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Section A

Design of the pseudospark discharge for a Raman FEL ☆

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1. Introduction

During the last decade, the pseudospark discharge of the type first explored by Christiansen and Schultheiss [1] has gained considerable attention because of its capability of producing a high quality electron beam. In addition, its potential application to high power switch development, electron beam lithography and plasma processing are very attractive.

The pseudospark discharge is a new kind of gas discharge, based on the principles of a hollow cathode discharge and has of the property of a self-sustaining discharge. A high brightness electron beam of 10^{11} A/m^{2}rad^2 at 20 keV and 70 A peak current is produced by a pseudospark [2] an electron beam with intense current density ($> 10^4$ A/cm^2), narrow beam diameter (< 1 mm) and very low emittance (tens of mm mrad) well qualified for use in free electron lasers. Several experiments have been reported in which high-brightness electron beams have been produced in pseudospark devices operating in the voltage range 20–50 keV [3].

The design of a pseudospark device operating at a voltage of 300–400 keV for a Raman FEL at SIOFM is presented. This study is to explore the scaling laws at high voltage. The preliminary results of the brightness diagnostics of pseudosparks produced electron beams are given.

2. Design consideration

It is well-known that electrical breakdown in gases is described by the Paschen law $U = f(pd)$, where p is the gas pressure (Torr) and d is the distance between anode and cathode (cm). A typical breakdown curve as a function of pd is numerically simulated as shown in Fig. 1. It is characterized by a nearly linear rise at pd-values from 1.9 Torr cm to 10 Torr cm, a minimum around 0.53 to 1.0 Torr cm and a steep rise below the minimum. Above the minimum is a glow discharge. The region from 0.01 to 0.1 Torr cm is known as the pseudospark discharge. The breakdown below 7.5×10^{-4} Torr cm is called vacuum breakdown.

The breakdown voltage U of a multigap pseudospark device has been measured systematically for a wide range of ambient gas pressures p and anode–cathode gap distances d [2]. The breakdown voltage U (kV) is a function of $(p^2d)^{2.2}$. This is in contrast to Paschen's law, which is a function only of pd, i.e. $(pd)U =$ constant. Now we use the experimental formula from Rhee's experiments [2], $(p^2d)^kU =$ constant, where constant = 0.2, $k = 2.2$.

For our design of $U = 400$ kV, we have $(p^2d)^{2.2} = 5 \times 10^{-4}$. The main discharge parameters can be considered as follows: if $p = 0.1$ Torr, $d = 3.2$ cm, the distance is too short; if $p = 0.01$ Torr, $d = 316$ cm, the distance is too long. If we take a compromise pressure $p = 0.056$ Torr, then $d = 10$ cm.

The distance d (cm) as a function of the pressure p at a given voltage was calculated as shown in Fig. 2. In the range of 100–500 kV, the curves at high pressure tend to

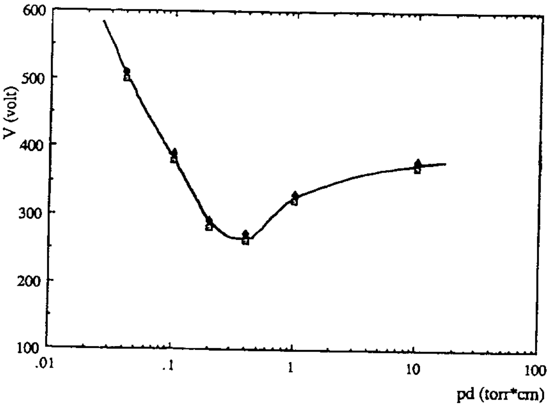

Fig. 1. A typical Paschen curve with numerical simulations.

