STIMULATION OF VOLUMETRIC DISCHARGES IN A GAS AT HIGH PRESSURE BY AN ELECTRON BEAM OBTAINED USING A LOW-PRESSURE DISCHARGE

Yu. I. Bychkov, Yu. E. Kreindel', G. A. Mesyats, and A. G. Filonov

UDC 537.52

The possibility of triggering a semi-self-sustained discharge in a gas at higher than atmospheric pressure through the ionization of the gas in the volume of an electron beam [1] has opened up great prospects for the creation of powerful gas lasers [2]. Cathodes operating on the principle of explosive emission [3] as well as incandescent cathodes are used as the electron sources in the electron guns. Electron sources with explosive emission enable one to obtain high electron current densities with a duration of 10^{-8}-10^{-6} sec. Using incandescent cathodes one can obtain electron beams in a wide range of pulse duration but these sources have a number of drawbacks such as the high power consumption at the heater and the destruction of the cathode when air enters the chamber.

For electroionization CO_2 lasers electron sources are required which are reliable in operation and which can provide electron beams of long duration (from 10^{-5} sec to continuous) at a high succession frequency and with a large emission surface.

In a number of cases this problem can be solved by the use of plasma sources of electrons (PSEL) [4, 5] based on the extraction of electrons from low-pressure discharges containing a cold cathode. The chief merits of this method are the following:

1) in using PSEL, pulsed beams can be obtained through the use of low-voltage pulsed discharges of low pressure. Pulsed electron emission, which is often difficult to achieve using thermocathodes because of their thermal inertia, is provided at a constant accelerating voltage by the pulsed discharges in PSEL;

2) low-pressure discharges can burn stably in large volumes. In principle this opens up the possibility of creating large plasma emission surfaces and electron beams with a large area and the required cross sectional configuration. The large emission surfaces can be obtained at low pressures as a result of the plasma passing from the discharge chamber into a special equipotential cavity, called the expander;

3) the PSEL with a cold cathode are not sensitive to ion bombardment or to a sudden breakdown in the air-tightness of the vacuum system in a wide range of low pressures, which considerably increases the reliability of instruments using them and simplifies their operation.

The stimulation of a high-pressure volumetric discharge using an electron beam extracted from a pulsed low-pressure discharge was carried out using the experimental apparatus illustrated schematically in Fig. 1. The apparatus includes a sectioned accelerating tube containing the PSEL which provides an electron beam current of up to 3 A, an accelerator power pack based on an Arkad'ev-Marks generator providing identical voltage pulses up to 30 μsec long with an amplitude of up to 250 kV, and a high-pressure discharge chamber. The voltage to the PSEL electrodes and the sectioned accelerator tube was supplied from the Arkad'ev-Marks generator through an ohmic voltage divider.

A PSEL based on an arc constriction discharge with a cold cathode in a magnetic field [5] was used in the apparatus. When gas was admitted into the source and a pulsed voltage was supplied between the steel cathodes 1 and 2 and the intermediate copper loop anode 3 a Penning discharge was ignited and converted into an arc which was transferred through the opening in the intermediate anode to the main anode 4.

Tomsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 162-164, March-April, 1974. Original article submitted September 27, 1973.

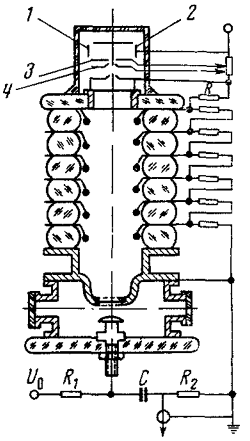

Fig. 1

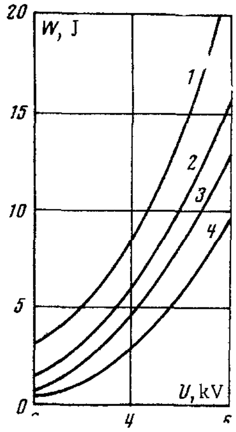

Fig. 2

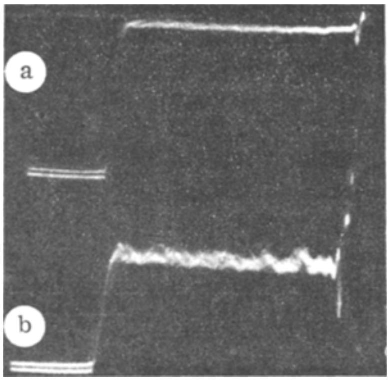

Fig. 3

The magnetic field between the cathodes, produced by permanent magnets, did not exceed 600 Oe. The electrons were drawn off from the developed boundary of the plasma with the help of an extracting electrode, passing through a small opening in the main anode into an expander 15 mm in diameter. In the extraction region the magnetic field is deformed by a ferromagnetic insert molded into the intermediate anode and by the steel main anode. A grid with a transparency of 0.8 mounted in the expander determines the shape and position of the emitting surface. This provides the rigid electron optics for the extraction of electrons from the plasma. The grid also increases the stability of the discharge and of the extraction of electrons from the plasma.

