SECONDARY EMISSION MAGNETRON INJECTION GUN THAT CONTROLLED BY MAGNETIC FIELD IN LONG PULSE MODE

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The origin variant of ignition the secondary emission magnetron injection gun at low voltage (3…25 kV) with use pulse magnetic filed and additional gas filling is described. Beam current up to 5 A with pulse its duration up to 10 ms was achieved. Perspectives of the gun application for generation of electron beams and high charge ions are discussed.

PACS: 29.17.+w

1. INTRODUCTION

Secondary Emission Magnetron Injection Gun (SEMIG) was proposed and tested in 1990 [1]. Path-breaking test of the gun was made in short pulse mode with duration nearly 50 ns. A main advantage of the gun in comparator with another cold-cathode vacuum gun is possibility to achieve a long pulse mode up. Next steps of pulse duration were show in table 1. Naturally pulse duration depend of level of current and increase with decreasing of the beam current. Come on beam current depend of voltage pulse amplitude. Therefore the gun for long pulse mode must be tested at low voltage pulse amplitude. In the first time secondary emission magnetron injection gun was ignited by the action of voltage pulse slope. A feature of the method is boundary of ignition at low-voltage side. The boundary may be high as several tens kilovolt. Moreover the voltage slope speed must be high enough. Besides the secondary emission mode may be supported by more low voltage up to several kilovolts. In this research low voltage ignition was tested. For this purpose pulse magnetic filed and additional gas filling was used. The similar method was used by Vaughan in secondary emission cold-cathode magnetron [2]. Recently we successfully tested this method in cold-cathode gun [3] and achieve pulse duration up to 1ms with current nearly 1 A. Pulse duration increasing was limited by arc ignition. The goal of follow research is next increasing of the pulse duration.

2. METHOD AND FACILITY

For the next increasing of pulse duration the arc ignition must be suppressed. We used two methods. The first one is outgasing of the cathode surface by heating in vacuum. The second is covering of cathode by refractory material.

The facility «Rassvet» was upgraded for the providing of experiments. Schema of the facility is shown in Fig.1.

The heater made from thick nichrome wire with 2 Ohm resistance was installed inside the hollow cathode for the removing of gases adsorbed on the cathode.

The heater was connected to a step-down isolation transformer. The transformer could supply the cathode voltage up to 20 kV relatively the grounded anode during the heating up. The step-down transformer was connected to an adjustable-ratio laboratory autotransformer. The heater voltage could be adjusted in the range 0…5 V. The thermocouple based on the alloys copel-alumel was mounted beside the heater in order to control the temperature of the operating part of the cathode. Such thermocouple supplies high measured voltage.

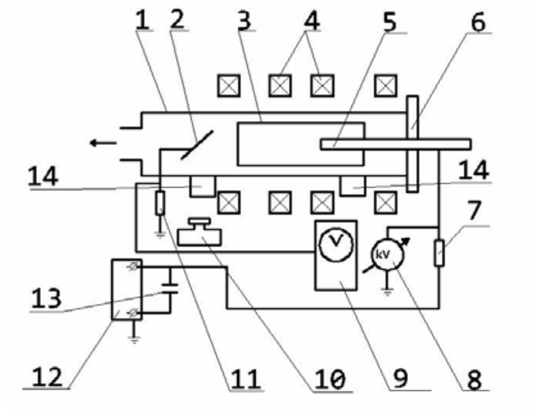

Fig.1. Facility "Rassvet" ("Sunrise")
1 - tube vacuum chamber (ceramic insulator);
2 - collector with luminescence cover; 3 - tube anode (stainless steel); 4 - coils of pulse magnetic field;
5 - cathode; 6 - metal flange for cathode maintaining;
7 - protective resistor; 8 - kilovoltmeter;
9 - oscilloscope with memory; 10 - digital camera;
11 - signal resistor; 12 - high-voltage source;
13 - storage capacitor;
14 - optical windows for observation

