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LASER AIMING LIGHT

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The laser aiming light (LAL) for use with small arms was developed and field tested. The aiming light was designed with advanced state-of-the-art components consisting of a room temperature laser diode, low impedance laser diode mount, and microelectronic pulser. The LAL has an emission wavelength ranging from 820 to 850 nanometers for use with night vision goggles. The LAL housing is single structured, that is, 6.25 inches long, 0.78 inch diameter, with a 1.20-inch-diameter lens compartment: the LAL weighs 7.87 ounces. The LAL is powered by an 11.2-volt

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battery, and the average optical output power ranges from 50 to 350 microwatts. The aiming light has a boresight mechanism that interfaces with the rifle adapter. The LAL was field tested on the M-16 rifle in the single as well as rapid-fire mode and did not exhibit degradation. The laser aiming light is considered to be eye-safe.

FOREWORD

The investigation covered by this report was conducted under authority of DA Task 1S663719DK/70/03.

The investigation was performed from January 1971 to March 1973 by Michael Hacskaylo, Physicist, Night Vision Laboratory. The author wishes to acknowledge the engineering support of Howard L. Dunmire, the electronics technical support of Andy J. Repasy and the night firing arrangements of Robert L. Stone, all of the Night Vision Laboratory. The study was made under the supervision of Steve B. Gibson, Chief, Optical Radiation Team, under the direction of Edward J. Sheehan, Director, Systems Development Technical Area, and also under the direction of Benjamin Goldberg, Director, Night Vision Laboratory, U. S. Army Electronics Command (USAECOM), Fort Belvoir, Virginia.

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LASER AIMING LIGHT

I. INTRODUCTION

1. **Background.** The previous development of an aiming light for firing small arms, to be used with night vision goggles, incorporated the non-coherent light-emitting diode (LED) as the light source. The LED aiming light was rather bulky due to the inefficient optical system required to project a narrow beam. However, in recent years, the development of laser diodes has progressed to the point where such diodes (namely, GaAlAs) can operate at room temperature with high efficiencies. Since the electro-optical characteristics of the laser diode are superior to the LED, a task was initiated to develop a laser aiming light.

Three technical barriers had to be resolved in order to design an aiming light of minimal size and weight. The first is the development of a low impedance laser diode mount, i.e., a mount which minimizes the impedance induced by short pulses (100-nanosecond range) at high peak current pulses (25 amperes). The second barrier is the utilization of the Fraunhofer diffraction patterns produced by a small light pipe (0.008-inch diameter) which is used as an integrator for the 0.006-inch-wide diode. The third barrier is the development of a low-voltage, miniaturized microelectronic-hybrid pulser to drive the diode at 5 kilohertz with a 150-nanosecond pulse at 25 amperes peak drive current.

This report, which describes the development, operational characteristics, and field testing of the infrared-laser aiming light, is presented in sufficient detail so that those unfamiliar with all related technical disciplines can obtain a reasonable degree of comprehension.

II. INVESTIGATION

2. **Scope.** The designs of the aiming-light housing, the electronic pulser with associated power supply (battery), and the optical systems are predicated on the most efficient laser diode mount that can be developed during the program. Thus, the initial portion of this section will describe the electro-optical characteristics of the laser diode and the properties of the low impedance mount incorporating the microintegrator.

3. **GaAlAs Laser Diode Characteristics.** The electron-injection laser diodes are of the GaAlAs, single hetero-junction, close-confinement structure and are doped for a specific emission radiation wavelength ranging from 820 to 850 nanometers. The

close-confinement diodes were developed by Kressel and Nelson,[1] were improved by subsequent contractual effort sponsored by the Electronics Command Night Vision Laboratory,[2] and are being developed on a production program.[3] The laser diodes are fabricated by the liquid-phase epitaxy method. An n-type $Ga_xAl_{1-x}As$ layer is grown onto a single-crystal GaAs (100) substrate and followed by a p-type $Ga_yAl_{1-y}As$ layer, where $x = 0.03$ and $y = 0.05$ mole fractions. Zinc is diffused into the n-layer to a depth of approximately 2.5 micrometers. This diffused p-layer in the n-layer $Ga_xAl_{1-x}As$ is the region where the recombination occurs and is the optical cavity where the lasing mode is generated. The width of the emitting surface is 0.006 inch wide. The total diode thickness is 0.003 inch, and the length is 0.012 inch. The resistance of the diode ranges from 120 to 200 milliohms. The power conversion efficiency of the diodes varies from 3 to 6 percent at 25° C. The threshold current of the 0.006-inch by 0.012-inch diode is 11 amperes at room temperature. The dependency of the threshold current on temperature is shown in Fig. 1. The dependency is semi-logarithmic in the temperature range of -50° C to +50° C, with the threshold current increasing from 5 to 14 amperes in that range. The pulsing repetition rate is 5 kilohertz.

The light output was measured as a function of temperature of the diode when it was operated at 5 kilohertz with a peak diode current of 20 amperes. The light output is an inverse linear function of the temperature (Fig. 1). Although not shown here, it is noted that the diode efficiency exhibits a similar temperature-dependency curve;[4] thus, to some extent, the diode is self-compensating over this temperature range.

4. **Low Impedance Diode Package.** The low impedance package (LIP) was designed and fabricated at the ECOM Night Vision Laboratory.[5] The design was based on the coaxial transmission line principle. The impedance of the package was reduced from 1 ohm (commercial package) to the magnitude of 10 to 20 milliohms. A cross-section view of the LIP is shown in Fig. 2. The current/voltage characteristics of the LIP operational with a 0.006-inch-wide diode are shown in Fig. 3 for 70-nanosecond and 150-nanosecond pulse widths (at half-peak current value). The impedance is 0.200 ohm for the 70-nanosecond current pulse and 0.130 ohm for the 150-nanosecond current pulse. The "threshold" voltage of approximately 1.2 volts is the forward voltage

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[1] H. Kressel and H. Nelson, "Improved Red and Infrared Light-Emitting $Al_xGa_{1-x}As$ Laser Diodes Using the Close-Confinement Structure," *Applied Physics Letters*, Vol. 15, No. 1, 1969, pp. 7-9.

