Electroionization discharge with recuperation of the electron beam

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A method is proposed for exciting the gas of an electroionization laser, with recuperation of the electron-beam energy, so that a high per-unit gas excitation energy can be reached at a high beam-energy utilization coefficient.

The ionization of a gas by fast electrons makes it possible to produce a volume discharge at high gas pressures[1,2] and by the same token reach a high specific gas-excitation energy, a fact utilized in electroionization lasers.[2,3] The specific energy input Q to the gas from the electric-field source increases almost quadratically with increasing E/P,[4,5] where E is the intensity of the electric field in the gas and P is the gas pressure. However, the intensity of the static field cannot be raised above the self-breakdown field intensity. As a result of working at low E (up to 30 kV/cm), the value of Q attained does not exceed 10 J/cm^3 at characteristic electron-beam currents ~1 kA and current-pulse durations ~10^{-8} sec.

To increase the specific energy in such devices it is necessary to use more powerful accelerators, since the volume-discharge current is proportional to the ionizing action of the beam, and the discharge duration is approximately equal to the duration of the beam pulse.[4] At the same time, in the existing installations, only a negligible fraction of the beam energy goes to the ionization of the discharge-gap gas, since the range of the high-energy electrons in the gas is usually much larger than the interelectrode gap.

The field intensity in the gas can be increased by using a pulsed voltage and by producing an overvoltage across the discharge gap. But this raises the difficulty of synchronizing the voltage pulses with the electron-beam pulses.

In the setup developed by us, a schematic diagram of which is shown in Fig. 1, these difficulties are overcome by applying the potential difference across the discharge gap from the same pulsed-voltage source 1, from which the accelerating tube with the explosive-emission cathode 2 is fed. The anode 3 is common to the accelerator tube and to the discharge chamber, and is transparent to the electron beam. The beam passing through the anode enters the discharge-gap gas and is decelerated by the opposing electric field between the anode 3 and the cathode 4, losing part of its energy to the gas ionization and returning part of the energy to the voltage source 1 (recuperation of the electron-beam energy). The recuperated energy goes to acceleration of new electrons (i.e., the pulse becomes longer).

Since the ionization cross section at low electron energies is much larger, the beam decelerated by the electric field produces a much larger ionization in the gas than the usual high-energy beam. It is therefore possible to attain much larger volume-discharge currents than in ordinary installations.

The bulk of the secondary electrons is produced in the gas near the cathode 4, where the beam electrons are decelerated to a minimum energy, meaning that they have the largest ionization cross section. The secondary electrons are moved by the electric field towards the anode, thereby exciting the gas molecules and determining the discharge current. At sufficiently high field intensity, these electrons begin to accelerate and "run away" along the field.[6] The beam electrons also drift in the same direction after giving up their kinetic energy. The beam electrons cannot reach the cathode 4, so that part of the discharge gap directly in front of cathode 4 remains not ionized. However, as the result of redistribution of the electric field in the discharge gap, the field intensity in the cathode layer increases, exceeding the ionization threshold of the gas, and the latter breaks down, thus becoming in fact an unbounded electron emitter.[4]

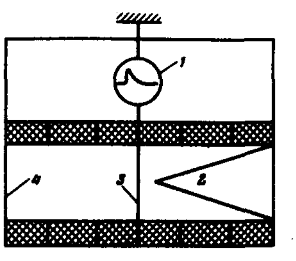

FIG. 1. Schematic diagram of experimental setup.

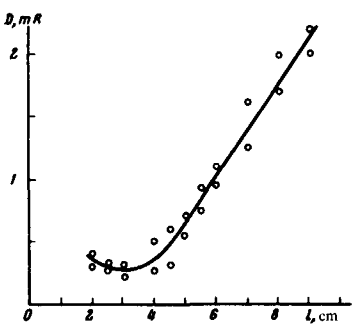

FIG. 2. Dependence of the x-ray dose on the length of the discharge gap.

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A brightly glowing near-cathode layer up to 1 cm thick can be clearly seen on the photographs of the glow of the air in the discharge gap at atmospheric pressure; these photographs were taken with the described setup at gap lengths from 2 to 8 cm. The remaining region between the electrodes has a much weaker uniform violet glow.

A pulse of voltage ~300 kV and duration $\sim 10^{-8}$ sec was applied simultaneously to the accelerating tube and to the discharge gap, at a beam current up to 1 kA from a storage line 1 storing up to 20 J. At such a low energy stored in the line, the discharge current did not exceed the beam current greatly (by not more than 10 times), and the values of Q were naturally not high, but these experiments have demonstrated the feasibility of the scheme and have made it possible to develop the experimental technique. An electric field intensity more than 100 kV/cm was reached in the gap without producing a discharge channel. The dependence of the integrated x-ray dose registered by DK-0.2 dosimeters, on the length l of the discharge gap is shown in Fig. 2. The minimum at $l=3$ is due apparently to the fact that an intense "runaway" of the electrons sets in at $l \lesssim 3$ cm, and that the electrons bombard the anode foil and thus produce x rays.

The results show that in this system, using a sufficiently powerful storage line (with a stored energy ~1 kJ) it is possible to obtain a specific energy input ~100 J/cm^3 to the gas at a high electron-beam energy utilization coefficient.

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