AD-753 419

RETINAL EFFECTS OF MULTIPLE PULSE GALLIUM ARSENIDE LASER

Robert W. Ebbers

School of Aerospace Medicine
Brooks Air Force Base, Texas

November 1972

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Unclassified

Security Classification

AD-753419

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) USAF School of Aerospace Medicine Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

RETINAL EFFECTS OF MULTIPLE PULSE GALLIUM ARSENIDE LASER

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final report - 1971

5. AUTHOR(S) (First name, middle initial, last name)

Robert W. Ebbers, Major, USAF, BSC

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1972	11	12

8a. CONTRACT OR GRANT NO. b. PROJECT NO. 6301 c. Task No. 630105 d. Work Unit No. 025	9a. ORIGINATOR'S REPORT NUMBER(S) SAM-TR-72-25 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	USAF School of Aerospace Medicine Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235

13. ABSTRACT

The eyes of 38 anesthetized rhesus monkeys were exposed to near infrared laser radiation from a repetitive pulse gallium arsenide laser. Pulse repetition frequencies of 40 pps and 1,000 pps were utilized with a 20 nsec. pulse width at the wavelength of 905 nm. Lesions for threshold determination were placed in the temporal paramacular area and could be produced only by varying exposure duration with fixed energy output. Therefore, the resultant 50% probability of damage values (ED-50) were expressed as total exposure duration rather than energy per pulse. The ED-50 value of 0.72 sec. for the 1,000 pps exposure is significantly lower than the 22.3 sec. for the 40 pps exposure and demonstrates a cumulative effect.

Ia

DD FORM 1 NOV 65 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Eye damage						
Retinal burns						
Laser eye burns						

Ib

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ROBERT W. EBBERS, Major, USAF, BSC

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FOREWORD

This work was accomplished in the Oculo-Thermal Branch of the Radiobiology Division, under task No. 630105-025, during 1971. The paper was submitted on 1 August 1972.

The author wishes to acknowledge the contributions of: Major Joe E. Manz, Jr., who (while on temporary duty from AFWL) aided in laser operation, measurement calibration, and collection of data; and of Richard C. McNee, of the Biometrics Division, whose aid in experimental design and analysis of data was invaluable.

The animals involved in this study were maintained in accordance with the "Guide for Laboratory Animal Facilities and Care" as published by the National Academy of Sciences-National Research Council.

This report has been reviewed and is approved.

EVAN R. GOLTRA, Colonel, USAF, MC
Commander

RETINAL EFFECTS OF MULTIPLE PULSE GALLIUM ARSENIDE LASER

I. INTRODUCTION

Retinal damage thresholds from lasers have been determined for several different wavelengths of the more commonly used lasers. These thresholds have been ascertained for times ranging from nanoseconds to seconds by use of the appropriate type of laser--single pulse or continuous wave. Work has only recently begun on the effects of multiple pulse lasers (1, 2, 3). It has been postulated by Gibson (4) that cumulative effects will occur as a function of the rate of deposition of energy as determined by the pulse repetition frequency (PRF). Because of the rapidly growing inventory of multiple pulse lasers in the Air Force, the acquisition of such data is imperative for permissible exposure levels (PEL) determination (5, 6).

Threshold determinations for multiple pulse gallium arsenide (GaAs) lasers have presented greater problems than have other multiple pulse lasers in that even single pulse determinations in the 0.85 to 0.9 µm. wavelength range have been difficult. This difficulty has been due to relatively low power, wide-beam divergence, and multiple-array sources, as well as the lack of other lasers at 0.85 to 0.9 µm. wavelengths for comparison. Studies on the GaAs laser cane resulted in no retinal effect being observed (7-11). The only known previous case of retinal burns from a GaAs laser was reported at Frankford Arsenal (Phila., Pa.). There, researchers used a single-diode GaAs laser, cooled to 77° K. (thus shifting the wavelength from 0.9 to 0.85 µm.), with a PRF of 120,000 pps, 500 nanosecond (nsec.) pulse length and an exposure duration of 1 sec. They determined a 50% probability (ED-50) of 60 mw. for retinal damage (12). Although this data point is important, it has little applicability to most Air Force GaAs systems; for they have quite different operating characteristics.

The experimental work being reported here was performed on an operational multiple pulse GaAs laser for which a Safe Eye Exposure Distance (SEED) was required prior to range testing. Rhesus monkeys (*Macaca mulatta*) were exposed.