[2] H. Kressel et al., "(AlGa)As Laser Study," Final Report, Contract No. DAAK02-69-C-0213, USAMERDC, Fort Belvoir, Virginia, April 1970.

[3] T. Gonda, "Production Engineering Measure for Low Radiant Power Infrared Sources," 4th Quarterly Progress Report, RCA Contract No. DAAB05-71-C-2602, IED, USAECOM, Philadelphia, Pennsylvania, November 1971.

[4] H. Kressel and H. Nelson, "Improved Red and Infrared Light-Emitting $Al_xGa_{1-x}As$ Laser Diodes Using the Close-Confinement Structure," *Applied Physics Letters*, Vol. 15, No. 1, 1969, pp. 7-9.

[5] M. Hacskaylo, "Low Impedance Laser Diode Mount," Patent Pending, 1973.

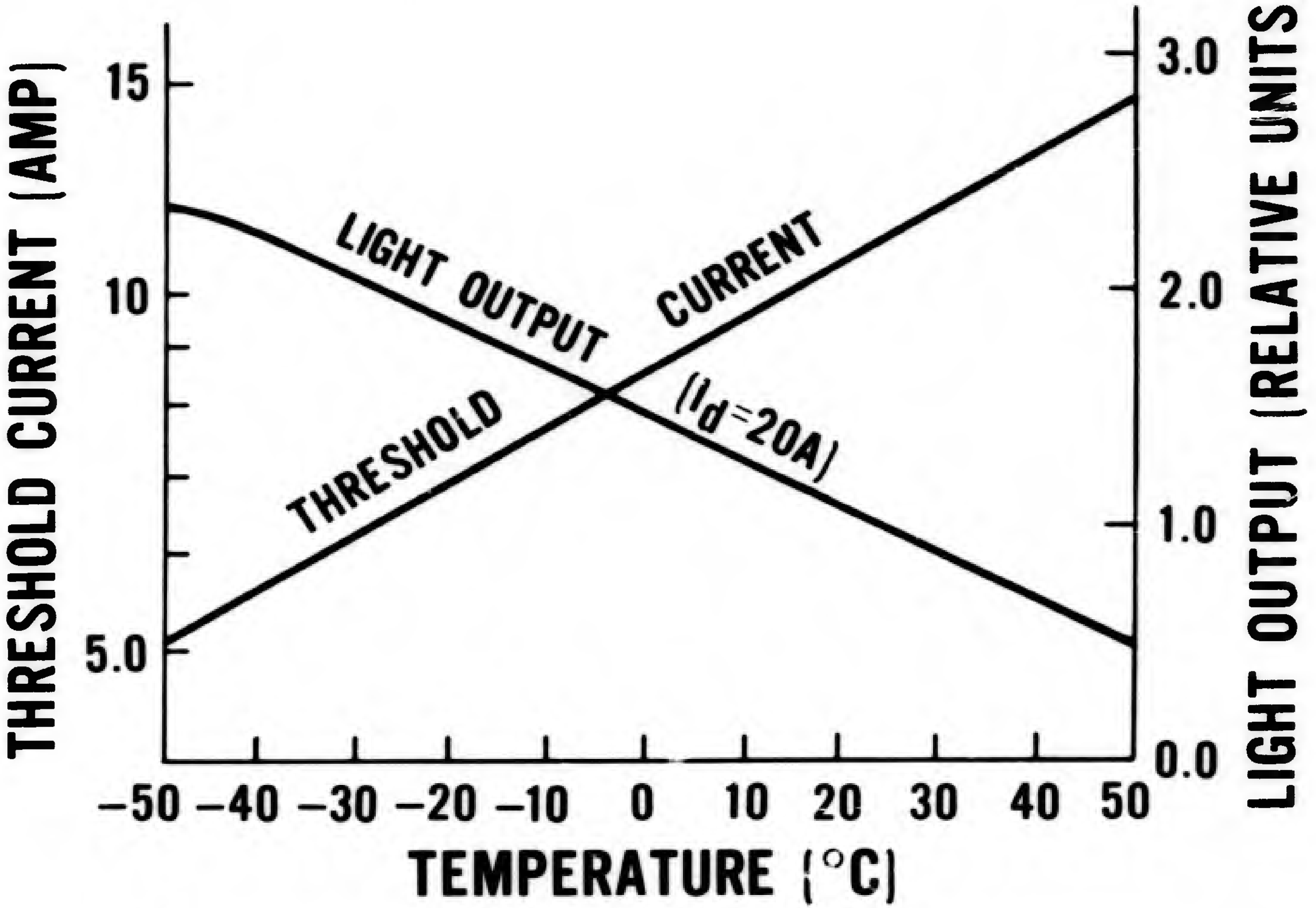

Fig. 1. Threshold current and relative light output of a GaAlAs laser diode as a function of temperature.

