Design & Development of Mini Dense Plasma Focus for Electronic Industry to Study Single Event Upset Phenomenon

Bachelors of Science in Electrical Engineering

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June 27, 2022

Design & Development of Mini Dense Plasma Focus for Electronic Industry to Study Single Event Upset Phenomenon

By

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A thesis submitted in partial fulfilment of the requirement for degree of

Bachelors of Science in Electrical Engineering

Supervisor: Dr. Syed Muhammad Zafar Iqbal

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June 27, 2022

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Any part of this thesis has not been submitted anywhere else for any other degree. This thesis is submitted to Department of Electrical Engineering, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan in partial fulfilment of the requirements for the degree of BS Electrical Engineering.

Supervisor: Dr. Syed Muhammad Zafar Iqbal Signature: ____________________

Co-Supervisor (If any): Signature: ____________________

External Examiner: Signature: ____________________

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Abstract

Advancement of technology in the semiconductor industry is dependent on cost-effective manufacturing of integrated circuits. Novel methods are currently being investigated for the limiting step, lithography, to cut costs and drive innovation.In 1995 An Lee diffusion model was developed and used to predict the expected peak diffusion times at various pressures and distances from the source plasma. The momentum cross-sections used in this model were derived using the method proposed by S.Lee. It's great in investigating the single event phenomenon will also be discuss in details in this thesis. A lot of work has been done on SEU which is future great application of DPF in industry to investigate this phenomenon in electronic devices.

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1. Project Introduction

1.1. History of Plasma Focus

The original concept of Dense Plasma Focus device was given by N.V. Filippov in 1954. He noticed the effect while working on early pinch machines in the Union of Soviet Socialist Republics (USSR). After giving the idea of DPF, many other scientist give ideas about this device but this device was first invented and made by J.W.Mather in 1960s. After this many other scientist continue working on this device and did different experiments on this device and use it for different purposes.
The basic design of this device derives from the z-pinch concept. Both the DPF and pinch devices use large electrical currents run through a gas to cause it to ionize into a plasma and then pinch down on itself to increase the density and temperature of the plasma.

1.2. Project Background of SEU

The original concept of Dense Plasma Focus device was given by N.V. Filippov in 1954. He noticed the effect while working on early pinch machines in the Union of Soviet Socialist Republics (USSR). After giving the idea of DPF, many other scientist give ideas about this device but this device was first invented and made by J.W.Mather in 1960s. After this many other scientist continue working on this device and did different experiments on this device and use it for different purposes. The basic design of this device derives from the z-pinch concept. Both the DPF and pinch devices use large electrical currents run through a gas to cause it to ionize into a plasma and then pinch down on itself to increase the density and temperature of the plasma. [24]

1.2.1. Previous Work of SEU

The work detailed is meant to show that ambipolar diffusion is the dominant mechanism for plasma transport of a high-density plasma (such as Z-pinch) traveling through ambient background. Previous work was done on the pinch debris and plasma characteristics has been carried out at the Center for Plasma-Material Interactions [?]. Some of these works have focused on the measurement of ion/neutral energies that emanate from the pinch.

Previous works used background pressures of helium, neon, and argon from a few mTorr to 22 mTorr of pressure. Compared to industrial systems that use over 1 Torr of hydrogen, this data in insufficient. It was unknown in early age how an EUV-capable plasma interacts in a highly-collisional regime as it expands into the chamber volume. Work was also done to determine if any secondary plasmas or sources of electrons were being measured, but again this was at a much lower pressure with different background gases.

In particular, EUV core plasma expansion, photoionization, ion impact ionization, and electron ionization to determine relevant contributions to peaks in the triple Langmuir probe traces. In This thesis, we perform similar calculations as a comparison to the reference. The majority of this main peak was attributed to the expanding EUV generating plasma from the pinch into the larger chamber. A back-calculation

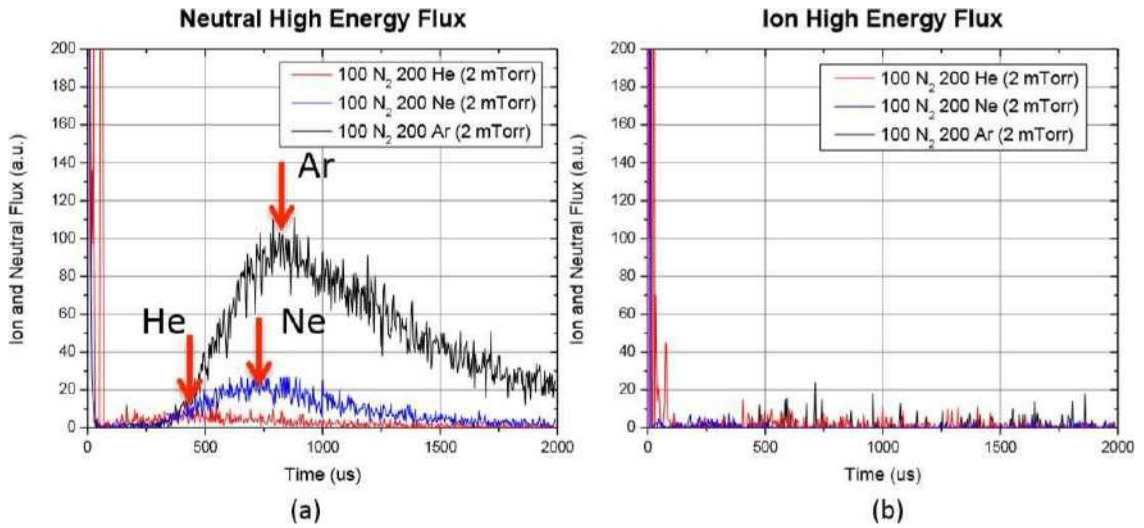

Figure 1.1: *Energetic flux measurements of neutrals (a) and ions(b). The particle flux out of the pinch with energies greater than 100 eV is mostly neutral with even 2 mTorr of background gas. These pinches were with N2 as the pinch gas and thus the highest peak for neutral flux is argon. A target mass similar to the incident mass means more efficient energy transfer during collisions[8].*

from the main chamber to the pinch using the measured main peak density lead to 1020 cm-3, right in the middle of the EUV generating regime 1019-21 cm-3. The author then took the first couple of peaks and did the same calculation and found 1021 cm-3, leading the experimenter to believe that the majority of the trace was just expansion of the EUV core plasma.

The photo-ionization, ion-impact and electron-impact contributions were then analyzed to ensure the previous conclusion was correct. Using photo-ionization cross sections from above figure, the following table was created to estimate the contributions. The contributions were two orders of magnitude less than what was

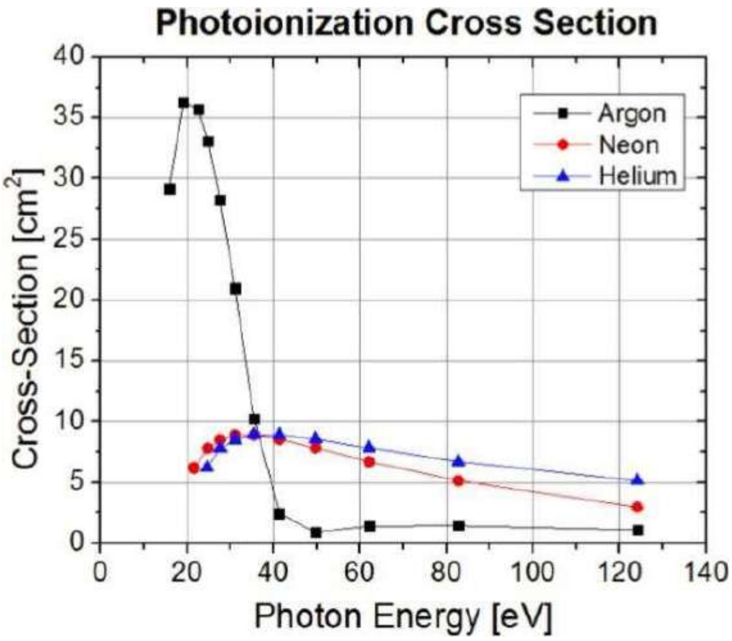

Figure 1.2: *The photo ionization of He, Ne, and Ar gas as a function of photon energy for the applicable DUV range of 10-125 eV.*

observed. Even at the highest pressure, 22 mTorr, using Ar buffer gas and N2 pinch gas the experimenter saw an order of magnitude higher peak than what can be attributed to photoionization.

Pressure [mTorr]	e/cm^3 @0.36 m	Buffer Gas Mass [AMU]	e/cm^3 @0.36 m	Pinch Gas Mass [AMU]	e/cm^3 @0.36 m
0.3	3.13E+10	4	1.00E+10	4	2.62E+11
2	1.04E+11	20	5.01E+10	20	3.02E+11
6	3.00E+11	40	1.04E+11	40	2.90E+11
12	6.00E+11				
22	1.15E+12				

Figure 1.3: *Estimated photoionization contributions to electron density for various gases and pressures. The densities are significantly smaller than the density observed with the TLP[9].*

Next he looks theion-impact ionization at as a possible source of density. Taking values measured with no buffer gas present in fig shown below the resulting ion-impact ionization densities were significantly lower than what was recorded. A source of error is that there were no ion-atom ionization cross-sections found for any gas other than Ar. It is thus impossible to compare ionization to charge transfer or momentum transfer cross sections. An attempt at this was made later in the fast ion theory.

The photo-electric effect was found to be a very small contribution (1E4 cm-3 too low). This was also evaluated in the photon theory and a similar conclusion was found. Finally, the scientist in the previous work did not believe that electron contributions were large enough to warrant a calculation. While at pressures below 22 mTorr this assumption may be correct. The fast electron theory shows that pressures close to what is used in industry the electron contribution cannot be ignored.

