A novel approach for high voltage glow discharge enhanced by a wire anode array

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An anode wire discharge utilized for electron generation in a novel donut-shaped plasma-based electron beam source for non-thermal applications is presented. The anode wire arrangement allows a highly efficient electron trapping, which greatly enhances the electron lifetime and thus enables ion generation at low pressures. Therefore, it is possible to sustain a plasma at low pressures in order to extract a homogeneous ion beam from the plasma. The ions are accelerated by the high voltage onto the cathode in order to release secondary electrons and to form the electron beam. In this presentation the first investigations and calculations on the anode wire discharge will be presented.

Introduction

Non-thermal treatment of surfaces by an electron beam is a widely used technology in the fields of e.g. medical product sterilization, curing lacquers, polymers modification, seeds disinfection and water treatment. Usually the electron sources provide a planar or a coaxial beam, so a complex combination of several sources is necessary when the desired application requires an all side treatment. For example, in the case of medical product sterilization two planar sources are combined in order to irradiate the entire 3D product surface. However, even in this particular case it is an enormous technical effort to ensure sterilization quality [1].

In order to overcome this challenge Fraunhofer FEP has developed a new kind of plasma cold cathode electron source, in which electrons are propagated in the radial direction towards the inner treatment area. Therefore, 3D surfaces and especially rotationally symmetric surfaces can be irradiated homogeneously.

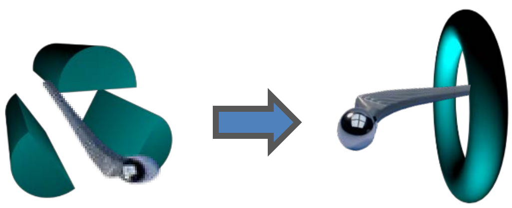

Fig 1: Conceptual design of EB medical products sterilization. Left, with linear sources a complex EB gun arrangement is necessary. Right, with a toroidal source all sides are equally treated.

Basic principle

Traditionally electrons are extracted from a hot filament due to thermionic emission. In contrast the physical process that drives and controls the electron emission in a cold cathode source is the ion bombardment from a high voltage glow discharge onto the cathode leading to secondary electron emission. In Fig. 2 a sketch of the presented cold cathode source is depicted.

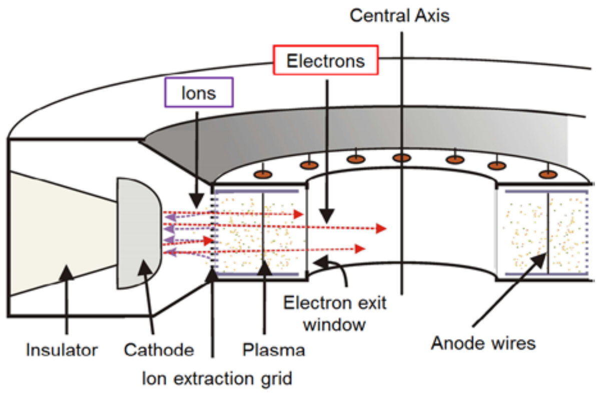

Fig 2: Novel cold cathode electron source conceptual design. An ion beam is extracted from the auxiliary gas discharge chamber and accelerated towards a cold cathode (120kV), from which the electron beam is released due to the ion impingement. Electrons are accelerated in the radial direction towards the centre. The beam can pass through the plasma with almost no energy loss due to negligible electron-Helium interaction. Then the extraction window (a 15µm Ti-foil) is reached and the electrons are transmitted towards the treatment zone at atmospheric pressure.

In order to extract a stable electron beam from a cold cathode with electron energies in the order of 120 keV it is necessary to work in a narrow pressure range. The operating region must be below the Cranberg criterion curve [2], if a higher voltage is applied there would be a vacuum breakdown. However, the Paschen curve also limits the working parameters, because if the pressure is too high plasma would be ignited between the cathode and the anode grid system. Therefore, the operating region is defined by a dark area in front of the cathode in which plasma cannot appear.

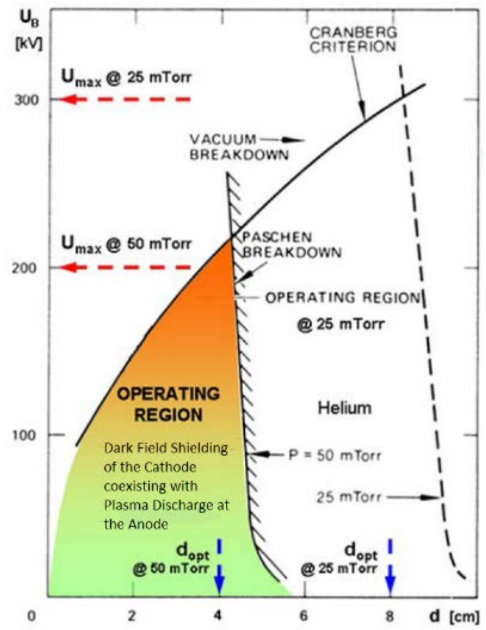

Fig 3: working pressure range (from [3]).

