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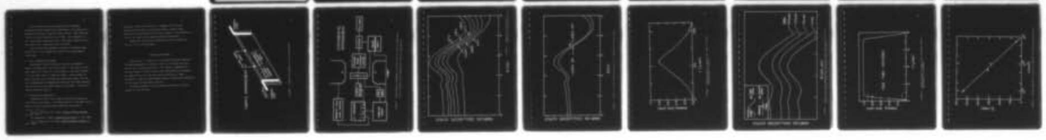

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Annual Summary Report

[redacted] Laser Optical Biasing on the Quantum Transport Properties of n-InSb

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by
David G. Seiler
Department of Physics
North Texas State University
Denton [redacted]
October 1, 1975 - September 30, 1976

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We report here the first experimental attempt to measure the mean energy of photoexcited carriers in n-InSb using the Shubnikov-de Haas (SdH) effect as a temperature probe. Preliminary measurements with a mechanically chopped CO_2 laser beam have shown that the laser radiation changes the amplitude of the SdH oscillations.

The research being done is directed at obtaining fundamental information concerning the effects of CO and CO_2 laser radiation on the quantum transport properties of n-InSb.

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FOREWORD

This Annual Summary Report by David G. Seiler, Department of Physics, North Texas State University covers research progress for the period October 1, 1975 to September 30, 1976.

SUMMARY

Optical biasing of the transport properties of semiconductors under intense laser radiation is a new unexplored area for studying the dynamics of electrons in solids. The research being done is directed at obtaining fundamental radiation on the quantum transport properties of n-InSb.

We report here the first experimental attempt to measure the mean energy of photoexcited carriers in n-InSb using the Shubnikov-de Haas (SdH) effect as a temperature probe. Preliminary measurements with a mechanically chopped CO_2 laser beam have shown that the laser radiation changes the amplitude of the SdH oscillations. Improvements in the turn-on time of the laser are being implemented through (1) focusing of the laser beam through a narrow slot in a chopper blade; (2) design and construction of a Q-switched laser which will have a much faster rise time, a very narrow pulse width, and a higher peak power; (3) acquisition and installation of an electro-optic Q-switch and modulator.

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EXPERIMENTAL WORK

Much time and effort during the past year was devoted to acquiring or building the necessary pieces of equipment for the research project. In addition, there have been many experimental techniques to learn. These have included the following:

(1) Low temperature optical dewar. Initial operation of this commercial dewar was prevented by a leak in a weld joint. The dewar was shipped back to the factory for repairs. During the past year, experience in reliable operation of this dewar has been obtained.

(2) Sample preparation. A sample polishing jig was built and the associated polishing procedures established. The jig allows accurate alignment and rigid holding of the sample for optical polishing. Samples of InSb can be polished on a Buehler polishing wheel to thicknesses down to about 25 microns. This was found necessary for 50 ohm impedance matching for the pulse measurements.

(3) Ultraminiature coaxial cables of 50 ohms wave impedance have been incorporated into the cryostat from the sample out to the pulse generator and amplifier terminals. This, along with number 2 above, enables electrical pulses of about 2 nsec rise and fall times to be used.

(4) Strain-free mounting techniques for the InSb samples using small diameter gold wires have been learned and utilized.

(5) Laser tubes can now be made at NTSU and facilities for cutting Brewster's angle on the ends of the tubes have been fabricated and installed.

(6) Sample holder: a sample holder with alignment apertures was designed and constructed. Use of a phenolic holder was discarded when it was discovered that the CO_2 laser radiation was quite easily absorbed by the phenolic holder causing some charring. We are now testing a metallic holder.

(7) Alignment procedures were established to allow coupling of the laser energy into the sample. A system using a three-dimensionally translatable sample lens to both focus and steer the beam into the sample was designed and built.

(8) The pulse generating equipment and sampling oscilloscope techniques have been learned and preliminary measurements taken with them.

(9) cw Lasers: At present, there are three cw lasers for this project: a half-meter CO_2, two-meter CO_2, and a two-meter CO. The half-meter CO_2 has been used for our preliminary measurements. It provides up to 5 watts cw power in a TEM_{oo} mode pattern. Both two-meter lasers have a grating rotation system for line selectibility. Drawings for a grating rotation system, used at Lawrence Livermore for spin-flip Raman laser studies using ultra-stable CO and CO_2 lasers, were obtained from Charles Rhodes.

(10) TEA double-discharge CO_2 laser. This laser has been designed and built. It produces 150 nsec pulses in the megawatt range. Shorter pulse widths on the order of 1 nsec can be obtained by passive mode locking with a p-type germanium crystal.

EXPERIMENTAL RESULTS

An n-InSb sample of concentration $n \overset{\wedge}{\sim} 1 \times 10^{15}\ \mathrm{cm}^{-3}$ was mounted in a Janis optical dewar which allowed the temperature of the sample to be controlled from 1.5 to 4.2K. The sample was mounted with two degrees of freedom to allow for its proper alignment with the laser beam. The sample size and lead geometry is shown in Figure 1. As shown in Figure 1, the magnetic field B is parallel to the current and the laser beam is perpendicular to the current. All contacts to the sample were made with indium solder and 25 micron diameter gold wire. A photodetector (a pyroelectric type) was used during alignment to check the amount of transmitted radiation. In addition, during the data gathering process, the transmitted radiation is measured to check for laser stability and to monitor the magnetoabsorption. A block diagram of the experimental arrangement that was used in obtaining the first preliminary results is shown in Figure 2.

The temperature dependence of the Shubnikov-de Haas (SdH) effect is shown in Figure 3 for different lattice temperatures.