By looking other works at the plasma itself to understand where the high energy ions are created. An illustration of this phenomenon is given in Figure shown below, albeit with hydrogen impurities added to illustrate how low atomic mass impurities can act as a ”buffer” and reduce the electric field the main pinch gas, in this case xenon, sees. When fast electrons leave the pinch, they leave behind a large number of ions. While the ions can be accelerated by the ambipolar electric field that develops, another phenomenon called the ”coulomb explosion” occurs. The pinch ions are bunched and feels strong coulombic repulsion that helps accelerate them to keV energies in an extremely short amount of time. The previous work helps to inform the current work regarding high energy ion and electron transport.

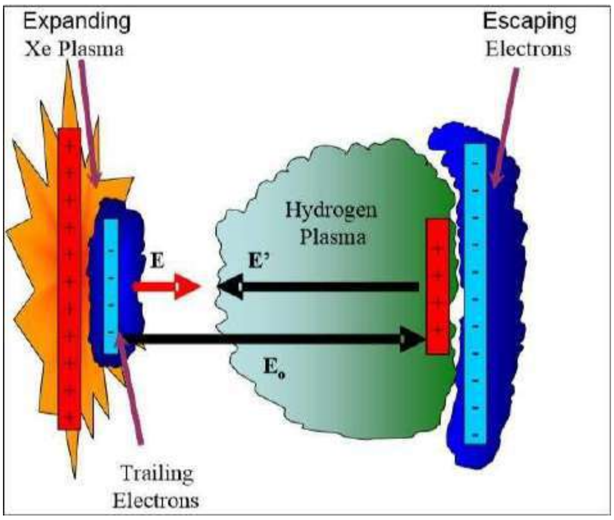

Figure 1.4: *Depiction of the acceleration process the pinch plasma undergoes once it expands from the initial pinch volume. The electrons escape first drawing any light ions, in this case hydrogen, forward. The trailing electrons from the bulk plasma are the accelerated by these high energy ions. Finally, the bulk ions are pulled by the trailing electrons. If there were no hydrogen/light ions present in the pinch, the ions would accelerate using the E0*

1.2.2. Present Work of SEU

The goal of this industry is to determine the main mechanism behind EUV plasma transport in industrial machines. This goal is achieved by using an XTS 13-35 Z-pinch as the EUV plasma source attached to the XCEED diagnostic chamber. Triple Langmuir probe measurements are taken at different axial positions and pressures to properly measure the pinch expansion and behavior as a result of collisions. Relevance of various secondary plasma formation mechanisms at industrial pressures will be discussed and analyzed.

A theoretical model is developed for ambipolar diffusion, a mixture of gas species and the forward scattering nature of the high energy particles that emanate from the Z- pinch. The outputs of model are diffusion times associated with the bulk plasma peaks. These times will be compared with the experimentally measured peak arrival times (transport time to the probes). Finally, conclusions will be drawn as to the major contributors to the plasma transport at various pressures and the implications for industry.

1.3. Project Objective

Specimens of materials for prospective use in chambers of nuclear fusion reactors with inertial plasma confinement, namely, W, ODS steels, Eurofer 97 steel, a number of ceramics, etc., have been irradiated by dense plasma focus devices and a laser in the Q-switched mode of operation with a wide range of parameters, including some that noticeably exceeded those expected in reactors. By means of 1-ns laser interferometry and neutron measurements, the characteristics of plasma streams and fast ion beams, as well as the dynamics of their interaction with solid-state targets, have been investigated. 3D profilometry, optical and scanning electron microscopy, atomic emission spectroscopy, X-ray elemental and structural analyses, and precise weighing of specimens before and after irradiation have provided data on the roughening threshold and the susceptibility to damage of the materials under investigation. Analysis of the results, together with numerical modeling, has revealed the important role of shock waves in the damage processes. It has been shown that a so-called integral damage factor may be used only within restricted ranges of the irradiation parameters. It has also been found that in the irradiation regime with well-developed gasdynamic motion of secondary plasma, the overall amount of radiation energy is spent preferentially either on removing large masses of cool matter from the material surface or on heating a small amount of plasma to high temperature (and, consequently, imparting to it a high velocity), depending on the power flux density and characteristics of the pulsed irradiation.

1.4. Main Objective

The goal of this research is to design and develop the prototype DPF device for the study of single event upset (SEU) phenomenon.
The main objective of this project is to design & develop a DPF device using ANASYS software. The sub-objectives of this project are as under:

- To use Ansys Software for the design of DPF device.
- To develop a mini-DPF device having electrodes of different materials.
- To configure HV pulsed discharge to the designed DPF device.
- To test the designed DPF device for SEU applications.

1.5. Sub Objective

Intense bursts of X-rays and charged particles are emitted, as are nuclear fusion neutrons, when operated in deuterium. There is ongoing research that demonstrates potential applications as a soft X-rays source for next generation microelectronics lithography, surface machining, pulse X-ray and neutron source for medical and security inspection application and materials modification among others.

1.6. Problem Statement

The Dense Plasma Focus (DPF) is a device attached with the pulsed discharged system to study high voltage discharge behaviour between two electrodes using different gases. The DPF device has a great interest in the free generation of electricity in electrical engineering for many decades. The DPF devices with different electrode configurations and geometries have been used to study its efficiency and operation considered a promising solution for green energy. The use of different gases produces different electron densities (Ne) and ions (Ni) including nuclear particles, mostly neutrons which are its important parameters. Some peculiar characteristics of the DPF device such as the yield of neutrons might have a promising scope in the single event upset (SEU) phenomenon that happens due to the radiation effect. The radiation phenomenon is considered the cause of Soft Errors, TID & DD Effects in electronic devices such as SRAM, DRAM, SSD, Power MOSFETs & Diodes. DPF Radiation testing could also be used to probe the reliability of these devices. The DPF device is a quite safe nuclear source that has great potential in the electronic industry for SEU applications.

1.7. Project Scope

This device is clean energy source and by using different material and gases we can obtained different rays in one device. But other nuclear devices are specialized for for emitting one or two nuclear rays at a time.
So this DPF device have many chances to used in industries at large level in future.

1.8. Motivation

Motivation of this project is that this device is useful for making of nuclear rays because other nuclear radiations production devices are difficult to handle and lot of care and parameters are required to control those devices. Nuclear radiation are very dangerous and effect life. people face different deceases in area where these nuclear radiations are present. Also handling of radiations is very difficult task.

Because these radiations travel to long distance. The power plants which produce these nuclear radiations buried the nuclear waste in earth to prevent the bad effects of the radiations.

The DPF device is useful because we can control this machine easily and operate as we want. Also this device control the radiations because when we want to produce the nuclear radiations we run the machine and produced the radiations we want and then stop the machine to stop the production of radiations.

2. Literature Review

2.1. What is Plasma

Plasma electrons, ions and neutral particles are ripped away from the atoms is superheated matter (hot gas) that consist of the forming an ionized gas. Plasma is fourth state of matter. The plasma is either made by providing high voltage or providing high temperature to gas. Every gas has its on plasma state depending upon their properties and characteristics.

Plasma is an ionized gas and its existence as the fourth state of matter was first recognized by Sir William Crookes in 1879. Later, the word ”PLASMA” was first used to ionized gases in 1929 by an American chemist and physicist Dr. Irving Langmuir who had his accomplishment extended from surface chemistry to clouds. Plasma in the space and in the stars around them comprises over 99.9% of the observable universe. The best example is sun which is real plasma [6].

Molecules are held in place and arranged in a regular pattern in solids. In liquids, molecules flow easily and assume the container shape and in gases, molecules are free and are far apart. When more energy injects into the gas, some atoms may lose their electrons and some molecules may acquire extra electrons, forming a mixture of electrons, positively, negatively charged and neutral particles, called ”plasma”.

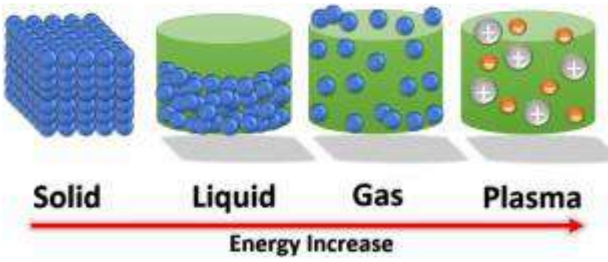

Figure 2.1: *The four states of matter at different stages of energy: solid, liquid, gas, and plasma*

2.2. Hot Plasma

Plasma which has very high temperature like stars temperature is called hot plasma. The hot plasmas, have temperatures from few to several KeV making matter to be in almost fully-ionized state.By definition, the high energy density plasmas, refers to the plasmas which are heated and compressed to extreme energy densities, exceeding $10^{11} J/m^3$ This plasma produced is very hot and have temperature ranging from 5000K to on words. The best example of hot plasma is sun whose surface temperature is 6000 C^0. The plasmas which have energy densities in the range of $(1 - 10) \times 10^{10} J/m^3$ are also now classified as high energy density plasmas and hence the DPF devices fall in this category.

2.3. Types of Dense Plasma Focus

A dense plasma focus (DPF) is a type of plasma generating system originally developed as a fusion power device starting in the early 1960s. The system demonstrated scaling laws that suggested it would not be useful in the commercial power role, and since the 1980s it has been used primarily as a fusion teaching system, and as a source of neutran and X-rays.

