A wide bandwidth detection and display system for use with TEA CO_2 lasers

A. F. Gibson, M. F. Kimmitt, P. N. D. Maggs, and B. Norris

Department of Physics, University of Essex, Colchester, Essex, England
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A photoconductive detector based on intravalence band transitions in p-type germanium is described. The detector responsivity is sufficient to drive a travelling-wave oscilloscope (Tektronix 519) without amplification, and consequently has an over-all bandwidth sufficient to display 300-ps-duration pulses from a mode-locked TEA CO_2 laser.

The use of p-type germanium as a nonlinear absorber to passively mode lock TEA CO_2 lasers was described in a previous letter.[1] After correcting for the limited bandwidth of the display system (Tektronix 7904; rise time, 800 ps) it was estimated that the duration of the generated pulses was $\lesssim$500 ps. Subsequent work with higher-pressure lasers has confirmed the ability of germanium to produce subnanosecond pulses by passive mode locking.[2]

Alcock and Walker[3] have recently described a method of CO_2 laser radiation detection of sufficiently high responsivity to permit direct display of the subnanosecond pulses on a Tektronix 519 travelling-wave oscilloscope. The method relies on mixing the CO_2 laser radiation with radiation from a Nd^{3+} YAG laser in a proustite crystal and detecting the resultant upconverted radiation with a high-speed photodiode. In this communication we describe a simpler method which achieves the same objective, namely, direct display on a Tektronix 519. Our technique is based on intravalence-band photoconductivity in p-type germanium.

Absorption of 10-μm radiation by p-type germanium excites holes from the heavy-hole band to the light-hole band; it is this transition and the saturation that arises from depletion of the heavy-hole density, which is exploited in the nonlinear absorber used in mode locking. The excitation of the holes to higher energies within the valence band reduces their mobility and an increase in sample resistivity results. This negative photoconductivity, though related to the absorption saturation, can be observed at much lower intensities and indeed was first observed without the aid of a laser.[4] Over the past decade it has been studied by a number of authors.[5] The intrinsic response time is the same as that of the absorption saturation, (about 3 ps), so the response of a practical detector is likely to be limited by the transit time of light through the detector element. The magnitude of the photoconductive response passes through a broad maximum with a resistivity of about 4 Ω cm. If the sample is oriented to avoid photon drag effects, is thin compared with the absorption length (about 2 cm for 4-Ω cm material), and all relevant surfaces are antireflection coated, the fractional change in conductance $\Delta Y/Y$ per unit intensity I is given by[6]

$$\frac{\Delta Y/Y}{I}=\frac{\sigma_p\tau}{\hbar\omega}\,\frac{\Delta\mu}{\mu}=\frac{1}{I_s}\,\frac{\Delta\mu}{\mu}=\frac{0.7}{I_s}$$

where $\hbar\omega$ is the laser photon energy, σ_p is the absorption cross section of holes, and τ is the response time. The relationship with the absorption saturation effect is indicated by the inclusion of I_s, the saturation power density (10 MW cm^{-2} at 10.6 μm), and the numerical value of the fractional change in mobility, $\Delta\mu/\mu$, refers to 4-Ω cm material. It follows that the detector will be nonlinear at intensities of the order of I_s or above.

Though the fractional change in conductance is not large (7% at $\frac{1}{10}I_s$ or 10 kW mm^{-2}) a substantial responsivity can be obtained by applying a sufficiently high voltage. This is pulsed (with a duration of 10 μs) and timed to start a few μs before the laser discharge. The circuit arrangement is shown in Fig. 1. The first section of the detector crystal, which is the photoconductive element and typically a few mm long, is connected directly to the 125-Ω coaxial input cable of the Tektronix 519 oscilloscope. Pulse voltages up to 300 V have been used and noninjecting (e.g., gold-gallium alloy) contacts to the germanium are essential if a significant drop in detector resistance due to electron injection is to be avoided. The capacitor C differentiates the relatively long, 10 μs, applied voltage pulses and the diodes clip off the resultant spikes if these exceed about 50 V. The rear portion of the detector crystal is used as a conventional photon drag detector[7] to trigger the time base of

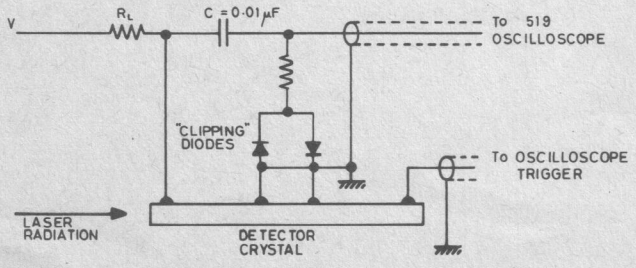

FIG. 1. Photoconductive detector and associated circuit.

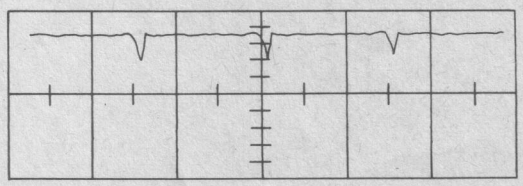

FIG. 2. Part of a mode-locked pulse train. Time base, 5 ns/div; vertical scale, 10 V/div.

the oscilloscope; by separating the triggering function from the signal it is possible to delay one relative to the other and examine any desired portion of a mode-locked pulse train.

Part of a train of mode-locked pulses generated by a germanium mode-locked TEA CO_2 laser displayed by the above technique on a Tektronix 519 is shown in Fig. 2. The responsivity of the photoconductive element was 60 $V MW^{-1}$. The rise time of the oscilloscope is estimated to be 250 ps so the displayed pulses are of about 300-ps duration. Apart from demonstrating the bandwidth of the detection and display technique the observations confirm without ambiguity that p-type germanium absorbers can generate mode-locked pulses whose duration is limited by the laser amplifier bandwidth.

[1]A. F. Gibson, M. F. Kimmitt, and B. Norris, Appl. Phys. Lett. 24, 306 (1974).
[2]A. J. Alcock and A. C. Walker, Appl. Phys. Lett. 25, 299 (1974).
[3]A. J. Alcock and A. C. Walker, Appl. Phys. Lett. 23, 467 (1973).
[4]T. S. Moss and T. D. H. Hawkins, Proc. Phys. Soc. Lond. 76, 565 (1960).
[5]A. M. Danishevskii, A. A. Kastal'skii, B. S. Ryvkin, S. M. Ryvkin, and I. D. Yaroshetskii, JETP Lett. 10, 302 (1969); H. Hattori, O. Fujitani, and M. Umeno. J. Phys. Soc. Jpn. 36, 485 (1974).
[6]A. F. Gibson and P. N. D. Maggs, J. Phys. D 7, 292 (1974).
[7]A. F. Gibson, M. F. Kimmitt, and A. C. Walker, Appl. Phys. Lett. 17, 75 (1970).