The thermocouple connected to digital multimeter DT-830B operating in the voltage measurement mode within the voltage scale 200 mV controls the temperature with acceptable accuracy. Calibration curves loaded from the web was revised in two temperature points: ambient temperature and water boiling temperature. As far as the cathode was made from relatively long (50 cm) thin-wall stainless steel pipe and was placed into vacuum, it has good thermal insulation. The heater having relatively low power (≈12 W) has been succeeded to heat it up to 440°C during approximately 2 hours. Such design had also considerable thermal time lag. The disconnecting of the heater during few seconds didn't change the thermocouple multimeter readings. The thermal contact of the heater and pipe interior was provided due to the proper mechanical contact in the outside ambient. After the switching off the heater it was cooling down to the pipe temperature quickly. This fact pointed on the validity of the temperature readings. If temperature discontinuities should take place, it would point on the heat over-flow directly from the heater to thermocouple and on the invalidity of readings of the last one.

PROBLEMS OF ATOMIC SCIENCE AND TECHNOLOGY. 2010. № 3.
Series: Nuclear Physics Investigations (54), p.40-43.

The improving of the cathode resistance to the arc excitation can be made by its coating by a refractory conducting material. Nitride of titan was chosen for the coating. The temperature of its melting point achieves 2950°C. This material is cheap relatively and the technology of its coating on stainless steel is well worked out. Another important factor of the cathode material choice is a value of a secondary emission coefficient. Nitride of titan has the secondary emission coefficient that corresponds approximately to the secondary emission coefficient value of refractory metals (1.3 in a maximum) [4, 5]. The operating part of the cathode was coated by the nitride of titan layer with thickness 10 μm using the method of arc dispersion in a nitrogen environment.

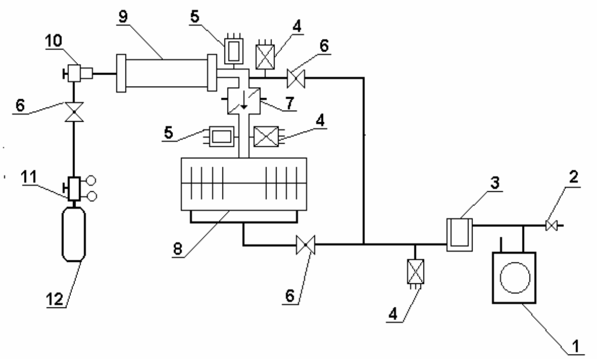

Fig.2. Vacuum schema of the facility "Rassvet" ("Sunrise")
1 - forepump; 2 - valve of fall-over of air; 3 - cryogen trap with liquid nitrogen; 4 - rough-vacuum gauge; 5 - hot-cathode high-vacuum gauge; 6 - vacuum valves; 7 - managed vacuum breech-block; 8 - turbomolecular pump of TMN-200; 9 - vacuum chamber; 10 - gas filler; 11 - gas reducing gear; 12 - bulb with working gas

The possibility of secondary emission discharge excitation was tested recently [3] applying the pressure increasing in a vacuum system by a partial closing of a pumping-down valve of a vacuum pump. In such conditions a self-sustained secondary emission discharge is excited at low voltage values in the few kilovolt range. Electron beam current in this case is in the range from the tenth fractions to few units of ampere. However, the duration of the beam generation was limited by the arc discharge excitation and achieved 1 ms. One of the reasons of the arc discharge excitation may be the residual oxygen at the decreasing of a pumping-down speed. It is known that oxide films conduce to the arc discharge excitation [6]. To prevent the formation of such films for the excitation of a gas discharge passing into a secondary emission one it was applied a leak-in of hydrogen like in the Vaughan magnetron [12]. As far as a turbo-molecular pump was used for the installation pumping out, hydrogen was injected into the exhaust pipe of the pump. The purity of the leaking-in hydrogen was provided due to a considerable difference in the compression degree of air and hydrogen components. Vacuum schema of the facility is shown in Fig.2.