There are different of dense plasma focus. These types are given by different scientist and have different shapes and working purpose and they produce different types of plasma and rays.
Different types of dense plasma focuses are given below:

- Mather Type Plasma Focus
- Flippov Type Plasma Focus
- Spherical Plasma Focus

2.4. Mather Type Plasma Focus

The Mather type is a modification of the coaxial plasma gun operated at a higher fill pressure. It consists of two coaxial electrodes separated by an insulator sleeve, placed in a vacuum chamber. The Filippov machine, on the other hand, was developed as a modification of the Z-pinch to hide the insulator zone from the pinch region and prevent re-strikes caused by radiation from the plasma.
Mather type Plasma Focus device is made of two coaxial electrodes which are in rods forms. The electrodes are mounted on conducted plates which are of same metal as of rods and a insulating material is also placed between these plates to prevent to prevent short circuit. These coaxial electrodes are places in chamber which is air tight are vacuum chamber. These electrodes are immersed in a low-pressure gas and the electrodes are connected to a capacitor bank and this capacitor bank is connected to high voltages. After applying the high voltages to capacitor bank the electrodes emit electrons and produced plasma sheath and a beam which is used for testing purpose

This mather type DPF device was first invented and made by J.W.Mather in 1960s. He work on principle of N.V. Filippov, who noticed the effect of pinch and other radiation effect while working on the pinch machines in USSR. J.W.Mather worked on his concept and made a DPF device A famous scientist S.Lee made is shown a

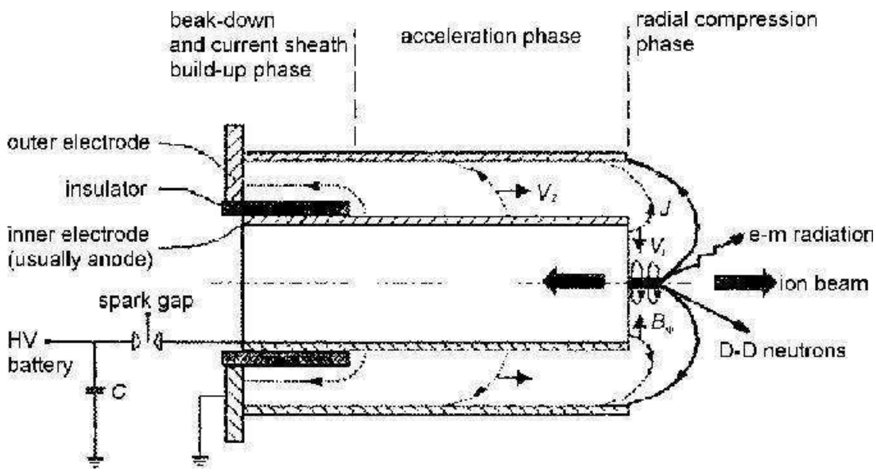

Figure 2.2: *old mather type DPF device made by J.W.Mather[20]*

Mather type DPF device model and made its calculations which is shown below.

2.5. Single Event Phenomenon

A single-event upset (SEU) is a change of state caused by one single ionizing particle like (ions, electrons, photons...) striking a sensitive node in a micro-electronic device, such as in microprocessor, semiconductor memories or power transistor. This state changes is a result of the free charge created by ionization into or close

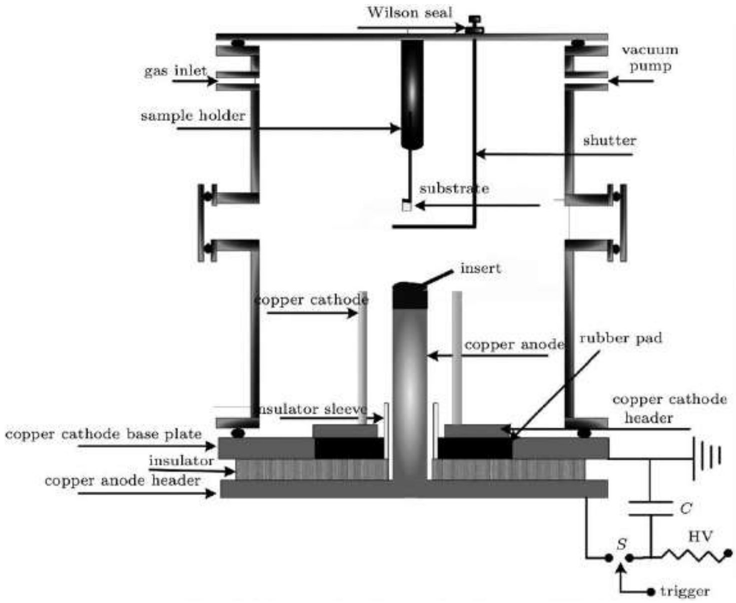

Figure 2.3: *DPF Device model proposed by S.Lee [11]*

to an important node of a logic element (e.g. memory ”bit”). The error in device output caused as a result of the strike is called an SEU or soft error.

The SEU is not considered permanently damaging to the circuits of transistors functionality unlike the case of single-event latch up (SEL), single-event gate rapture (SEGR) or single-event burnout (SEB). These are all examples described above of a general class of radiation effects in electronic devices called single-event effects(SEEs).

Single-event upsets phenomenons were first described during above-ground nuclear testing from 1954 to 1957, when many deviation were observed in electronic monitoring equipment. During the 1960s, further problems were observed in space electronics , although this was so difficult to separate soft failures from other forms of interference. Hughes satellite experienced an upset where the communication with the satellite was lost for 96 seconds and then recaptured in 1972. Scientists Dr. Edward C. Smith, Al Holman and Dr. Dan Binder explained the deviation as a single-event upset (SEU) and published their first SEU paper in the IEEE Transactions on Nuclear Science journal in 1975.[2] Timothy C. May and M.H. Woods described the first evidence of soft errors from alpha particles in packaging materials in 1978. James Ziegler of IBM along with W. Lanford of Yale, first described the mechanism whereby a sea-level cosmic rays could cause a single event upset in electronics in 1979.[17]

Terrestrial SEU arises due to cosmic particles colliding with atoms in the atmosphere, which creates cascades or showers of neutrons and protons, which in turn may interact with electronic circuits. At deep sub-micron geometries, this effects semiconductor devices in the atmosphere.

High-energy ionizing particles exist as part of the natural background, referred to as Galactic Cosmic Rays (GSR) in space,. Sloar particles event and high-energy protons trapped in the Earth's megnetosphere (Van Allen radiation belts) exacerbate this problem. High energies associated with this phenomenon in the space particle environment generally render increased spacecraft shielding useless in terms of eliminating SEU and catastrophic single-event phenomena (e.g. destructive latch up). Secondary atmospheric neutron particles are generated by cosmic rays can also have sufficiently high energy for producing SEUs in electronics on aircraft flights over the poles or at high altitude. Small amounts of radioactive elements in chip packages also lead to SEUs.

2.6. Application of DPF for SEP

The mini-DPF device would be tested for SEU applications by capturing X-ray images of PCB patterns

3. Methodology

3.1. Project Framework

A way of optimizing the machine is to choose the dimensions of the electrodes, both length and diameters, and the operational pressure in relation to the characteristics of the energy source. Moreover, the current should be at its maximum when the plasma sheath moves from the base, in the case of Mather DPF, to the top of the inner electrode along the z-axis (axial direction). It is at such instance that a filament of hot and dense plasma is formed in front of the inner electrode and is at its maximum compression.

We will use the Mather type DPF device for testing the SEU whose construction and workin principle is given below.

3.1.1. Design of Mather Type DPF Device

The mather type DPF device was first invented by J.W.Mather in 1960s. He work on principle of N.V. Filippov, who noticed the effect of pinch and other radiation effect while working on the pinch machines in USSR. J.W.Mather worked on his concept and made a DPF device.

The main parts of Mather type DPF device are given below.

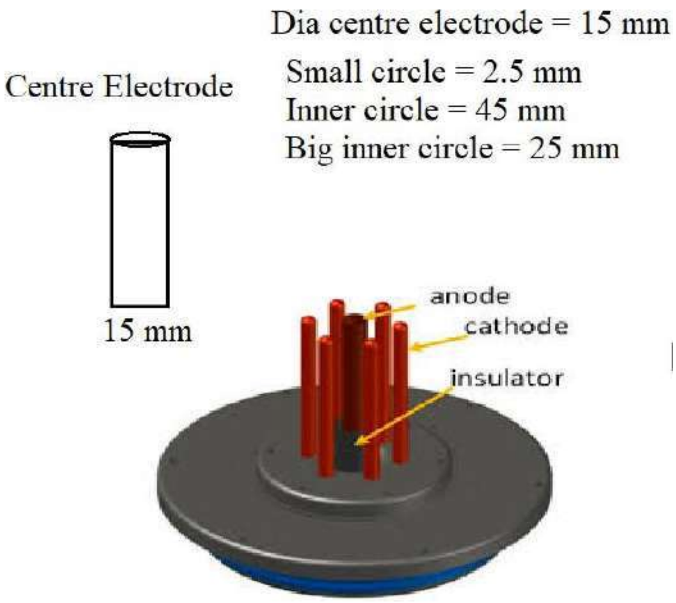

Figure 3.1: prototype copper design of Dense plasma focus

- Two copper rods Electrodes i.e Cathode & Hollow Anode
- Electrode Plates for mounting the Rod electrodes
- Insulator for separation of electrode plates
- Capacitor bank
- Substrate on which beam strikes after generation
- High Voltage Cables
- High Voltages
- Spark gap
- Gas

Descrption

Mather type Plasma Focus device is made of two coaxial electrodes which are in rods forms. The electrodes are mounted on conducted plates which are of same metal as of rods and a insulating material is also placed between these plates to prevent to prevent short circuit between two electrodes. These coaxial electrodes are places in chamber which is air tight are vacuum chamber. These electrodes are immersed in a low-pressure gas and the electrodes are connected to a capacitor bank through a transmission line typically via a spark gap which acts as a fast switch. Electrodes are connected to transmission line because voltages given to them are very high and commercial can not bear the pressure of voltages. We give voltages to these plates through a capacitor bank. A spark gap is also keep between capacitor bank and cathode plate. This spark gap acts as a switch. The energy stored in capacitor bank when spark gap is open switch. As we charge the capacitor to desired value then we less the distance between spheres through computer. The dielectric is air between the sphere gap. When capacitors are fully charged then by closing the decreasing the distance the between them air breakdown and a path developed between these electrodes and switch will be closed. The energy stored in capacitor bank is given to electrodes. These electrodes emit electrons due to high energy. These electrons ionize the gas molecules and made ions. The gas when ionized consists of positive, negative and neutral ions. A portion of this energy is converted into plasma energy during the rapid collapse of the sheath beyond the anode tip. From anode tip a beam is generated which strikes to substrate.

