ABSTRACT

PRODUCTION OF PULSED LOW ENERGY ELECTRON BEAMS

by
Shyam Das

In this thesis, an experimental setup for the production of low energy electron beams based on Explosive Electron Emission (EEE) is used to study the transmission of pulsed low energy electron beams through silicon nitride foils. The electron beam density before and after the foil are measured.

The experimental values fully agree with the theoretical estimates. Work done in this thesis is a judicious combination of vacuum technology, pulsing of high voltage sources, thermal physics and electronics.

Diagrams and photographs of the experimental setup are presented. A paper was presented at the American Vacuum Society (AVS) symposium at Rutgers University in New Brunswick in May 1997 to the effect of this work

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A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology and Rutgers University
In Partial Fulfillment of the Requirements of the Degree of
Master of Science in Applied Physics

Department of Physics

August 1999

APPROVAL PAGE

PRODUCTION OF PULSED LOW ENERGY ELECTRON BEAMS

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This thesis is dedicated to the Charismatic Indian Godman Sai Baba

ACKNOWLEDGEMENT

The author wishes to express his sincere gratitude to his advisors, Professor Ken K. Chin and Former Professor S. A. Korenev for their valuable inspiration, encouragement , guidance and support throughout the period of this Master's program ,without which this work would not have been completed. I also thank thesis committee member Prof.O.L.Russo for his support and guidance.

The author also is grateful to Dr. Ronald Kane and Anette Damiano of Graduate studies for their help and support.

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CHAPTER 1

INTRODUCTION

1.1 Theory of Explosive Electron Emission(EEE)

By the application of an electric field to a surface, current may be drawn from localized areas, such as insulating inclusions or microprotrusions[1]. The emission current is commonly known as field enhanced electron emission (EEE)[1]. If the electric field is high enough ohmic heating of these discrete electron emission sites can cause them to explosively vaporize(see fig 1.1). The vaporised cathode material is bombarded by electrons emitted through thermionic emission at the hot molten cathode surface and it becomes ionized resulting in a dense plasma. This process is known as "explosive electron emission".

The plasma surface at the cathode can emit a very high current of electrons typically limited by the Child –Langmuir law[1]. The plasma expands at the rate of a few cms/μsec, largely determined by the thermal and electrical properties of the cathode material(which determine the specific energy required to cause cathode flare formation)as indicated in Equation(1.1), which has been found to give good agreement if the resistivity is taken to be in the range of 30-100 times its room temperature value

$$v=((4Y/(Y-1))J^{2}tK/\Pi^{2}\rho)^{1/2} \quad [1] \qquad (1.1)$$

Where,

Y the adiabatic parameter for the plasma

v the expansion velocity

K the resistivity

J the emission current density

t the transition time to explosion

ρ density of the cathode material

The plasma expansion represents a limiting factor on the usefulness of this type of cathode as both the diode geometry and the accelerating potential vary with time. Additionally the beam parameters have a rather large spread due to the lack of direction in the initial emission from the expanding plasma cloud[1].

Cathodes with explosive electron emission have gained the widest use among the plasma cathodes emloyed in pulsed electron sources[3]. Explosive emission cathodes consist of two main elements: an adapter and a cathode plasma initiator[3]. The former connects the electron source to the cathode edge and the latter forms the cathode plasma. Cathode plasma initiators utilize multipoint devices such as carbon fiber structures. The carbon fiber cathode is resistant to ion bombardment and the delay of the beam current with respect to the voltage is small, among other advantages. Its main advantage is the high geometric electric field amplification factor the fibers. However, technological difficulties [3]in the production of an even end surface result in shielding of the electric field in the electron beam current pulses and increases the transverse non uniformity of beam current density. Carbon fiber cathode[3] has a stable current rise for relatively low voltages (~10kv) the current oscillations in the carbon fiber cathode were evidently due to the presence of an organic matrix. The I-V characteristic of a diode with the proposed cathode follows Child's Law[5].

Cathodes of carbon fiber plastic[5] provide a more stable rise of electron beam current than other cathodes. To obtain low energy electron beams the source includes a vacuum chamber, a supporting high voltage insulator of teflon, a cathode rod with a cathode plasma initiator based on a carbon fiber, a split anode, two short magnetic lenses and a rogovsky coil,the emitter diameter was 10mm, the diameter of the hole in the split anode was 5mm and the pressure in the system was 10^-5 torr[3]. A photograph of the electron gun is shown in Fig 1.2. A schematic diagram[3] of the electron gun is shown in Fig 1.3 and the voltage current characteristics of the gun is shown in Fig 1.4.

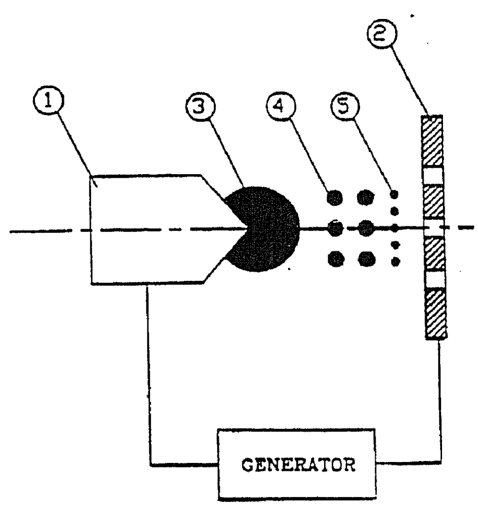


Fig 1.1 Schematic Diagram of Explosive Electron Emission[3]