II. METHODS

Retinal damage thresholds were determined on the eyes of anesthetized primates. The gallium arsenide laser used to make these exposures had the following specifications:

peak power = 5.5 kw.

pulse width = 30 nsec. at the half-power point

two PRF settings = 40 pps and 1,000 pps

wavelength = 905 nm.

beam divergence = 1.5°

output aperture = 2" x 2"

The laser was actually an array consisting of 16 subarrays, in which each subarray had 10 elements (or chips), and each element had 2 diodes in parallel. Thus, optically, a total of 320 diodes were simultaneously lasing in the total array. A front view of the laser shows the array with the 16 subarrays (fig. 1). This laser was developed for the Air Force by IBM (Gaithersburg, Md.).

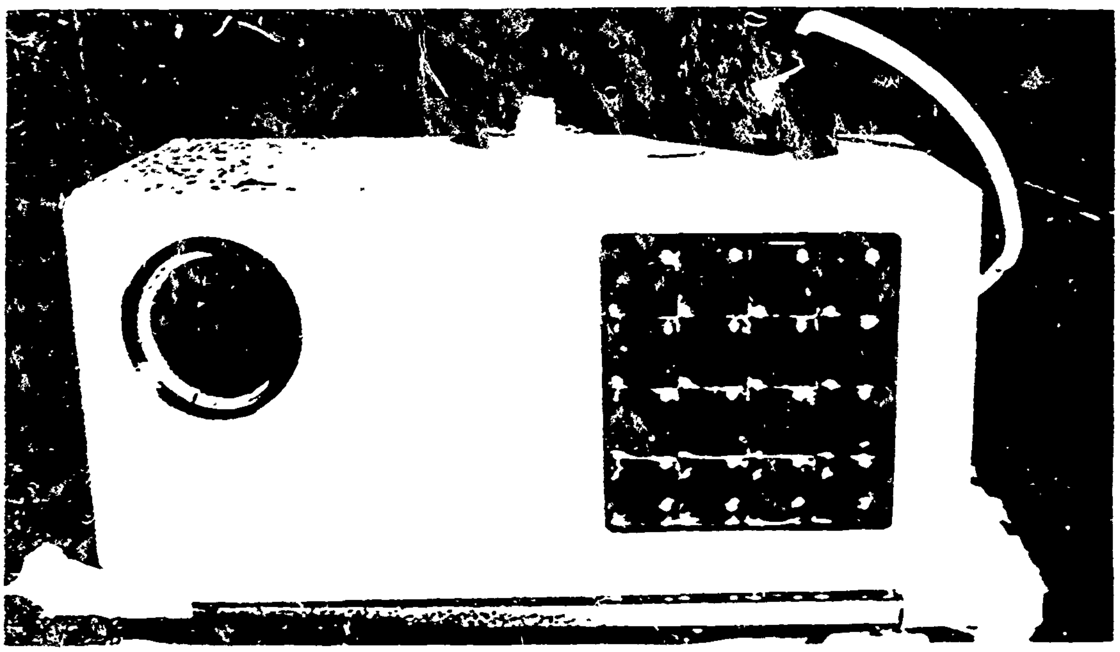

FIGURE 1

Front view of gallium arsenide laser. (Note: Reflections from photoflash can be seen on the array. The laser was not operating.)

The exposure configuration is shown in figure 2. The diverging laser beam was apertured by the iris diaphragm of the Compur electronic shutter (Burke and James, Inc., Chicago, Ill.) to provide a full pupil (7 mm.) beam diameter at the corneal plane of the primate's eye. The shutter controlled the exposure duration. A pellicle beam-splitter served the dual purpose of introducing a Helium-Neon (HeNe) alignment gas laser (Spectra Physics, Mountain View, Calif.) coaxial to the GaAs laser beam and of splitting off a portion of the beam for monitoring purposes. An SGD-100 silicon photodiode (Edgerton, Germeshausen & Grier, Inc., Salem, Mass.) was used to monitor the GaAs beam. The output from the photodiode was fed into a Systron-Donner 7034 (Concord, Calif.) counter-timer to record the number of pulses per exposure and into a Tektronix 549 oscilloscope (Beaverton, Ore.) to display the pulse amplitude. These data were periodically cross-calibrated with an Eppley thermopile (Eppley Lab., Newport, R.I.) placed at the plane of the primate's eye. The calibration conversions are shown in table I.

