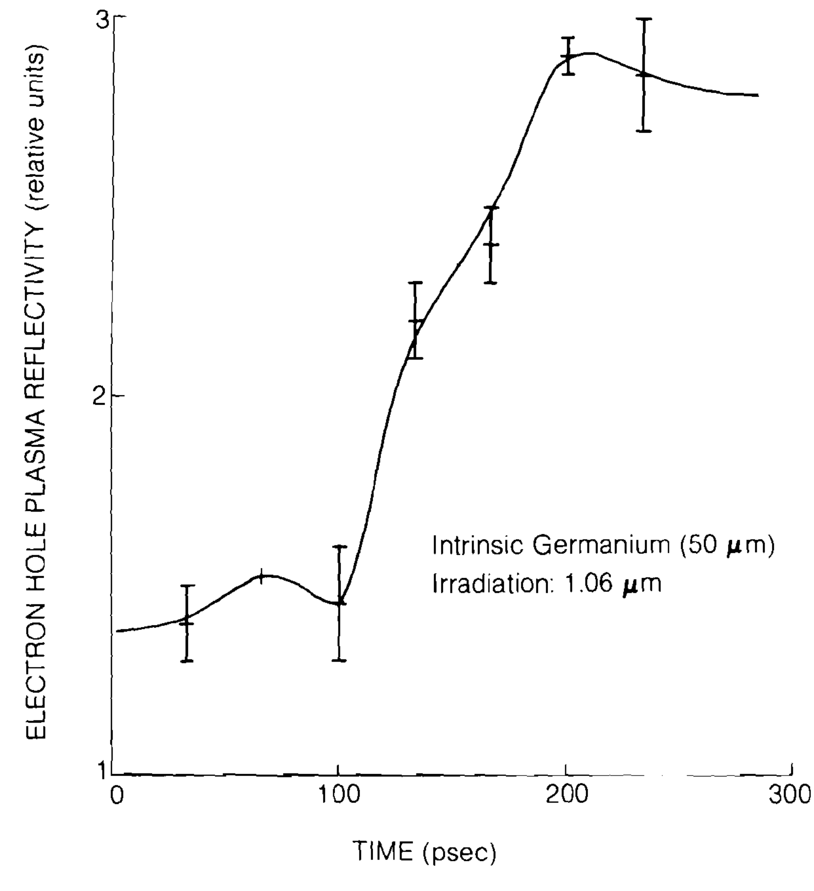


Figure 49
The derivative of the signal unfolded with the laser pulsewidth leads to an upper limit of the microwave pulse of 50 psec.