1. Iniator of Cathode Plasma

2. Anode

3. Cathode Plasma

5. Electrons

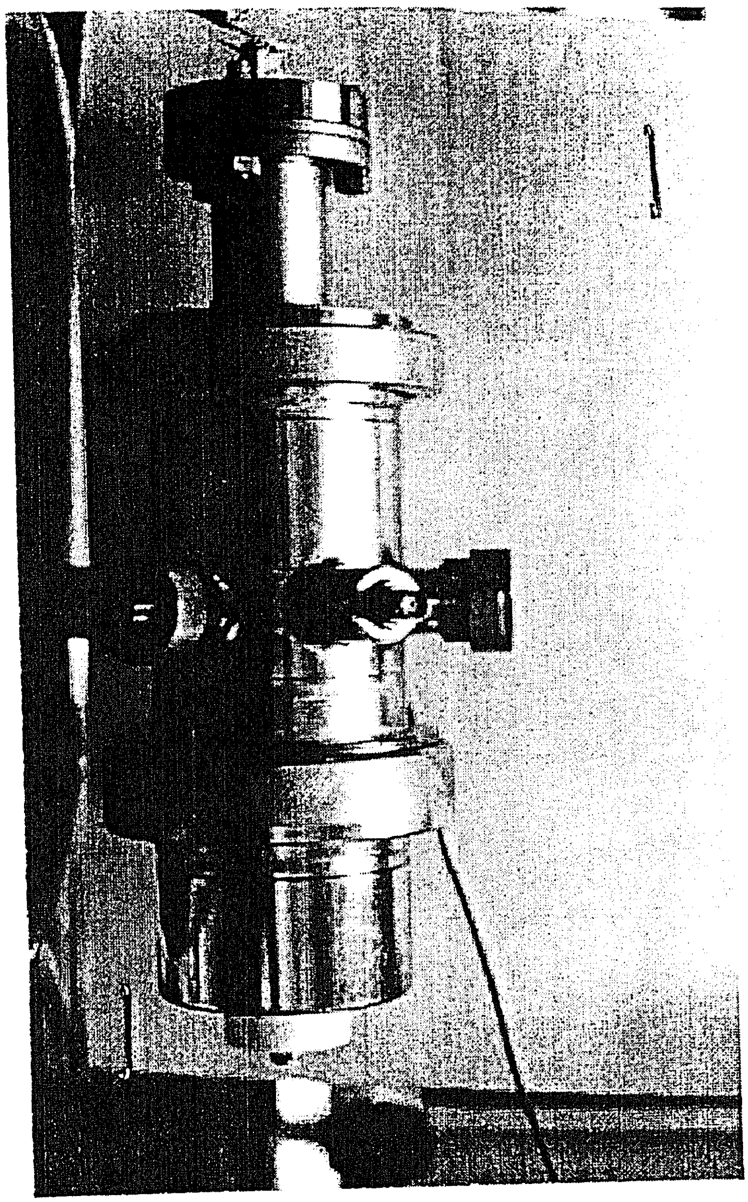


Fig1.2 Photograph of Electron Gun

1: SPLIT ANODE, 2: CATHODE PLASMA INITIATOR, 3: CATHODE ROD, 4: HIGH VOLTAGE INSULATOR, 5:HIGH VOLTAGE CABLE, 6: SEALING NUT, 7: VACUUM TIGHT CONNECTOR, 8: MAGNETIC LENSES, 9:ROGOVSKY COIL, 10 :OUTPUT CAP, 11 :VACUUM CHAMBER

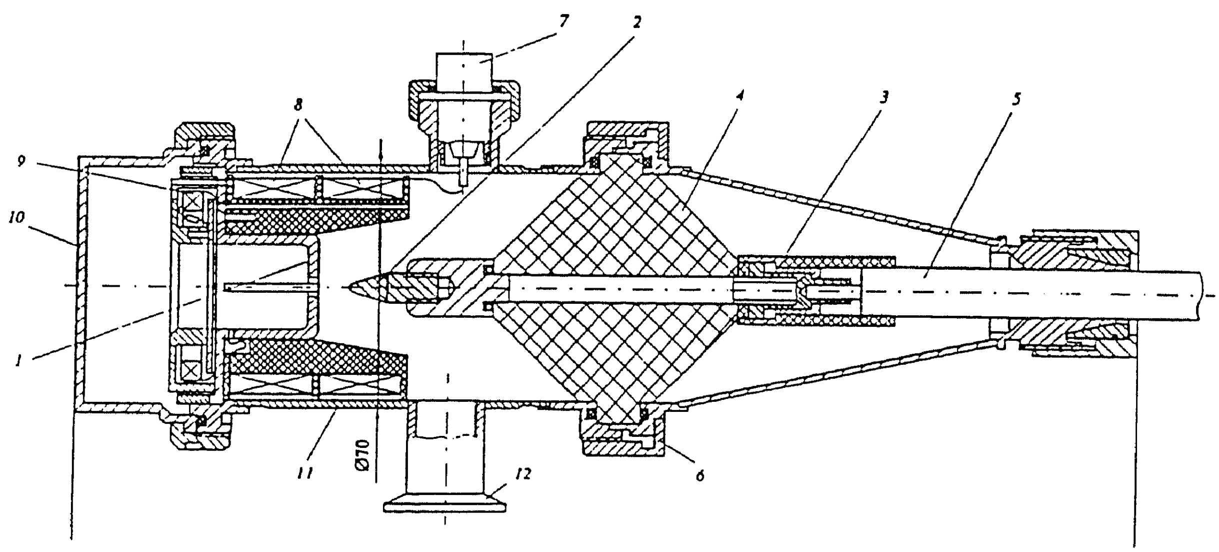


Fig 1.3 Schematic Diagram of Explosive Electron Gun[3]