3.2. AutoCAD Design of DPF

We made the design for our DPF device on AutoCAD first to make the prototype model. We adjust the different parameters to make the design on AutoCAD.

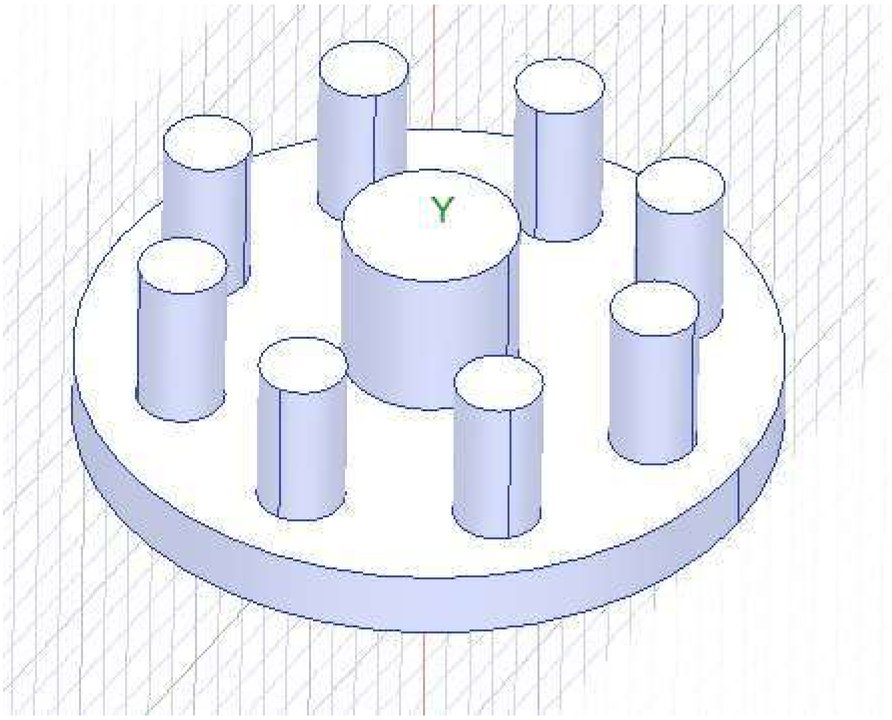

Figure 3.2: *AutoCAD 3D design for prototype DPF device*

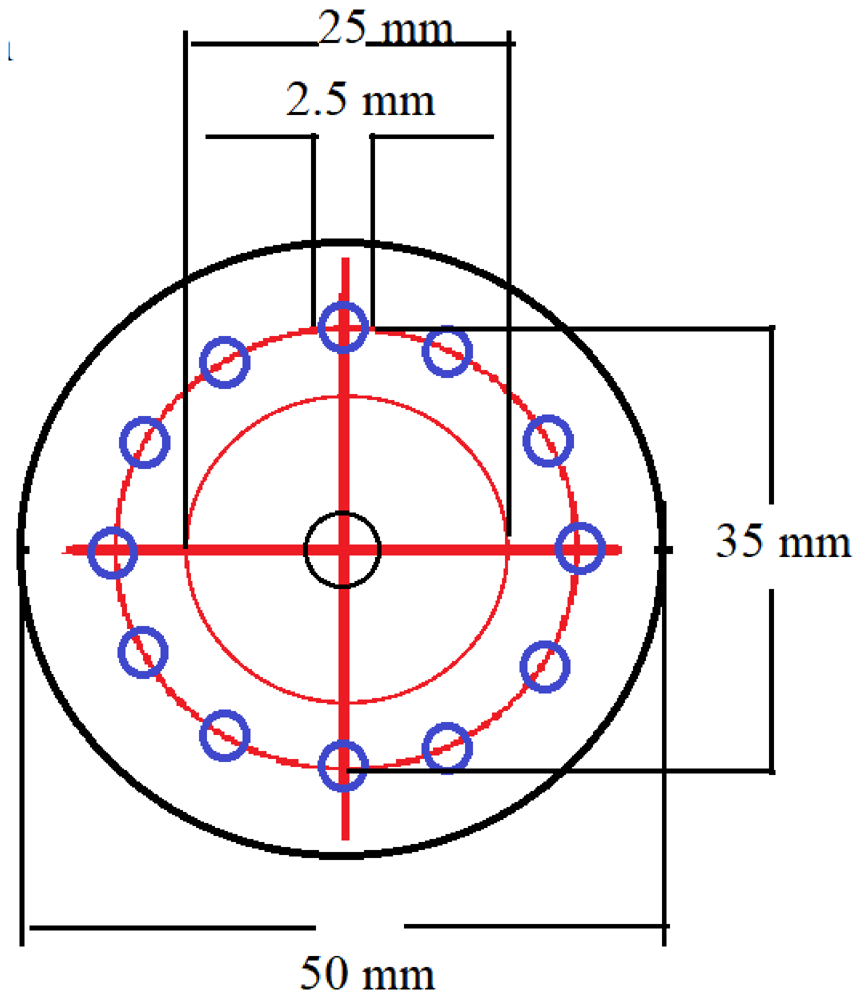

Figure 3.3: *AutoCAD 2D design for prototype DPF device*

3.3. Experimental Approach

3.3.1. Simulation Study of DPF

We made model of DPF on software suggested by supervisor. This software is ANSYS Maxwell. This software is developed by ANSYS.Inc.

3.3.2. Introduction to Ansys MAxwell

Ansys Maxwell is an EM field solver for electric machines, transformers, wireless charging, permanent magnet latches, actuators and other electro mechanical devices. It solves static, frequency-domain and time-varying magnetic and electric fields.

We use Mxwell 3D for making the prototype design of DPF device. What is Maxwell 3D? Maxwell 3D allows for the simulation and analysis of high-performance electromagnetic and electromechanical components common to automotive, military/aerospace, and industrial applications.

3.3.3. DPF Model in Ansys Maxwell

We first made a model on AutoCAD and then import this design to Ansys Maxwell and then applied other parameters, voltages and electric field and check the variations.

Parameters used for the prototype design of DPF are given below:

- Material Used: Copper
- Cathod each Rod diameter: 10mm
- Anode Rod diameter: 20mm

- Anode type: Hollow
- Voltages apllied: 2000V

After applying the voltages and by applying electric field to the model, the resulting models and shapes made shown below:
After applying mesh to model the resulting shape of model is show below:

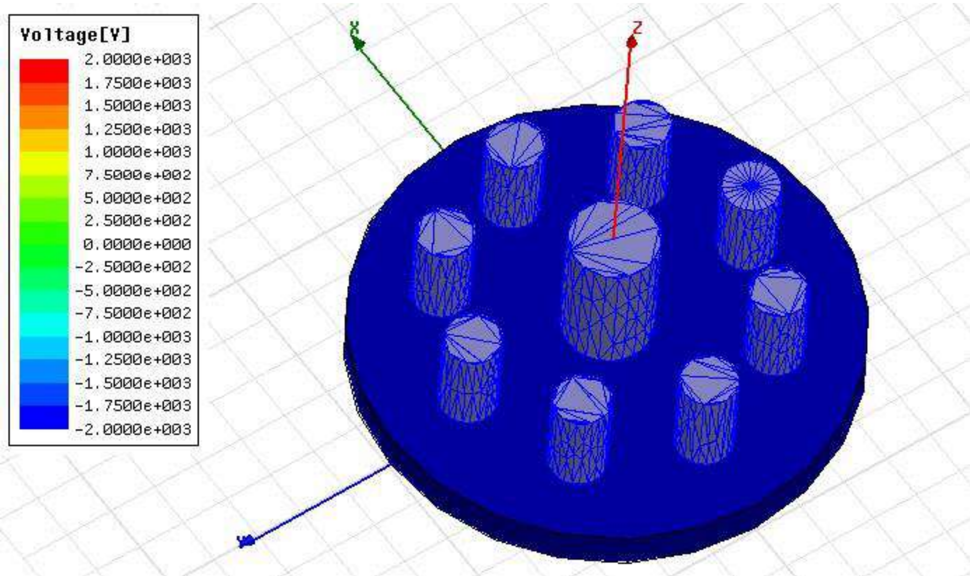

Figure 3.4: *After applying mesh to model*

When run the model in software then the current sheath made and lift upward due to magnetic force is shown below in 3.12:
The sheath at the start is very thin and difficult to see because process was started as shown in fig 3.12 above but as process continues the current sheath more visible because more gas is ionized by electrons of cathode as shown in below fig 3.13:

Now sheath is more visible in figure below and lift upward between electrodes due to magnetic force JxB. The bands in column in the fig at side is shown that how

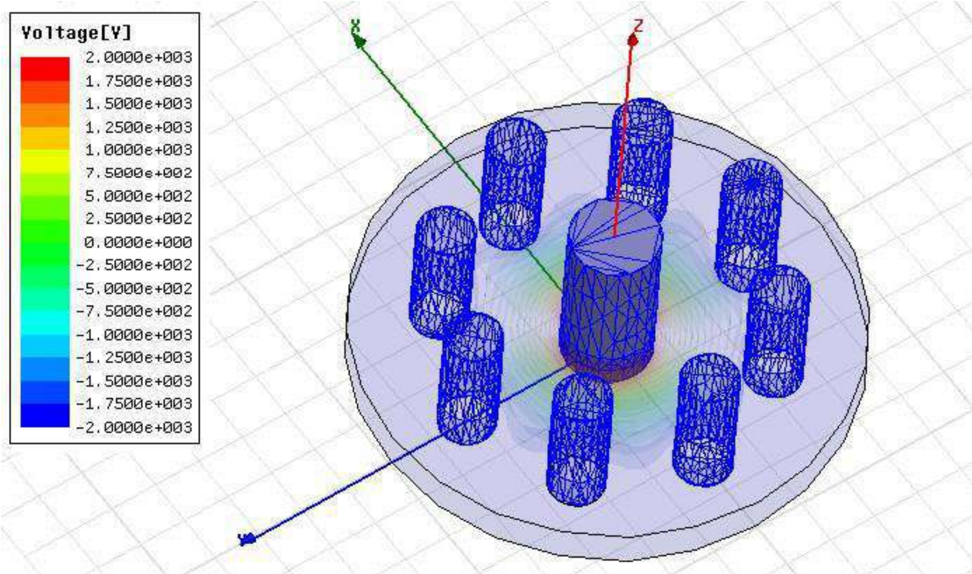

Figure 3.5: *Current sheath made between cathode rods and anode rod*

much voltages are applied at which place and the model shows the areas where voltage intensity applied either low or high. That the show in fig 3.14.

