Reprinted from the PROCEEDINGS OF THE IEEE
VOL. 58, NO. 9, SEPTEMBER, 1970
pp. 1398–1400

Electric Strength of Some Liquid Dielectrics Subjected to a *Q*-Switched Laser Pulse

Abstract—A concentrated *Q*-switched neodymium laser beam was used to break down the following dielectric liquids: doubly distilled water, xylene, cyclohexane, and benzene. The threshold value for each liquid was determined by taking the average for ten exposures for each sample, the five highest for which breakdown did not occur, and the five lowest for which breakdown did occur. Measurement of the laser power density in each sample was used to calculate the field strength of the beam by use of the Poynting vector.

INTRODUCTION

The study of dielectric breakdown in liquids by very high electric fields has been long and arduous, with much of the work concentrated on static field breakdown. The explanation of threshold breakdown always in-

Manuscript received March 30, 1970.

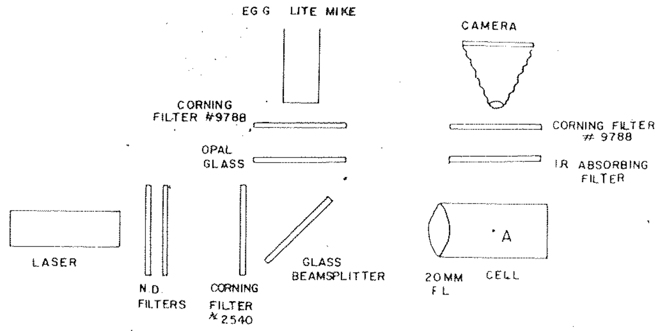

Fig. 1. Experimental arrangement for detecting and measuring breakdown intensities. From [2].

cluded contributions from the physical arrangement, such as electrode material and configuration, and gap spacing. Especially in the static case, this led to differences among the results of various experimenters. Most recent measurements have been made using microsecond pulse techniques and the values obtained by various workers are now in fair agreement.

Recently a technique was developed to investigate the electric strength of some liquids subjected to nanosecond voltage pulses [1]. Gap spacing was an important parameter in determining threshold values and extraordinary effort was extended to maintain the proper physical condition of the electrodes. These two variables complicate what would in general be a simple experiment.

In the course of our study on shock waves generated in dielectric liquids using a Q-switched laser, we found that the dominant initiating mechanism was dielectric breakdown followed by generation of a shock wave [2]. The results of the investigation demonstrated the potential of the laser as a source of high electric fields in the nanosecond pulse region for use in studying the breakdown of liquids without resorting to the use of electrodes. In our experimental setup we were restricted to a pulse duration of about 50 nanoseconds. Although our experimental setup is simple, the method and results presented here are unique and hopefully will lead to a better understanding of the dielectric properties of some liquids.

Experimental Setup

The physical arrangement for initiating and recording dielectric breakdown is shown in Fig. 1. A Q-switched neodymium laser was used with a half-power duration of 50 ns. The intensity was controlled with neutral density filters. An infrared filter, Corning model 2540, removed visible light generated by the flash lamps in the laser head. The split portion of the beam was made diffuse by a piece of opal glass and further attenuated by Corning filter 9788, and was finally detected by an EG&G Lite Mike. The transmitted portion of the beam was focused into the cell containing the dielectric liquid, where breakdown occurred. The position of breakdown, denoted A in Fig. 1, occurred at a different position for each liquid depending upon its index of refraction. The light, generated by the breakdown, after being filtered to remove the 1.06 μ radiation and properly attenuated, was detected by either a camera or a photodiode. Generally, a photodiode was used for indicating breakdown and the camera was used primarily for noting the number of breakdown points as the laser power was increased. The system was calibrated, i.e., the reflectivity of the beam splitter was determined experimentally, in the range of power levels expected to be used in the study. The physical arrangement was kept constant throughout the entire experiment.

To determine the spot size of the focused beam in each liquid, an optimum amount of aluminum was evaporated onto a glass cover slide. The amount was determined empirically by systematically reducing the coating thickness to a point where the laser beam, highly attenuated, would evaporate an amount that was discernible under a microscope. The cover slide was attached to a precision graduated mechanical stage readable to 0.1 mm and stationed in the liquid at the approximate focal point that had been determined earlier. It was then made to traverse the focal plane in both directions at a different position for each corresponding laser shot. The number of exposures generally was about ten. The slide was then examined under a measuring microscope and the minimum spot size was determined.