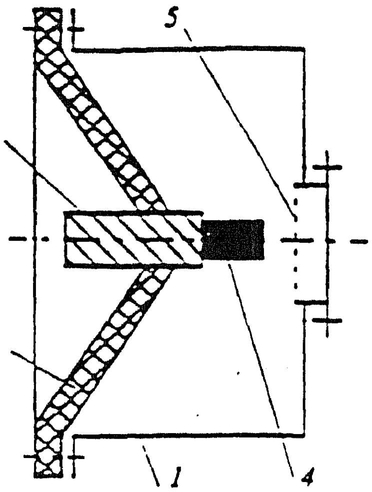
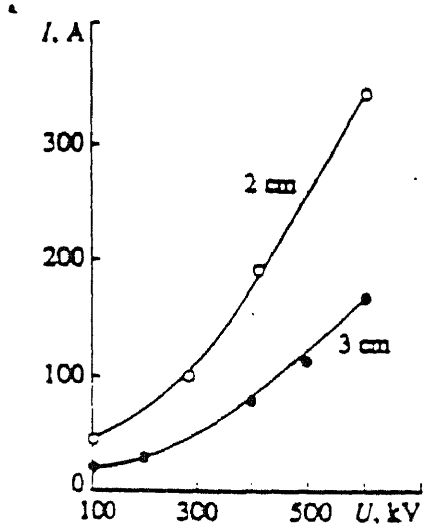
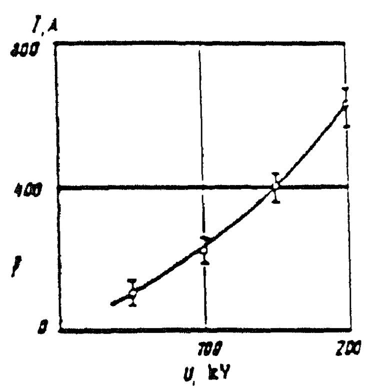


Diagram of the electron gun: (1) vacuum chamber; (2) high-voltage insulator; (3) cathode rod; (4) bismuth ceramics-based cathode-plasma initiator; (5) anode.



Current-voltage characteristic of the diode at an anode-cathode gap of 2 and 3 cm; the beam pulse-current duration is 1 μs.



Volt-ampere characteristic of diode with cathode of carbon-fiber plastic. $D = 1$ cm; cathode diameter 2 cm.

Fig 1.4 Voltage Current Characteristics of Electron Gun[3]

1.2 The Objective of this Thesis

In this thesis an electron gun based on explosive electron emission [3](fig1.2) is used to study the transmission of electron beams through silicon nitride foil. To excite a gas volume at atmospheric pressure by an electron beam, thin partitions are required to separate the vacuum chamber(source of electrons) from the working (gas) chamber so that most of the electron are transmitted into the gas chamber. Moreover to get the gas volume like a rare gas to lase very high electron densities are needed which is possible only in the pulsed mode in the system described in this thesis. Increasing the current in the dc mode would result in damage to the foil. Hence there is a tradeoff between the foil thickness and the current density after the foil in the gas chamber[6]. To achieve high current densities the electron beam should be in the pulsed mode. This thesis discusses the construction of a system for the study of transmission of pulsed electron beams through thin silicon nitride foils with the ultimate goal of obtaining a new low energy excimer laser[6].

CHAPTER 2

EXPERIMENTAL SETUP

2.1 Vacuum System for Electron Gun

The diagram for vacuum system is shown in fig 2.1. The vacuum system is based on a mechanical pump and an oil based water cooled diffusion pump. The mechanical pump produces low vacuum down to 10^-3 torr and the oil based diffusion pump brings the vacuum further down to 10^-5 torr. The electron gun is connected to the diffusion pump thus evacuating it to approximately to 10^-5 torr. The diffusion pump must always be backed up by a mechanical pump. It works on the following principle. The mechanical pump bring the vacuum to 10^-3 torr when the diffusion pump is turned on. A thermocouple gauge is used to monitor the vacuum produced by the mechanical pump. Silicone oil was used in the diffusion pump. It has a heating element which vaporises the oil and the oil molecules adhere to the remaining air molecules which the mechanical pump could not evacuate. This adhesion increases the mass of the air molecules and thus are drawn away by the mechanical pump. The diffusion pump is cooled to prevent the oil from charring out. An ion gauge is used to monitor the vacuum produced by the diffusion pump. The photograph of the entire experimental setup which largely consists of the vacuum system is shown in Fig 2.2.