The extracting voltage is 30 kV and the flow rate of the working gas (air, argon) does not exceed 80 cm^3/h. The ratio of the electron current extracted from the plasma to the discharge current is 40%. The relatively high efficiency of the electron extraction makes it possible to supply the electron source from the divider which distributes the voltage between the sections of the accelerator tube, and thus avoids having a separate emitter power system under high voltage, which is necessary when a thermocathode is used.

Thanks to the use of pulsed electron emission provided by the pulsed discharge the average power consumed by the discharge at a duration of 10 μsec and a repetition frequency of 1 Hz does not exceed 0.1 W, which increases the economy of the electron-beam system and eliminates the difficulties of providing a thermal system of construction. The accelerated electron beam with a diameter of 10 cm was admitted into the high-pressure gas through aluminum foil or mylar film. The volume of the high-pressure gas-discharge chamber was 30 cm^3 and it was supplied from a 2 μF capacitor.

The volumetric discharge was studied in pure N_2 and CO_2 gases and in their mixtures at pressures of 1-2.5 atm. With a field strength of less than 8 kV/cm the discharge is semi-self-sustained, burns for the duration of the electron beam, and then ceases with the voltage kept unchanged on the electrodes. A typical dependence of the supply of energy to the gas on the field strength is presented in Fig. 2, where the curves marked with numbers pertain to different states of the gas: 1) pure N_2; 2) CO_2:N_2 is 1:3; 3) CO_2:N_2 is 1:2; 4) pure CO_2. The beam current is 0.3 A and the pressure is 1 atm. A spark discharge develops at higher field strengths. For example, with $E \approx 10$ kV/cm a spark channel develops 10 μsec after the extinction of the volumetric discharge, and with $E > 11$ kV/cm the volumetric discharge changes into a spark discharge.

Thus, a stable volumetric discharge occurs at field strengths of 8 kv/cm or less and the duration of the discharge is equal to the duration of the electron beam.

The use of pulsed low-pressure discharges makes it possible to obtain pulsed electron beams not only with a pulsed but also with a constant accelerating voltage. An electron beam is described in [4] which has a plasma cathode based on the extraction of electrons from a half-cathode reflected discharge which, with modulation of the discharge and a constant accelerating voltage of up to 30 kV, provided pulsed beams with durations of the trapezoidal pulse of 10, 50, 100, 300, and 10^4 μsec at a repetition frequency of from 1 to 600 Hz. Oscillograms of the modulating voltage (*a*) and the electron beam (b) with a duration $\tau = 150$ μsec are presented in Fig. 3.

The possibility of modulation using voltage pulses of low power permits the creation of sources of electron beams with a high repetition frequency.

LITERATURE CITED

1. B. M. Koval'chuk, V. V. Kremnev, and G. A. Mesyats, "Avalanche discharge in a gas and the generation of nano- and subnanosecond pulses of high current," Dokl. Akad. Nauk SSSR, 191, No. 1 (1970).
2. N. G. Basov, É. M. Belenov, V. A. Danilychev, and A. F. Suchkov, "A pulsed CO_2 laser containing a high-pressure gas mixture," Quantum Electronics [in Russian], No. 3, Sovet-sko Radio, Moscow (1971).
3. G. A. Mesyats, A. S. Nasibov, and V. V. Kremnev, Formation of High-Voltage Nanosecond Pulses [in Russian], Énergiya, Moscow (1970).
4. P. P. Golik, V. A. Gruzdev, Yu. E. Kreindel', and L. A. Levshuk, "An electron gun with a plasma cathode," Prib. Tekh. Éksperim., No. 5 (1968).
5. Yu. E. Kreindel' and V. A. Nikitinskii, "An electron source based on a plasmotron containing a Penning tube," Prib. Tekh. Éksperim., No. 1 (1970).