Concept of Electron Source Based on Pulsed Plasma Discharge

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Abstract

The disadvantage of continuous electron beam machine is electron current limitation and hence the heating impact on the target. So it is needed a new machine which will give higher current in the pulsed mode operation. This paper offers the possibility of pulsed plasma discharge as a pulse electron source. By using simple equations, some interesting parameters such as plasma current, rise time etc can be computed. The results provide basic understanding in designing this machine.

1. Introduction

Today, accelerator has been used in a wide field such as medicine, industries and environment. As an institute based on accelerator technology, we have developed many kinds of machine, such as an electron beam machine which can deliver 10 mA of electron beam current in 350 kV of operating voltage, ion implantation, neutron generator, plasma sputtering and plasma nitriding[1]. Some of them are shown in Figure 1. In general, the electron source of an electron beam machine is based on filament, and it is operated continuously. A disadvantage of this machine is that the electron beam current is limited by filament current, and because it is operated in continuous mode, the irradiated target will be heated by electron beam. Meanwhile some materials such as semiconductor material, it is necessary to avoid temperature increasing on their surface [2]. In another case, some materials need to be treated with high doses of electron beam in large area. So, a new kind of electron beam machine which could be operated in pulse mode, and has a high current is needed. Such machine has been operated in Russia, Japan and probably in several other countries in the world. It is used, for example, to treat semiconductor material and natural rubber. The machine can deliver electron beam current up to 100 A, pulse width of 40 μsec, energy 200 keV, repetition rate 0.1 up to 50 Hz. As an exporter country of natural rubber, actually South East Asian countries could develop such machine, and as an institute based on accelerator activity, our institute will start to develop it. There are several kinds of electron sources which could deliver high current electron beam with wide beam, for example, ribbon electron source and secondary emission electron sources, beside plasma based electron source. This paper, introduced a concept of electron source based on pulsed plasma discharge.

