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Investigations on Pseudospark-based Electron and Ion Beam Generation and Applications

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Introduction

The pseudospark discharge has undergone intensive studies with regard to its unusual and interesting discharge properties during last fifteen years. It has attracted significant attention from diverse fields such as pulsed-power switching, electron beam generation, free electron masers, ion beam generation, extreme-ultraviolet radiation sources, and microthrusters, etc. During a pseudospark discharge, low temperature plasma is formed as a copious source of electrons and ions and can be regarded as a low work function surface that facilitates electron or ion extraction by applying voltages of different polarity. This paper will present experiments and measurements of pseudospark-sourced electron and ion beams for accelerators. Pulsed electron beams with current intensities over 10^8 Am^{-2}, high brightness up to 10^{12}A m^{-2} rad^{-2} and emittance of tens of mm mrad were produced from a multi-gap pseudospark discharge. The transportation of the pseudospark electron beams is also investigated in order to produce high peak current, high quality, short (~100 picosecond) or long duration (2~100ns) high-brightness electron beam pulses.

Pseudospark electron beam investigation

During a pseudospark discharge, a low temperature plasma is formed as a copious source of electrons and can be regarded as a low work function surface that facilitates electron extraction. Initial study of electron beam production was carried out on a single-gap pseudospark system for a wide range of parameters, including cathode cavity length, cathode hole size, applied voltage, external capacitance and the inductance in the discharge circuit [1]. Higher-energy electron beam production, more suitable for high power microwave generation, was studied using a multi-gap pseudospark apparatus. Electron beam pulses of duration of tens of ns, current density (>10^8 Am^{-2}), brightness of up to 10^{12} Am^{-2}rad^{-2} and emittance of tens of mm mrad were measured from a pseudospark discharge [2]. A typical pseudospark electron beam trace is shown in Figure 1.

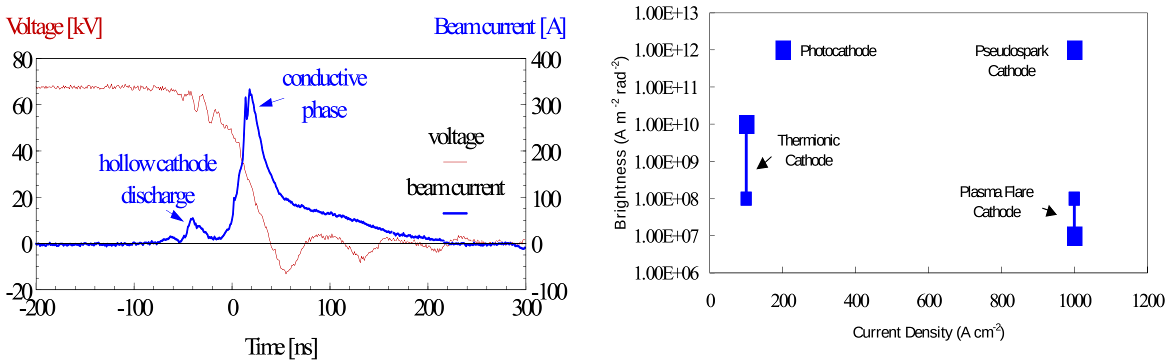

Figure 1: *Typical beam current and voltage traces from the 8-gap pseudospark discharge used for Cherenkov maser experiments and Brightness as a function of current density for various electron beam sources*

This beam has a higher combined current density and brightness compared to electron beams formed from any other known type of electron source (Figure 1). The CP beam had been transported in a plasma induced ion background and simultaneously accelerated by an accelerating potential [3].

Applications: Cherenkov Masers

The HCP beam was initially applied in a Cherenkov maser interaction [4,5]. The schematic setup of the initial pseudospark-based Cherenkov maser amplifier is shown in Figure 2. The main components of the experiment were the pseudospark-based electron beam source, the magnetic field for beam transport, the Cherenkov interaction region, electrical/beam diagnostics and the microwave launching/diagnostic system.