The SdH amplitudes are seen to be quite sensitive to the lattice temperature. This lattice temperature dependence provides a means for determining the rise in electron temperature with laser irradiation. The results of the first measurements of the effects of laser light on the SdH effect in InSb are shown in Figure 4. Here a temperature rise from about 1.5 K to 2.5 K is indicated. A small cw Co_2 laser running at 4 watts in a TEM_{oo} mode pattern was used along with a 10% duty cycle chopper blade. Only microsecond electrical pulses were used in this first series of experiments. The next series of experiments involved nanosecond electrical pulses which could be applied because of the use of coaxial cable and small sample thicknesses.

The parameters of the mechanical chopper operation that have so far been used are:

angular frequency, $w = 898\ sec^{-1}$
slot width, $s = 0.2$ cm.
beam radius, $b = 0.25$ cm.
distance of beam from rotation axis, $d = 3.5$ cm

Using these parameters the temporal shape of the light pulse was calculated and is shown in Figure 5 for a Gaussian intensity distribution. The rise and fall times are in the range of 1×10^{-4} sec. Using this shaped light pulse, SdH measurements were taken with a 5 nsec wide current pulse and with various delay times between the rise of the light pulse and the rise of the electrical pulse. The results are shown in Figure 6. The light and current pulse configurations are shown in the insert of Figure 6. Both the 0 microseconds and 500 microseconds delay mean that there was no laser beam irradiating the sample. For the 23 microseconds delay, SdH measurements show a decrease in amplitude which correlates with the increase of the laser intensity. The 100 microsecond delay measurements show even more of a decrease in amplitude, which corresponds to a higher laser intensity. A 500 microsecond delay means that the laser light pulse has been turned off, since the repetition rate is in the millisecond range.

It is immediately obvious that we cannot detect time dependent changes of the mean carrier energy with this configuration. The simplest approach to improving the rise time of the optical pulse is in optimizing the chopper parameters. Thus, the angular frequency and the distance of the beam from the rotation axis should be increased, whereas the beam width and the slot width should be decreased. The optimal set of achievable parameters using the present chopper equipped with a modified single-slot chopper blade and a beam focusing arrangement is as follows:

$w = 1005 \text{ sec}^{-1}$

$s = 0.038 \text{ cm}$

$b = 0.0018 \text{ cm}$

$d = 5 \text{ cm}$

The calculated shape of the expected light pulse is shown in Figure 7. It exhibits a rise time of about 430 nsec and a pulse length of about 6.5 microseconds. Here we have used a

1" lens, one meter from the front output coupler, which will give an 18 micron Gaussian radius. Experiments are now being carried out with this configuration.

A phenomenologically defined energy relaxation time derived from energy balance considerations was given by Bauer and Kahlert[1] for n-InSb as a function of carrier concentration and electron temperature. Their results at approximately a 12 K electron temperature are shown in Figure 8, where the maximum energy relaxation time (τ_ε) is plotted as a function of the electron concentration, n. From an extrapolation of their results to lower carrier concentrations, we expect a value of τ_ε of about 200-300 nsec for a sample of 1×10^{15} cm^{-3}. Thus the improved chopper operation will give rise times of the same order of magnitude. However, further improvement in the rise and fall time of the optical light pulse is desirable to be able to measure any time dependencies. The next section is devoted to two ways of improving not only the rise and fall times of the light pulse, but which will also increase the peak power. Both Q-switching and electro-optic modulation or switching will be utilized in the coming year.

FUTURE PLANS

Q-switching of CO_2 laser

Q-switching (or Q-spoiling) is the process whereby the quality factor Q of the laser resonant cavity is suddenly

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[1] G. Bauer and H. Kahlert, J. Phys. C.: Solid State Physics 6, 1253 (1973)

increased from a condition where the laser is below oscillation threshold to a condition above threshold. The energy stored up in the nonlasing condition will be released after the Q is increased if the spontaneous lifetime of the laser levels is longer than the stimulated radiative lifetime. Consequently a pulse of laser light is produced, after which the output decays to the cw power level (this is zero for a laser below threshold). Repetitive Q-switched pulses can be obtained if the time intervals between the Q changes are comparable **to** or greater than the recovery time of the laser medium.

A. With Rotating Mirrors

Q-switching of the 10.6 micron CO_2 laser was first reported by Kovacs, Flynn, and Javan.[2] In this type of a system, one of the laser cavity end mirrors is rotated about an axis perpendicular to the laser axis. The laser can oscillate when the mirror is within a certain tolerance angle $\theta/2$ from perfect alignment. The turn-on time can be made very small by rapid rotation of the mirror, so that fast switching can be done. Using a CO_2 laser oscillating cw at 3 W power, Kovacs et al. obtained Q-switched pulses with an estimated 20 nsec or less width at 400 Hz and approximately 50 kW peak power. They found it took about 300 nsec for the laser medium to recover between pulses. The optimum performance was obtained with the mirror rotating at 500 rotations/sec.

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[2] M.A. Kovacs, G.W. Flynn, and A. Jovan, <u>Applied Physics Letters</u> 8, 62 (1966).

Patel and Shaw and co-workers[3] at Bell Telephone Laboratories have repetitively Q-switched a CO_2 laser with a diffraction grating inside the laser cavity. They obtained 3 kW on a single transition at 10.5915 μ for operation in the lowest order transverse mode. The laser pulses were 250 nsec wide with a repetition rate of 120 Hz.

Thus, Q-switching appears to be able to provide laser pulses with a fast enough rise-time for our measurements to be taken.

