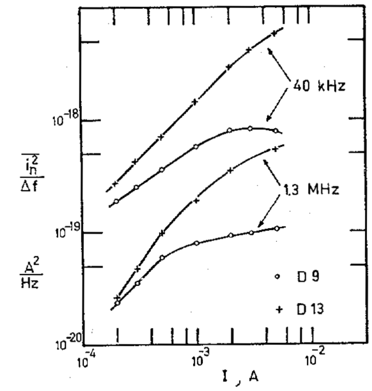

Fig. 2. Mean-square noise currents at an effective bandwidth of 1 Hz as a function of diode current I. Same diodes as in Fig. 1.

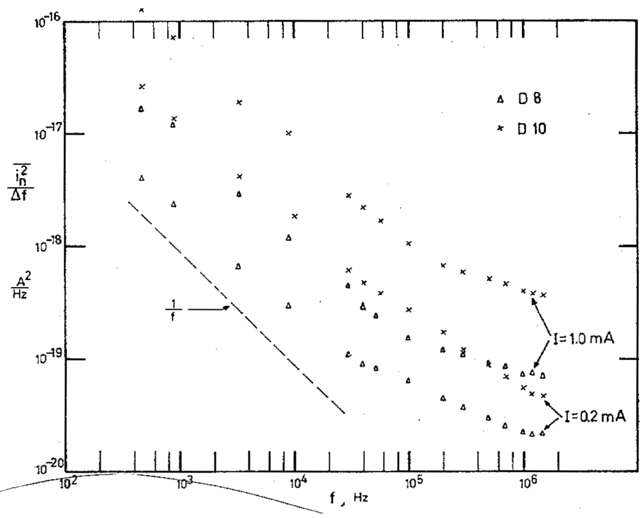

Fig. 3. $\overline{i_n^2}/\Delta f$ as a function of frequency for the diodes $D8$ and $D10$.

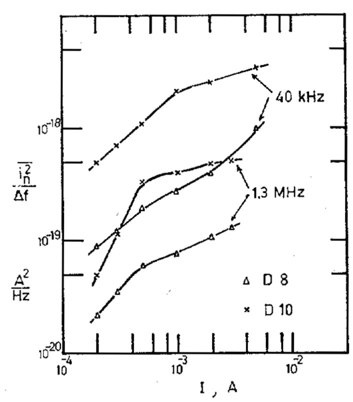

Fig. 4. $\overline{i_n^2}/\Delta f$ as a function of diode current. Same diodes as in Fig. 3.

[7]. With increasing current, m was found to decrease for the diodes tested.

Fig. 2 represents $\overline{i_n^2}$ as a function of forward diode current I for the same diodes as in Fig. 1. The measurements have been made at two different frequencies. The first frequency was 40 kHz, i.e., at a part of the spectrum where effects causing the $1/f$ noise are present. The second frequency was 1.3 MHz, i.e., at a part of the spectrum where $\overline{i_n^2}$ is approximately independent of frequency. The mean-square noise current for lower diode currents is proportional to I^β (Fig. 2), β having higher values at 1.3 MHz than at 40 kHz. For $D9$, β passes from about 0.7 to about 1.1. The corresponding values for $D13$ are 1 and 1.4.

Fig. 3 shows the current noise spectra of the diodes $D8$ and $D10$. For these diodes $\overline{i_n^2}$ is not a simple function of the frequency. For relatively lower frequencies (<100 kHz), $\overline{i_n^2}$ shows an approximate $1/f$ behavior, which is not the case as the frequency increases above about 100 kHz. However, for the diode $D8$, $\overline{i_n^2}$ seems to stabilize to a constant value for higher frequencies. The current dependence of $\overline{i_n^2}$ for the diodes $D8$ and $D10$ is plotted in Fig. 4. Here again the measurements have been made at 40 kHz and 1.3 MHz. The coefficient β, associated with the relation $\overline{i_n^2} \sim I^\beta$ at lower currents, has a value of about 0.9 at 40 kHz for both diodes. At 1.3 MHz β becomes 1.2 for the diode $D8$ and much larger (2.1) for $D10$.

From the above figures it may be said that GaAs laser diodes show noise spectra different from those relative to p-n diodes investigated until now. The frequency dependence of $\overline{i_n^2}$ may show a $1/f$ behavior at lower frequencies. The noise level of the tested diodes is considerably higher than $2e \cdot I \cdot \Delta f$.