For the discharge excitation at higher voltage values one may refuse a gas leak-in and apply more conventional method based on electron avalanche excitation during a voltage pulse falling down. The special exciting device was developed for this purpose. Electric schema of the facility is shown in Fig.3.

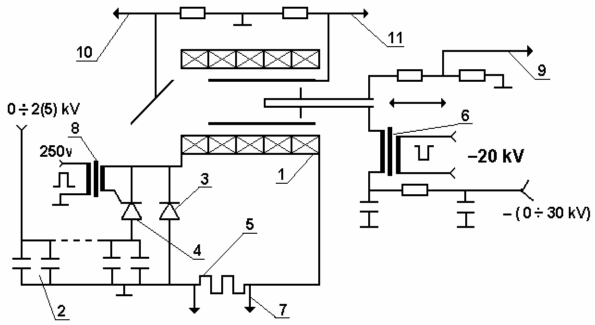

Fig.3. Electric schema of the facility "Rassvet" ("Sunrise")
1 - coils of pulse magnetic field; 2 - battery of pulse capacities 4500 mkF, 5 кV; 3 - antivibration diode of D181-320-16; 4 - tiristor of T173-1250-28; 5 - measuring shunt 300 A, 75 mV; 6 - high-frequency high-voltage transformer; 7 - signal of current of solenoid; 8 - dividing transformer of block for tiristor start; 9 - signal of voltage on a cathode; 10 - signal of current of collector; 11 - Signal of current of anode

3. EXPERIMENTATION AND RESULTS

Before the experimentation the maximal achieved pulse duration was 1 ms [3]. At the beginning of experimentation the storing capacitor of less capacitance of 0.25 μF was used to protect the cathode surface from damage by arc discharge. The capacitance has been increasing up to 4.5 μF within the increasing of the beam pulse duration. The pulse duration in this case may be achieved 10 ms and the arc excitation may be suppressed. The beam current was generating usually after turning on pulse magnetic field during both the field rising slope and the field falling slope. This depended on the leaking-in gas concentration. The increasing of the gas concentration may move the moment of the beam generation from the field falling slope to the field rising slope. The cathode heating up caused the reducing of the beam current pulse duration with further its increasing. The pulse duration was increasing after the cathode cooling down. Then it increased after multiple triggering of the gun (20-30 times). The maximum pulse duration value and the most unoften arc discharge excitation were observed after the end of the heating and trigger conditioning of the cathode. The gun was triggered even without additional leak-in of the gas before the cathode heating up. The gun was triggered in high vacuum i.e. at the pressure of few thousandth fractions of Pascal. After the cathode heated up it was not succeeded to trigger the gun without additional leak-in of the gas even using the triggering pulse synchronized with a magnetic field pulse. The arc discharge was observed on an oscillogram as sharp increasing of the cathode current up to the value defined by a nominal impedance of a barrier resistor in the cathode circuit. The voltage fell down up to zero on it at the same time. The cathode current appeared some times in the chain cathode-anode across magnetic field. In an insignificant time interval the current transferred then from the anode to the collector along magnetic field direction. In the most cases the current of the cathode arc transferred to the collector at once. Oscillograms of the current and voltage at maximum pulse duration are shown on the Fig.4.

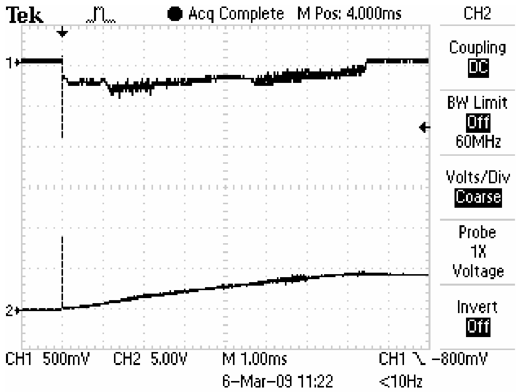

Fig.4. Oscillograms: 1 - the beam (collector) current (upper); 2 - the gun voltage (down)

After experiments the cathode was extracted from a vacuum chamber and the cathode's picture was taken using Canon S5 IS digital camera. The picture of the cathode is shown on the Fig.5.

