Generation of high currents and potentials in the interaction of radiowaves with a rod. Direct conversion of electromagnetic energy to current energy

G. A. Askar'yan, G. M. Batanov, N. K. Berezhetskaya, S. I. Gritsinin, I. A. Kossyi, and I. M. Raevskiĭ
P. N. Lebedev Physics Institute, USSR Academy of Sciences

(Submitted 18 April 1979)

Pis'ma Zh. Eksp. Teor. Fiz. **29**, No. 11, 706–709 (5 June 1979)

Generation of high currents and voltages under the effect of rf radiation on a rod is investigated. Currents of ~200 A for loads of ~1ohm, and potentials of ≲1.5 kV at current densities of ~100 kW/cm^2 are obtained. Possible mechanisms for the generation of currents and potentials that far exceed the electron vibration energy are indicated. A possibility of effective energy conversion of radiowaves into current with efficiency > 10% is shown.

PACS numbers: 84.70. + p, 84.60.Rb

Generation of currents and magnetic fields in a plasma under the effect of high-power electromagnetic radiation is of a high scientific and practical importance. However, conversion of wave energy into a current is characterized by a very low efficiency. A sharp increase in the current from a target was obtained without an applied potential when a pulsed ruby laser ($\lambda = 0.7\ \mu$m) beam was coupled to it, attaining 100 A at an optimal pressure of ambient gas ~10^{-2} mm Hg [1]; the effect was proposed therein as a means of laser energy conversion from optical to electric current (at a P~30-MW laser power, electric power w_J~10 kW was obtained, i.e., ~3×10^{-2}% conversion efficiency). These results and proposals were reiterated in subsequent works.[2,3] In particular, generation of current under the effect of a CO_2 laser beam ($\lambda = 10\ \mu$m) was investigated,[3] and potentials of 700 V and currents of 14 A were obtained with a conversion efficiency of ~10^{-1}%. Of high interest was investigation of this effect at long wavelengths, including radiowaves.

In this work we investigate potentials and currents from a probe under the effect of centimeter radiowaves and report on a thousand-fold higher conversion efficiency. Figure 1 shows a diagram of the experimental setup. Pulsed rf signals pass through a window into a metal chamber (1), where at power densities of ~100 kW/cm^2 they are coupled to a metal probe (2) placed in a dielectric matrix to reduce breakdown. Plasma generated at the rod was from a breakdown at the surface due to a spark or focusing an auxiliary pulsed laser beam on the surface. The probe was connected to chamber through a load (3) and a voltage across it was fed to an oscillograph. The duration of SHF signals could be varied from 10 to 70 μsec. Pre-breakdown pressure in the chamber could be varied from 10^{-5} to 10^{-1} mm Hg. Voltage pulses up to 1.5 kV at high loads ($R > 100$ ohm) and currents to 200 A at low loads ($R \sim 1$ ohm) were obtained. Figure 2 shows oscillograms of rf (a) and voltage (b) pulses for different loads. A non-steady-state of voltage growth is seen especially at small loads.

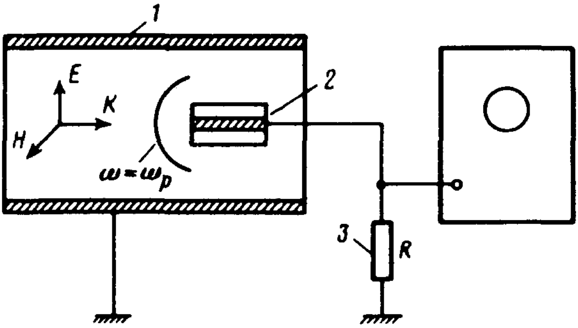

FIG. 1. Experimental setup: 1—metal chamber; 2—probe, metal rod in dielectric matrix; 3—load.

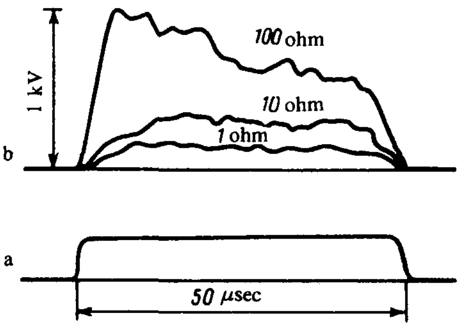

FIG. 2. Oscillograms of rf pulse (a) and voltage pulses (b) at various loads.

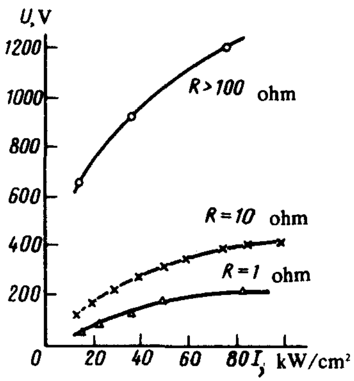

FIG. 3. Dependence of voltage $U = RJ$ on power density.

