A SIMPLE SELF-TRIGGERED PLASMA SHUTTER*

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A simple self-triggered plasma shutter for switching a high power laser beam was demonstrated. The triggering action comes from the surface plasma of a metal target. Several materials were tested and it was found that for copper, the amplitude fluctuation in the triggering was only 5%.

Recently it has been shown that a laser induced gas breakdown can be triggered by injecting the starting electrons into the focal volume [1]. This "plasma shutter" has been applied to the generation of ultrashort CO_2 pulses by optical free induction decay and has potential application as an optical isolator in high power laser systems. It has also been reported that the delay and the jitter are both in the subnanosecond range. This is consistent with the avalanche ionization concept of gas breakdown [e.g. 2], the validity of which depends on the presence of a starting electron. When a starting electron is not available, the avalanche theory of the breakdown threshold will not work and in fact, the threshold can be made very high. It was found that in ultraclean gases with subnanosecond CO_2 pulses, the breakdown threshold can be made to be as high as 10^{13} W/cm^2 [3].

The idea of the plasma shutter is then to inject electrons into these regions of ultrahigh field strengths to initiate the avalanche. Due to the ultrahigh laser intensity, the shutter speed is very fast and was measured to be ~10 ps [4]. Previously, the injection was done with a d.c. spark source placed close to the focal volume. The d.c. surface spark photoionized the atoms and molecules in the focal region by its uv radiation. The electronic circuitry was rather complicated, however.

In this communication, we wish to describe a very simple plasma shutter which requires no external electronics. Fig. 1 shows the experimental setup. The idea is to form the surface spark not with d.c. electrodes, but instead by focussing a small portion of the laser onto a metal block [5]. The resulting microplasma will then trigger the plasma shutter by uv photo-ionization, since plasmas are known to be efficient generators of uv radiation [6]. The laser source was a hybrid TEA laser and a low pressure cw section. The gain of the low pressure section was inhomogeneously broadened and had a linewidth of about 60 MHz which was nearly the same as the spacing between the longitudinal modes of the laser cavity. Single mode operation was achieved by this method [7]. This was important because the mode beating would then be suppressed and the laser pulse would have a smooth profile with very small amplitude fluctuation. The TEA section had pin resistor type electrodes in a helical geometry to restrict lasing in the lowest transverse mode [8]. The output was a smooth reproducibel 200 nsec CO_2 laser pulse with a peak power of about 0.7 MW. The 1:1 telescope in fig. 1 constitutes the plasma shutter. The lenses were $f/1$ Ge doublets well-corrected for spherical aberration and had a guaranteed focal diameter of 17 μm for the CO_2 wavelength [9]. An Irtran 1-inch focal length lens provided the focussing for the production of the triggering plasma. The beam splitter was an uncoated NaCl flat. We estimated that the peak power at the focus of the triggering lens was about 4×10^9 W/cm^2, which was large enough to produce surface breakdown on any material. The focus of the triggering lens was about 2 mm from the focus of the main lenses. The distance was chosen such that the separation between the foci

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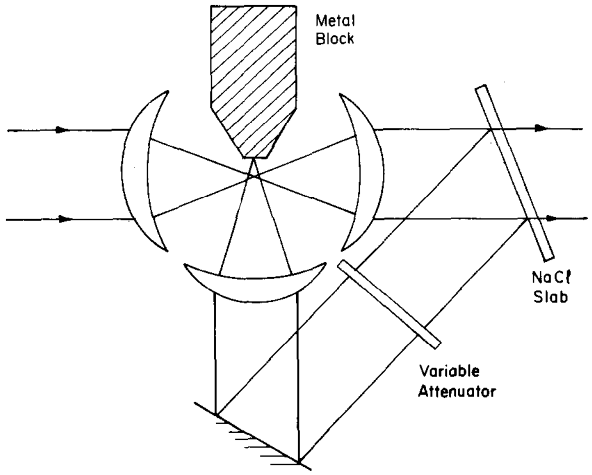

Fig. 1. Schematic diagram of the surface plasma triggered plasma shutter. A stream of clean N_2 gas was flowed through the focal volume and is not shown for simplicity. The attenuation in the triggering arm was used to control the delay of the triggering and hence the fluctuation.

