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LASER-INDUCED CURRENT PULSES FROM A TARGET IN A GAS

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The electron current induced by a laser beam focused on a metal target is investigated; the target is located in a chamber filled with a gas at 10^{-6}–10^{-1} Torr. The current flows between the target and the chamber walls in the absence of an external voltage. With increasing gas pressure the current grows from 3 A to 100 A; the maximum appearing at 10^{-2} Torr is followed by a sharp decrease. The current pulse begins during the laser giant pulse and has a very much longer duration, up to 1 μsec. The current appears very much sooner than the arrival of the main cloud of plasma at the walls. It is therefore assumed that the gas is rendered conductive through photoionization by radiation from the target plasma or by a plasma leader. A "foreplasma" that appears before the arrival of the main plasma and that compensates the Coulomb charge of the rapidly generated large current was recorded using both microwave and diamagnetic diagnostics. Possible mechanisms of current production are considered (photo- or thermoelectronic emission and thermo-emf, diffusion of foreplasma electrons etc.). A similarity is noted between the observed effect and current pulses arising in association with high-temperature radiation bursts in gases near conducting surfaces. The observed effect can also be utilized in laser-type or other thermoelectronic energy converters.

EXPERIMENTAL investigations of the effects produced by giant pulses from a laser focused on a solid target [1-4] have shown that the target can serve as the source of a very appreciable electron current. For example, when an accelerating voltage of the order of a few kilovolts is present the current pulse can endure ~1 μsec and reach 10^3 A. Namba et al.[3] have reported the existence of a large electron current pulse from a target in a vacuum in the absence of an external accelerating voltage. These experiments, with one exception, were performed in a vacuum of the order 10^{-6}–10^{-10} Torr; however, Isenor [5] increased the pressure to 10^{-3} Torr.

The present work continues the investigation, reported in [5], of the way in which gas pressure influences the magnitude of the electron current generated by laser emission directed at a target without the application of an external electric field. The current from the target is found to increase rapidly up to a certain critical pressure.

The experimental arrangement is shown in Fig. 1. The chamber 1 contains a target 2 on which a laser

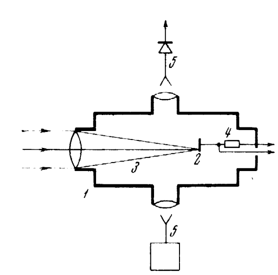

FIG. 1. Experimental arrangement.

beam 3 is focused. We registered the current flowing along a rod to which the target was fastened. The magnitude of the current was determined from the potential drop in a resistance 4. The chamber, of 10-cm diameter and 20-cm length, was made of stainless steel. The laser beam was focused with a lens of 14-cm focal length. A fraction of the light was deflected by plane-parallel quartz plates to a photomultiplier and to a photomultiplier and to a calorimeter for the purpose of monitoring the laser power and energy. The giant pulses were generated in a Q-switched ruby laser 12 cm long and 1.2 cm.in diameter by means of a ro-

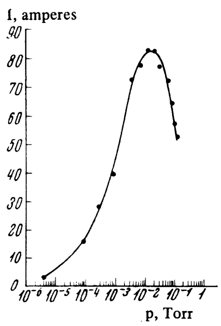

FIG. 2. Pressure dependence of electron emission current.

tating prism. The pulse duration was ~60 nsec and its energy was ~1.5 J. The gas pressure in the chamber was regulated in the range 3×10^{-6}–5×10^{-1} Torr by means of a leak.

Figure 2 shows the dependence of the current emitted from the target on the gas pressure in the chamber. Figure 3 shows oscillograms of current pulses registered for different pressures.

At $p = 4 \times 10^{-6}$ Torr the emitted electron current is 3 A. At $\sim 10^{-2}$ Torr the current pulse increases to 80 A. In the interval 3×10^{-6}–10^{-3} Torr the current-pressure dependence is well approximated by $I = kp^{\alpha}$, where $\alpha = 0.5$–0.7. At still higher pressures the pulse amplitude is reduced.