B. With a Mechanical Chopper

Meyerhofer[4] used a mechanical shutter arrangement in which a notched metal disk was rotated to chop the CO_2 laser beam inside the cavity at a point where it had been focused to a very small spot by means of lenses. Pulse widths of about 200 nsec were achieved with repetition rates of 5 kHz. One disadvantage that Meyerhofer found was that some material was burned off of the metal wheel on each pass. This is the least attractive option.

C. Electro-optic Modulation

Bridges and Cheo[5] used a GaAs electro-optic modulator to Q-switch a CO_2 laser. A voltage applied to the GaAs crystal makes it act as a quarter-wave plate and along with a

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[3] C. K.N. Patel and E.D. Shaw, Physical Review Letters 24, 451 (1970).

[4] D. Meyerhofer, IEEE J. Quantum Electronics 4, 762 (1968).

[5] T.J. Bridges and P.K. Cheo, Applied Physics Letters 14, 262 (1969).

polarizer, spoiled the cavity Q. Dumping of the cavity energy near the peak of oscillation gave a single output pulse of 10 kW peak power and 25 nsec duration. The repetition rate is the same as for rotating mirror Q-switching.

Commercial electro-optic switches can now be obtained for the 5 or 10 micron region.

TECHNICAL PERSONNEL

This year Dr. H. Kahlert of the Ludwig Boltzmann Institut für Festkorperphysik in Vienna, Austria is working with this project as a research associate. Dr. Kahlert completed his doctoral degree in 1965 and has since published over 30 papers. His expertise lies in the area of hot electrons in semiconductors. Both his experimental and his theoretical background in this area are now being utilized.

Graduate students are also working part-time on various aspects of this project.

