tribution was not measured. It is not anticipated that this diagnostic would be highly sensitive to plasma conditions because the spectrally integrated radiation that was monitored was neither specularly reflected nor normal to the critical surface.

In summary, the laser radiation transmitted through the thin film decreases by an order of magnitude as the laser flux increases from 10^{13} to 10^{14} W/cm^2. The ion time-of-flight measurements show an increase in the front plasma expansion velocity and a corresponding decrease in the rear plasma expansion velocity with increasing laser flux above a threshold of 10^{14} W/cm^2. The results are indicative of reduced energy transport through the film. These phenomena may be ascribed to the existence of an anomalously reduced thermal conductivity.

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Electrical triggering of an optical breakdown plasma with subnanosecond jitter*

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We have shown that CO_2-laser-induced breakdown in ultraclean gas follows less than 1 nsec after the injection of free electrons into the focal volume. While this confirms our understanding of the plasma nucleation mechanisms, it is also the first example of a new class of electro-optic switch in which a small electrical signal is able to control the transmission of a powerful laser beam.

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Nonreproducibility of the experimental data has hampered our understanding of laser-induced breakdown in gases. This has involved both shot-to-shot fluctuations in the measured breakdown thresholds, as well as disagreements in the results reported by different workers.[1-3] We now believe that the nonreproducibility in the early data resulted from plasma nucleation on dust particles,[4] and in certain cases from the lack of initiating electrons for an avalanche.[5] Indeed, in ultraclean gases, it is possible to exceed the avalanche threshold by 4 orders of magnitude in intensity, without producing a plasma.[6]

The necessity of preionization in providing starting electrons for reproducible avalanche thresholds was first recognized by Brown and Smith.[7] Woods and Bloembergen[8] extended the preionization technique to a series of different gases over a wide range of pressures, giving reproducible quantitative confirmation of the dc scaling laws[9] for avalanche breakdown.

The experiments reported here were performed in ultraclean nonpreionized nitrogen gas. Neither free electrons nor dust particles were available for initiating a plasma. This permitted the transmission of a CO_2 laser intensity of 10^{11} W/cm^2, greatly in excess of the avalanche threshold. At a chosen instant during the laser pulse free electrons were injected into the focal volume by uv photoionization from a small electrical spark. Within a fraction of a nanosecond after this triggering event, a dense optical breakdown plasma formed, blocking off transmission of the laser beam.

In addition to confirming our physical understanding of the mechanisms contributing to laser-induced breakdown, this experiment represents the first example of a

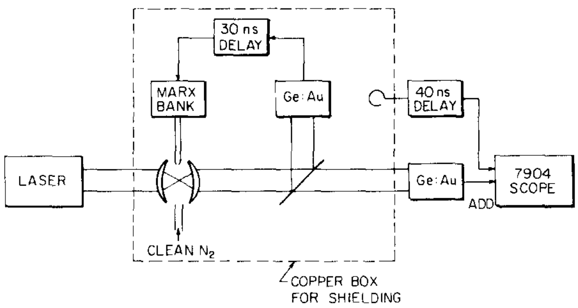


FIG. 1. Experimental arrangement. The electro-optic switch is contained inside a copper enclosure represented by the dashed lines. The laser breakdown plasma is triggered by the uv source, which is in turn driven by the thyristorized Marx bank. The beam splitter sends a small part of the laser beam to a Ge : Au detector which provides a trigger signal to the Marx bank. External to the enclosure, a high-speed Ge : Au detector monitors transmission of the laser beam. The antenna picks up the rf signal from the firing of the uv source which, after a 40-nsec delay, is displayed on the oscilloscope together with the transmitted laser pulse.

new class of electro-optic switch. In these devices, an electrical trigger is used to synchronize the firing of the ultrafast[6] optical breakdown shutter.[10] Therefore, the transmission of a powerful laser beam may be controlled by a small electrical signal.