TABLE I

Calibration values for output from photodiode

Experimental conversions	PRP settings 40	1,000 (pps)
Thermopile reading (μv)	1.8	22.0
X Calibration factor (μw/μv)	14.0	14.0
= Total power (μw)	25.2	308.0
or Energy/Second (μj/sec.)	25.2	308.0
÷ Measured PRF (pps)	40.0	972.0
= Energy/Pulse (μj/p)	0.63	0.3169
÷ Scope sensitivity (v/p)	12.0	6.0
= Scope calibration factor (μj/v)	0.0525	0.0528

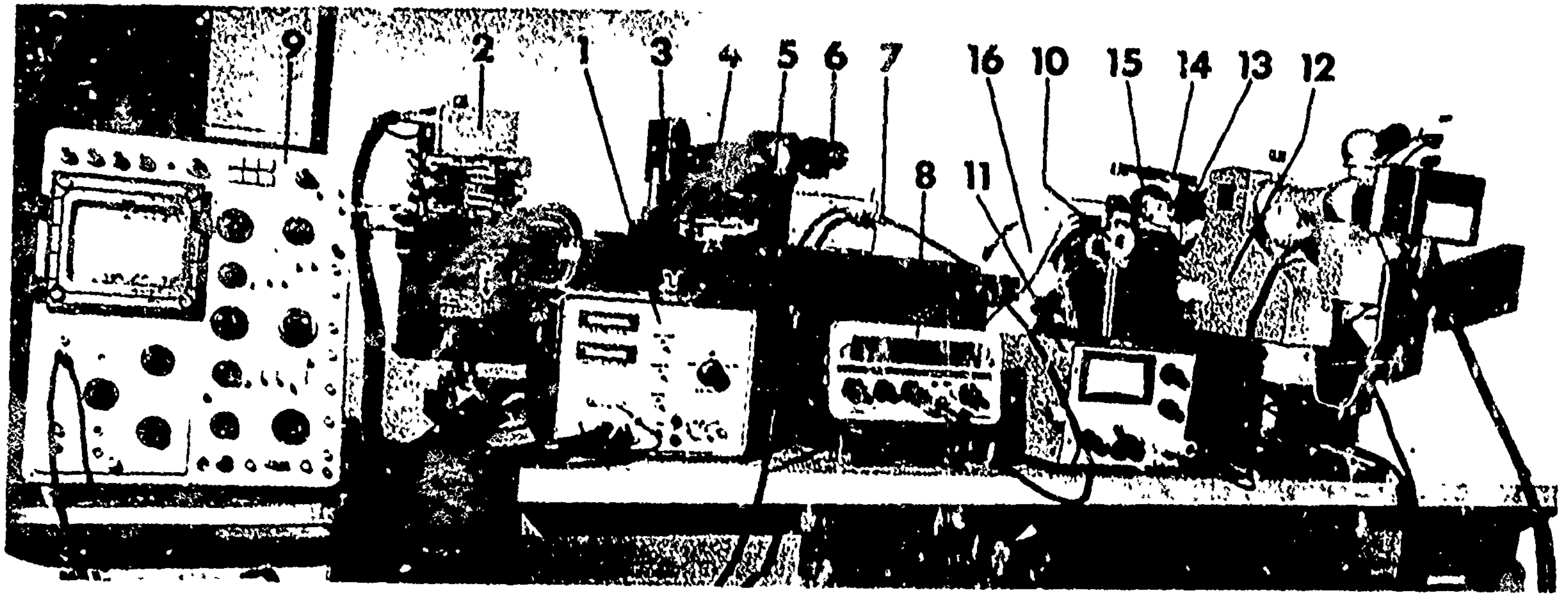

FIGURE 2

Experimental exposure configuration, on which are listed: (1) Laser power supply; (2) GaAs laser; (3) Compur electronic shutter; (4) HeNe alignment laser; (5) pellicle beam splitter; (6) photodiode; (7) battery box for photodiode; (8) counter-timer; (9) oscilloscope; (10) thermopile; (11) microvolt-ammeter; (12) fundus camera with Polaroid back; (13) mirror; (14) animal mount; (15) subject monkey; and (16) heating pad.