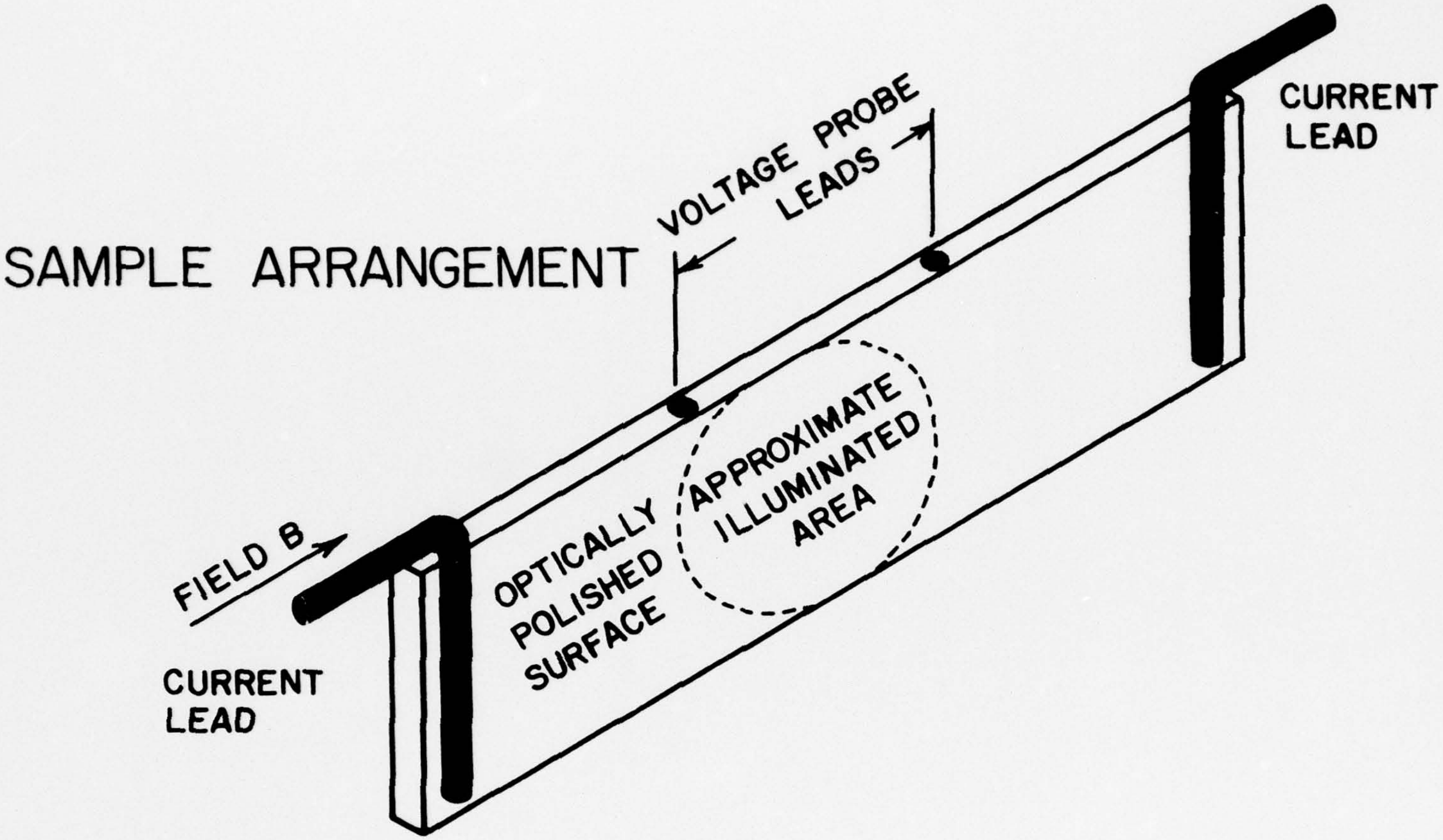

FIGURE 1. Sample Arrangement with lead placement

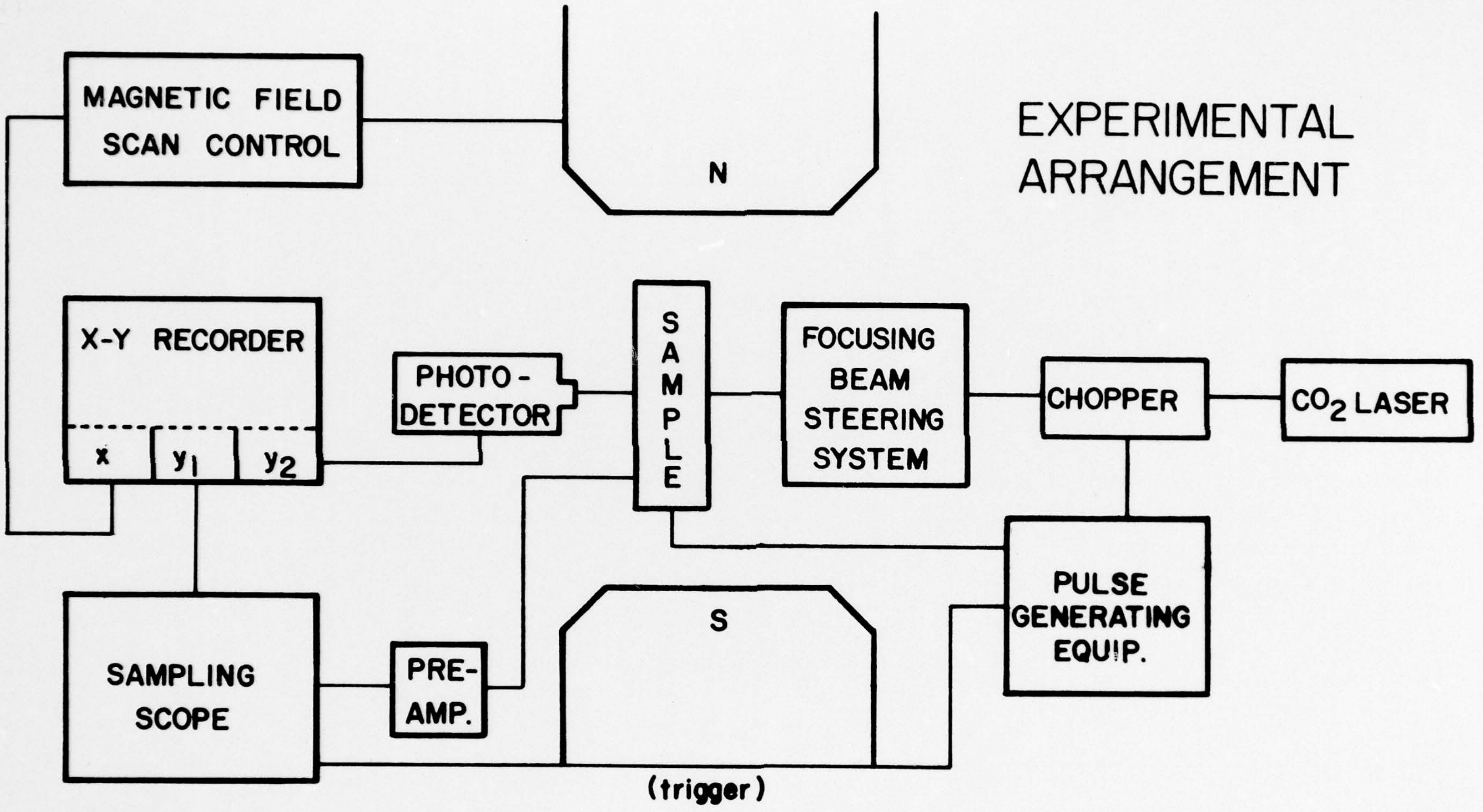

FIGURE 2. Experimental Arrangement of Electrical and Optical Equipment Used in Taking Laser Induced Hot Electron Experiments.