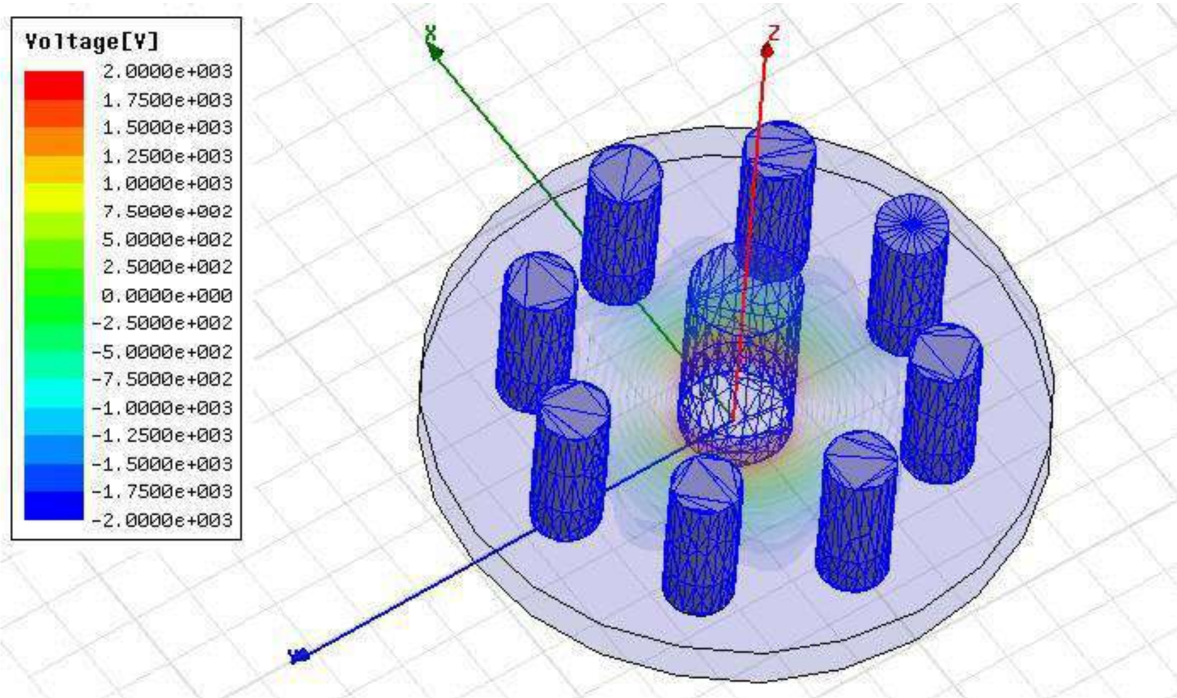

Figure 3.6: *Current sheath is more visible than first one*

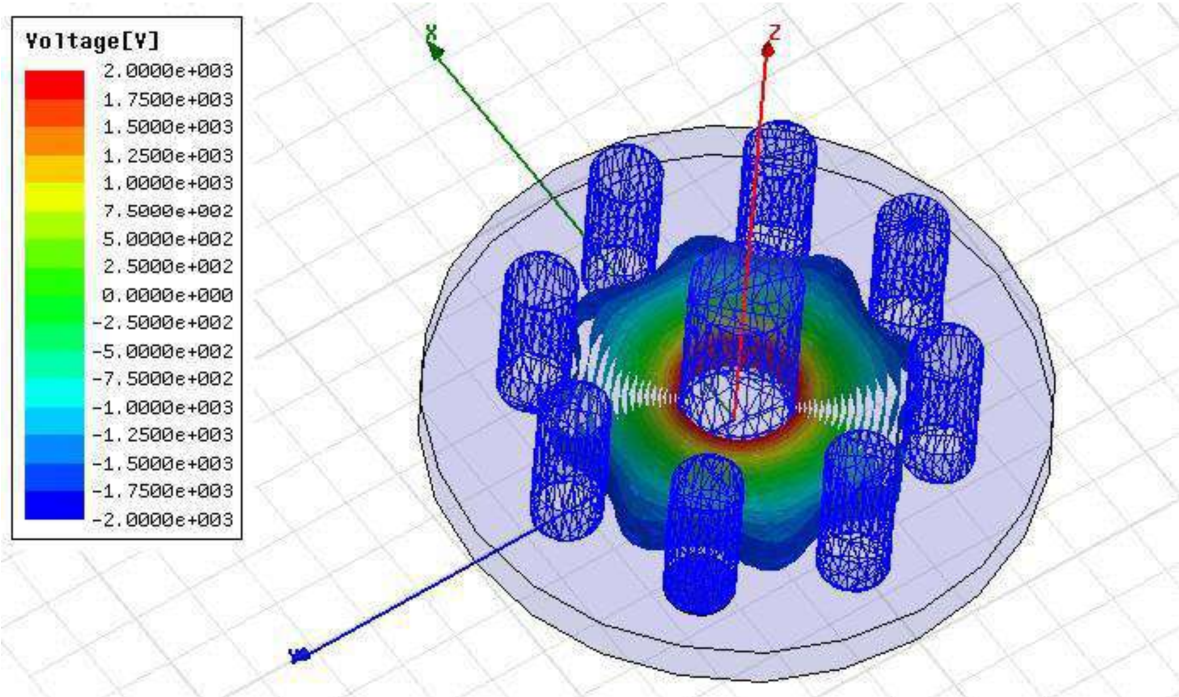

Figure 3.7: *Current sheath is lidt upward to anode to make a beam due to magnetic force JxB*

4. Results & Discussion

4.1. Results Numerical Lee Model Method

In order to evaluate the performance of the UofS-I DPF device, the experimental waveforms are compared with the Lee model current trace. The Lee model worksheet has been configured for the UofS-I DPF machine with known capacitance, inductance, electrode's dimensions, and the operating parameters, which are presented in fig below.

	A	B	C	D	E	F
1	Plasma Focus Computation: 5 Phase Model by S Lee: RADPFV5.15de.c					
2	I. Axial Phase	II. Radial Inward Shock		III. Radial Reflected Shock		IV. Slow Co
3	Device:					
4	Lo	Co	b	a	zo	ro mOhm
5	143	5	4.5	1.5	5	18
6	massf	currf	massfr	currfr	Model Parameters	
7	0.046	0.7	0.31	0.7		
8	Vo	Po	MW	A	At-1 mol-2	Operational
9	20	0.2	40	18	1	Parameters

Figure 4.1: *The model and operational parameters of the UofS-I DPF encoded onto the Lee code excel file for simulation and computation: The first two rows in the box are the DPF geometrical and electrical circuit parameters, the next two are the fitting and model parameters, and the last two are the operating parameters*

The following parameters are used: Capacitor inductance $L_0 = 143nH$, capacitor bank capacitance $C_0 = 5\mu F$, cathode radius b = 4.5 cm, anode radius a = 1.5 cm, anode length z_0 = 5 cm, and capacitor resistance $r_0 = 18m\Omega$.

Figure 5.2 shows the short-circuit current waveform of the device obtained from a Pearson Rogowski coil. The period and the frequency of the current waveform are measured to be T = 5.3 μs and f = 188 kHz, respectively. Consequently, the frequency of the waveform is used to calculate the static inductance, L_0, based on the known capacitance. The decaying envelope of the oscillations in the plot can be used to calculate the resistance in the circuit, but that is not a main concern for the circuit analysis or the Lee model. Furthermore, the Lee code is also used to find the

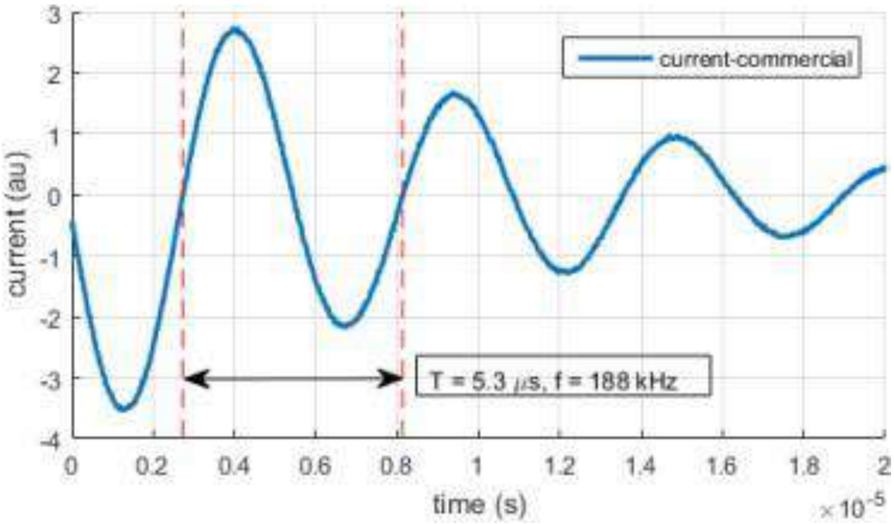

Figure 4.2: *A short-circuit RLC current waveform signal of the UofS-I DPF measured using a Rogowski coil (solid blue), with a recorded and measured time period of around 5.3 μ s and a frequency of 188 kHz calculated from the zeroes of the sinusoid (vertical dashed red)*

optimal operation conditions. Figure 5.3 shows several current traces computed from the Lee code. The current waveforms are plotted as a function of time and charging voltage ranging from 15 to 25 kV with a fixed operating pressure of 150 mTorr of argon gas.