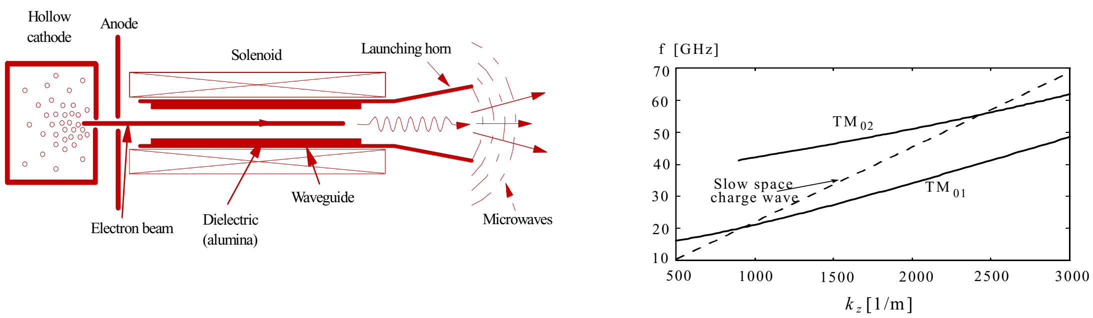

Figure 2: *Initial Cherenkov maser experiment outline and dispersion diagram*

The Cherenkov interaction cavity was made of a section of cylindrical waveguide, 9.5 mm in diameter, lined with a 1.75 mm thick layer of dielectric (alumina, $\varepsilon_r = 9.5$). The dielectric liner was used to slow down the normal electromagnetic modes in the cylindrical waveguide, allowing a resonant interaction to occur between a TM or HE waveguide mode and the rectilinear electron beam. Coherence of the generated radiation arises due to bunching of electrons in phase with respect to the electromagnetic wave. The calculated dispersion diagram in Figure 2 shows the waveguide modes and slow space charge mode of the electron beam of 75 kV, 10A [6]. It was found experimentally that significant microwave radiation was generated only when the dielectric was present in the interaction space, although if there was no dielectric in the cylindrical waveguide, then a very small background microwave output was detected. This demonstrated in conjunction with the observation that the microwave output signal was independent of the guide magnetic field over the range 0.13 to 0.26 T that the radiation from the experiment was due to the Cherenkov interaction mechanism. In addition, two components of the microwave pulse were observed corresponding to the two energy components of the electron beam during the pseudospark discharge breakdown. Another interesting result was the discovery that the small background signal was always present even without the guide B-field or dielectric lining in the waveguide. These results demonstrated that the microwave radiation grew from the background seed signal, which seemed to be from the pseudospark discharge itself.

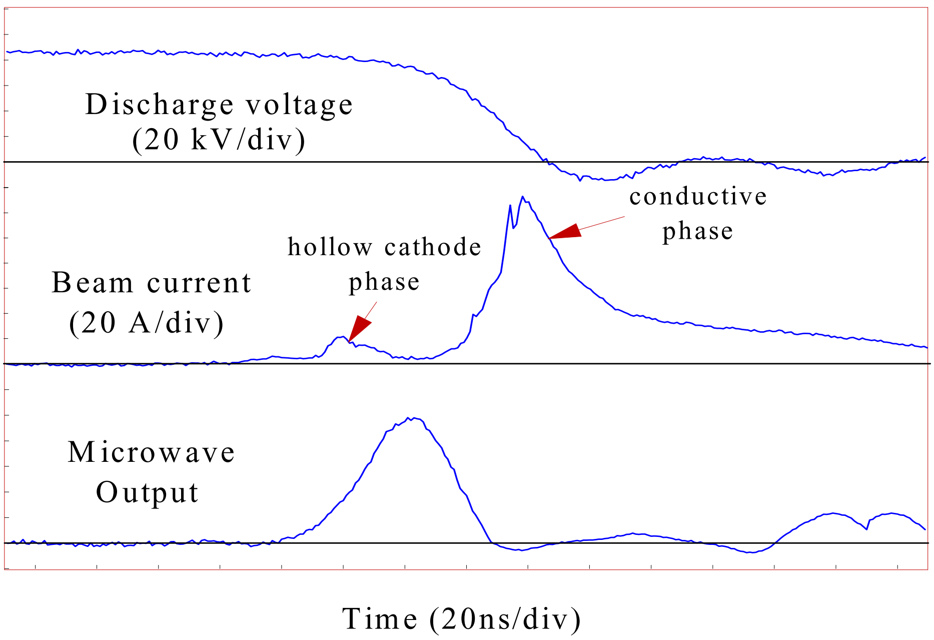

Figure 3: *Typical waveforms of pseudospark discharge voltage, the beam current and the microwave pulse*

The temporal profile of the microwave output radiation from the maser is shown in the lower part of Figure 3, time correlated with the electron-beam current and voltage profiles. The frequency range of the microwave radiation from the Cherenkov maser amplifier was measured to be between 25.5 and 28.6 GHz by applying different cut-off filters in the detection waveguide. The output antenna pattern associated with the azimuthal E-field component was measured to be independent of the presence of the dielectric and close to zero, confirming the operation of a TM mode. The measured pattern was in good agreement with the results from bench experiments in which a 27 GHz TM_{01} microwave signal was launched using the same antenna. This confirmed the operating mode to be TM_{01} mode. The peak power was measured to be 2 ± 0.2 kW. A relative spectral energy distribution was obtained and approximately 65% of the radiation was found to lie in the 25-28.6 GHz frequency band.

Summary and Ongoing Work

High brightness electron beams have been generated from a pseudospark discharge. The electron beam was applied in a Cherenkov interaction experiment with no input seed signal. Microwave radiation was generated by Cherenkov amplification of the background noise. The frequency of the microwave output after the Cherenkov maser interaction was measured to be 25.5-28.6GHz and the dominant mode was the TM_{01}. The peak power was 2 ± 0.2 kW. The experiment was simulated by a particle-in-cell (PIC) code, called MAGIC giving good agreement with previous analytical calculations. A future experiment will utilise an input wave from a 35GHz magnetron. Investigations are also underway to produce ion beams from the Pseudospark discharge.

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