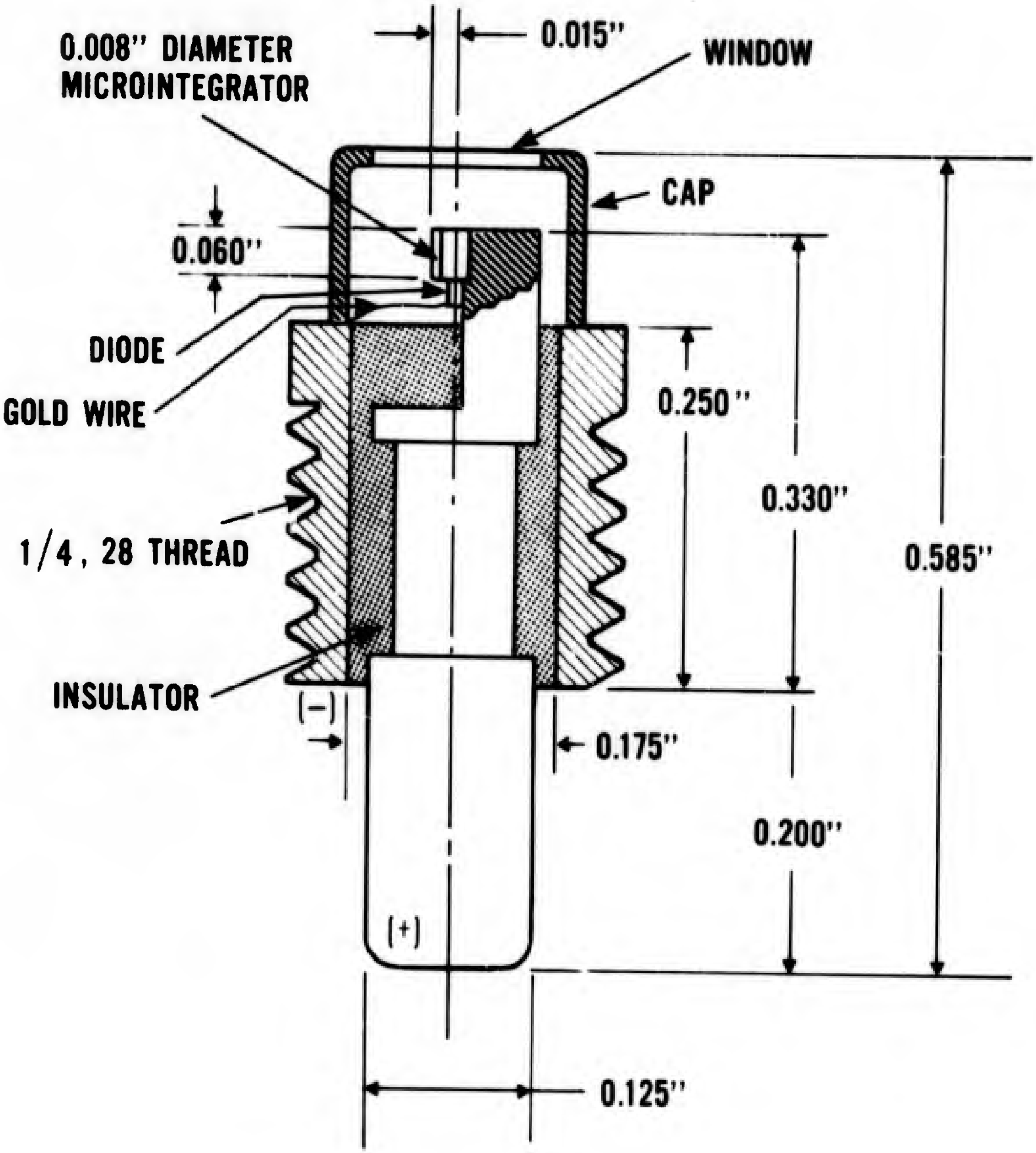

Fig. 2. Cross section of the low impedance package developed for the laser aiming light.

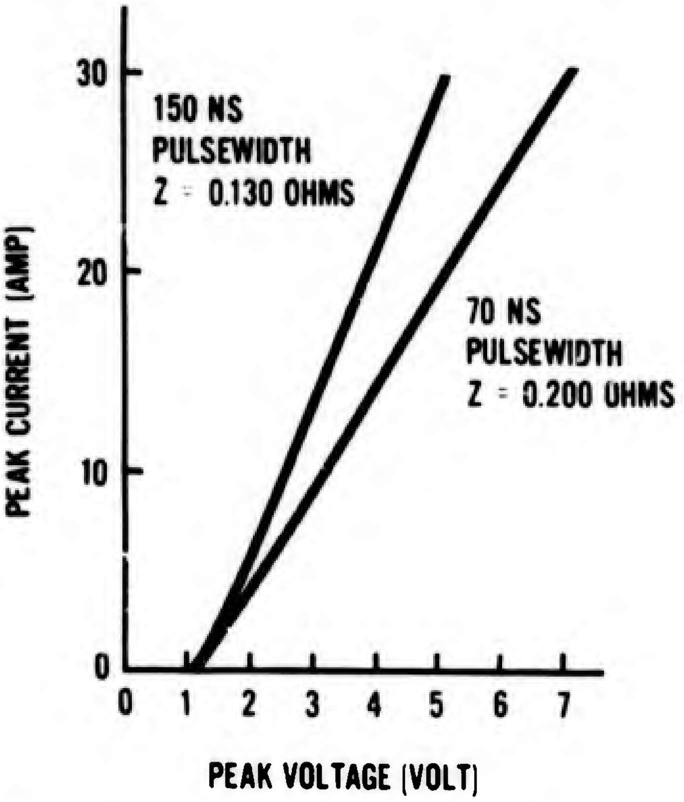

Fig. 3. Current/voltage characteristics of the low impedance package with a 0.006-inch-wide GaAlAs laser diode.

of the diode, i.e., no appreciable current flow is experienced until this value is reached.