Fig.5 Cathode photo after performance. Diameter of cathode road 20 mm

One may see that the cathode rod is covered by the dense layer of carbon in the operating area of the gun. Only the end of the cathode remained almost clean. Such a carbon usually appears on anodes of electron guns wherein the fraction of the beam is intercepted by an anode. The reason of carbon formation is the polymerization of oil tracks and other organic contaminations on a surface under electron bombardment. The presence of a carbon may be an additional evidence of the self-sustained electron-electron secondary emission since it related directly with a cathode electron bombardment. Ion bombardment vice versa results in cleaning of cathode. The argument of the arc discharge excitation on the cathode is erosion traces of the arc operation on its surface. As one may see on the zoomed in area of the cathode picture these traces are branched and extended along magnetic field direction. Such direction features the cathode spot of a vacuum arc. The conductivity of the carbon film was tested using the multimeter by touching of probes of the surface in places of the most continuous and thick carbon film. The resistance between probes was less one Ohm. The contact of the carbon covered surface with white paper sheet tracked it sharply. It is possible to assume that the basic component of the carbon is graphite providing high conductivity of the film. Oil and other organic impurities provide the iridescent coloring and the secondary electron emission coefficient exceeding unit.

The further increasing of the beam current pulse duration was limited in our case by the duration of the magnetic field pulse. It was impossible to increase the magnetic field pulse duration without the further considerable reconstruction of the magnetic field feeding source.

4. ASPECTS OF FURTHER PULSE DURATION INCREASING

Unlike of high-current cold cathode electron sources based on explosive emission the operation of the considered secondary emission source is not associated with electron-ion plasma generation. The source has not principal limitations of the pulsed duration associated with a cathode plasma movement. However, the combination of high-current at relatively low voltage with long pulse duration may result in plasma formation along a beam track in high vacuum conditions. The initiation of the beam instability will result in further growth of concentration of charged particles retained by a magnetic field. Fractures on beam current pulses satisfy the similar considering. They, it seems, correspond to plasma formation and to further plasma processes of the initiation of plasma-beam discharge and to the step-like change of a plasma generation mode in such discharge. One may assume that it is necessary not only to remove adsorbed gas from a cathode but also to increase vacuum in the gun considerably for achieving the continuous operation mode of similar source. The proper estimations and calculations are difficult enough and are beyond of the present research frame. Besides, the problem of the collector heat removing should be solved for the continuous mode. At the same time using a collector made from a refractory material with sufficient thermal inertia one may increase pulse duration in one-two orders of magnitude. To implement long life time it is necessary to operate with clean vacuum systems without oil vapors being the origin of a carbon on a cathode. It not always possibly because of relative costliness and complication of vacuum options those are fully free of oil in a vacuum volume. The problem of a carbon formation may be solved also by choosing of optimum temperature condition providing desorption of organic vapors from the surface of a cathode at its heating up by electron bombardment during the operation time or by using an additional heater. Another approach can be the dosed leak-in of gases (for example, heavy inert, in particular argon) for pickling out of the film due to an ion cathode dispersion.