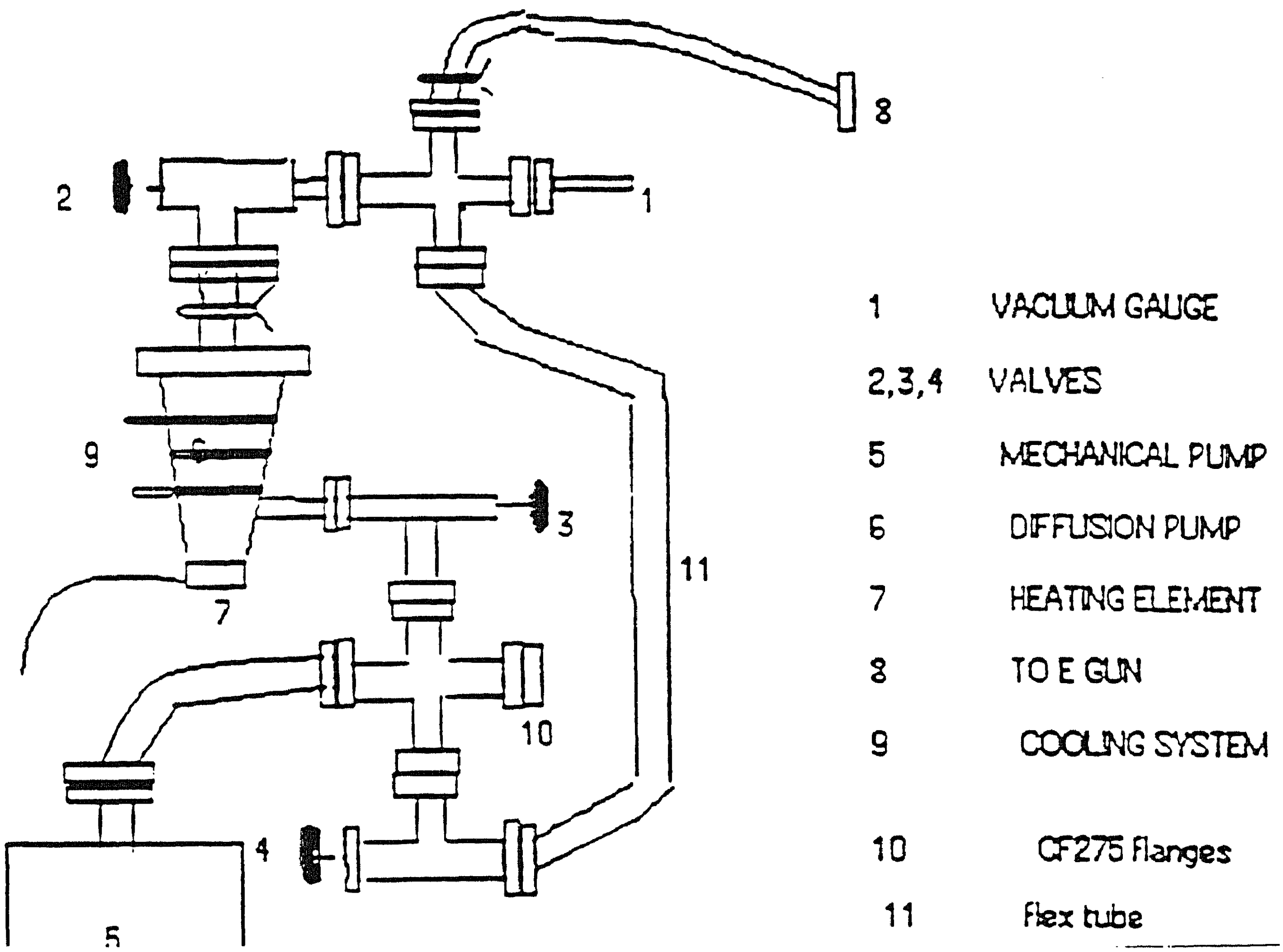


Fig 2.1 Vacuum System for Electron Gun

2.2 Pulsing Circuit for Electron Gun

The diagram for the pulsing circuit for the electron gun is shown in fig 2.3. This circuit consists of a 30kV /1mA dc power supply, a 100 MΩ charging resistor, 3 high voltage capacitors each of 0.01μF(40kv voltage rating) and a discharging resistor of 1KΩ . The capacitors are in series. The discharge is triggered by the voltage breakdown in air produced by two conductors placed approximately 10-12 mm apart. The charge on the capacitors starts to rise until the voltage between the conductors is sufficient enough to cause breakdown in air. Once the breakdown takes place the circuit is complete as one of the conductors is grounded and the capacitors begin to discharge. The voltage for breakdown should be synchronized with the voltage of the dc power source, to produce the discharge. This is done by adjusting the distance between the two air separated conductors.