A voltage of 2.7 to 3.2 volts is required for onset of lasing, i.e., for a diode threshold current of 11 amperes. Thus, the diode current value of 30 amperes is three times the threshold value, which is an optimum current operational condition.

5. **Electro-Optical Characteristics.** The electro-optical characteristics of the laser diode mounted on the low impedance package were used for the design of the electronic pulser and power supply (battery) and will be described in this section. The optical radiation patterns of the diode driven at 5 kilohertz frequency, 150 nanoseconds pulse width, and 30 amperes peak current are shown in Fig. 4.

The beam spread of the 0.006-inch diode (Fig. 4, curve A) is in the plane parallel to the light-emitting junction. The beam spread is 25 degrees at the 1/10-peak intensity points and 13.5 degrees at the half-peak intensity points.

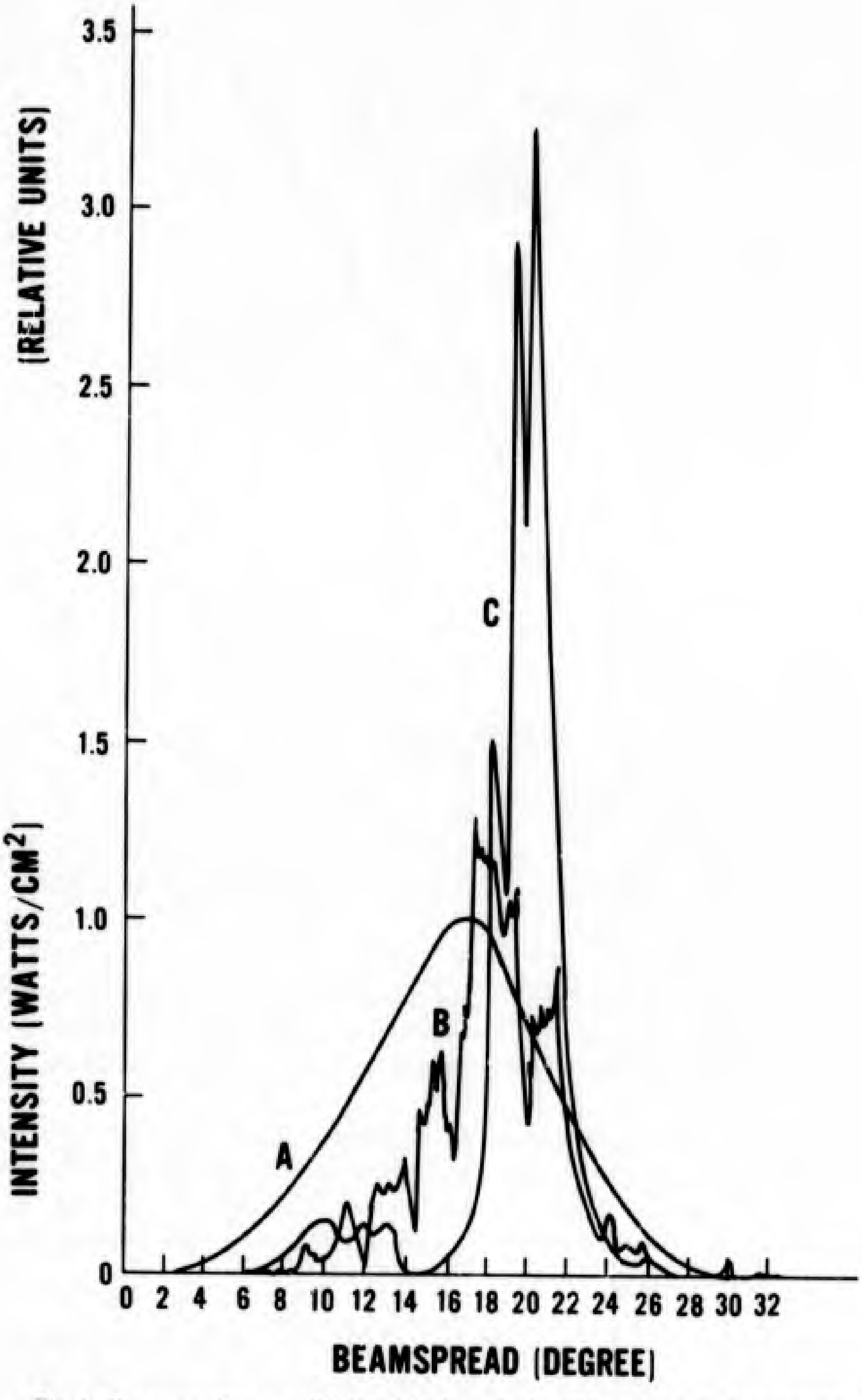

Fig. 4. Beamspread curves. "A" is of the laser diode, "B" is of the diode symmetrically centered at the incident aperture of the microintegrator, and "C" is of the diode positioned off-axis by approximately one-half of the radius of the microintegrator.

The incorporation of a hollow integrator changes the beam spread in an unexpected manner. Due to the small dimensions of the integrator, Fraunhofer diffraction phenomena occur. Fraunhofer diffraction is the name given to the interference of light caused by small rectangular, square, circular, or elliptical apertures.[6] The dimensions (side or diameter) are in the range of approximately 10 millimeters or less (1 millimeter = 1000 micrometers). It should be noted that the apertures do not have a thickness dimension. The interference phenomenon occurs even though the wavelength is 0.5 to 1.0 micrometer and is several orders of magnitudes smaller than the apertures. An 0.008-inch-diameter aperture is approximately 200 micrometers.

