CHAPTER 1

INTRODUCTION

1.1 : The vacuum spark

In the early stages of vacuum spark research, the vacuum spark was proposed as a spectroscopic source in the extreme ultraviolet region *[Millikan, 1918]*. Later in the sixties, Händel *[1963]* used the vacuum spark device as a flash x-ray tube. Only in the late sixties it was discovered that in low inductance vacuum spark discharges, regions of micropinches are formed in which the state of matter approaches that in the stars *[Cohen et al., 1968]*.

Initially, research on the vacuum spark was motivated by the need for a laboratory source of x-ray spectra comparable to the stellar spectra *[Gol'ts et al., 1975] [Elton & Lie, 1972] [Feldman et. al., 1975] [Fraenkel & Schwob, 1972] [Aglitskii et al., 1986]*. Recently the possibility of using the pulsed x-ray from a vacuum spark discharge as an industrial source and for pumping laser system *[Finkenthal et. al., 1986]* have been proposed. Pulsed x-rays from laser produced plasmas have been used for time-resolved x-ray diffraction studies *[Lunney et. al., 1986] [Wark et. al., 1987]*. Since the x-rays produced from vacuum sparks are similar to those of the laser produced plasmas, the vacuum spark can also be used for this purpose.

The plasma formed in a vacuum spark discharge consists of ions and atoms of the electrode material. This types of plasmas are prolific emitters of x-ray. Sometimes the radiation is emitted in multiple bursts whose energies increase as the discharge current increases.

The x-ray sources have radii of 1.5 - 300 μm *[Antsiferov e. al., 1989]* and an axial dimension of 40 - 100 μm *[Welch et al., 1974] [Feldman et al., 1975]*. The electron temperature of the plasma ranges from 1 to 10 keV with electron densities of 10^{20} cm^{-3} to 10^{23} cm^{-3} *[Welch & Clothiaux, 1974] [Lee, 1975] [Negus & Peacock, 1979]*. Therefore, these x-ray sources are sometimes called 'plasma points' or 'hot spots'.

Various groups of researchers have studied the vacuum spark as a possible x-ray source. Wong et al. *[1989]* have shown the feasibility of such a system for contact radiography. A study of the vacuum spark as a reproducible x-ray source has been carried out *[Wong & Lee, 1984]*. It has also been shown that the charging voltage and anode-cathode separation strongly influence the characteristics of the x-ray emission.

Zver'kov et al. *[1987]* studied simultaneously the spectrum of the x-ray emission of a micropinch over a broad spectral range, the structure of the discharge for various anodes; and their dependence on the initial charging voltage and anode-cathode gap. It was found that the efficiency of the conversion of energy from the capacitor into energy of the x-radiation (in particular, soft x-rays) depends on the anode-cathode gap, similar to the observation reported by Wong & Lee *[1984]*.

Skowronek et al. *[1989]* had studied the characteristics of a low energy vacuum spark x-ray source and found it to be comparable to other more powerful and sophisticated devices *[Collins et al., 1986]*.

1.2 : Hot spot formation in a vacuum spark discharge

Over the years, many experimental and theoretical works have been carried out on the vacuum spark discharge. The details can be found in reviews by Korop et. al. *[1979]* and Koshelev & Pereira *[1991]*. The former reviewed works done during the seventies while the latter reviewed works up to 1990.

Various theories have been proposed to explain the formation of hot spots or micropinches in vacuum spark discharges. However, the most consistent model that can explain qualitatively and quantitatively the processes occurring in a vacuum spark discharge is the radiative collapse model proposed by Vikhrev et al. *[1982]*. The phenomenon of radiative collapse was first investigated in detail by Shearer *[1976]*, Vikhrev *[1978]* and Vikhrev & Gureev *[1978]*. The radiative collapse model explains that the formation of hot spots is the result of the contraction of a Z-pinch due to the outflow of plasma and radiative energy loss.

Another theory was proposed by Fukai & Clothiaux *[1974]* to explain the mechanism for the hard x-ray emission observed in the vacuum spark discharge. This mechanism was based on the hypothesis that in the process of sausage instability (m = 0) in a plasma pinch, the plasma could have very high resistivity due to the constriction and strong turbulence, so that the conduction current was virtually cut off. In such a case, strong electric fields should appear which could accelerate the electrons and ions to produce hard x-rays as energetic as 20 times the discharge potential.

Cilliers et al. *[1975]* also proposed that due to high transient voltages that arise from sudden interruption of current, pulsed electron beams were generated.

The interaction between the electron beams and the low temperature anode vapours or plasmas produce dense plasmas that emit x-radiation.

Negus & Peacock *[1979]* suggested that the formation of the hot spot may be due to a thermal instability in the beam, induced perhaps by shrinkage of the plasma column due to radiation cooling. They also suggested that the localisation of the initial plasma in the diode gap may be contributed by the explosion of micro-particles from the electrode.

Uhm & Lee *[1989]* developed a magnetic field diffusion theory to explain the high energy x-ray emission observed in the vacuum spark plasma. According to this model, the expansion of the plasma column from its pinch radius to a large radius would induce an intense electric field due to an abrupt change in the inductance. This field would accelerate the charged particles to high energy. The resultant plasma current is well collimated at the axis. In addition, the electron energy in this collimated flux can be easily more than 20 times the electrode voltage. This electron beam generates high energy x-radiation by interacting with the dense plasma.

Presently, the radiative collapse model is the most reasonable model that accounts for the formation of plasma points. In this model, the contraction occurs in two steps. First, the plasma column in a micropinch contracts to a radius of ~100 μm with low temperature (~eV) and density (~10^{19} cm^{-3}). Then the plasma column expands slightly followed by the outflow of plasma from the constriction. With the radius remaining nearly constant, the temperature increases. The second contraction occurs a few ns after the first, during which the radius drops to ~1-10 μm with an increase in the temperature (~keV) and density (~10^{24} cm^{-3}). The lifetime of the second contraction is $\sim 10^{-10}$ s and most of the emission occurs during this period. The high values of temperature and density lead to multiple ionization of the plasma ions. After the second contraction, the constriction region expands because of the anomalous Joule heating in it. Thus, this model can explain the high density (10^{23} - 10^{24} cm^{-3}), high temperature (~keV) and intense emission of radiation observed in vacuum spark discharges.

It can also explain the two types of plasma points observed *[Aglitskii, 1986] [Antsiferov, 1989]*. According to the radiative collapse theory, the first type which consists of a minute region ($\sim\leq 10$ μm) of ions stripped to the *K*-shell with extreme values of density (10^{23} - 10^{24} cm^{-3}) and temperature ($T_e \geq$ keV) is a short stage in the radiative collapse of a pinch. The second type which is an order of magnitude larger in size and two orders of magnitude smaller in density, emitting few (or no) resonance lines; is a plasma point that cannot achieve a full collapse due to insufficient radiation.

In summary, the radiative collapse model proposed by Vikhrev et. al *[1982]* explains that the formation of hot spots in a vacuum spark discharge is caused by a local contraction due to the plasma outflow from the neck of the sausage aided by large radiative energy losses.

1.3 : The outline of this thesis

In this chapter, a brief account of the experimental and theoretical work carried out in vacuum spark research is presented. In chapter 2, the vacuum spark system and triggering system used are described. The x-ray diagnostics and instrumentation are given in chapter 3. In chapter 4, a qualitative description of the effect of electrode configuration on the plasma x-ray emission is given. In chapter 5, the plasma parameters are measured and using these values the emitted x-ray spectrum and energy are calculated. A discussion of the experimental results and recommendations for future work are given in chapter 6.