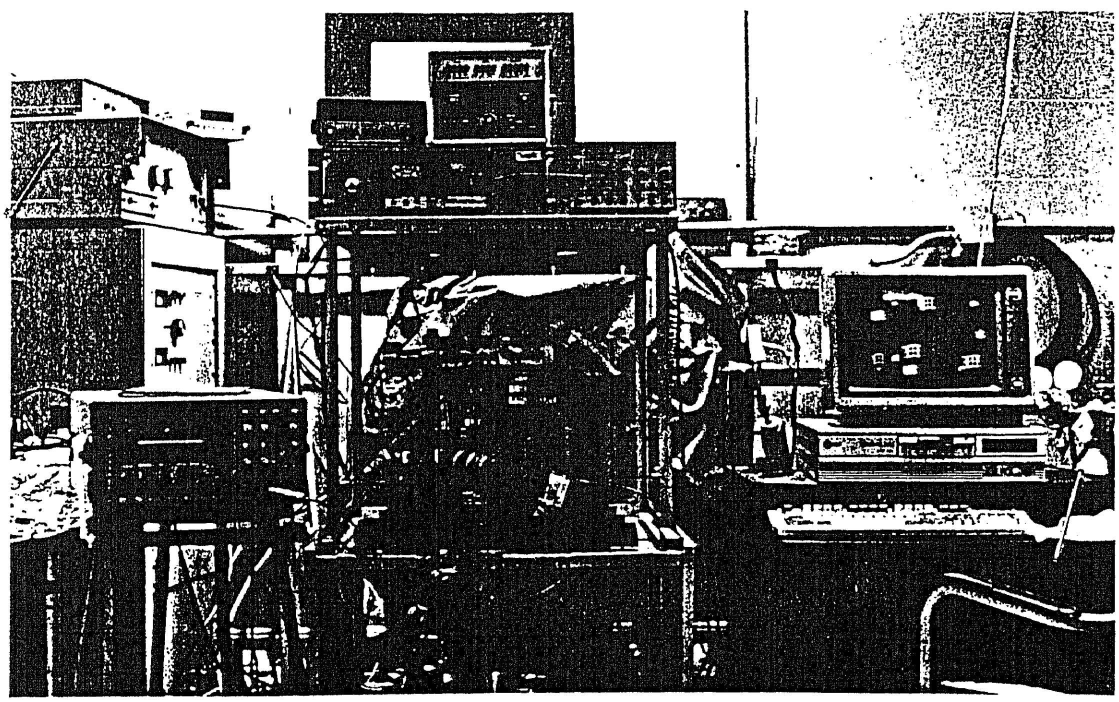


Fig 2.2 Photograph of Experimental Setup

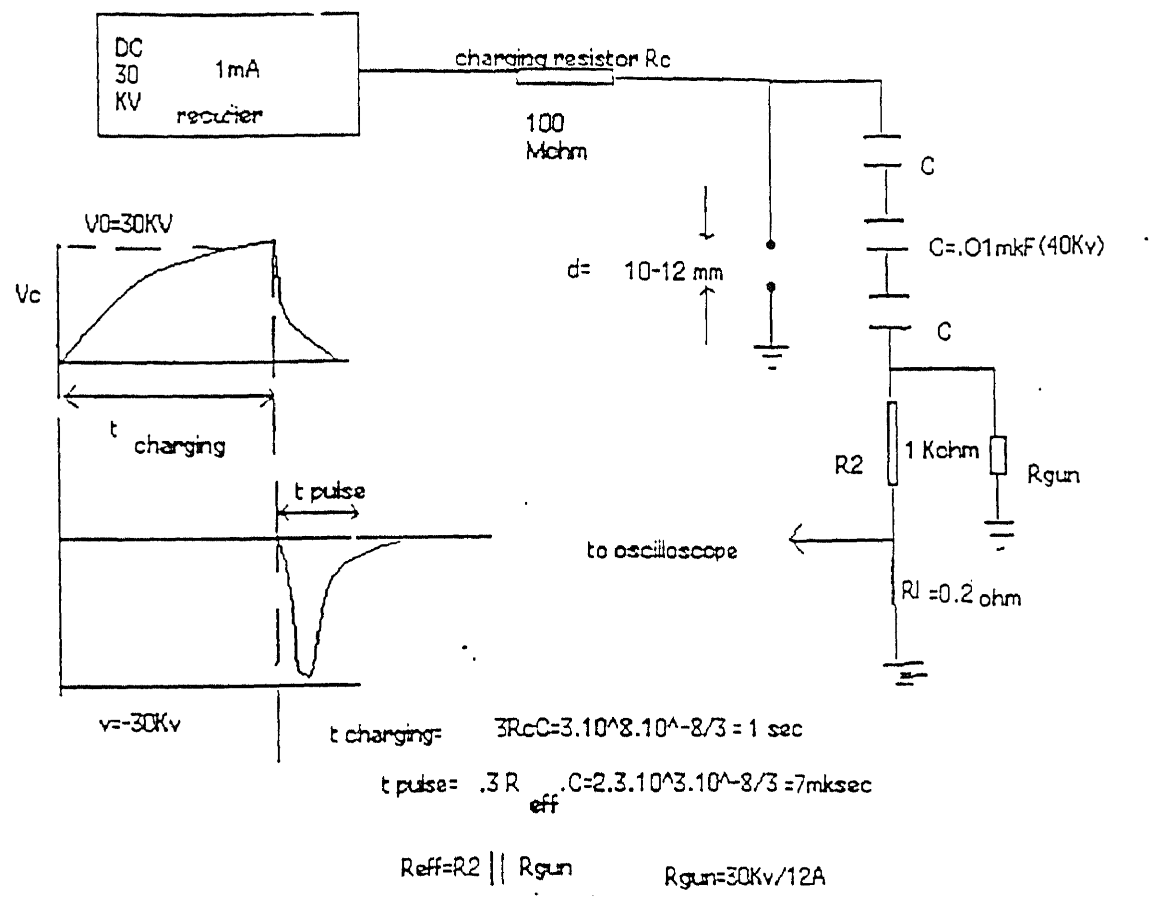
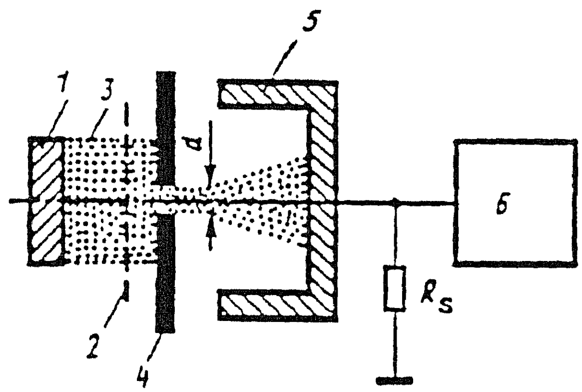