The Fraunhofer diffraction pattern shows a central maximum (zero order) with other maxima (higher orders) being lower in intensity and appearing in a periodic fashion on either side of the central maximum. The diffraction pattern of the circular aperture exhibits the central maximum, having the circular shape of the aperture, with other maxima being discrete, concentric rings. The intensities and positions of the diffraction patterns can be described by mathematical equations which are a function of the dimensions of the apertures.[7]

The dimension of length, when added to the apertures, modifies the diffraction patterns. The extended apertures will exhibit a superposition of the aperture diffractions (Fraunhofer) and reflections of the optically polished walls (curved or flat surfaces) of the microintegrators. In general, the diffraction patterns of the microintegrators duplicate the Fraunhofer diffraction patterns when the light sources (a line source as from a laser diode, or a point source) are symmetrically centered on the aperture. The diffraction pattern of a 0.006-inch laser diode, symmetrically centered at the incident aperture of a 0.008-inch-diameter optically polished brass integrator 0.100 inch long,[8] is shown in Fig. 4, curve B. If the light source is moved in a direction perpendicular to the length to a distance of approximately 0.4 of the radius (of the cylindrical microintegrator), the first-order lobe increases and the central maximum (zero order) decreases in intensities and as shown in Fig. 4, curve C. The intensity of the first order is at least 2.5 times larger than the central lobe. The band width of the first order is approximately 3 degrees at the half-peak intensity points. This is a factor of five smaller than the band width of the light emitted from the laser light source without an aperture. The mathematical equations of this effect (defined as a focusing microintegrator) have not been formulated and are considered to be more cumbersome than the mathematical equations pertaining to the Fraunhofer aperture.[9] The optical losses

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[6] M. Born and E. Wolfe, "Principles of Optics," 2nd Ed., The MacMillan Company, New York, 1961, pp. 392-401.

[7] Born and Wolfe, *op. cit.*

[8] National Jet Drill Co., Cumberland, Maryland.

[9] M. Hacskaylo, "Focusing Microintegrator," Patent Pending, 1973.

of the integrator were measured to be approximately 35 percent. The loss factor appears to be a function of the absorption coefficient of the brass rather than losses due to aperturing or scattering.

The far-field images (at 30 feet) of the diodes are shown in Fig. 5. In part A, the image of the diode cavity is projected as a narrow rectangular bar when the integrator is not used. In part B, the exit aperture of the hollow integrator is projected in a circular pattern. This diameter corresponds to a 4.0-milliradian beam. The intensity profile of the image of part B is shown in part C of Fig. 5. The beam shows slight structure, indicating that the integrator is effective in providing a nearly uniform circular source for projection. The beam angle is 3.2 milliradians with a diameter of 2.7 centimeters at the half-peak intensity point. The projected beam at 100 yards would be 10.5 inches in diameter.

The optical system consists of a double convex, 51.9-millimeter-focal length, 21-millimeter-diameter single lens, coated for transmission at 8500 angstroms. The glass is a borosilicate crown glass, type "X," with an index of refraction of 1.7 and low dispersion at 8500 angstroms.[10] The transmission at 8500 angstroms is better than 98 percent.

The optical output power of the diodes was measured by an Eppley thermopile, No. 10398. The optical output coverage ranged from 50 to 350 microwatts for four laser-aiming-light systems. The radiation hazard of the laser aiming lights was evaluated by the U. S. Army Environmental Hygiene Agency to determine the eye safety level for the laser aiming lights.[11] The maximum power density was measured to be 50 mw/cm^2. The units are considered to be eye-safe since the most intense unit emitted 1 x 10^{-8} joules/cm^2. The eye-safe threshold is presently considered to be 1 x 10^{-7} joules/cm^2.

6. **Electronic Characteristics.** The pulser was designed and fabricated so that it would operate from the 11.2-volt battery and be capable of delivering a 5- to 8-volt pulse driving a 20- to 30-ampere current pulse to the diode.[12] The pulser contains an internal clock that will operate at a nominal 5 kilohertz with a nominal pulse width of 150 nanoseconds. The clock is designed of complementary MOS circuitry in order that the clock will operate as the battery voltage drops. The hybridized circuitry is constructed on ceramic substrates using discrete silicon chips, and thick-film and thin-film

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[10] American Optical Corporation, Buffalo, New York.

[11] M. D. Sliney, "Preliminary Hazard Analysis of Gallium-Aluminum-Arsenide Laser Aiming Light"—Experimental Developmental Models, Radiation Protection Special Study No. 42-007-71/73, USAEHA-RL, Edgewood Arsenal, Maryland, 31 August 1972.

[12] "Miniaturized Solid State Pulse Power Supply," Washington Technological Associates, Inc., Rockville, Maryland, Contract No. DAAK02-72-C-0261, USAMERDC, Fort Belvoir, Virginia.