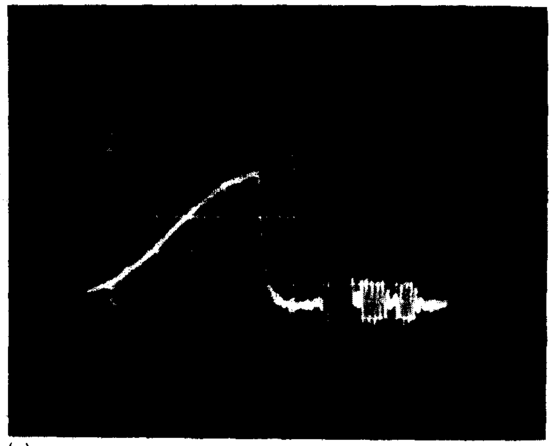
Among the applications which suggest themselves, these electro-optic gates will be used to synchronize the switching action in the optical free induction decay pulse generator,[10-12] thereby providing an ultrashort CO_2 laser pulse of reproducible amplitude and shape and at a desired instant in time. These triggered gates may be also employed instead of Faraday isolators, for protecting an amplifier chain against back reflections from a target.

The experiment was done with a conventional single longitudinal mode TEA CO_2 laser,[13] of about 1-MW peak power. Figure 1 depicts the experimental setup. The laser pulse was passed through a pair of 2.5-cm-focal-length lense acting as a 1 : 1 telescope. Clean nitrogen gas from a cylinder was blown through the focal region to prevent untriggered spontaneous breakdown. Part of the pulse was then taken out by a beam splitter to trigger a 25-stage thyristorized[14] Marx bank. It was found that the circuit gave about 4 kV with a measured 5-nsec rise time. This provided the input to the uv photoionization source. The source was a 0.25-mm spark gap, of the surface breakdown type, which is a well-known generator of hard uv radiation.[15]

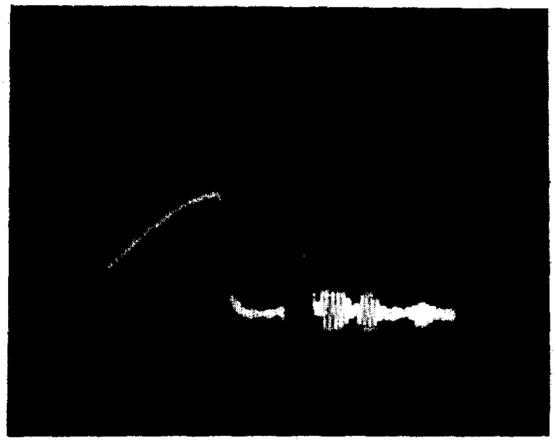
In order to trigger the photoionization source right at the peak of the laser pulse, rather than on the early rising portion, a 30-nsec-delay cable was inserted ahead of the Marx bank. The entire system was enclosed in a small copper box for shielding against spontaneous triggering of the Marx bank by electromagnetic interference from the thyratron in the main laser.

For measurement of the delay and jitter between the uv source and the optical breakdown plasma, a small microwave antenna inside the copper box was used to pick up the rf interference from the uv source. We compared the timing of this signal with the instant at which the laser breakdown plasma formed blocking transmission of the optical beam. To display both the laser pulse and the pickup signal simultaneously, we delayed the antenna signal by 40 nsec and added the two channels together on a Tektronix 7904 oscilloscope. A typical picture is shown in Fig. 2(a). The first half of the trace is the usual laser pulse, cut off near the peak by the optical breakdown plasma. Delayed by 40 nsec is the rf burst from the uv source. The difference between the delay observed on the oscilloscope and that produced by the delay cable represents the actual time delay of the optical breakdown plasma after the uv trigger. In Fig. 2(b) we show a picture with three overlapping traces to demonstrate the low jitter of the triggering and the reproducibility of the electromagnetic pickup.