5. POSSIBLE APPLICATIONS OF THE OBTAINED RESULTS IN ACCELERATING TECHNOLOGY

Cryogenic superconducting accelerating structures are applied more frequently in an accelerating technique recently. They, as a rule, operate in a long-pulse or continuous mode. For example, the most known design for the TESLA project can operate with pulse duration 1.5 ms at pulse repetition rate 10 Hz. The application of a cold cathode may reduce thermal influxes to initial sections of the accelerator considerably. The high current density of such cathode may be the factor permitting to achieve the high brightness of a beam within long pulse duration. This factor together with the cathode resistance to back electron bombardment and with the possibility of a beam modulation directly in a gun may serve as an important advantage. This advantage against thermionic guns applied now and got distribution recently guns based on laser driven photoemission cathodes together with the simplicity of the similar gun and long life time may serve the basis for application of such guns in the developing resonance linear accelerators. High vacuum that is free of oil vapors and other contaminations featuring superconducting cryogenic accelerators will allow preventing the formation of a carbon film on the surface of a secondary-emission cathode. Another potential advantage may be a polarized electron beam generation using only the cathode from proper material [7].

Long pulse duration mode or the continuous one is usually used in industrial high-power accelerators. Simplicity, reliability and long life time may be basic advantages here.

RF power for such accelerators is supplied by vacuum electron devices comprising a high-current electron source that operates with the same pulse duration. Such RF power sources always have own magnetic field source which may be applied for the proper secondary-emission electron source practically. Vacuum-brazed design will provide the cleanness of a vacuum system and the absence of a carbon on a cathode.

Multi-charge ion sources with the high ionization degree may become another essential application domain of such gun. Ions with maximum charge are generated exactly in such sources in present time. The cathode of such source operates in magnetic field. Besides, electric parameters of the electron gun in such sources are close to the obtained ones in the described experiments. Such sources are featured by oil-free super-high vacuum pumping down. The leak-in of the operating gas in the source may trigger secondary-emission gun. The prospects of application of such electron gun are described more detailed in the article accepted to the publication [8].

CONCLUSIONS

Cold cathode magnetron gun may generate electron beam pulses with the duration exceeding 10 ms. It was successfully achieved by the cathode heating up and by its conditioning.

The further increasing of the pulse duration was limited not by the gun properties and an arc discharge exciting, but by the parameters of the used installation. It is assumed to upgrade the installation properly in the near future.

The presence of oil vapors in the vacuum system on the cathode surface results in a considerable carbon coating of the cathode within so long pulse duration that prevents to stable gun operation.

To provide the long-term stable operation of such gun it is necessary to prevent formation of a carbon on the cathode. This probably can be achieved by application of the fully oil-free super-high vacuum pumping down. These types of pumping down are of a tendency in the newest accelerating technology presently.

There are other possibilities to overcome the consequences of the found out phenomenon.

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Статья поступила в редакцию 07.09.2009 г.

ВТОРИЧНО-ЭМИССИОННАЯ МАГНЕТРОННАЯ ПУШКА, УПРАВЛЯЕМАЯ МАГНИТНЫМ ПОЛЕМ В РЕЖИМЕ ДЛИТЕЛЬНОГО ИМПУЛЬСА

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Описан оригинальный вариант запуска вторично-эмиссионной магнетронной пушки при пониженном напряжении (3…25 кВ) путем использования импульсного магнитного поля и дополнительного напуска газа. Достигнут ток пучка до 5 А с длительностью импульса до 10 мс. Обсуждены перспективы использования пушки для генерации электронного пучка и многозарядных ионов.

ПОВТОРНО-ЕМІСІЙНА МАГНЕТРОННА ГАРМАТА, КЕРОВАНА МАГНІТНИМ ПОЛЕМ В РЕЖИМІ ТРИВАЛОГО ІМПУЛЬСУ

С.О. Черенщиков, В.Д. Коцубанов, І.К. Нікольський

Описано оригінальний варіант запуску повторно-емісійної магнетронної гармати при зниженій напрузі (3...25 кВ) шляхом використання імпульсного магнітного поля та додаткового напуску газу. Досягнуто струм пучка до 5 А з тривалістю імпульсу до 10 мс. Обговорено перспективи використання гармати для генерації електронного пучка та багатозарядних іонів.