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Project Report

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Air Breakdown Initiated by Particles in an HF Laser Beam

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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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FOR THE COMMANDER

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Group 51

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ABSTRACT

Thresholds were measured for air breakdown initiated by particles in a 3.5 μsec, 2.9 μm laser beam. The pulsed chemical laser at Boeing Aerospace Corporation was used ͵r these studies. The thresholds for 50 μm diameter graphite, NaCl, Al_2O_3 particles and 10 μm and 30 μm quartz fibers were found to be factors of three to five higher than the comparable thresholds for 10.6 μm lasers. The material dependence for the threshold was found to differ from that for short pulse 10.6 μm breakdown. The radial plasma growth rate was measured and found to be approximately equal to the growth rate at 10.6 μm for an intensity of $3x10^7$ W/cm^2.

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AIR BREAKDOWN INITIATED BY PARTICLES IN AN HF LASER BEAM

I. INTRODUCTION

The intensity thresholds for air breakdown initiated by particles in a 10.6 μm laser beam have been found to decrease with increasing laser pulse length.[1,2,3] Values as low as 2×10^6 W/cm^2 for 100 μsec pulse have been reported. There exists no comprehensive theory which can quantitatively explain these so called "long pulse" breakdown data. There are, however, fairly good theoretical descriptions[4,5] for laser induced aerosol breakdown data[6,7] at short pulse lengths ($\tau \lesssim 200$ nsec). The dependence of aerosol breakdown thresholds on wavelength has been studied experimentally[7,8] but only for short pulse lengths ($\tau \lesssim 150$ nsec). These data indicated an approximate λ^{-2} scaling for the short pulse aerosol breakdown thresholds.

This report gives the results of a three-week experimental study of aerosol breakdown for long pulse, short wavelength lasers. The objectives of the experiment were to establish a data base for the wavelength dependence of long pulse aerosol breakdown and to measure the radial growth rate of the breakdown plasma. Use of the pulse chemical laser facilities[9] at Boeing Aerospace Corporation, Seattle, Washington, was purchased from 12-30 July 1976. A total of approximately 186 laser shots were obtained during the experiment. All the device performance characteristics met or exceeded the minimum requirements specified in the contract.

II. EXPERIMENTAL PROCEDURE

The experimental set up is shown in Figure 1. A pulsed HF laser[9]

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operating in a stable cavity configuration produced an approximately 5"x5" beam with lines from 2.75 to 3.1 μm ($\overline{\lambda} \simeq 2.9$ μm). The beam was brought to a focus with a 6" diameter, 12" focal length CaF_2 lens (L1). A similar lens (L2) was used to recollimate the beam. The input beam energy was monitored with a $BaTiO_3$ detector (E1) which was calibrated against an RdF calorimeter placed just after lens L1. The transmitted energy was monitored with a $BaTiO_3$ detector (E2). The incident and transmitted pulse shapes were monitored with fast pyroelectric Molectron detectors (P1 and P2). A photo diode (PD) measured the light emission from the breakdown region. A HeNe beam was used for alignment via a removable mirror (RM). Time-resolved data on the plasma growth rate were obtained with a two-frame image converter camera system. The difference in frame times for the two cameras (ICC1 and ICC2) was $\simeq$ 500 nsec.

The insert in Figure 1 shows the setup used for the measurement of the beam profile at focus. Lens L2 was repositioned to provide a magnified (x 2.5) image of the focus. A 32-element pyroelectric array (Laser Precision Corporation) placed at this image plane was used for the beam profile measurements.

The optical components BS1, L1, L2, and W2 were made of CaF_2, the remaining components (A, L3, L4, BS2, L5, L6 and W1) were made of GE 125 quartz.

The focal volume of lens L1 was seeded with large aerosols (50 μm diameter) at a density such that there were approximately 50 particles present in the focal volume on each shot. For the quartz fiber thresholds, single fibers were suspended at the beam focus. The beam was attenuated with a

series of coated attenuators (A). Threshold was defined as the intensity for 50% probability of breakdown.