Fig 2.3 Pulsing Circuit for Electron Gun

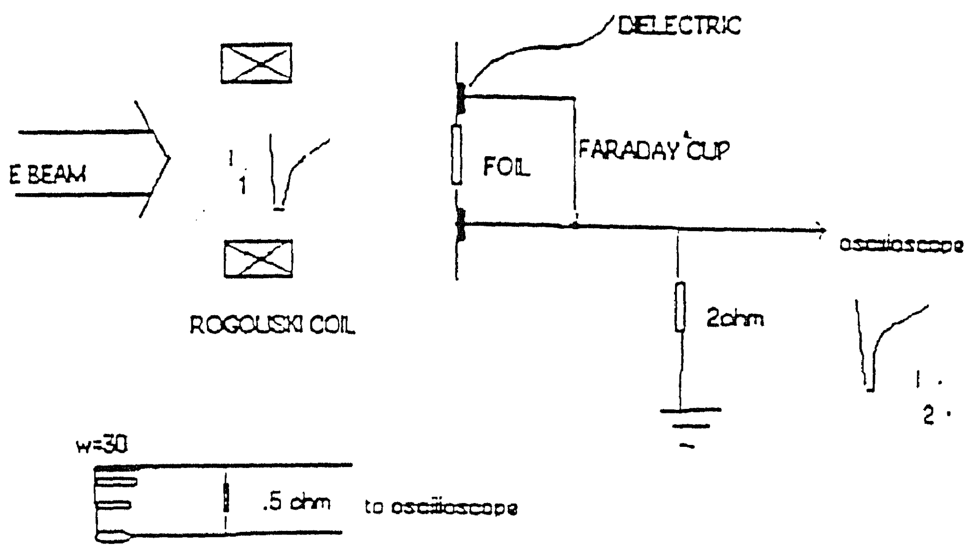
2.3 Experimental Chamber and Measurement Techniques

The Experimental chamber consists of a thin silicon nitride foil of thickness 200nm[6] and area 1mm^2[6]. One side of the foil faces the vacuum chamber and the other side is glued to a faraday cup of length 1cm.The Faraday cup[6] is connected to a resistor whose other end is grounded. Voltage measure across the resistor using an oscilloscope gives an estimate of the current density of the evacuated air behind the foil. The chamber is evacuated by a small hole away from the direction of the electron beam connecting the electron gun and the experimental chamber. A Rogovsky coil[4] measures the current density of the electron beam before the foil. Both these voltages are measured using an oscilloscope. A diagram of the setup for measuring the current characteristics is shown in fig 2.4.



Setup for measurement of current characteristics: 1) cathode; 2) anode; 3) electron beam; 4) collimator with opening (with slit); 5) collector with current shunt; 6) oscilloscope.

Fig2.4 Setup for Measurement of Current Characteristics[4]



I1 = Vw/R = 200 mv.30/.5 = 12 A

I2 = 150 mv / 2 ohm = 75 mA

J1 = 12 A / 15mm*15mm = 60 mA/mm^2

J2 = 75mA / 1mm*1mm = 75mA/mm^2

Fig 3.1 Factor of Transmission of Electron Beam

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Results

Current of 12 A was measured from the Rogovsky coil[4]and this gives a current density of 60mA/mm^2 assuming a square beam cross section of 15mm. Current after the foil from the Faraday cup was measured to give a value of 75mA which gives a current density of 75mA/mm^2 since the foil has a square dimension of 1mm. Fig 3.1 shows the factor of e-beam transmission through the foil and Fig 3.2 shows a photograph of the oscilloscope traces of the electron beam before and after the foil.

3.2 Discussion

The discrepancy in the results could arise due to the fact that the actual beam cross section before the foil is not known and an assumption of 15mm beam cross section was made.