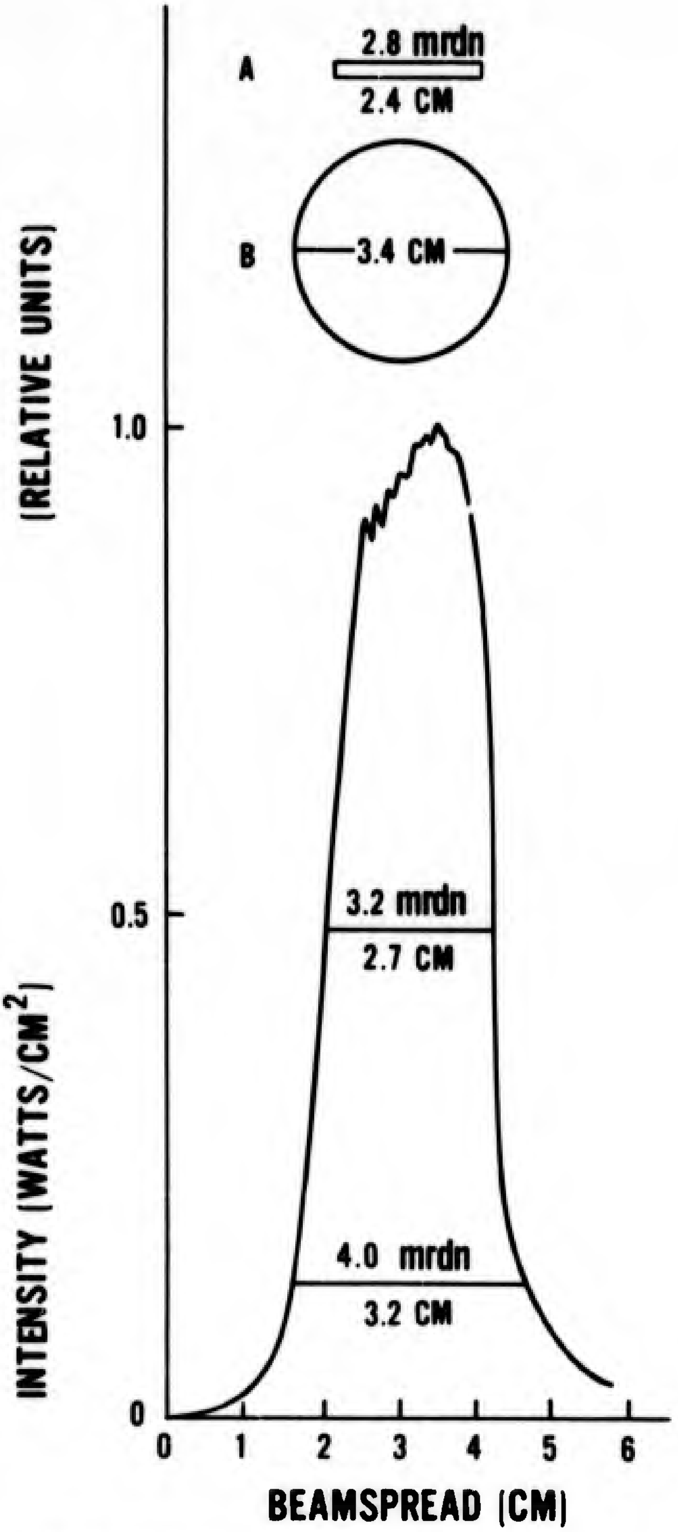

Fig. 5. Part A: far-field image of diode without an integrator: part B: far-field image of diode with an integrator, with the intensity profile of this image below.

components. The nominal operating voltage is 8 volts at a dc current of 15 milliamperes.

The battery selected to drive the aiming light for a continuous 8-hour period is the Mallory TR-118. The open-circuit voltage is 11.2 volts with a 350 milliampere-hour capacity. The operational life of the battery at a constant 15-milliampere drain is shown as a function of temperature in Fig. 6. The maximum and minimum voltage range of the aiming light is shown in Fig. 7. In relating the data of Fig. 6 to the data of Fig. 7, it may be seen that the battery is well suited for the LAL requirement at room temperature. At 40° C, the battery will operate the LAL but not at twice threshold. At 0° C, the battery voltage is lower, but the required drive voltage is also lower and the system is operational. However, at lower temperatures, the voltage drops off rapidly—more than the required driving voltage.[13] Thus, the LAL is temperature compensated to about 0° C, and will operate for 8 hours continuously. To temperatures of -40° C, the continuous operational time is limited to about 1 to 2 hours. The efficiency of the LAL in the temperature range of 30° C to -10° C changes from 0.20 to 1.5 percent.

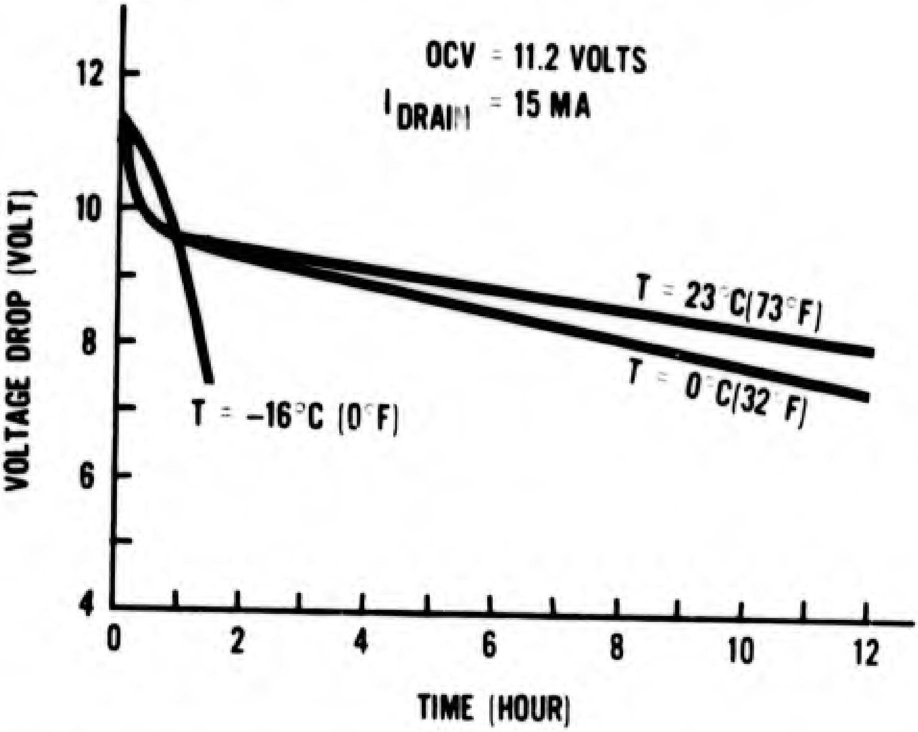

Fig. 6. Voltage characteristics of 11.2-volt mercury battery at a constant 15-milliampere current drain as a function of time at 23° C, 0° C, and -16.5° C.