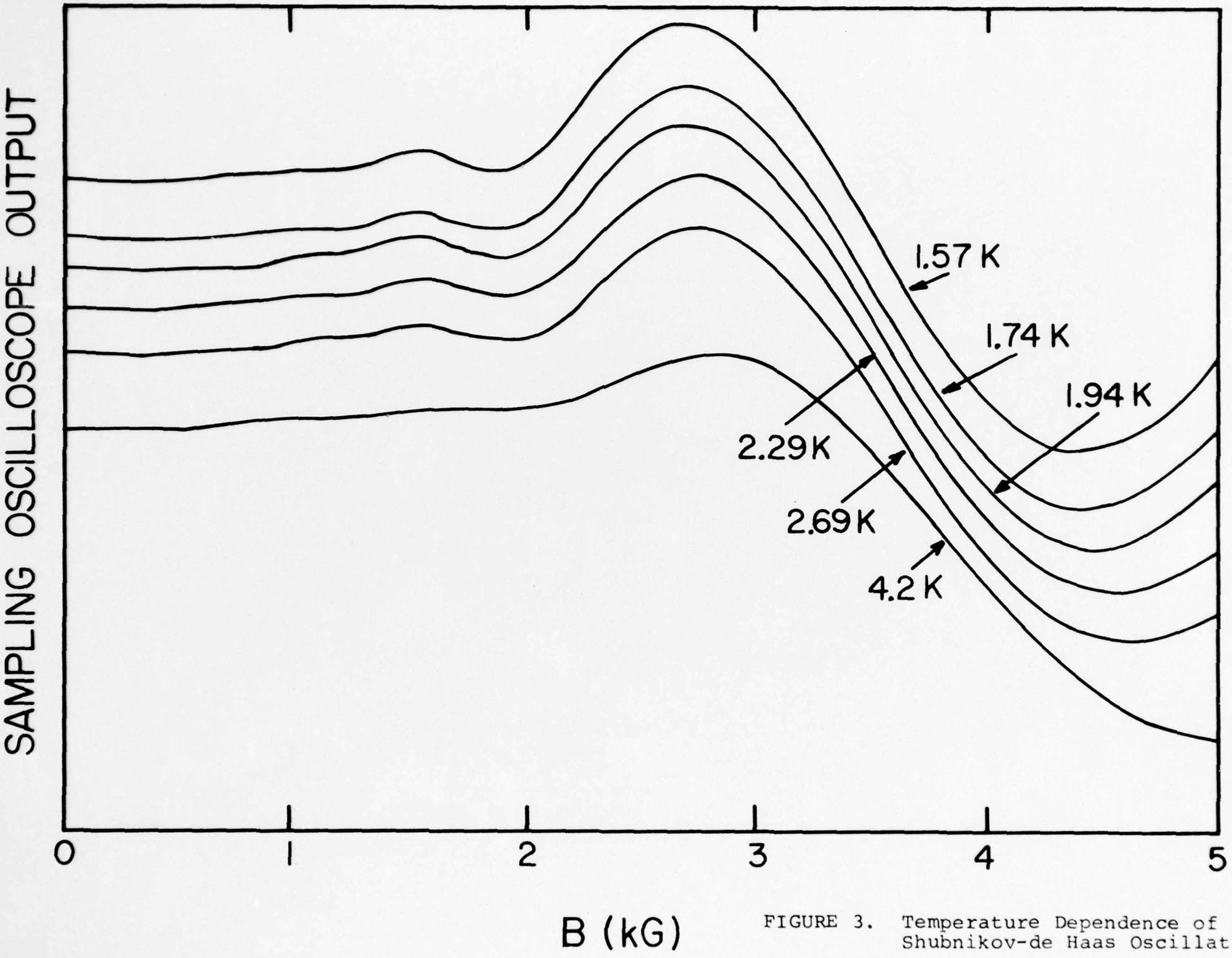

FIGURE 3. Temperature Dependence of Shubnikov-de Haas Oscillations

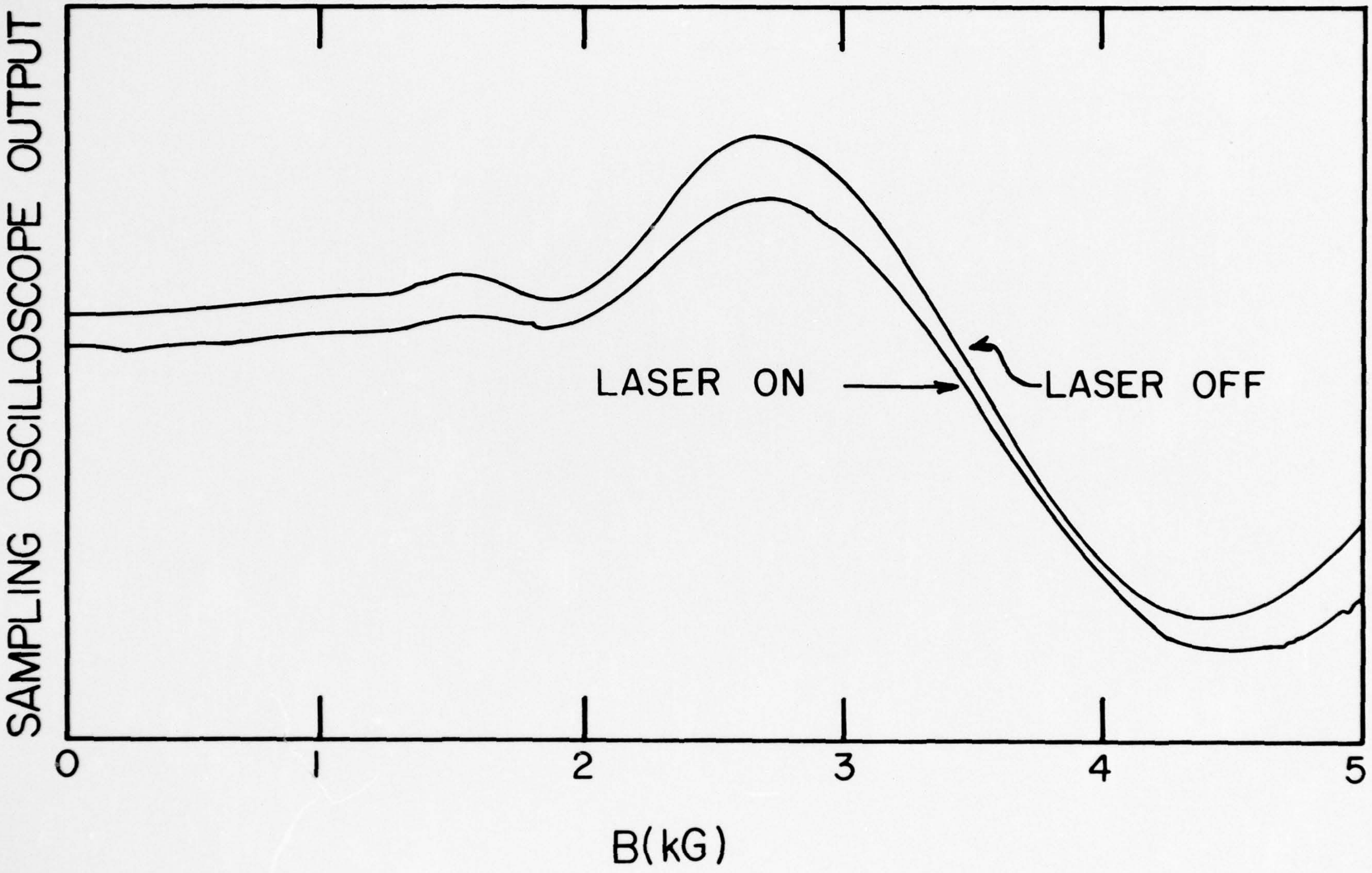