Figure 3 shows the dependence of voltage $U = RJ$ on radiowave power density I_0 for loads R, and Fig. 4, the dependence of U, J and $w = JU$ on the load.

The experimental results indicate a possibility of attaining high currents and efficiencies of the order of tens of percent; this option appears more interesting than the laser method of conversion. Efficiency of energy conversion from an electromagnetic wave to current in the probe circuit is maximum in the region of low background pressures. At pressure exceeding 10^{-4} mm Hg a rapid decrease of the current J is observed.

The possible mechanisms that provide electron emission and generation of EMF are as follows: resonant acceleration of electrons from the plasma resonance region ($\omega = \omega_r$) under the effect of a field component that is normal to the surface of plasma resonance layer (we should note that the layer surface in our case may be curved and, therefore, the normal component of field may be very significant). It is also possible that the electron emission is associated with a temperature tail or quasi-temperature electron distribution as a result of plasma heating by radiowaves or by electron acceleration in the modulation instability. We should note that the electron energies responsible for the potentials exceed by several-fold the vibrational energies

$$\mathcal{E}_e = \frac{e^2 E_0^2}{2m\omega^2} = \frac{2\pi e^2 I}{mc\,\omega^2} \lesssim 10 \text{ eV}.$$

It is interesting to note that in our case the magnetic field may noticeably affect the electron transport processes.

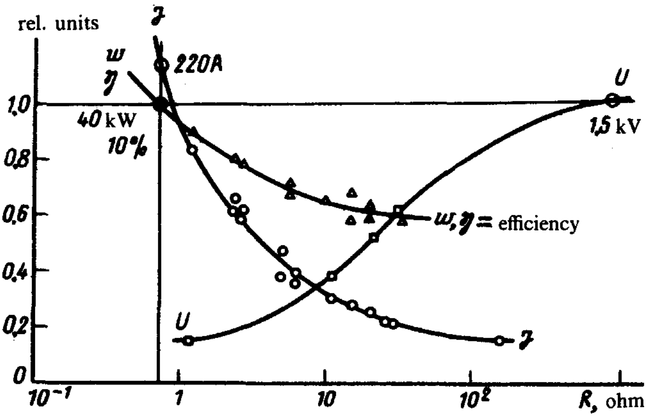

FIG. 4. Dependence of voltage U, current J, power w, and efficiency on load.

Until now, we considered the external current and fields emanating from the plasma, although these processes also amplify internal fields and currents in the plasma originating from the target under the effect of radiation, which were first observed in Ref. 4 several years before publication of subsequent works.[5]

The obtained results offer hopeful means for an effective transformation of multimode electromagnetic waves into currents[6–9] at high densities, for which the known conversion methods[7–9] are inapplicable.

To demonstrate the practical uses of the foregoing, a 30-W bulb and a condenser were inserted in the circuit; the bulb produces continuous illumination at a 30 Hz supply frequency.

In conclusion, the authors thank Professor M.S. Rabinovich and Academicians, P.L. Kapitza, and A.V. Gaponov for support of the work and discussion of the results.

[1]T.U. Arifov, G.A. Askar'yan, I.M. Raevskiĭ and N.M. Tarasova, Zh. Eksp. Teor. Fiz. 55, 386 (1968) [sic!].

[2]M.G. Drouet *et al.*, Appl. Phys. Lett. **28**, 426 (1976); *ibid.* **29**, 469 (1976); *ibid.* **31**, 647 (1977).
[3]W.T. Selfvast and L.H. Szeto, Appl. Phys. Lett. **31**, 726 (1977); Priroda, No. 10, 133 (1978).
[4]G.A. Askar'yan, M.S. Rabinovich, A.D. Smirnova and V.B. Studenov, Pis'ma Zh. Eksp. Teor. Fiz. **5**, 116 (1967) [JETP Lett. **5**, 93 (1967)].
[5]J.A. Stamper *et al.*, Phys. Rev. Lett. **26**, 1012 (1971) .
[6]P.L. Kapitza, Elektronika bol'shikh moshchnosteĭ (High Power Electronics), M., USSR Academy of Sciences, 1962.
[7]Microwave Power Engineering, E. Okress, Ed., Acad. Press, N.Y., 1968 (Russ. transl. "SVCh energetika," E. Okress, Ed., M., Mir, 1971).
[8]V.A. Vanke, V.A. Lopukhin and V.L. Savvin. Obzor "Problemy solnechnykh kosmicheskikh elektrostantiĭ (Problems of Solar Space Electric Power Stations: A. Review), Usp. Fiz. Nauk **123**, 633 (1977).
[9]E.J. Nalos, Proc. IEEE **66**, 276 (1978); New Developments in Electromagnetic Energy Beaming (Russ. transl. of a TII ER review No. 3, 1978).