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[13] P. D. Travesky, "Temperature Operation of 8.75 Volt Mercury Batteries," USAERDL, Fort Belvoir, Virginia, June 1964.

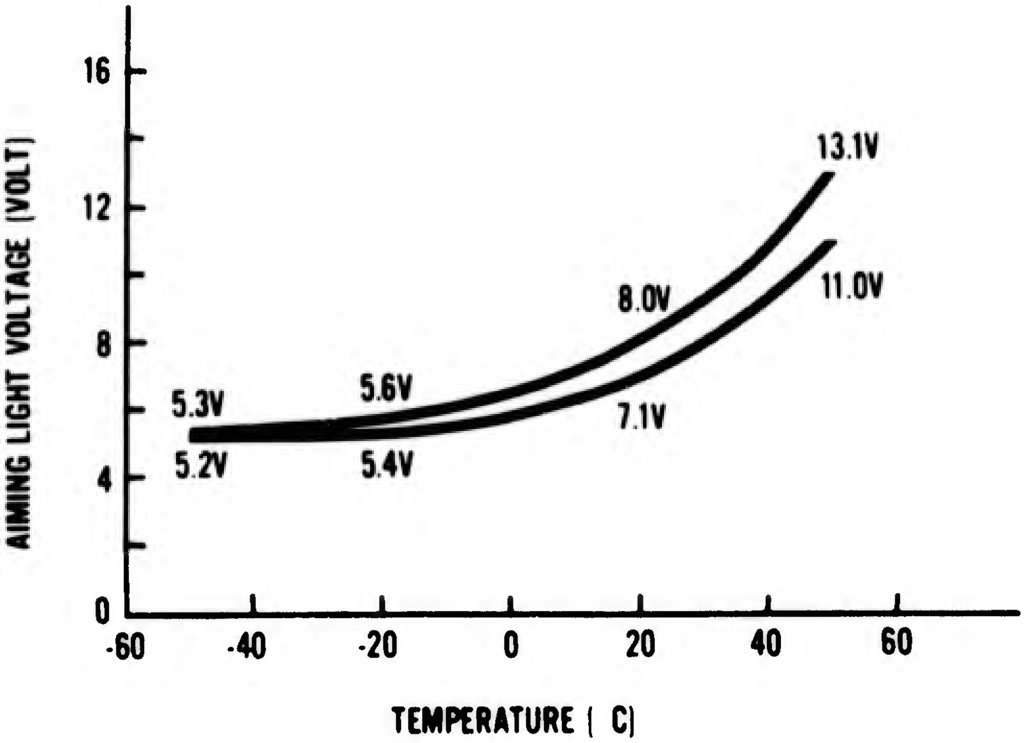

Fig. 7. Operational voltage range of the aiming light as a function of temperature.

7. **Laser-Aiming Light Design.** The LAL, including the boresight mechanism and weapon adapter (shown in Fig. 8), was designed and fabricated at this laboratory.[14] Part (a) of Fig. 8 shows the positions and details of the lens compartment, electronics housing, diode, battery, and end cap (far right). The dimensions of the LAL housing are 6.250 inches long, 0.780 inch in diameter at the cap, and 1.20 inches diameter at the lens compartment. The weight of the LAL is 7.87 ounces (224.5 grams), with the breakdown as follows: housing with bracket, 5.68 ounces (161.2 grams); lens and retaining rings, 0.40 ounce (11.3 grams); pulser and diode, 0.51 ounce (14.5 grams); and battery, 1.28 ounces (36.5 grams). The front view, or target end, of the LAL is shown in Fig. 8, part (b). The adapter (as shown in both parts of the Figure) is fabricated such that the boresight mechanism (X-Y direction) is external to the laser light source. The adjustment mechanism is designed such that the minimal adjustment corresponds to ±2 inches at 100 yards. The LAL with the component parts is shown in Fig. 9. The vertical and horizontal boresighting adjustment mechanism as well as the mount lock of the weapon adapter are also shown.

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[14] M. Hacskaylo and H. L. Dunmire, "Laser Aiming Light," Patent Pending, 1973.