Acknowledgment

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Laser-Triggered Switching in a Liquid Dielectric

***Abstract*—A laser-triggered spark gap using a liquid dielectric has been investigated. A parametric study has been performed relating the delay and jitter characteristics of the switch to the laser parameters. Delay times of less than 30 ns were observed with apparent subnanosecond jitter times.**

Guenther *et al.* have demonstrated the technique of laser triggering a high-voltage switch, and for their dielectric medium, they used gases at various pressures [1]–[3]. We have extended their work by performing a similar study using a liquid dielectric.

Our goal in pursuing this study was to observe the delay and jitter characteristics of the breakdown process when one uses liquid rather than gas dielectrics. Due to the increase in medium density, one would expect significantly different behavior in the liquid. This was observed. Using a similar experimental arrangement as Pendleton and Guenther [1], our delay times increased by about three orders of magnitude from tens of nanoseconds to tens of microseconds. These increased delay times are similar to the times one would measure for streamer propagation in the gap [4], [5].

We found that we could reduce the delay times to tens of nanoseconds in the liquid medium by focusing the laser onto one of the electrodes through a hole drilled in the first. In this case, it appeared

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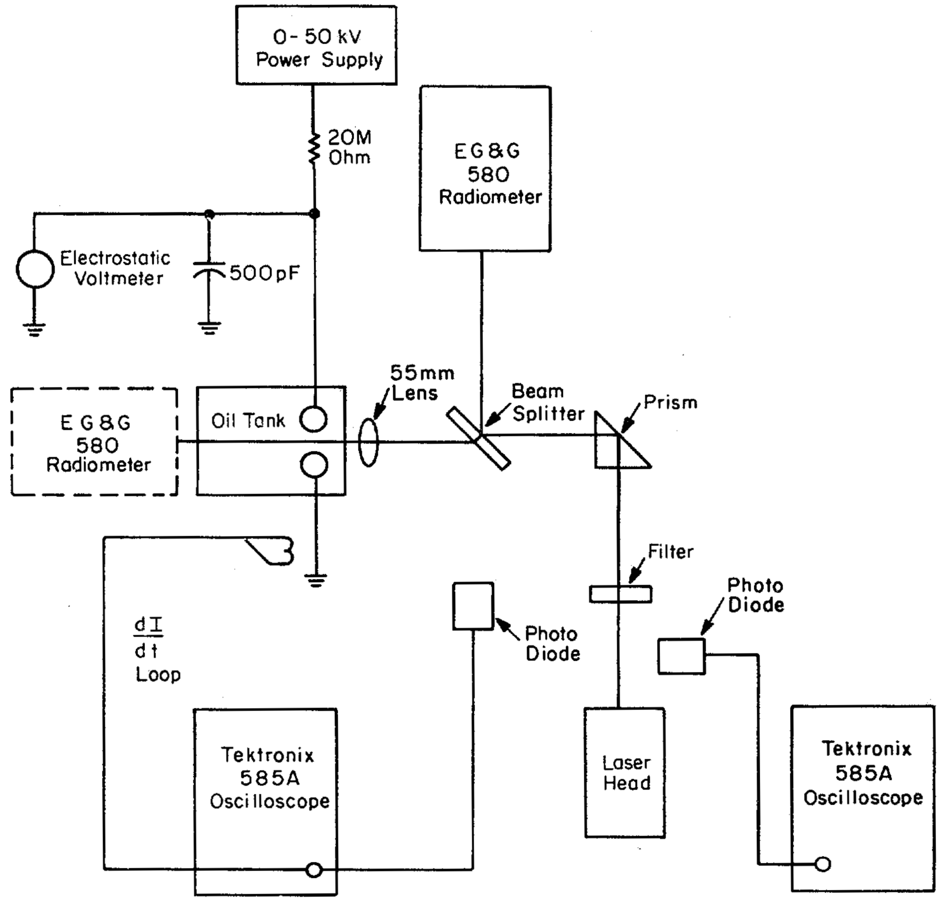

Fig. 1. Initial experimental arrangement.

TABLE I
Minimum Laser Pulse Energy to Cause Gap Breakdown*

Applied Gap Voltage (kV)	Percent of Median Self-Breakdown Voltage (47kV) (%)	Minimum laser pulse energy to trigger (joules)
2	4.3	3.8
3	6.4	2.0
4	8.5	1.8
6	12.8	1.1
10	21.0	1.0

*Focal point at center of gap.

that the whole gap region, or a major portion of it, was ionized during the laser pulse duration. This would then account for the reduction in delay time since little, if any, streamer propagation through the liquid was required to close the gap. We will now describe our results in more detail.