It is very important to stress that the plasma focus current waveform is significantly distorted from the unloaded damped sinusoidal waveform of the RLC circuit discharge. Such distortions are mainly due to the electrodynamic effects of the motion of the plasma, particularly the axial and radial dynamics, as well as the SXR emission of the plasma. It is also good to note that the dynamic resistance caused by the motion of the plasma in the radial phase dominates and causes the current dip in the current trace, as can be seen in Fig. 5.3

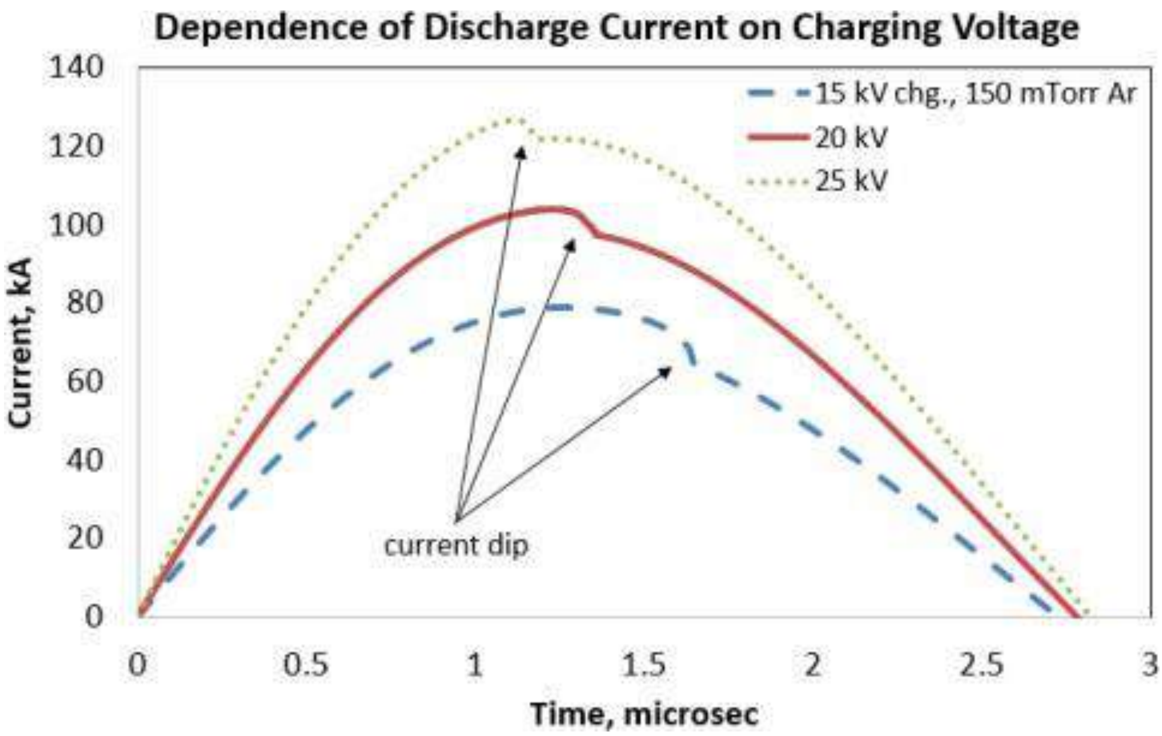

Figure 4.3: *Calculated current waveforms at various charging voltages: 15 kV (dashed blue), 20 kV (solid red), and 25 kV (dotted green) at a fixed operating pressure of 150 mTorr of argon gas using the Lee code. An increase in current and a time shift of the current drop to the left, is evident due to an increase in charging voltage.*

Figure 5.3 also shows how the current dip shifts to an earlier time when the charging voltage is increased, as well as increasing the discharge current (both at a fixed operating pressure of 150 mTorr). This is because of the faster motion of the current sheath at larger charging voltage and discharge current during the axial phase due to a larger JxB force. At 15 kV, the pinch occurs well after the current peak, which is not preferred.

This is to maximize the stored inductive energy in the DPF head which, in turn, is converted to the energy in the pinched plasma. Thus, if one sets the operating pressure to 150 mTorr of argon gas, one can deduce from Fig. 5.3 that a charging voltage of 20 kV is optimal that has a pinch time at 1.3 μs. Likewise, Fig.5.4 shows the shifting effects of the pinch time caused by varying the operating pressure ranging from 100 to 300 mTorr (with a fixed charging voltage of 20 kV). It is apparent that the current drop is shifted to an earlier time as the pressure is decreased. Thus, if one operates at a fixed charging voltage of 20 kV, the optimal operating pressure in argon gas must be around 150 mTorr, where the current drop occurs at the current peak.

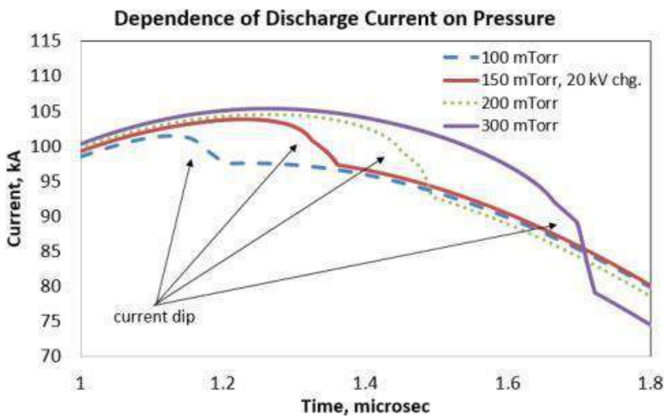

Figure 4.4: *Calculated current waveforms at various operating pressures: 100 mTorr (dashed blue), 150 mTorr (solid red), 200 mTorr (dotted green) and 300 mTorr (solid violet) of argon gas at a fixed charging voltage of 20 kV using the Lee code. A time shift of the current drop to the left is evident as the pressure is decreased.*

The Lee code provides rich information on the plasma dynamics based only on the critical experimental current waveform fitted with the computed current waveform. The simulation provides information on the plasma radius and speed in the radial phase, the pinch time and duration, the plasma temperature, the tube voltage, and the radiation power, just to name a few. An example of a good fitting in the Lee code can bee seen in Fig. 5.5. The fitting is obtained by varying the model parameters (mass and current factors for the axial and radial phases).

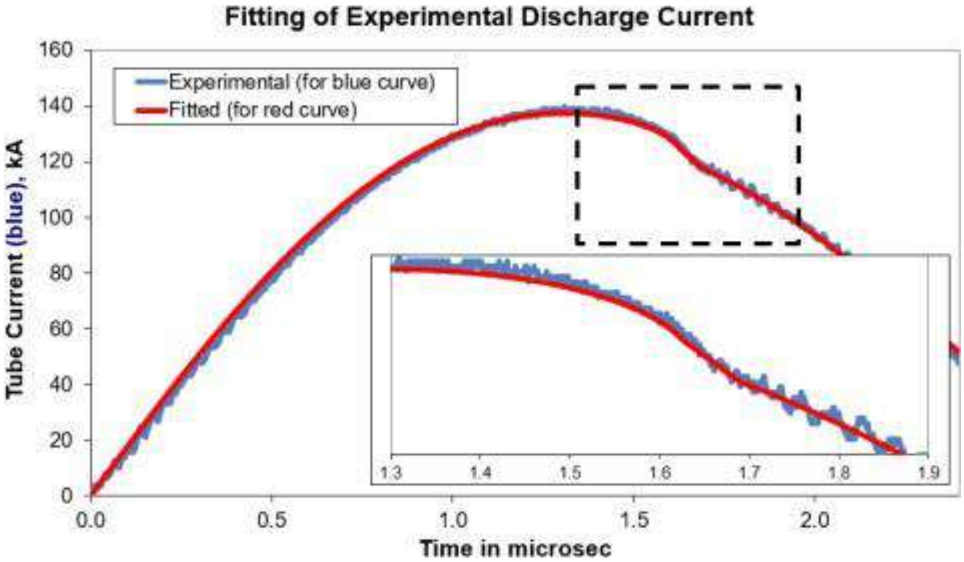

Figure 4.5: *Comparison between the experimental (blue) and computed (red) discharge current waveforms. The fitting is nearly perfect, and both shows that the pinch phase starts at around 1.5 μs*

Figure 5.6 below shows the computed current trace as well as the anode voltage, and showing the current dip at the current peak. The radial phase starts at 1.275 μs with a duration of 0.218 μ s, and the duration of the pinch is 19.0 ns. It is good to point out that the end of the axial phase, which is the start of the radial phase, does not occur at the apparent current dip, but slightly earlier. In fact, the Lee code expects that there is no distinct indication on the current trace that precisely marks the start of the radial phase[10]. The end of the axial hase likely occurs when the current trace starts to plateau, right before the current dips.