FIGURE 4. Effect of Laser Radiation (4 watts) on Shubnikov-de Haas Effect.

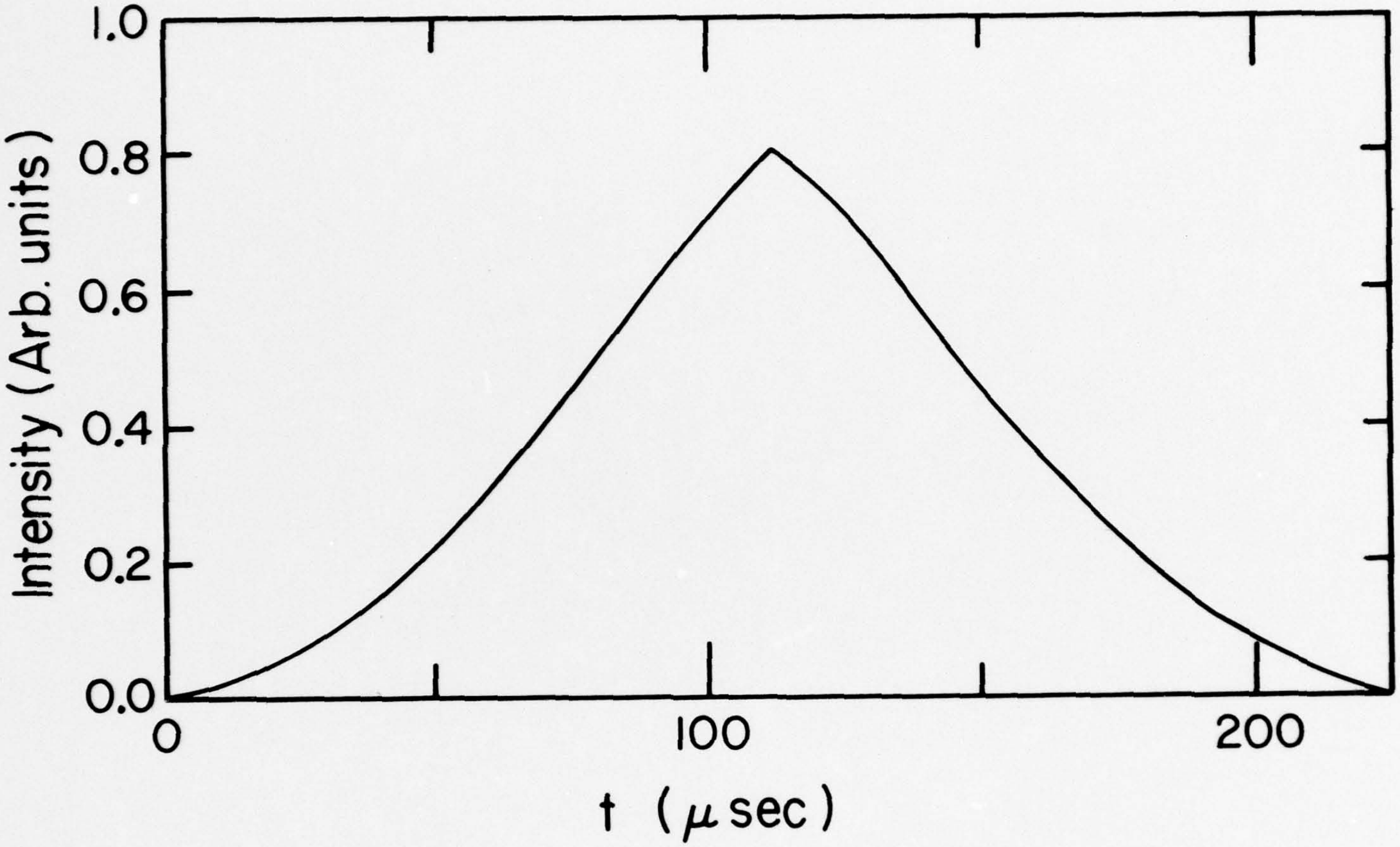

FIGURE 5. Temporal shape of light pulse used in taking measurements of Figure 4.