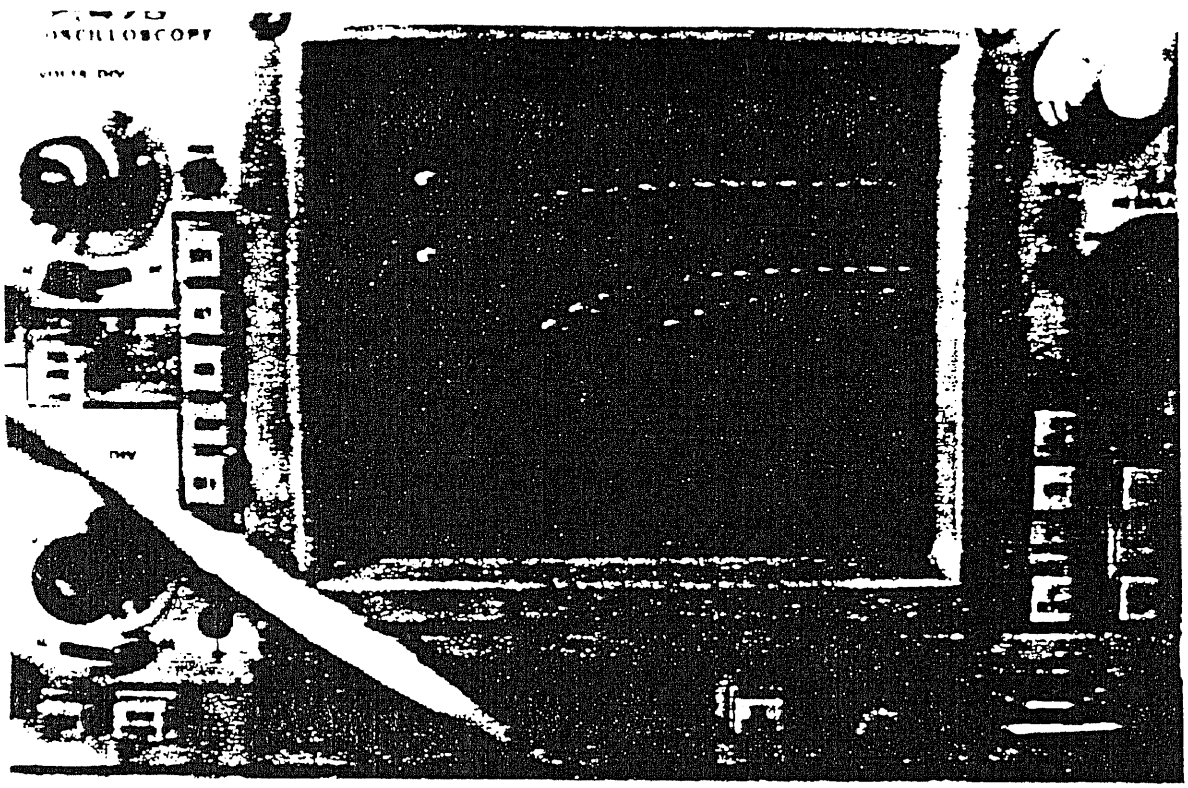


Fig3.2 Photograph of Oscilloscope Traces of Beam before and after Foil

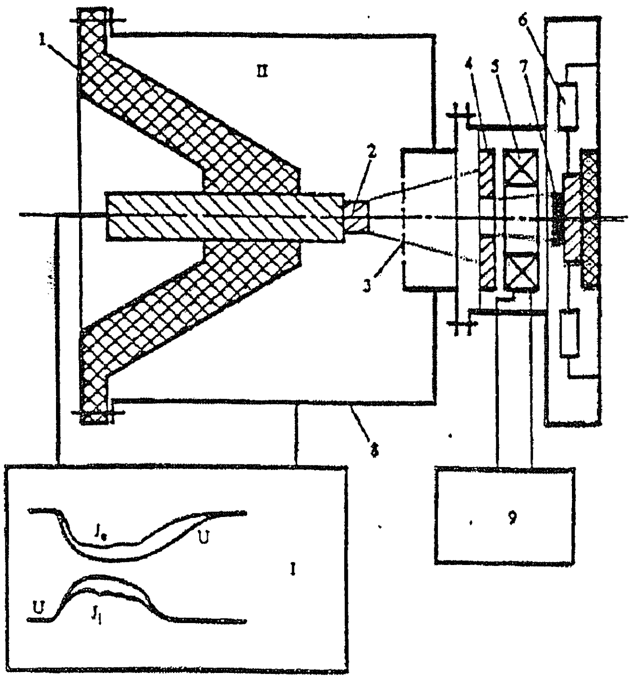


Fig 5.2 Block Diagram of an Electron-ion Accelerator Mounted onto a Small Sample Chamber[7]

1. High Voltage Insulator
2. The Cathode
3. The Anode
4. The Collimator
5. A Current Transformer
6. Shunt of Current
7. Film Deposition
8. Vacuum Chamber
9. Oscilloscope

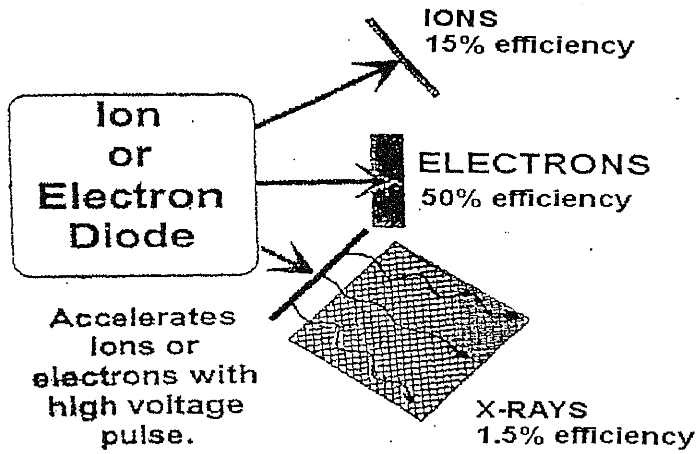


Fig 5.1 Efficiency of Interaction of Pulsed Electron/Ion/Xrays With Solid State[7]

CHAPTER 4

THEORETICAL ESTIMATE OF TEMPERATURE RISE IN THE FOIL

Joule energy =**v i t** (4.1)

Where v is the energy(volts)stopped or lost in the foil

i is the current through the foil

T is the pulse width

Now **v i t = m s d**θ (4.2)

Where m is the mass of the foil

S is the specific heat

dθ is the change in temperature

v = 30kv*5/100 assuming 5% loss in the foil[6]

i = 60mA

T=7μsec

Specific heat of silicon nitride=690j/kg/K (see fig 4.1)

Mass of the foil = volume*density

Density of silicon nitride =3.4*10^3kg/m^3

Volume of the foil = area * thickness

Area = 10^-6m^2

Thickness = 200nm

Substituting these values in equation 4.1 gives dθ =1400

dθ is therefore less than the melting point of silicon nitride(1900 C) see fig 4.1