III.   RESULTS

The beam profiles obtained from array measurements are shown in Figure 2. The array gave a one dimensional cut through the beam at a given y position for each shot. The resolution was 0.4 mm in the x direction and 0.8 mm in the y direction. The z axis in Figure 2 gives the energy fluence per joule. The peak value at the focus was approximately 6.25 cm^{-2}. This corresponds to an effective spot area (energy divided by peak energy fluence) $\bar{A} \simeq 0.16$ cm^2.

The laser pulse shape is shown in Figure 3. The effective pulse length (energy divided by peak power) $\bar{\tau} \simeq 3.5$ µsec.

Breakdown thresholds were obtained for 50 µm carbon (graphite), NaCl, Al_2O_3 particles and for 10 µm and 30 µm quartz fibers. Figure 3 shows a comparison of the incident and transmitted laser power and the light emitted from the breakdown. Breakdown was characterized by a rapid attenuation of the laser beam and an exponential growth of the emitted light.

The threshold data are summarized in Table 1. The values of intensity correspond to the peak value at focus which gave a 50% probability of break-down. The estimated uncertainty for these data is $\simeq \pm 20\%$. Also shown in the table are the estimated threshold values for 10.6 µm breakdown at 3.5 µsec pulse lengths. These were obtained by extrapolating published data[1,2,3] to a 3.5 µsec pulse and have an uncertainty of $\simeq \pm 30\%$.

TABLE I

SUMMARY OF EXPERIMENTAL RESULTS

Breakdown Threshold (W/cm^2)

Particle	λ=2.9 µm τ=3.5 µsec	λ=10.6 µm estimated for τ=3.5 µsec
50 µm Carbon (graphite)	8×10^7 (± 20%)	1.5×10^7 (± 30%)
50 µm NaCl	2.4×10^7 (± 20%)	8×10^6 (± 30%)
50 µm Al$_2$O$_3$	3.2×10^7 (± 20%)	8×10^6 (± 30%)
10µm quartz Fiber	4.5×10^7 (± 20%)	1.5×10^7 (± 30%)
30 µm quartz Fiber	3.4×10^7 (± 20%)	10^7 (± 30%)

Growth Rate (cm/sec) for I=3×10^7 W/cm^2

λ=2.9 µm	λ=10.6 µm
2.5×10^5 (±20%)	1.75×10^5 (± 20%)

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The plasma growth rate was measured with the two frame image converter camera system shown in Figure 1. For these measurements a 150 μm wire inserted in the beam, with axis parallel to the camera's optical axis, was used to ignite the breakdowns. Estimates of the radial growth rates for particle-initiated breakdowns were also made based on the cutoff rate of the trans-mitted beam. These were found to be consistent with the wire induced break-down growth rates. The measured growth rate is shown in Table 1 together with 10.6 μm growth rate[3] at the same intensity.

IV.   CONCLUSIONS

The measured breakdown thresholds at $\lambda=2.9$ μm were consistently higher by factors of 3 to 5 than the corresponding 10.6 μm data. Although it is difficult to make a quantitative comparison, because of the differences in laser pulse shapes and the measurement uncertainties, it appears that the threshold for $\tau=3.5$ μsec scales approximately as λ^{-1}. This is to be compared to short pulse ($\tau=150$ nsec) results[7,8] where for large particles it was found that the threshold scaled approximately as λ^{-2}.

The thresholds measured in this experiment had a different material dependence than those for short pulse 10.6 μm experiments.[6] For example, for ($\lambda=2.9$ μm, $\tau=3.5$ μsec) the carbon threshold was a factor three higher than that for NaCl, while for ($\lambda=10.6$ μm, $\tau=150$ nsec) the NaCl threshold was a factor of two higher than that for carbon.

The plasma growth rate measured for $\lambda=2.8$ μm was comparable to the value at 10.6 μm.

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The breakdown threshold results suggest that different physical processes are involved in long and short pulse breakdown.