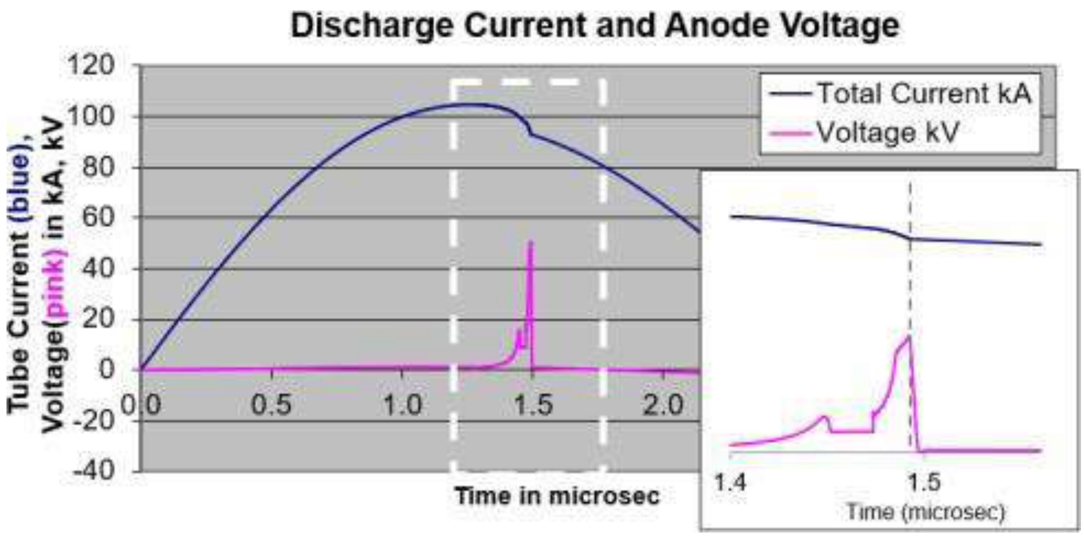

Figure 4.6: *The computed discharge current waveform (blue) and the anode voltage (pink) from the Lee code, showing the pinch effect corresponding to the peak of the voltage and the end of the current dip*

Figure 5.7 below shows the axial position and speed of the plasma sheath. The peak axial speed is also calculated to be 6.4 cm/μs. Expressing such value as 64 km/s gives an idea of how fast the speeds are in a DPF. Likewise, since it is in strong shock wave speeds, it can give n idea of the temperature by the conversion of a high kinetic energy to high temperature. The kinetic energy of argon ions at this speed can reach up to a 100 eV, or a temperature of around a million Kelvin.

The gap in Fig 5.7 (between 1.25 μs and 1.5 μs) indicates that the plasma sheath has shifted its trajectory from the axial to the radial inward direction.

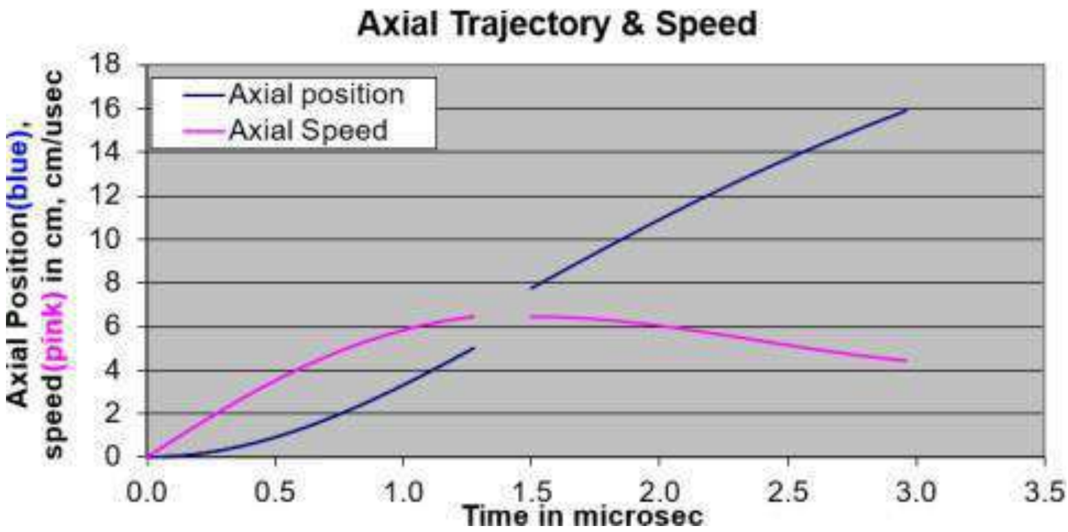

Figure 4.7: *The computed axial plasma position (in blue) and the speed (in pink) in the axial trajectory, with a peak axial speed of 6.4 cm/μs. The gap in the curves indicate that the plasma trajectory is in the radial direction.*

4.2. Modern Trends

In modern trends, DPF device is used for the checking of Single Event Upset phenomenon in electronic devices. If devices are placed in area where nuclear radiations are in large amount then these electrons devices are effected by these radiations. The internal circuit of those devices may either damage or these devices are completely fail. To avoid this situation, industries check that how much radiations an electronic device can bear so by the help of DPF device. After checking these devices they sell their goods to people or markets.

Nuclear areas may be of areas where nuclear items are present in earth or space where satellites sent for different experiments. In space different types of nuclear or other radiations present. In satellites, electronic devices are present to operate the internal system. When these satellites went to space, these satellites are subjected to different radiation and got damage. To prevent this, electronic devices also tested by DPF.

5. Conclusion

5.1. Modern Trends of DPF & Future Work

In modern trends, DPF device is used for the checking of Single Event Upset phenomenon in electronic devices. If devices are placed in area where nuclear radiations are in large amount then these electrons devices are effected by these radiations. The internal circuit of those devices may either damage or these devices are completely fail. To avoid this situation, industries check that how much radiations an electronic device can bear so by the help of DPF device. After checking these devices they sell their goods to people or markets.

Nuclear areas may be of areas where nuclear items are present in earth or space where satellites sent for different experiments. In space different types of nuclear or other radiations present. In satellites, electronic devices are present to operate the internal system. When these satellites went to space, these satellites are subjected to different radiation and got damage. To prevent this, electronic devices also tested by DPF.

A. Appendix

A.1. Sustainable Development Goals (SDGs)

The Sustainable Development Goals or Global Goals are a collection of 17 interlinked global goals designed to be a ”blueprint to achieve a better and more sustainable future for all”. The SDGs were set up in 2015 by the United Nations General Assembly and is intended to be achieved by 2030.
The goals achieved in our project are described below

A.1.1. GOAL 1: Affordable and Clean Energy:

Our project follow the rule of affordable and clean energy. The environment provides a series of renewable and non-renewable energy sources i.e. solar, wind, hydropower, geothermal, biofuels, natural gas, coal, petroleum, uranium.

A.1.2. GOAL 2: Decent Work and Economic Growth:

Our project follow the rule of decent work and economic growth. Economic growth should be a positive force for the whole planet. That is why our financial progress creates decent and fulfilling jobs while not harming the environment. We can sale it a proper rate so that every industry can afford it easily.

A.1.3. GOAL 3: Industry, Innovation and Infrastructure:

Our project follow the rule of Industry, Innovation and Infrastructure. Industrialization drives economic growth, creates job opportunities and thereby reduces income poverty. Innovation advances the technological capabilities of industrial sectors and prompts the development of new skills. Information about targets and progress can be found on the official SDG website.

A.1.4. GOAL 4: No Hazardous Effect using DPF for SEU:

Our project follow the rule of no hazardous effect on environment. This machine has no affect on environment when use because no smoke or hazardous radiations are produce during action.

A.1.5. GOAL 5: Use in Electronic Industry:

Our project also achieve this SDG goal. This device is use in electronic industry to test the electronics devices so that during working devices work properly and their abilities do not effect due to radiation effects. Due to testing, electronic devices work for long time.

A.2. Complex Engineering Problem Attributes

A.2.1. Problem Identification

Depth of knowledge required:

The Dense Plasma Focus is device used generate the dense plasma when high voltages are applied to electrodes (cathode and anode) through a capacitor bank. This device is very useful in future to make the different nuclear radiations like alpha rays, beta rays, gamma rays, X-rays etc. depending upon the materials and gases used in chamber. This device is easily to control because rays produced in this device are in chamber and doesn't escape out. A special part of these rays or radiation used for useful purpose. Other nuclear devices are very difficult to handle and special measurements are made to control them. The radiations produced in those devices are uncontrolled at some instant and escape out of the device. Other difficulty is that we can't control the reaction of such nuclear devices. While in DPF device reaction is controlled because reaction occurred when voltages are provided to electrode and gas ionized. In the absence of voltages, gas will not ionized and reaction will not occur and in that ways radiations will not produce. We can produced a beam of electrons and X-rays so that we can take benefit of all radiations produced by ionization of gas. We can also control the intensity of radiations produced in ionization of gas by using low voltage or different materials. So we a deep knowledge about this device and its parameters to use it correctly for useful purpose. It has a great advantage in electronic industry to study the single event upset phenomenon in electronic components or devices. When these electronic components or devices are installed in the area where radiations are in very large intensity then these electronic devices are subjected to those radiations and get effected. Before installing, those devices are tested through DPF device to study how much intensity of radiations these device can bear. So if intensity is much greater then a electronic device bearing capacity then special measurements are made to overcome these radiations.

A.2.2. Select Appropriate Technique and Equipment / Tools

Range of conflicting requirements:

(a) Safety Measurement:

Safety of yourself is most important in doing the experiment. DPF takes very high voltages to operate so it is important that safety measurements must be taken before using this device or before testing. Do not touch the body of DPF device when testing is in process otherwise it is hazard for health and may cause death or damage of tissues. Keep a safe distance from the device so that your health safe.

(b) Protection from Radiations:

When DPF device is operated, different types of radiation emitted from this device. These radiation may be x-rays, gamma rays, beta rays or alpha rays. These all are health hazard for humans. If these radiation subjected to human, then it can damage the tissue and also cause paralysis to human body. So it is important to place this device in chamber which can absorb these dangerous radiations.

(c) Uses of Substrate:

Always use a substrate in front of DPF device's anode. When a beam of electrons generated at anode then it should strike at substrate. The substrate of that material that can bear the beam intensity. If substrate is not placed in front of beam then it will strike the body front of it and thus damaged the front body. So it is important to place a substrate.

(d) Sphere Gap:

Always connect a sphere gap with high voltage. By using spark gap, we can control the supply of voltages applied to device.

Depth of analysis required:

We have complete information of equipment used in that experiment and should know their parameters. We should make complete analysis of DPF device when performed experiment. We can help through different websites and articles from google to calibrate our results and their parameters. Calculations should be made as correct as possible so that errors have minimum.

A.2.3. Implement the Relevant Standards / Procedures

Familiarity of issues:

We should complete familiar about the issue or problem due to which we perform the experiment. In our project issue is to in vestige the single event upset phenomenon in electronic devices due to which when electronic devices are subject to a nuclear radiations are damaged are their efficiency to perform working become low. Either their performance will low due SEUP or their internal circuit will damage. So we have to check their bear capacity that how much radiations this device can bear at a time.