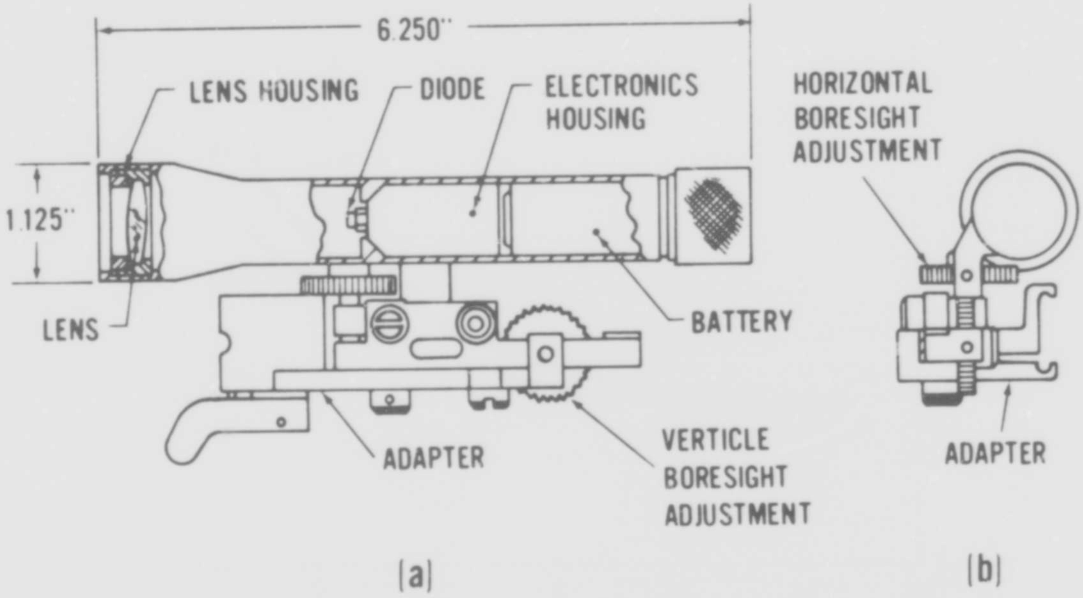

Fig. 8. Descriptive views of the laser-aiming-light housing: (a) the side view, and (b) the light-emitting end.

Fig. 9. The component parts of the laser aiming light.

8. **Field Evaluation.** The laser aiming light (LAL) was field tested at a rifle range. The tests were conducted under nighttime conditions. The LAL was mounted on an M-16 rifle, as shown in Fig. 10, and boresighted for a 6-inch yellow disc on a silhouette at a range of 50 yards. The infrared light was observed with a night vision goggle, type AN/PAS-5. The results of firing 12 rounds (by the author) exhibited a 6-inch circular pattern to the right of center of the 6-inch yellow disc. The second firing resulted in placing 19 rounds in a 4- by 10-inch rectangle as shown in Fig. 11. The rounds were fired in a "climbed" mode, i.e., each successive shot was purposely higher on the target than the previous shot. The LAL was remounted on another M-16 rifle and fired at a target *without reboresighting.* Six rounds were expended under rapid-fire conditions. The rounds were patterned in a 7-inch circle at the lower edge of a 6-inch yellow disc. Fifty rounds were fired during the field evaluation tests with comparable results.

During the firing of the rifles, the illuminated target was closely watched to determine if the projected beam was interrupted at the time of recoil. There was no evidence of an intermittent beam. The LAL components (battery, pulser, diode mount, and lens) did not exhibit degradation.

Fig. 10. The laser aiming light mounted on an M-16 rifle.

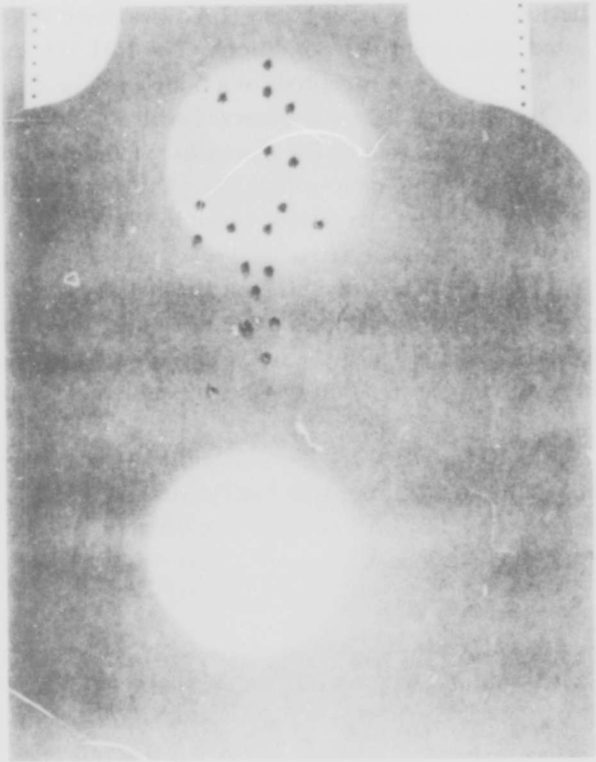

Fig. 11. The results of firing 19 rounds at night at a 6-inch disc on a silhouette at 50 yards.

III. SUMMARY

9. **Summary.** Prior art of an aiming-light system was limited to the non-coherent light-emitting diodes. This system was rather bulky and had an operational efficiency of approximately 0.1 percent. A lightweight and efficient laser aiming light was not possible by the incorporation of the then state-of-the-art key components. The development of the low-impedance diode mount, the focusing microintegrator, and the miniature pulser was carried out with the express purpose of designing a laser aiming light that combined a reduction in size and weight with increased operational efficiency (approx. 1 percent).

The investigations of the electro-optical characteristics of the key components and the determination of the operational characteristics were performed under laboratory conditions. The field testing of the laser aiming light when used with an M-16 rifle under nighttime conditions was successful. This success pointed out the fact that the engineering designs evolved in the laboratory and the operational characteristics of the system as measured in the Laboratory were both indeed realistic.

IV. CONCLUSIONS

10. **Conclusions.** The development of highly efficient GaAlAs laser diodes in conjunction with the low impedance diode mount and the miniature electronic pulser made possible the fabrication of a lightweight and compact semiconductor laser aiming light. The laser aiming light was shown to be operational by withstanding the shock of the M-16 rifle. The boresight mechanism of the LAL retained its effectiveness when transferred to another similar weapon without subsequent reboresighting. Based on present medical knowledge, the laser aiming light should not be a hazard to personnel.

Further reductions in size and weight as well as increased efficiency of the laser aiming light can be realized by the utilization of a fully integrated electronic pulser and by designing optics that will project only the focused beam generated by the asymmetrical Fraunhofer diffraction pattern.

V. RECOMMENDATION

11. **Recommendation.** Since the technology for the fabrication of the prototype advanced development model has been demonstrated and technical barriers have been resolved, it is recommended that the laser aiming light be committed to an engineering development program which will result in type classification.