For the first phase of the experiment, we chose to use a sphere-sphere gap arrangement similar to Pendleton and Guenther's [1]. The electrodes were made from brass balls 3.4 cm in diameter. To insure a reasonably uniform electric field in the central region, all experiments were performed at a gap spacing of 0.356 cm. The dielectric medium used throughout was Shell Diala A-X transformer oil.

It is important to know the self-breakdown properties of the gap in order to relate this to the delay and jitter information to be obtained later. This data was generated by a slow raising of the dc charging voltage until the breakdown occurred. The applied voltage was measured with an electrostatic voltmeter. We determined that for our arrangement, we had a self-breakdown band between 35 and 55 kV with the median breakdown voltage being 47 kV.

The laser used during the next phase of the experiment was a Korad K-2 system, capable of peak powers of 500 MW. An EG&G model 580 radiometer was used to measure the total energy of the

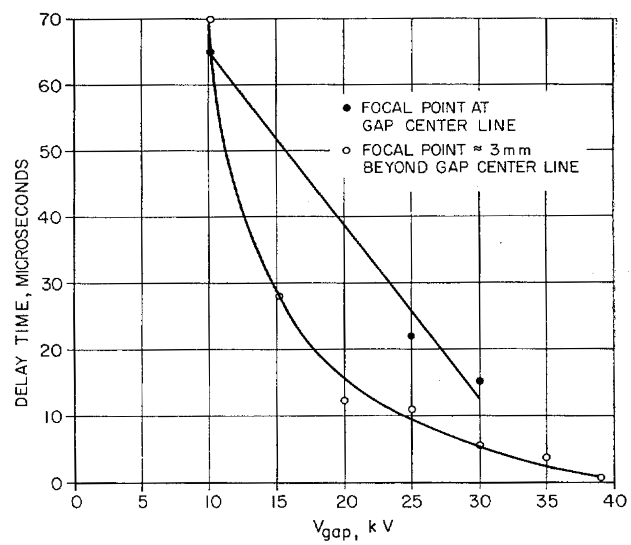

Fig. 2. Delay time versus applied gap voltage.

laser pulse. This was accomplished by deflecting a small percentage of the laser beam with a beam splitter into the narrow beam adapter of the radiometer. Our diagnostic indication of current flow in the circuit was the signal obtained from a single-turn dI/dt loop placed in the position shown in Fig. 1. The risetime of the breakdown pulse as observed on a Tektronix 519 oscilloscope was 10 ns. A 4×5 view camera placed over the gap provided a time integrated photograph of the breakdown process. When no breakdown occurred, the photograph gave some indication of the laser generated plasma distribution in the gap.