The foil can therefore withstand electron beam of current 60 mA pulse duration 7µsec and voltage 30kv even if we have vacuum after the foil which is the worst case scenario. If we have have air after the foil as is required (rare gas) to produce excimer light, the air gets heated up but to a lesser temperature due to the lower specific heat and greater mass than foil and thus heat flow takes place by Newton's law from the foil to air thus reducing foil damage.

the coupling equation from foil to air is

dTair/dt = βair*v*I, where (βair is constant) (4.3)

dTfoil/dt =βfoil*v*I-(Tf-Tair)α, where(α,βfoil are constants) (4.4)

Table 1 Table of Silicon Nitride Properties[8]

- crystal structure: hexagonal(amorphous for most vlsi applications)
- atomic weight : 140.28
- thermal conductivity 16-33 w/m-k
- thermal diffusivity .32 cm^2/s
- relative dielectric constant : 7.5
- index of refraction: 2.0
- dielectric constant: F/m

- electrical resistivity > 10e12 ohm-meter
- breakdown field v/m
- atomic density 1.48e22 molecules/cm^3
- density 3.44 g/cm^3
- coefficient of thermal linear expansion 2.8 e-6
- energy gap 4.7 ev
- specific heat .17 j/g-K
- melting point 1900 C
- poisson ratio .24
- youngs modulus 304 GPa
- koop hardness 2200
- modulus of rupture 414-580 MPa

Chemical Resistance

acids-concentrated	fair
acids-dilute	good
alkalis	fair
halogens	good
metals	fair

Mechanical Properties

compressive strength 550-650 mpa

hardness-vickers 800-1000 mpa

shear strength 190-240 mpa

tensile modulus 170-220 gpa

tensile strength 160 mpa

Thermal Properties

specific heat at 25 C 690 j/k/kg

upper continuous use temperature 1200-1500 C

Table 2 Table of Applications

Application to Metals[7]

- surface modification and hardening of metals and alloys with complex multicomponents. Increasing of hardness for many kinds of steel 3-80 times
- Surface melting of complex layer films and coatings. Melting Nb3Ge on the stainless steel
- Cleaning of surface and decreasing of roughness.
- Increasing of corrosion resistance of stainless steel by irradiation with high current ion beam
- Synthesis of hard lubrication layers

Application to Semiconductors[7]

- The synthesis of Sipt/Si structures for nuclear detectors with low leaked current.
- The synthesis of SiC on Si with good electrical characteristics and absence of H with comparison with CVD method of synthesis of SiC
- Rapid thermal annealing of semiconductors

Application to High Temperature Superconductivity[7]

- increasing critical current of HTSC by pulsed electron beam irradiation to 50-200 times.
- Focussing of electron beam by HTSC tubes and increasing of power density of beam to 100-150 times.
- Stabilization of surface of HTSC by irradiation with pulsed electron beams using surface melting

Applications to Graphite[7]

-Improve electrical insulation vacuum gap between Graphite electrodes by pulsed electron beam irradiation

Application to Polymers[7]

- Improve optical and hardness properties by pulsed electron and ion beam irradiation

Application to New Materials[7]

- Synthesis of DLC using pulsed electron beam irradiation of graphite
- Synthesis of DLC films using ion/electron beam irradiation
- Synthesis of CN structures using cryogenics method of deposition of films with pulsed electron beam irradiation

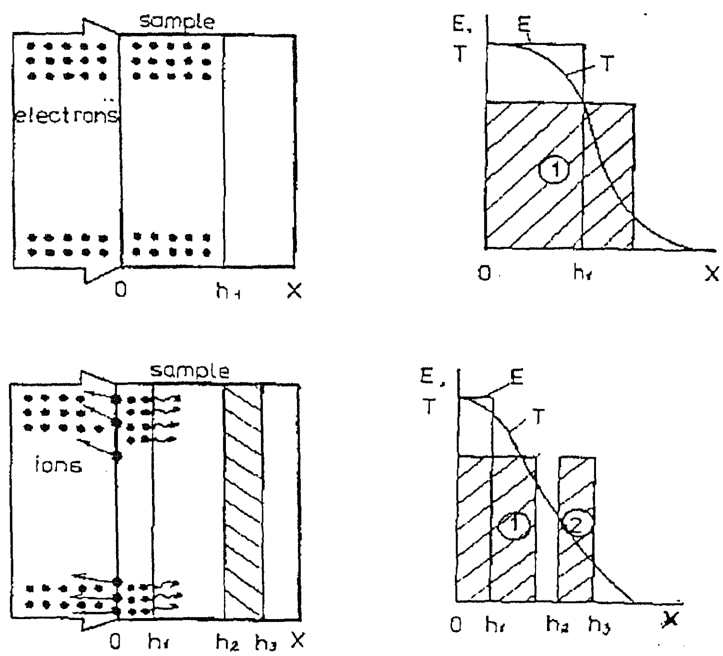


Fig 5.3 Schematic Interaction of Pulsed Electron and Ion Beams and Distribution of Temperature and Dissipation of Energy in Solid State[7]

CHAPTER 5

CONCLUSION AND FUTURE WORK

The theoretical estimate for temperature rise in foil lies well within the melting point of the foil. Hence pulsed electron beams produced by explosive electron emission are suitable for transmission through windows of silicon nitride and give us sufficient electron densities to produce intense excimer light and with the help of suitable optics this setup could be used to produce an excimer laser. Thus this experimental setup based on Explosive Electron Emission stands suitable for future work in producing intense excimer light and even an excimer laser.

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