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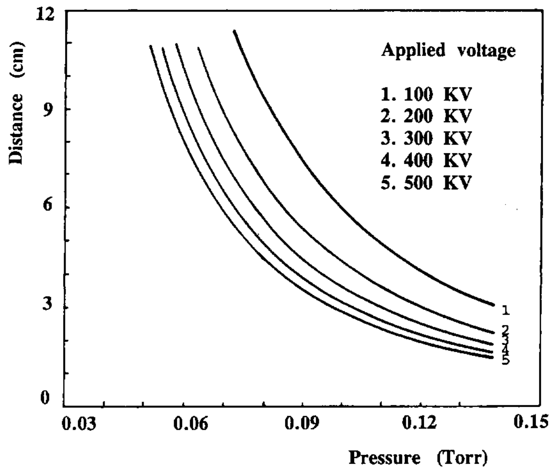

Fig. 2. The distance d (cm) is a function of the pressure p at a given voltage.

approximately 2 cm, while at the lower side of the pressure a reasonable distance should be 10 cm.

The experimental configuration of the pseudospark discharge is shown schematically in Fig. 3. The hollow cavity is a 3 cm diameter and 4.1 cm long cylindrical cavity. The discharge chamber consists of a planar cathode with a hollow cavity, sets of intermediate electrodes and insulators with a common channel, and a planar anode. The electrodes are made of brass and the insulators are of Plexiglas. The diameter of the channel is 3.2 mm and electrons generated in the hollow cathode region are accelerated through the channel to the extraction point on the anode side of the device. The anode–cathode gap distance is varied by employing a different number of intermediate electrode sets (each set is 10 mm thick).

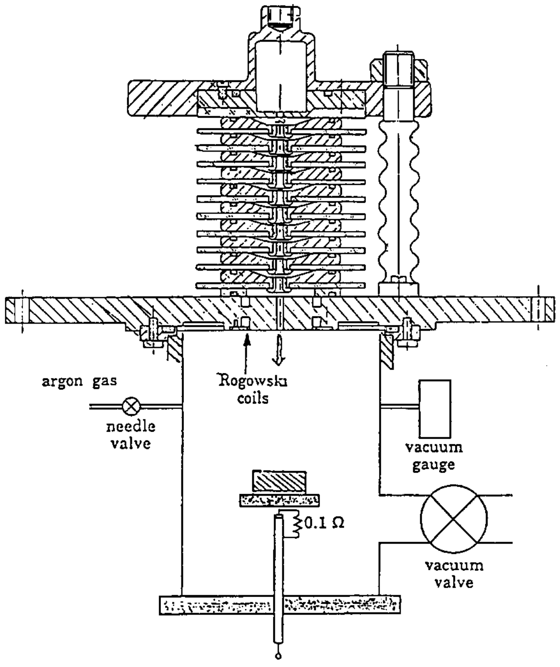

Fig. 3. The experimental configuration of the pseudospark discharge.

The mechanism of electron beam generation has been considered. The field escalation model can be used to describe the physical processes in intense pulsed electron beams and the multiple kinds of ion beams produced in the multilateral discharge chamber. The condition for the hollow cathode effect is written approximately as follows: $\phi p < 1$ Torr cm, where ϕ is the internal diameter of the hollow cathode.

The chamber contains a low-pressure gas-filling of typical 0.056 Torr. The gas pressure of the chamber is controlled by a Vacuum Auto Controller, with measuring and control range from 0.15 to 7.5×10^{-7} Torr. The accuracy of the auto controller is $\pm 1.5\%$ (full scale). The gas is filled by a piezo-electric needle valve, with maximum flow $> 2.25 \times 10^{-3}$ Torr cm^3/s.

When a high voltage pulse of 300–400 keV is applied between the anode and the cathode, a pseudospark discharge occurs (10–100 ns). A self-pinched electron beam is expected if the current exceeds some 10 A. Depending on the total current, the diameter of the electron beam at anode exit is expected to be between 0.1 and 0.5 mm.

A 63 cm long drift chamber was attached to the anode side to make room for diagnostics, including the emittance meter and the Faraday cup. A Rogowski coil was molded into the downstream side of the anode flange to monitor the electron beam current extracted through the anode hole. A Faraday cup was employed to measure the beam current at various axial positions. A pulse line accelerator which normally operates at 300–400 keV, 400–800 A, 40 ns was modified to produce a longer pulse duration of about 1 μs. The configuration is used by eliminating the output pulse forming switch and connecting the load to the output of the pulse transformer via a water coax section.

The hollow cathode effect occurring in and near the hollow cathode hole is responsible for electron beam generation in the pseudospark chamber operating in the left branch of Paschen curve.

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