In order to fulfil this pressure constraint and to provide an ion source for secondary electron emission at the cathode, a wire anode glow discharge must be simultaneously burning inside a shielded plasma chamber. The geometry of this compartment is based on McClure [4], whose original design consists of an anode wire inside a cathode cylinder, with which pressures in the order of 10^{-2} Pa can be reached with deuterium as working gas. The novel configuration used in the toroidal beam source has 20 equidistant wires which are acting as anode potential and are radially installed in the plasma chamber. The novel source can ignite Helium at pressures as low as 1.5 Pa with breakdown voltage of 1 kV.

Selected results

The efficiency of this configuration is based on electron trapping in the electric field (see Fig 4). Their average lifetime is considerably enhanced due to electron orbits around the wires because of angular momentum conservation, and consequently, due to a higher collision rate ion production is increased.

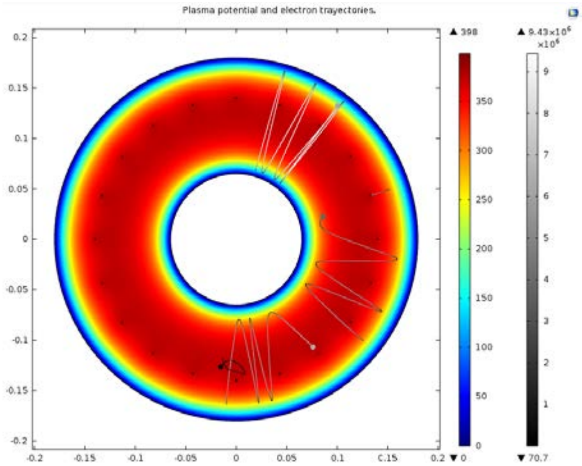

Fig. 4: Simulation of electron trajectories inside the plasma chamber simulated with the software COMSOL. Rainbow colours represents the plasma potential (V) and the greyscale is the particle velocity (m/s).

In figure 5 the calculated electron energy distribution function is depicted. It has been calculated with an ignited plasma as background potential and considering the electrons as particles. It can be seen that the most of the electrons are cold but there is a small fraction with energies above the helium ionisation energy of 26 eV [5]. The ionisation is performed by that small high energy tail.

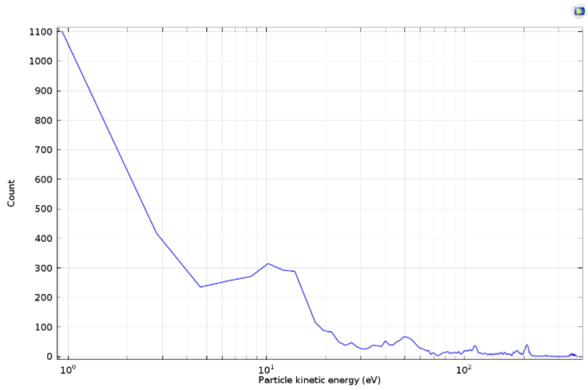

Fig 5: Calculated electron energy distribution.

This discharge concept has been tested and, although it is still in an early developing stage, Helium discharges can be stabilized at pressures in the order of 1.5 Pa (see Fig 6).

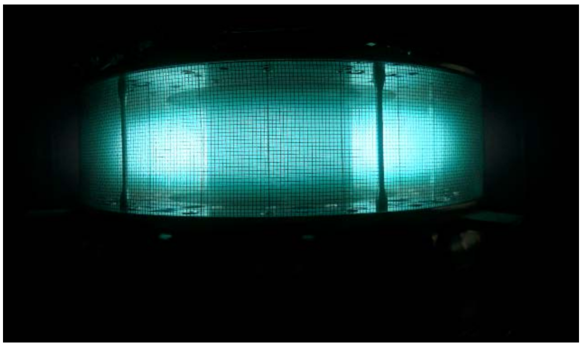

Fig. 6: wire-glow discharge, working parameters: p=1.5 Pa, I_D=81 mA and V_D=410 V.

In this contribution, the first investigations on the novel wire glow discharge plasma chamber will be reported.

References

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