A mirror mounted on the objective tube of a Zeiss fundus camera (Carl Zeiss, Inc., Oberkochen, W. Germany) directed the beam into the eye of the subject primate. The fundus camera was used for location of exposure sites and for postexposure observations and photography. The monkey was positioned on an adjustable animal mount and was covered with a heating pad so that body core temperature was controlled.

In preparation for exposure, each animal was tranquilized with phencyclidine hydrochloride (Sernylan). The desired level of anesthetization was achieved and maintained by administration of sodium pentobarbital (Nembutal) through an intracatheter. Retrobulbar injections of lidocaine hydrochloride (Xylocaine) were given to control eye movement. Pupil dilation was achieved by topical application of tropicamide (Mydriacyl). Each eye was examined ophthalmoscopically to insure a clear retinal area for exposure. Retinoscopy was also performed on each eye to determine refractive status. None of the eyes used in this study exceeded 0.5 diopter of refractive error in any meridian. A suture was placed in each upper eyelid to keep it open during exposure. Corneal contact lenses were inserted in each eye to prevent desiccation and thus preserve corneal integrity.

The usual experimental procedure is to hold time constant and vary the energy for a series of exposures. A few preliminary exposures revealed that this procedure could not be utilized in our study. Because retinal burns could be produced only at the maximum energy setting, the variable had to be time, and this could be determined either by total open-time of shutter or by number of pulses per exposure.

In addition, it was determined that all diodes were not operating consistently (fig. 3), and hence a uniform beam pattern was not expected. A photograph, taken with infrared film of the resultant beam pattern on a piece of cardboard at 1 m. from the laser (fig. 4), reveals that the beam overlap provides a uniform pattern over a sufficiently large area to be included in the aperture used.

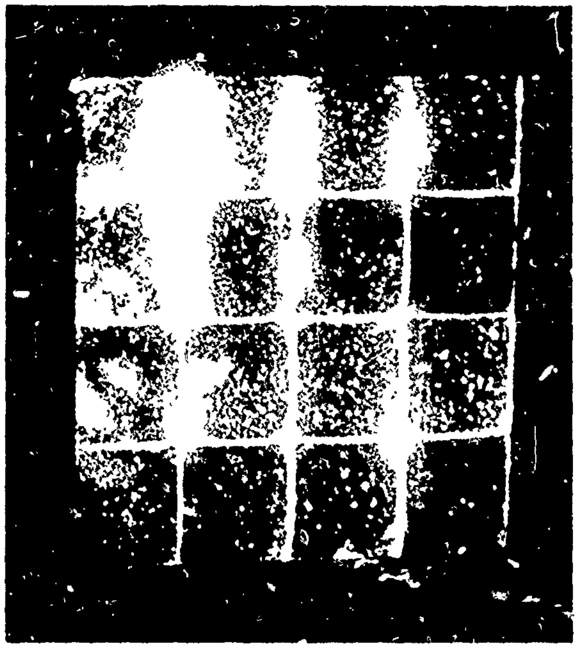

FIGURE 3

Infrared photograph of GaAs laser array while in operation. (Note: Hot spots)

FIGURE 4

Infrared photograph of GaAs laser-beam pattern on cardboard positioned at 1.0 m. from laser. (Note: Beam has expanded to approximately 3" x 3".)

Another problem was that the timer control of the shutter did not have sufficiently fine increments. As a result, in this study a stop watch and manual timing had to be used for some exposures, with duration then being calculated by converting into time the total number of pulses during the exposure.

Under these conditions, a total of 38 monkey eyes were exposed. Of these eyes, 20 had seven to ten exposures at 40 pps and also two exposures at 1,000 pps. Ten eyes were exposed to 1,000 pps only. All of these exposures were at 1.4 m. In addition, 8 eyes were exposed to 40 pps at 1.3 m. All of the exposures were placed on the temporal paramacular area of the retinae of the anesthetized monkeys. The criterion used was an ophthalmoscopically visible lesion observable within one hour.

The "up-and-down" method, used for the 40 pps exposures, consists of determining a tentative threshold and standard deviation with preliminary exposures. These tentative thresholds, expressed in seconds, were used as starting points. Subsequent exposures were 1 S.D. higher or lower, depending upon whether or not a lesion was observed. This up-and-down procedure was continued for all 40 pps exposures on an individual eye. While this method would also have been preferable for the 1,000 pps exposures, it could not be properly utilized because of the lack of sufficiently fine timer increments. By use of manual timing, attempts were made to keep the pulses per exposure near the tentative mean established by preliminary exposures at this PRF.