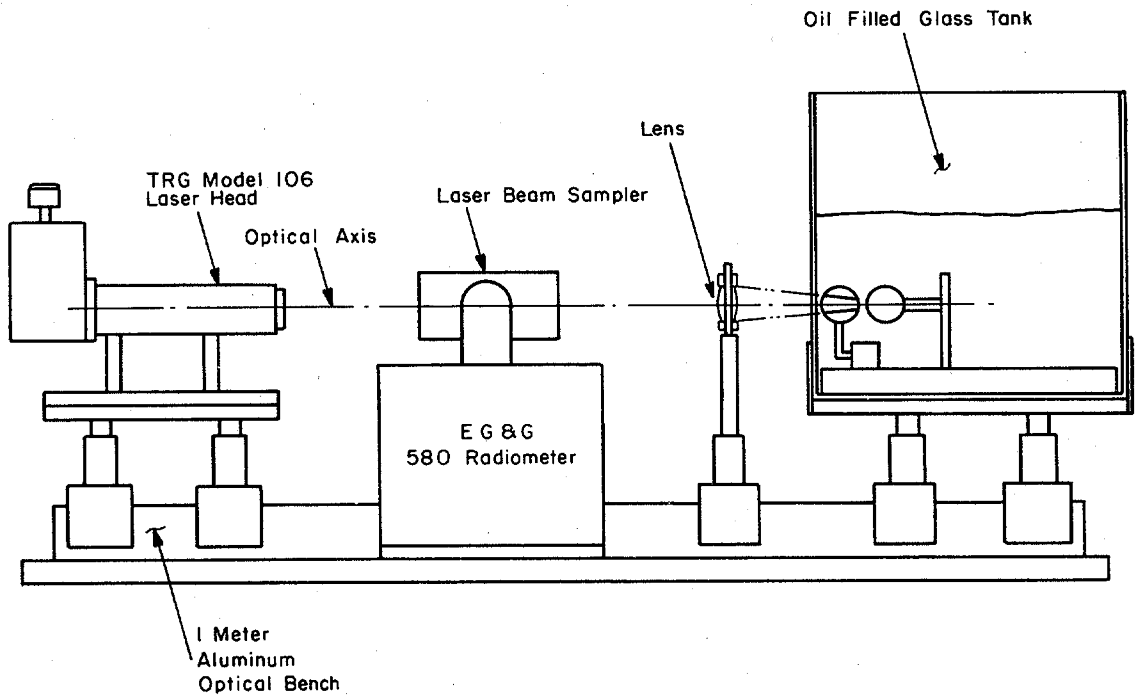

Fig. 3. Experimental arrangement for last phase of experiment.

We first measured the minimum laser pulse energy necessary to trigger a gap as a function of applied voltage. The results are shown in Table I. It can be seen that it was possible to observe a breakdown with as little as 2 kV applied voltage. This voltage is about four percent of the median self-breakdown voltage (47 kV).

We considered the most important measurements to be the delay time to closure once the laser beam reached the gap. These measurements were performed in the following manner. The photodiode signal was fed into the Tektronix 585 A oscilloscope to define time zero for the arrival of the laser light into the gap. When the gap broke down (at some later time), the dI/dt signal that was generated was fed into the same oscilloscope. The time difference, between the rising portions of the signals, defined the delay time, allowing for laser path and cable differences. The results of this measurement, made as a function of applied voltage and laser focal point, are shown in Fig. 2.

As can be seen, delay times are on the order of microseconds, but similar measurements made by Pendleton, when gases were used as the dielectric medium, produced nanosecond delay times [1]. The delay time differences might be explained by the electron mobility in the liquid dielectric. During the laser pulse duration, a small volume of plasma is generated in the center of the gap. This plasma occurs in less than 30 ns, but to obtain gap closure this disturbance must propagate through the medium. The concept is justified since streamer velocities in liquids that were measured by other experimenters indicate that our measured times are reasonable [4], [5].

One should note that the shortest delay times (other things being equal) occurred when the laser beam was focused slightly beyond the center of the gap (about 3 mm). In this configuration, a larger initial volume of plasma is created in the gap region due to the larger beam cross section. This decreases the necessary time to closure because of the higher field and shorter distance to closure that results from the larger initial plasma volume.

The curves of Fig. 2 are independent of laser pulse energy. We found, as did Pendleton and Guenther [1], that the delay time is independent of laser power above a threshold. They measured this threshold to be at 6 MW peak power for their experimental conditions. It became apparent that the shortest delay times and the best jitter times could be obtained if the entire gap region were ionized during the laser pulse duration. Time-integrated color photographs of laser initiated breakdown showed that the plasma volume extended back from the focal point. Thus, we felt that it might be possible to achieve nanosecond delay times by shining the laser beam through one of the balls and focusing it onto the second. This method was attempted during the next phase of the experiment.

Fig. 3 shows the experimental arrangement for this next phase. Note that we use a TRG model 106 laser. The diagnostic equipment was the same as that previously described, but the Tektronix 585 A oscilloscope was replaced by a Tektronix type 519 unit.

With this coaxial focusing arrangement, we ran a total of sixteen shots. The average delay time measured was 29 ns with a range of 3 ns. The jitter time was 2 ns. However, we observed seven consecutive shots of 30 ns delay time and another run of six consecutive shots of 27 ns. This seems to indicate that it may be possible to obtain subnanosecond jitter times with this method. Since the results are promising, we expect to continue these experiments in the near future and hope to intensify our efforts in this area.

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New Room Temperature CW Laser Transitions in YAlG : Nd

***Abstract*—Using a dispersive prism, the room temperature YAlG : Nd laser has been made to oscillate CW on a total of seven $^4F_{3/2} \rightarrow {}^4I_{11/2}$ transitions ranging in wavelength from 1.0519 μm to 1.1226 μm and a single $^4F_{3/2} \rightarrow {}^4I_{13/2}$ transition at 1.319 μm.**

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