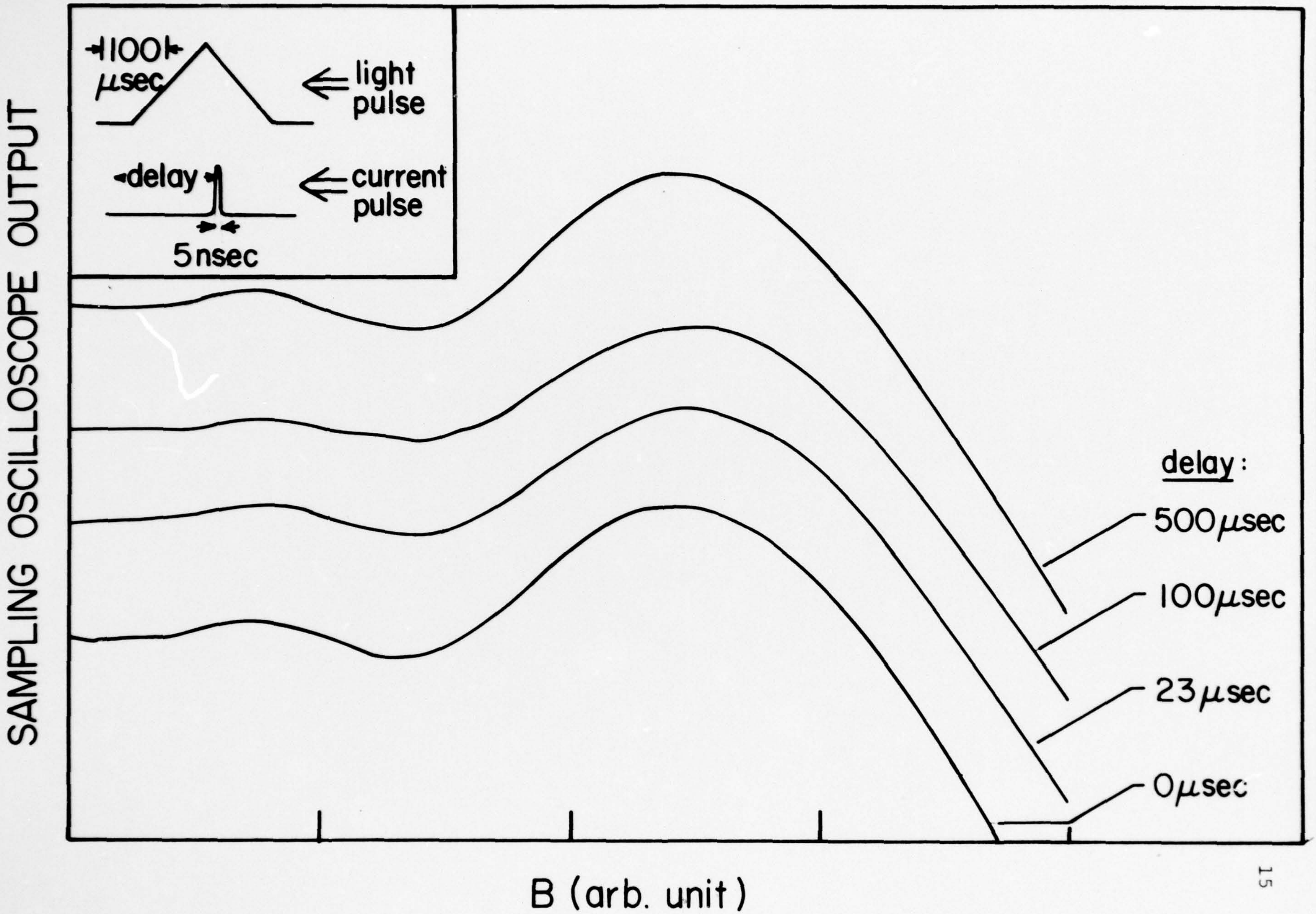

FIGURE 6. Shubnikov-de Haas Measurements Taken With Various Delays Between The Rise of the Current Pulse and The Rise of the Light Pulse.