ACKNOWLEDGMENTS

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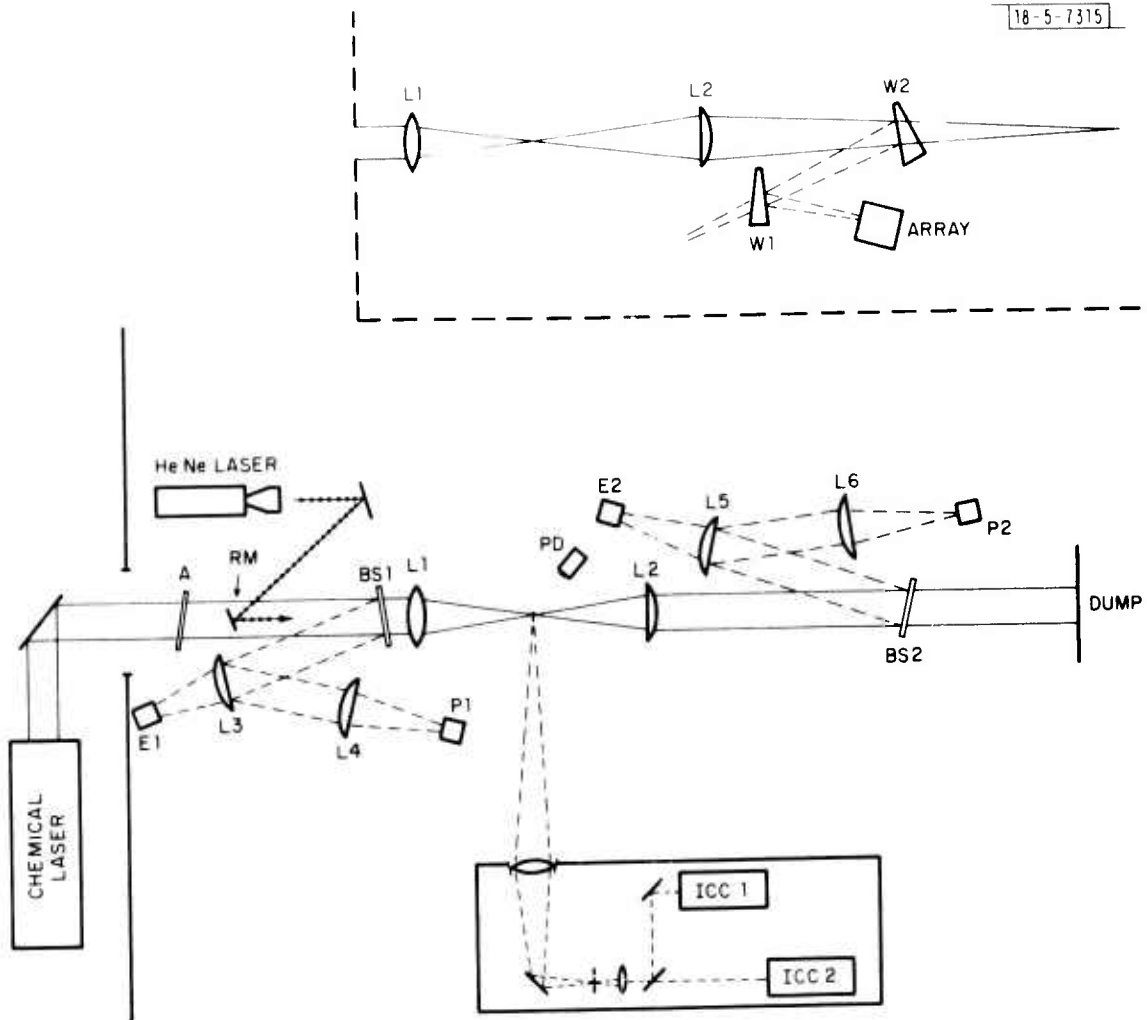
Fig. 1. Experimental set up for HF laser breakdown experiment. The focal volume of lens L1 was seeded with dust particles. The insert shows the arrangement for beam profile measurements.
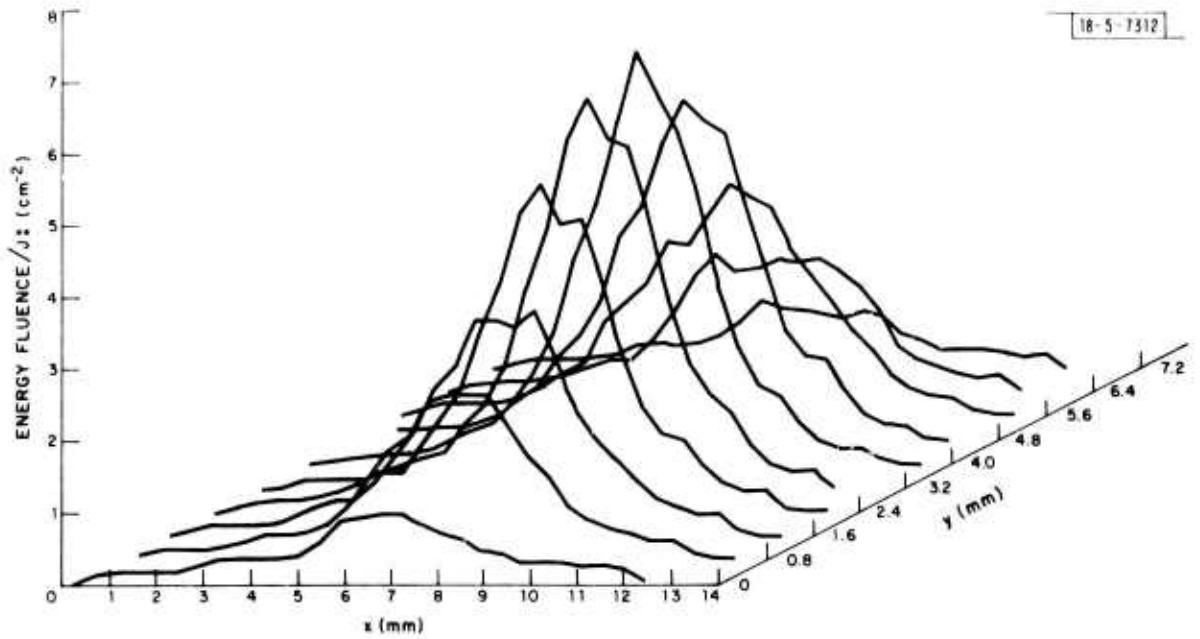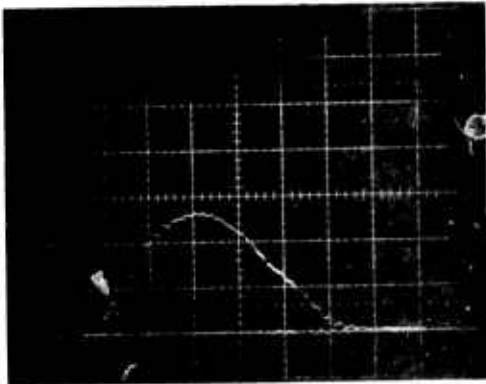
Fig. 2. Beam profile measured with pyroelectric array. The resolution was 0.4 mm in the x-direction and 0.8 mm in the y-direction.