III. RESULTS

The results of this study are shown in table II. The first column lists the PRFs; the second gives the distances from the laser aperture to the eye; and the third indicates the number of eyes exposed under each condition. In the fourth column, the ED-50 values and their respective 95% confidence limits are the total exposure duration values expressed in seconds. This value represents the 50% probability point for lesion production. The analyses used to obtain these values were performed in log units to be consistent with previous reporting techniques. The 40 pps data obtained by the up-and-down method were analyzed in time required to produce a lesion; but the 1,000 pps data were analyzed by number of pulses required to produce a lesion, and then converted to time by using the factor of 972 pps. The latter conversion was used because of the difficulty in determining sufficiently precise increments in time at the 1,000 pps setting. The midpoint--of the average pulses with no lesions and the average pulses with lesions in each eye--was used as an estimate of the sensitivity levels.

TABLE II

Total exposure duration as a criterion for the determination of ED-50 values

PRFs (pps)	Distance (meters)	N	ED-50 (sec.)	95% C.L. (sec.)
40	1.4	20	22.30	21.15-22.70
40	1.0	8	20.75	20.32-21.19
1000	1.4	27	0.72	0.71-0.73

C. L. = Confidence limits

The 1 m. distance ED-50 for 40 pps is significantly lower at the 0.001 level than the 1.4 m. ED-50. However, because of nonuniformity of the beam, the cross section being used for exposure may not have been the same when the laser was moved closer. Therefore, this difference should be viewed with caution, pending other verifying studies. The ED-50 value for 1,000 pps is significantly lower than the corresponding ED-50 value for 40 pps.

In addition to the foregoing ED-50 determination, the ED-50 were also expressed in total number of pulses per exposure (table III).

In the same manner, table IV indicates the total energy per exposure ED-50 required to produce a lesion. It must be stressed that the values in this table are energy per exposure (not energy per pulse, the form typically used for representing repetitive pulse ED-50's).

It should be noted that 17 of the 20 eyes with only two exposures at 1,000 pps had one "burn" and one "no-burn" and could be used in the analysis. Since the estimates of the sensitivity levels would be more variable on these eyes with only two exposures than on the other set of 10 eyes with ten exposures per eye, the ED-50 was estimated as the weighted average of the estimates from both sets of data.

TABLE III

Total number of pulses as a criterion for the determination of ED-50 values

PRFs (pps)	Distance (meters)	N	ED-50 (pulses)	95% C.L. (pulses)
40	1.4	20	892	846-908
40	1.0	8	830	813-848
1000	1.4	27	701	688-713

C. L. = Confidence limits

TABLE IV

Total energy per exposure as a criterion for the determination of ED-50 values

PRFs (pps)	Distance (meters)	N	ED-50 (μj)	95% C.L. (μj)
40	1.4	20	562	533-572
40	1.0	8	523	512-534
1000	1.4	27	222	218-226

C. L. = Confidence limits

IV. CONCLUSIONS

1. The results of this study support the contention that a cumulative effect occurs as the pulse rate increases. It has been shown that, with the gallium arsenide laser, the threshold time for damage to occur was lower for 1,000 pps than for 40 pps. This conclusion is based on the fact that less total exposure time and fewer pulses, even though the individual pulses have less energy, are necessary to create retinal damage at the higher repetitive pulse rate than at the lower.

2. The inability to vary energy makes it extremely difficult to relate the thresholds obtained to those from other laser systems (i.e., in terms of energy, these thresholds could only

be expressed as energy per exposure rather than energy per pulse). Hopefully, as the state-of-the-art progresses, GaAs lasers will be developed which have sufficient output to make energy a variable. As an alternate approach, the possibility of using other lasers at the GaAs wavelengths should be pursued.

3. The problems of wide-beam divergence and multiple source arrays also make threshold determinations and extrapolations difficult. Ideally, a well collimated single-diode GaAs laser should be used; but this is presently beyond the state-of-the-art.

4. The threshold values determined for this specific laser were used for Safe Eye Exposure Distance (SEED) calculations which permitted the laser to be range-tested.

5. Obviously, more work is necessary in this area. Specifically needed are thresholds which can be utilized for determining PEL applicable to all GaAs laser systems. Such data will be obtained as soon as the status of laser development permits.

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