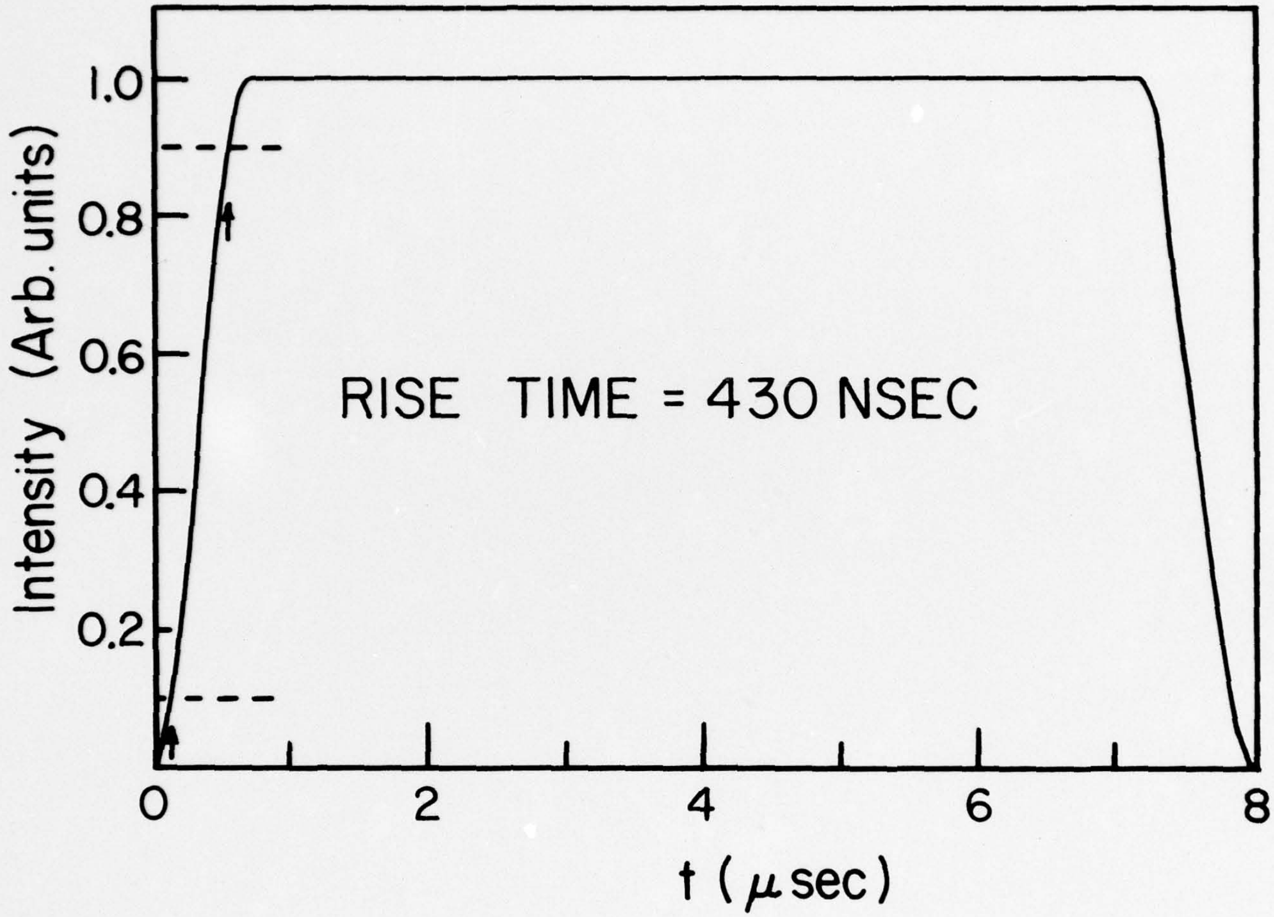

FIGURE 7. Temporal shape of light pulse now being used in measurements in progress.

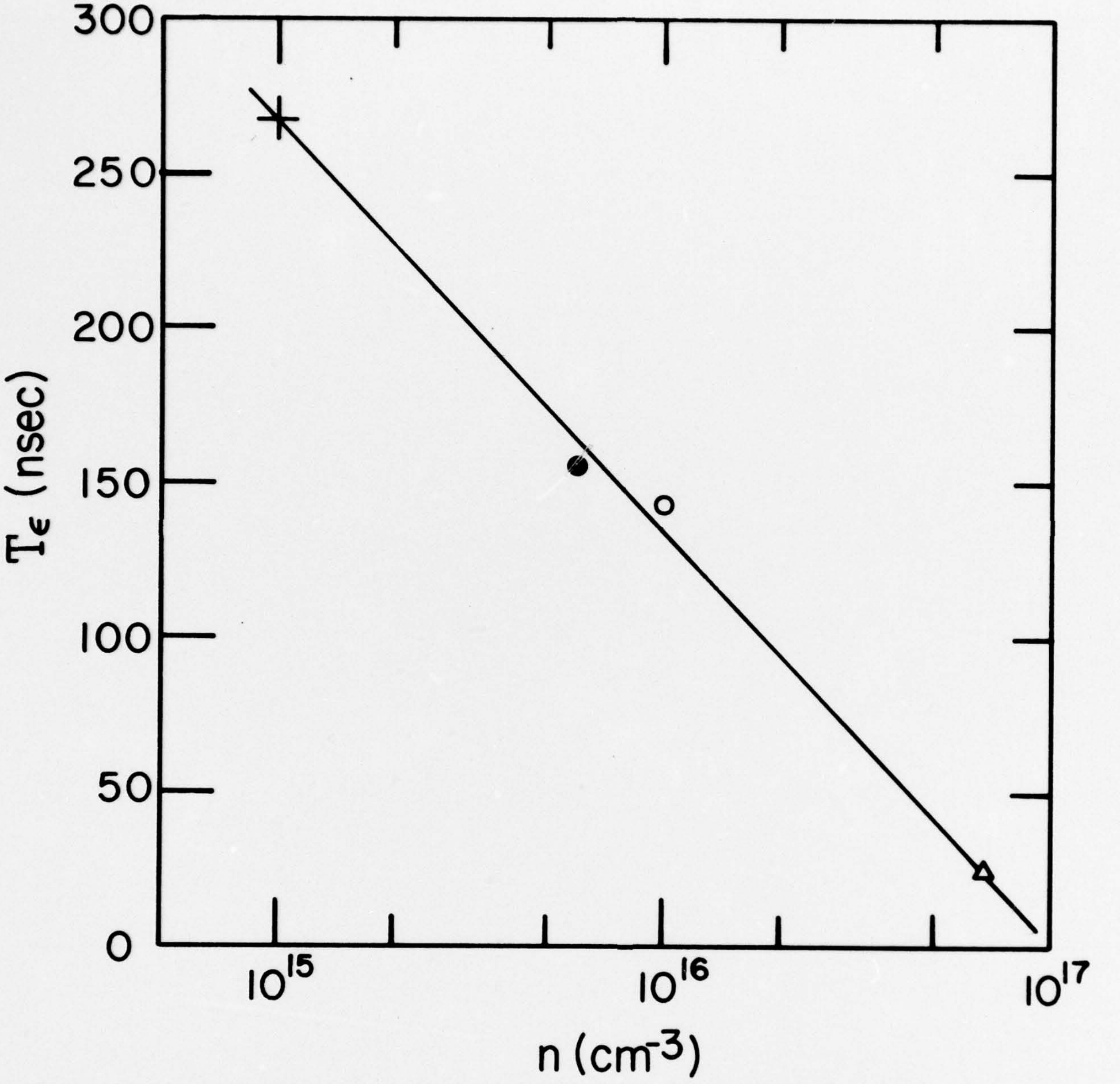

FIGURE 8. Energy relaxation time as a function of electron concentration.