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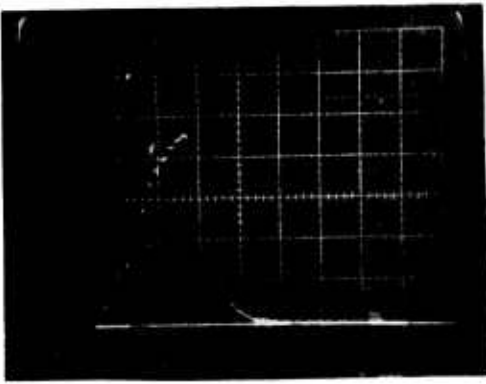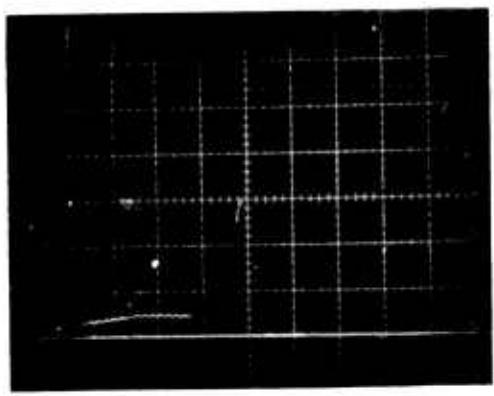
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1 μ sec/div

Fig. 3. Oscillographs of: incident laser power, transmitted
power, and light emitted from breakdown region.

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