# CHAPTER 1

# INTRODUCTION

The conventional method to produce electron beams usually involve either a very high voltage being applied across two electrodes (field effect) or a heated cathode (thermionic effect). In the case of the transient hollow cathode discharge, also known as the pseudospark discharge, the planar cathode in a discharge system is replaced by a cathode with a hollow structure, and operating at a low pressure environment. Because of its special geometry, a pre-breakdown phase occurs before the main discharge which leads to the generation of a collimated electron beam with high energy and high intensity.

The transient hollow cathode discharge is found to be able to produce electron beam at a lower charging voltage as compared with the conventional field effect electron beam source. The electron beam produced is self-focused and has high intensity. These interesting characteristics have attracted many researchers to work on this device.

## 1.1 The Transient Hollow Cathode Discharge (THCD)

The transient hollow cathode discharge is a discharge initiated across an anode and a hollow cathode operating at low pressure and at the left-hand branch of the Paschen curve. It was first observed by Christiansen *[J. Christiansen et al, 1979]*. He found that by using electrodes with holes at the centre, particle beams were collimated to flow through the axis of the electrodes even with low voltage of a few kilovolt.

A commonly used transient hollow cathode geometry is shown in Figure 1.1. The cathode has an opening on its axis leading into a hollow cathode region. When the voltage is applied between the electrodes, the electric field will build up from the hollow cathode region towards the centre of the anode. The electron beam is collimated and accelerated by this electric field.

In 1987, P. Choi and co-workers *[P. Choi et. al., 1987]* had done a research in the process of the pre-breakdown phase. It has been observed that a high-energy diffuse electron beam at low *pd* product of the order of 1 torr·mm in air with an electric field of 450V/mm without breakdown. At higher value of the *pd* product there is a clear transition to a second regime of beam formation which leads directly to the electrical breakdown of the gas. Eight years later, charge development and ionization growth in the pre-breakdown phase of the transient hollow cathode discharge has been further investigated by Favre and co-workers *[M. Favre et. al, 1995]*. Instead of air, they operated their system in three different gases, namely

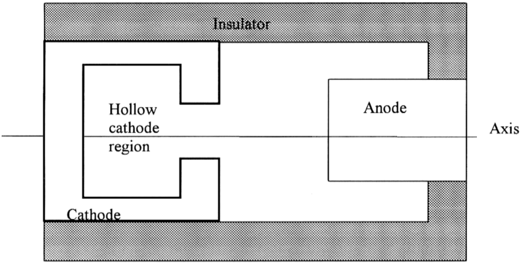

Figure 1.1 The basic design of the hollow cathode configuration.

hydrogen, nitrogen and argon. The pressure range is from 50 mtorr to 750 mtorr, with cathode apertures ranging from 1 mm to 5 mm diameter and the length of the hollow cathode ranging from 5 mm to 20 mm, with 10 cm electrode separation. The results show that increase in electron beam signal timed at the arrival of the virtual anode signal close to the cathode is faster in hydrogen than argon and nitrogen. With a large diameter aperture, the electron beam signal is observed to be enhanced. The data also suggest that the transient hollow cathode effect is not limited to discharge at low pressure but can also be observed at a pressure above the Paschen minimum. A statistical distribution regarding the pseudospark formation at low pressure was carried out based on the above experimental data *[P.Choi et al., 1995]*. The results show that the breakdown formation in a transient hollow cathode discharge can clearly be separated into three distinct regimes of ionization growth, they are 1) the initiation of ionization growth leading to the formation of a plasma region close to the anode, 2) the extension of this plasma region towards the cathode and 3) the ionization growth within the hollow cathode region under the much enhanced field as the anode potential is brought close to the cathode. Gastel and co-workers *[M. Gastel, et. al, 1995]* also found out that the pseudospark discharge starts with the ignition of a high voltage glow discharge along the discharge axis. During this phase high energetic ions are accelerated into the hollow cathode where they produce secondary electrons from the cathode surface. Their single gap system also shows that the intensities of the electron beam increases with increasing volume of the hollow cathode. Stetter and co-workers *[Michael Stetter, et. al., 1995]* have a similar explanation for the development of the pseudospark. According to their explanation, when the voltage was charged to a critical value, the Townsend discharge was initiated and subsequently the discharge developed into the hollow cathode phase.

The hollow cathode phase was a transient phase. An intense electron beam, which was formed during the super-emissive phase, will be released from the hollow cathode by the mechanism of field enhanced thermionic emission.

Instead of single gap system, J. Westheide *[J. Westheide, 1995]* had made a study on a multiple gap system with intermediate electrodes and insulators. The discharge was performed in argon or helium either in free-running or triggered mode. In this system, the electron beam energy for argon has been found to be much lower than that for helium, whereas the free-running mode produced a broadened beam as compared to the triggered mode. The high energy electron beam is found to be produced only at the beginning of the pseudospark discharge. Ramaswamy and co-workers *[K. Ramaswamy, et.al., 1994]* also concluded that the high-energy electrons in pseudospark phase are generated during the first 20-30 ns of the discharge. This results is in agreement with the Monte Carlo simulation by Pitchford *[L. C. Pitchford, 1995]*. According to Pitchford, two distinct energy components exist in the electron beam. The electrons in the high-energy component of the beam are those secondary electrons emitted from the cathode surfaces near the axis due to ion bombardment and accelerated in the sheaths and which arrived at the back surface of the anode without having experienced a collision. Electrons emitted from the positions inside the hollow cathode far from the axis contribute to the low energy component of the beam because they cannot exit the hollow cathode without undergoing collisions.