TABLE I
Characteristics of Laser Beam at Threshold of Dielectric Breakdown

Material	Power (watts)	Minimum Spot Size (cm)	Power Density ($\overline{W}$) (watts/cm^2)	Field Strength (V/cm)
Water	23.8×10^6	0.7×10^{-2}	6.2×10^{11}	18.8×10^6
Xylene	7.1×10^6	1.3×10^{-2}	5.2×10^{10}	5.1×10^6
Cyclohexane	32.3×10^6	1.2×10^{-2}	2.7×10^{11}	12.0×10^6
Benzene	5.2×10^6	1.2×10^{-2}	4.4×10^{10}	4.7×10^6

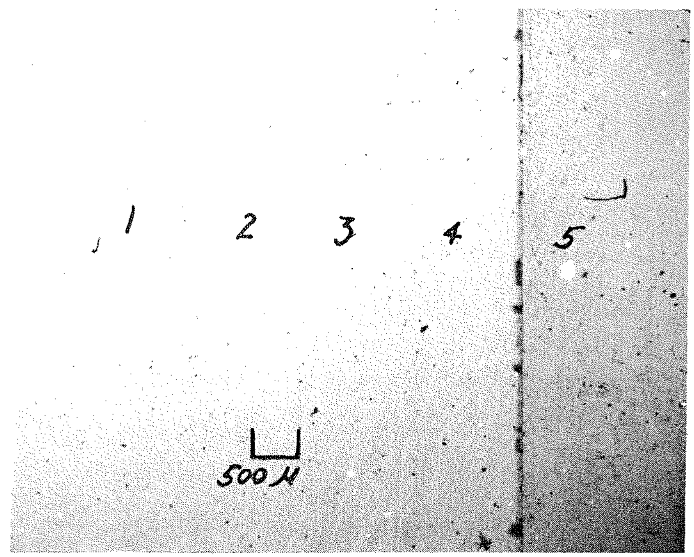

Fig. 2. Microphotograph of holes made by a Q-switched laser on an aluminized cover slide immersed in cyclohexane.

Results

The liquids studied in this experiment for electric field breakdown values are listed in Table I. The first measurement to be determined was the laser intensity necessary to just break down the liquid, i.e., threshold value. This was accomplished by attenuating the laser until only one or at most two points of breakdown were observed. Gross reduction in intensity was managed by insertion of neutral density filters in the path of the beam. The actual control of breakdown or no breakdown condition was accomplished by very small changes in the charging voltage. The threshold value for a sample using this setup was calculated by selecting the five lowest intensity values for which a single point of breakdown occurred and the five highest intensity values for which no breakdown occurred. The average of these ten values was considered to be the threshold for breakdown.

The minimum spot size for each sample was determined using the technique developed in this experiment and described previously. Fig. 2 presents a magnified photograph of the holes produced by the laser in an aluminized glass slide. The white dots, numbered 1 through 5, were made by consecutive laser pulses as the glass was positioned in the focal plane of the lens while testing a sample of cyclohexane. Each dot was made at a different position close to the focal point of the lens. The minimum spot size determined for each of the liquids is shown in Table I. Each value represents at least three similar measurements for each of the materials. Based on the power incident in the sample and the calculated area of the laser beam at the focus, it was possible to calculate the power density and the corresponding electric field strength, as given in Table I.

Discussion

There has been considerable interest in laser beam effects in liquids with regard to shock or acoustic effects in recent years [3]–[6]. It has been fairly well documented that dielectric breakdown by the intense electric field of the laser is the primary cause of these effects, at least in water. This phenomenon has been used by experimenters using intense beams to examine the properties of the plasma created at the interaction region [7]. We have used this unique property of the Q-switched laser, i.e., its intense electric field, to obtain a measure of the resistance of some liquids to breakdown. There are no experiments we know of with which to compare our results, but the closest is a recent study by Rudenko and Tsvetkov [1] using a similar material, doubly distilled water, and breakdown voltage pulses in the nanosecond region using a capacitor-type discharge. Their breakdown values ranged from about 2 to 4 MV/cm for gap spacing of from 50μ to 500 μ in the range of interest. For comparable pulse durations, their values are about one order of magnitude higher than the results obtained in this study.

This effort is a first attempt to use the laser for this type of study and is not meant to be a sophisticated experiment in dielectric strength measurements. Rather, it is an attempt to generate an interest in the use of the laser for this measurement and hopefully to learn something of the properties of liquids that make them good dielectrics.

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