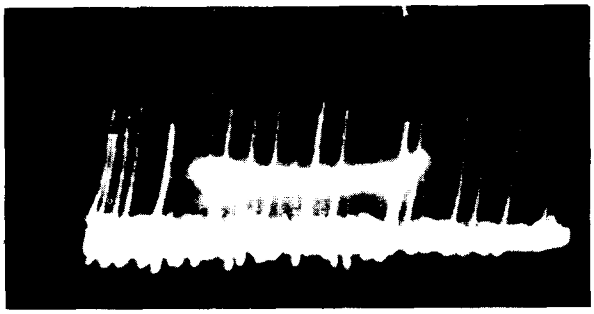

Fig. 2. Multiple exposure photograph of the triggered breakdown. Each spike in the picture is a single CO_2 laser pulse sharply cut off. The delay between the pulses is artificial. The statistics are worked out based on the height of the spikes.

were as close as possible without blocking the main beam. We have tried several metals and the results are shown in table 1. An explanation follows.

As an easy means of measuring quantitatively the stability of the triggering, we recorded the fluctuation in the pulse height where the triggering occurred. Fig. 2 shows a sample of the pictures that were used in working out the statistics. Each spike in the picture is a CO_2 pulse with a sharp cutoff indicating that a breakdown has occurred. It was found that the delay of the triggering depended on the intensity in the triggering arm. Experimentally, it turned out that with 2% of the main beam split off to the triggering arm, the triggering action occurred near the peak of the CO_2 pulse.

In table 1, we tabulate the results of the stability in the following two situations, (a) a strong triggering pulse (7% of main beam) where the triggering occurs very early, and (b) a weaker pulse situation (2% of main beam) where the triggering occurs near the peak. It can be seen that the weak beam case generally tends to have less fluctuation, which is intuitively obvious. With a strong beam, the surface plasma forms early while the intensity of the main beam is not quite high yet. Therefore we expect more fluctuation in the avalanche ionization process since the ionization growth rate is a strongly nonlinear function of the laser intensity.

Table 1
Root mean square fluctuation in the triggering.
STRONG and WEAK refers to a strong and weak triggering pulse respectively.

	Copper	Steel	Aluminum	Brass
STRONG	5.8%	7.2%	9.3%	11%
WEAK	–	6.9%	6.5%	–

In comparing the different metals, we should be cautious. The delay and jitter in the triggering depend strongly on the position of the metal target block. This is obviously due to the tight focussing of the triggering lens. The laser intensity in the metal surface varies strongly with distance, and this has strong effects on the size and hence the radiation of the microplasma. Consequently, from table 1, we can say that brass is the poorest material tested, but steel and copper should have about the same stability.

It was noted that after use, a damage spot could easily be seen on the metal surfaces. The lifetime of the metal target was very long and did not seem to be failing even after 10^4 shots. We have also tried several nonmetals such as bakelite, polyethylene and graphite. These materials tended to trigger only for a few shots and then failed. This is probably due to the rapid deterioration of the irradiated surface. Therefore, we can safely say that only metals are suitable targets for this application.

We can estimate the maximum power that can pass through the shutter. The maximum power is obviously limited by the breakdown threshold of the gas in the focus of the 1:1 telescope. With the cleanest gas available from boiled off cryogenic vapors, this threshold is determined by the tunnelling ionization of the gas molecules [10]. It had been determined that the absolute maximum threshold for gas breakdown was 10^{13} W/cm^2. By a simple scaling calculation, we can switch off a maximum laser power of 40 MW while still maintaining the speed of 10 ps in our plasma shutter.

In conclusion, we have achieved reasonable stability with this new simple triggering technique for the plasma shutter. The triggering can easily be synchronized and the root mean square fluctuation in the triggering is close to 5%. The speed of the shutter is 10 ps and the attenuation is essentially 100%. This class of plasma shutter is the known closest approximation to a perfect shutter in the high power regime.

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