Further study of breakdown voltage characteristics of single gap and multiple gap pseudospark was done by Liu and co-workers *[C.J. Liu, et. al., 1995]*. For a single gap pseudospark, the breakdown voltage was observed to be a function of the product of the gas pressure ($p$) squared and the electrodes gap distance ($d$) and the diameter of the hollow cavity ($D$), $p^2dD$, when the relative size of the cavity is large, that is $d/D<3$. When $d/D>3$, the breakdown voltage is not affected by the cavity. It is a function of the product $pd$, similar to the Paschen's law. For the multiple gap pseudospark, however, the breakdown voltage is found to be only a function of the product $p^2dD$ that is practically the same as that of the single-gap case. Thus, it appears that the intermediate electrodes play almost no role in the breakdown mechanism.

Besides the experimental work discussed above, Mittag and co-workers *[K. Mittag et. al., 1990]* had proposed a numerical model to simulate the pre-breakdown phase in a transient hollow cathode discharge. In this model the continuity equations for electrons and ions were solved simultaneously with Poisson's equation as a function of time in a two-dimension axially symmetrical geometry. A swarm model based on the local-field approximation was applied. This model predicted that the plasma density in the hollow cathode region would grow exponentially in time due to the electrons impact ionization and photon emission releasing secondary electrons from the cathode surface by photoelectric effect. Subsequently these led to an emission of high-current density electron beam through a small diameter hollow cathode along the axis.

In the present study, the geometry as shown in Figure 1.2 will be investigated. The wall of the chamber becomes the anode and a hole is drilled at the axis of the cathode to form the hollow cathode region. This design is different from that shown in Figure 1.1. The influence of various parameters such as the volume of the hollow cathode and the pressure will be studied in this project.

## 1.2 Applications of The Transient Hollow Cathode Discharge

There are a lot of studies carried out on the transient hollow cathode discharge due to its wide range of applications. Its various discharge properties and characteristics can be applied for different purposes. For example, it has been demonstrated that the transient hollow cathode discharge electron beam can be used effectively for the triggering of the vacuum spark, replacing the conventional methods of using the sliding spark or high power laser *[C. S. Wong, et. al., 1995]*. This triggering method has greatly simplified the operation and reduced the cost of the vacuum spark device.

Recently, due to the capability in obtaining high current density in a very short duration, the application of the transient hollow cathode discharge as a high power switch has been demonstrated. Unlike thyratron and spark gap, which have the disadvantage of charge transfer and life time limitation respectively, the transient hollow cathode discharge has been demonstrated to achieve a total Coulomb transfer of more than 500 kC *[R. Tkotz et. al, 1995]* and a lifetime of more than $10^9$ discharges in medium power. Used as a high current closing switch *[E. A. Koltypin et. al., 1971]*, high current density with unheated cathode is attainable without the usual erosion associated with an arc, and, therefore, can have longer lifetime than spark gap under similar conditions.

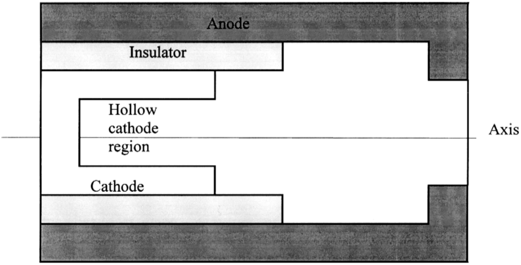

Figure 1.2 The hollow cathode configuration in this project.

Another application of the pseudospark-produced electron beam is in material processing *[R. Stark et. al,1995]*. The high power density of the electron beam is deposited only in a very thin layer and causes an explosion-like evaporation of the target material at the target surface. This effect may be utilized for surface hardening and thin film deposition of materials.

The demand for directed energy in science and engineering is increasing. Although the laser has been applied as directed energy for quite a long time, the high cost and the low energy conversion have retarded it being used commonly. A channel spark *[F. Hoffmann, et. al., 1992]*, which has a simple and low cost design, can produce a high efficiency directed energy carried by the electron beam to fulfil this demand. The channel spark consists of a THCD electron beam source and an electric accelerator tube made of glass. A system of several channel sparks arranged in parallel is capable of coating on an industrial scale large-surface substrates with any number of multicomponent substances. The energy of the channel spark electron beam which is concentrated in space and time can also be used to detect element with low atomic number in environment. As an example, phosphorus as pollutant in aerosols when hit by the electron beam can be identified by its fluorescence radiation.

## 1.3 The Outline Of This Thesis

This thesis is organized as follows:

Chapter 1 reviews briefly the history, the experimental and theoretical works done on the transient hollow cathode device.

Chapter 2 describes the experimental setup and the operational modes of the transient hollow cathode device studied in this project.

Chapter 3 describes the diagnostics and instrumentation techniques used in this project.

Chapter 4 focuses on the theoretical computation of the equipotential field and electric field line and also the experimental studies of the electron beam formation in the pre-breakdown phase. The pressure and the diameter of the hollow cathode are varied to study their effects on the electron beam formation. The electron beams energy is determined by measuring the emission electron beam target X-ray using the X-ray foil absorption technique.

Chapter 5 is the conclusion that summarizes the results in this project.