The dynamics and properties of the plasma were investigated by means of a microwave diagnostic technique (see 5 in Fig. 1) and also with plasma probes. From the delay time of the microwave cutoff ($\lambda = 8$ mm) and the lag of the probe signal behind the laser pulse we estimated the plasma velocity $v = 5 \times 10^6$ cm/sec for sufficiently high density. A comparison of the plasma transit time to the chamber walls and the duration of the electron current shows that the plasma front reaches the walls after the electron current has attained its maximum value. From this fact and the dependence of the current on the neutral-gas pressure in the chamber we conclude that a plasma which compensates the space charge, and which we call the "foreplasma", is formed in the volume of the chamber before the main plasma arrives. The generation of the foreplasma can be associated with ionization of the residual gas by ultraviolet emission from the target plasma. (Another hypothesis is that this ionization results from the ejection of a fast plasma fraction ahead of the main cloud.) The formation of the foreplasma is attested to by oscillograms showing blanking of the microwave signal.

The oscillograms in Fig. 3 show that increasing pressure leads to obstruction of the microwave radiation preceding cutoff by the main body of plasma; this indicates the formation of a foreplasma. Strong obstruction of the microwave by the foreplasma for $p \sim 10^{-1}$ Torr indicates $n_e \sim 10^{13}$ cm^{-3} in this case. The formation of the plasma permits compensation of the Coulomb-charge field within a time $t_1 \approx 1/4\pi\sigma$ if $t_1 > 1/\nu$ (here $\sigma = n_e e^2/m\nu$ is the plasma conductivity and ν is the collision frequency), or within a time $t_2 \approx 1/\omega_p$, if $t_2 < 1/\nu$ (here ω_p is the plasma frequency). The foreplasma density is sufficient to make these times small.

As an independent control of the microwave measurements we used a magnetic probe that registers dia-

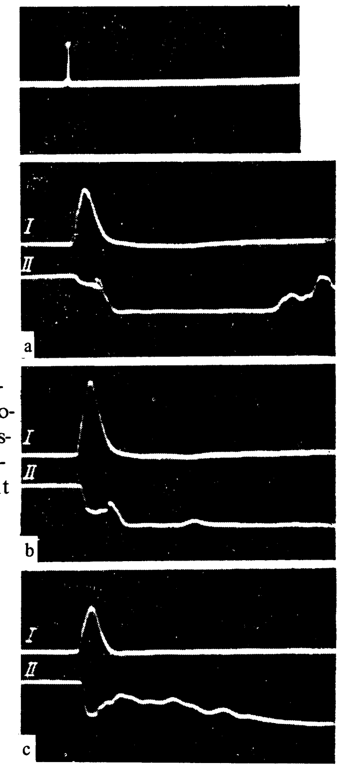

FIG. 3. Oscillograms of the electron emission current I and the microwave cutoff signal II at different pressures. The oscillogram at the top represents the registration of a laser light pulse. p = (a) 10^{-3}, (b) 2×10^{-2}, and (c) 10^{-1} Torr.

magnetic variations of the magnetic field. In these experiments a low magnetic field (10–20 Oe) was applied parallel to the chamber axis, and the probe registered the longitudinal variation of the magnetic field. At $p > 10^{-4}$ Torr an additional signal from the foreplasma is detected, preceding the diamagnetic signal from the main plasma. We note that the current from the target is not very strongly dependent on the laser power; even in the absence of Q switching the current pulse attained several amperes.

The large currents observed when a target in a gas was exposed to a focused light beam can be attributed to thermal emission and photoemission from the target (the photoemission being induced by plasma radiation), while the space charge is compensated by the foreplasma created in the residual gas. Therefore the presence of the gas can effect a manyfold increase of current from a target irradiated by a laser. The same effect can occur in connection with different geophysical processes and high-temperature bursts of ionizing radiation near conducting surfaces, and can be used in laser-type thermoelectronic converters.

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