With the uv source adjusted to be less than 1 mm from the focal region of the lens pair, it was found that the delay between the dc spark and the optical breakdown was 0.6 nsec with a maximum jitter of ± 0.25 nsec. For a distance of 2 mm between the dc spark gap and the focal region, the delay and jitter increased to 1 nsec



(a)



(b)

FIG. 2. (a) Typical oscilloscope photograph showing the laser pulse being cut off by the optical breakdown plasma. Delayed after this event by 40 nsec is the rf signal from the uv source. In real time, the uv source preceded the optical breakdown by $\lesssim 1$ nsec. (b) Three successive oscilloscope traces superimposed to show the low jitter inherent in the triggering process, and the reproducibility of the rf burst from the uv source. Both pictures have a horizontal scale of 20 nsec/div.

and ± 1 nsec, respectively. We found that the laser breakdown was still triggerable even at a distance of 3–4 cm but with a much larger jitter.

In view of these results it is interesting to estimate the efficiency of the surface breakdown spark as a uv photoionization source. In the 0.6-nsec delay time between the initiation of the dc spark and the formation of the laser plasma, the Marx bank is able to dump only 100 erg into the uv source. At the laser intensity used here, plasma formation is virtually instantaneous once an initial electron is provided. Since the focal volume is $\approx 10^{-7}$ cm^3, then 10^7 electrons/cm^3 must be produced by the photoionization source to provide, on the average, one electron in the focal volume. This electron density is produced at a range of about 1 mm away from the source, implying that at least 10^5 molecules are photoionized with an average ionization potential of 15 eV each. Therefore, only about 10^{-6} erg ends up in photoionization starting from 100 erg in the uv source. Thus, the surface breakdown spark has a photoionization efficiency of about 10^{-8}.

In conclusion, we have confirmed our physical ideas regarding the importance of starting electrons in laser-induced breakdown and have constructed a new type of electro-optic switch which uses a small electrical spark to control a powerful laser beam. The delay and jitter of this gate are in the subnanosecond range.

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Specific heat of cesium dideuterium arsenate (CsD_2AsO_4) from 0 to 120°C

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The specific heat of cesium dideuterium arsenate (CsD_2AsO_4) was measured with a scanning differential calorimetric method in the temperature range from 0 to 120°C. Using a least-squares curve fit, the power-series expression of the specific heat in this temperature range is found to be $C_p(\mathrm{cal\,g^{-1}\,deg^{-1}}) = 0.1111 + 1.80\times10^{-4}\,T(°C) - 5.9\times10^{-9}\,T^2(°C)$. The specific heats at 25 and 100°C are 0.1156 ± 0.0005 and 0.1290 ± 0.0005 cal g^{-1} deg^{-1}, respectively. The crystal can be 90° phase matched for the nonlinear second-harmonic generation of 1.06-μm lasers in this temperature range.

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The high-power second-harmonic generation of Nd-doped lasers at 1.06 μm is a very useful method for generating high-power visible laser pulses for the study of laser-heated plasma and for the pumping of short pulse dye lasers among other applications. One of the most widely used nonlinear crystals for the second-harmonic generation has been potassium dihydrogen-phosphate KH_2PO_4 (KDP) which belongs to the tetragonal symmetry point group $\bar{4}2m$ and is optically uniaxial. However, because of the nature of the critical phase matching required for the crystal, a high conversion efficiency for the second-harmonic generation is severely limited by the angular tolerance of the fundamental beam and by the Poynting-vector walkoff. On the other hand, cesium dideuterium arsenate (CsDA) has the property of 90° phase matching for doubling of 1.06-μm lasers.[1–4] High conversion efficiencies around 50% have been achieved by several workers.[5,6] The angular tolerance for the beam divergence for CsDA is about 50 times larger than that for KDP. Furthermore, CsDA has a much higher damage threshold as compared with those of lithium niobate ($LiNbO_3$) and barium sodium