Extent of applicable codes:

We should the know ethics that are used to perform this project experiment. We should adopt the codes which are universally applicable and not assumed by self.

- Device is cost effective

- Device can be used easily with some proper measurements.
- Source of green energy (have no effect on environment).
- Reaction is controllable.

Interdependence:

- We divided the work among our team members and work according to the Gantt chart we proposed at the time of Defense.
- We proposed project also depend on the number of users and the area where it can be implemented
- We did the simulation of DPF device on software suggested by supervisor, the designing of converters and the according to the Gantt chart and we completed our project in the given deadline and we also updated out respected supervisor about the weekly progress of the project.

A.2.4. Analysis and Results

Extent of stakeholder involvement and level of conflicting requirements:

- If someone wants to own our project, he should provide us the required details for the implementation of project in the society.
- We cannot give our proposed idea to the stakeholder and cannot share any kind of algorithm that will work for the power sharing between the houses.
- We can install the system in the society according to the instructions of the stakeholder.

Consequences:

Our project Maps the Goal-7 of SDGs. As in our project we provide a reliable and sustainable and modern green energy source which is free from environmental effects like greenhouse effect. it is also affordable for the industries to install it and test their electronic devices. By using this device industries can avoid the damaging of electronic devices due to radiations. Our DPF device is reliable.

Bibliography

[1] Institute for plasma focus studies.

[2] Single-event upset.

[3] LL Alves. The ist-lisbon database on lxcat. In *Journal of Physics: Conference Series*, volume 565, page 012007. IOP Publishing, 2014.

[4] Robert C Amme and John F McIlwain. Charge-exchange cross sections for argon ions in h2 and d2 below 1 kev. *The Journal of Chemical Physics*, 45(4):1224–1227, 1966.

[5] H Bruzzone and D Grondona. Magnetic probe measurements of the initial phase in a plasma focus device. *Plasma physics and controlled fusion*, 39(9):1315, 1997.

[6] Souvik Das. Brief introduction to plasma. 07 2019.

[7] Letitia P Davies. The photo-electric properties of some metals in the soft x-ray region. *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character*, 119(783):543–552, 1928.

[8] Sporre John R Curreli Davide Shchelkanov Ivan A Elg, Daniel T. Magnetic debris mitigation system for extreme ultraviolet sources. *Journal of Micro/Nanolithography MEMS and MOEMS*, 14:18, 2015.

[9] Sporre John R Curreli Davide Shchelkanov Ivan A Elg, Daniel T. Magnetic debris mitigation system for extreme ultraviolet sources. *Journal of Micro/Nanolithography MEMS and MOEMS*, 14:18, 2015.

[10] P Gautam and R Khanal. Introduction to numerical experiment on plasma focus using lee model code. *Himalayan Physics*, 5:137–141, 2014.

[11] Tousif Hussain, Riaz Ahmad, Zeshan Umar, and Ali Hussnain. Synthesis of tin/a-si3n4 thin film by using a mather type dense plasma focus system. *Chinese Physics B*, 22:055204, 05 2013.

[12] S. Lee. A sequential plasma focus. *IEEE Transactions on Plasma Science*, 19(5):912–919, 1991.

[13] Sing Lee. Plasma focus radiative model: Review of the lee model code. *Journal of Fusion Energy*, 33(4):319–335, 2014.

[14] Sing Lee and Sor Heoh Saw. Numerical experiments providing new insights into plasma focus fusion devices. *Energies*, 3(4):711–737, 2010.

[15] Michael A Lieberman and Alan J Lichtenberg. *Principles of plasma discharges and materials processing*. John Wiley & Sons, 2005.

[16] JW Mather. 15. dense plasma focus. In *Methods in Experimental Physics*, volume 9, pages 187–249. Elsevier, 1971.

[17] A.S. Oates. 7 - reliability of silicon integrated circuits. In Jonathan Swingler, editor, *Reliability Characterisation of Electrical and Electronic Systems*, pages 115–141. Woodhead Publishing, Oxford, 2015.

[18] Gianluca Panici. Investigation of plasma diffusion in extreme ultraviolet lithography sources. 2019.

[19] AV Phelps. The diffusion of charged particles in collisional plasmas: free and ambipolar diffusion at low and moderate pressures. *Journal of research of the National Institute of Standards and Technology*, 95(4):407, 1990.

[20] Marek Scholz, B. Bienkowska, M. Borowiecki, Irena Ivanova-Stanik, L. Karpinski, Wlodzimierz Stepniewski, M. Paduch, K. Tomaszewski, M.J. Sadowski, A. Szydlowski, P. Kubes, and J. Kravarik. Status of a mega-joule scale plasma-focus experiments. *Nukleonika*, 51:79–84, 01 2006.

[21] John R Sporre. Detection of energetic neutral flux emanating from extreme ultraviolet light lithography sources. 2010.

[22] John R Sporre. *Diagnosis of the flux emanating from the intermediate focus of an extreme ultraviolet light lithography source*. University of Illinois at Urbana-Champaign, 2013.

[23] Keith C Thompson, Erik L Antonsen, Matthew R Hendricks, Brian E Jurczyk, M Williams, and DN Ruzic. Experimental test chamber design for optics exposure testing and debris characterization of a xenon discharge produced plasma source for extreme ultraviolet lithography. *Microelectronic Engineering*, 83(3):476–484, 2006.

[24] M Zakaullah, G Murtaza, Imtiaz Ahmad, Farhart N Beg, MM Beg, and M Shabbir. Comparative study of low energy mather-type plasma focus devices. *Plasma Sources Science and Technology*, 4(1):117, 1995.

Bibliography

[1] Institute for plasma focus studies.

[2] Single-event upset.

[3] LL Alves. The ist-lisbon database on lxcat. In *Journal of Physics: Conference Series*, volume 565, page 012007. IOP Publishing, 2014.

[4] Robert C Amme and John F McIlwain. Charge-exchange cross sections for argon ions in h2 and d2 below 1 kev. *The Journal of Chemical Physics*, 45(4):1224–1227, 1966.

[5] H Bruzzone and D Grondona. Magnetic probe measurements of the initial phase in a plasma focus device. *Plasma physics and controlled fusion*, 39(9):1315, 1997.

[6] Souvik Das. Brief introduction to plasma. 07 2019.

[7] Letitia P Davies. The photo-electric properties of some metals in the soft x-ray region. *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character*, 119(783):543–552, 1928.

[8] Sporre John R Curreli Davide Shchelkanov Ivan A Elg, Daniel T. Magnetic debris mitigation system for extreme ultraviolet sources. *Journal of Micro/Nanolithography MEMS and MOEMS*, 14:18, 2015.

[9] Sporre John R Curreli Davide Shchelkanov Ivan A Elg, Daniel T. Magnetic debris mitigation system for extreme ultraviolet sources. *Journal of Micro/Nanolithography MEMS and MOEMS*, 14:18, 2015.

[10] P Gautam and R Khanal. Introduction to numerical experiment on plasma focus using lee model code. *Himalayan Physics*, 5:137–141, 2014.

[11] Tousif Hussain, Riaz Ahmad, Zeshan Umar, and Ali Hussnain. Synthesis of tin/a-si3n4 thin film by using a mather type dense plasma focus system. *Chinese Physics B*, 22:055204, 05 2013.

[12] S. Lee. A sequential plasma focus. *IEEE Transactions on Plasma Science*, 19(5):912–919, 1991.

[13] Sing Lee. Plasma focus radiative model: Review of the lee model code. *Journal of Fusion Energy*, 33(4):319–335, 2014.

[14] Sing Lee and Sor Heoh Saw. Numerical experiments providing new insights into plasma focus fusion devices. *Energies*, 3(4):711–737, 2010.

[15] Michael A Lieberman and Alan J Lichtenberg. *Principles of plasma discharges and materials processing*. John Wiley & Sons, 2005.

[16] JW Mather. 15. dense plasma focus. In *Methods in Experimental Physics*, volume 9, pages 187–249. Elsevier, 1971.

[17] A.S. Oates. 7 - reliability of silicon integrated circuits. In Jonathan Swingler, editor, *Reliability Characterisation of Electrical and Electronic Systems*, pages 115–141. Woodhead Publishing, Oxford, 2015.

[18] Gianluca Panici. Investigation of plasma diffusion in extreme ultraviolet lithography sources. 2019.

[19] AV Phelps. The diffusion of charged particles in collisional plasmas: free and ambipolar diffusion at low and moderate pressures. *Journal of research of the National Institute of Standards and Technology*, 95(4):407, 1990.

[20] Marek Scholz, B. Bienkowska, M. Borowiecki, Irena Ivanova-Stanik, L. Karpinski, Wlodzimierz Stepniewski, M. Paduch, K. Tomaszewski, M.J. Sadowski, A. Szydlowski, P. Kubes, and J. Kravarik. Status of a mega-joule scale plasma-focus experiments. *Nukleonika*, 51:79–84, 01 2006.

[21] John R Sporre. Detection of energetic neutral flux emanating from extreme ultraviolet light lithography sources. 2010.

[22] John R Sporre. *Diagnosis of the flux emanating from the intermediate focus of an extreme ultraviolet light lithography source*. University of Illinois at Urbana-Champaign, 2013.

[23] Keith C Thompson, Erik L Antonsen, Matthew R Hendricks, Brian E Jurczyk, M Williams, and DN Ruzic. Experimental test chamber design for optics exposure testing and debris characterization of a xenon discharge produced plasma source for extreme ultraviolet lithography. *Microelectronic Engineering*, 83(3):476–484, 2006.

[24] M Zakaullah, G Murtaza, Imtiaz Ahmad, Farhart N Beg, MM Beg, and M Shabbir. Comparative study of low energy mather-type plasma focus devices. *Plasma Sources Science and Technology*, 4(1):117, 1995.