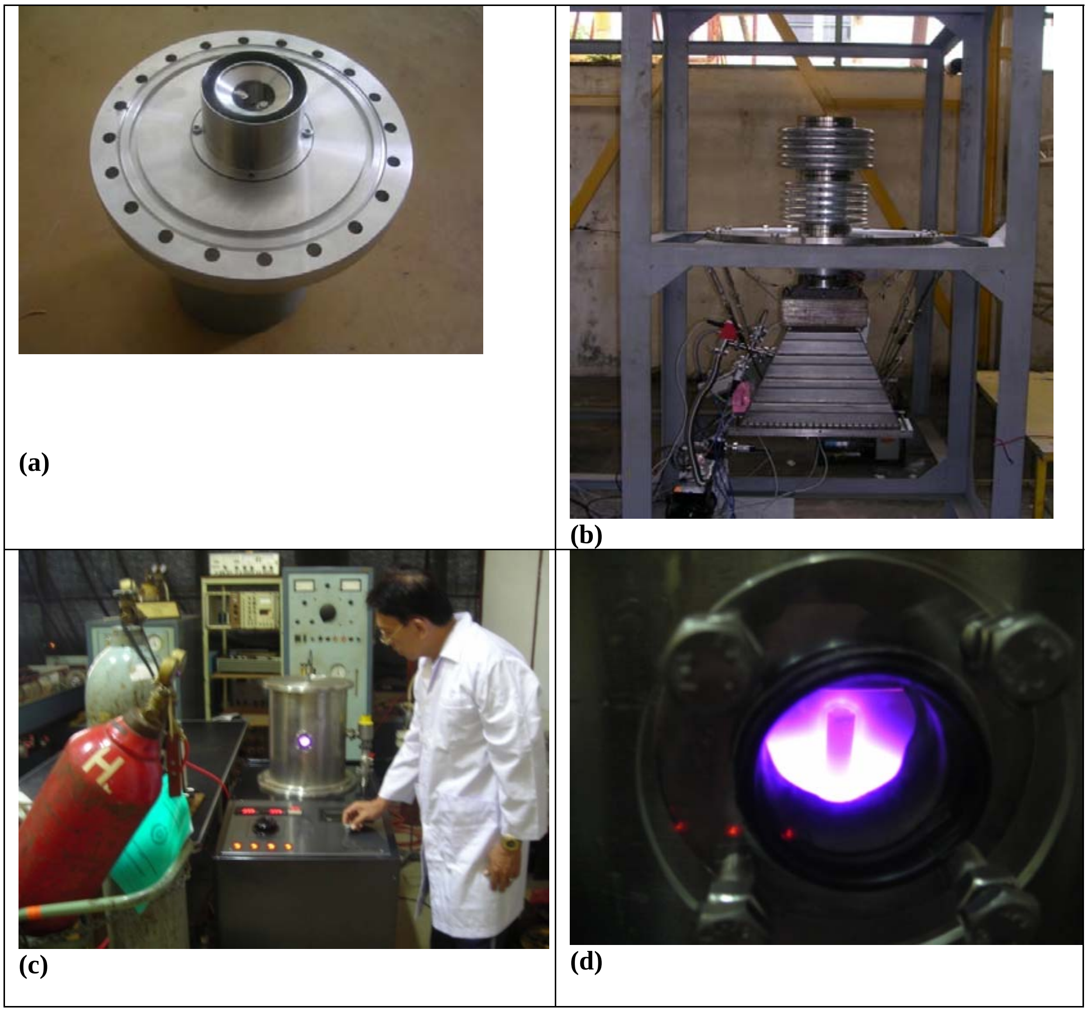


Fig. 1. Some pictures of home made machines at PTAPB. Electron gun based on filament (a), Electron beam machine in construction (b), Plasma Nitriding machine (c), and an automotive component treated by plasma nitriding machine(d).

2. Basic Theory

By definition that plasma consists of ions and electrons, in principle, the electrons of the plasma could be attracted by an electrode which has positive potential, and if this electrode is made of grid, it is expected that some of electrons pass through this grid. Figure 2 shows the extraction of electron from the plasma.

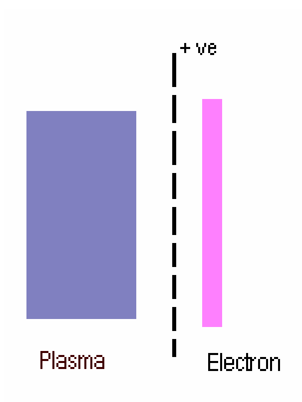


Fig 2. Electrons are extracted from plasma by positive potential grid.

From Figure 2, it can be noted that at first, plasma is built up by a high voltage generator, and afterwards their electrons are pulled out by a positive potential grid. This method uses two generators, the first is used to generate plasma, and the second is used to pull their electrons. The advantage of this type is, their generators will operate independently, and the electron beam energy can be varied; it depends on the attracting voltage. The disadvantage is that it needs some synchronization between plasma generator and the attracting voltage.

A simple method is proposed by using only one generator. This generator has two functions: first function is to generate plasma and the second is to pull the electrons from plasma. The interesting property in the generator is that it should be positive pulse voltage. Figure 3 shows a working principle of such system. Though, this system is simple, but its plasma characteristics depend on the generator.

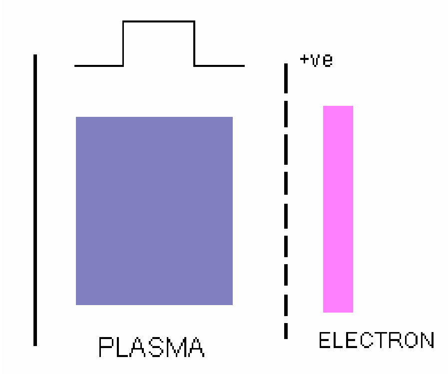


Fig. 3. Electron extraction by pulse positive voltage grid.

This simple system can be represented by an experimental circuit system, as shown in Figure 4.

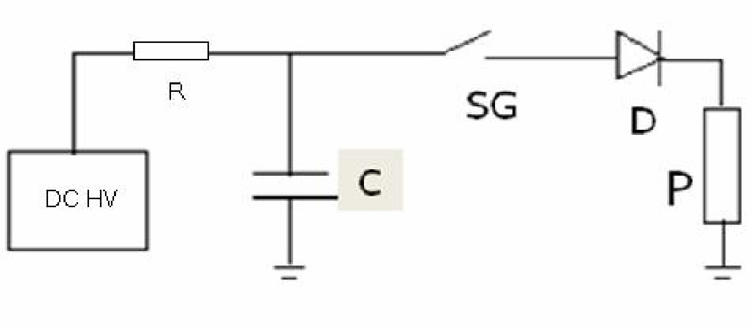


Fig 4. Schematic circuit of pulse plasma discharge system.

DC HV is direct current high voltage, R is charging resistor, C capacitor bank, SG Spark-Gap, D diode, and P is plasma chamber. The capacitor bank C is charged by DC HV through resistor R, and then the electrical energy of the capacitor bank is transferred to plasma chamber P by spark-gap SG through D, such that only positive voltage will pass through. Plasma chamber P represents a system which contains cathode, and grid anode, as shown in Figure 5.

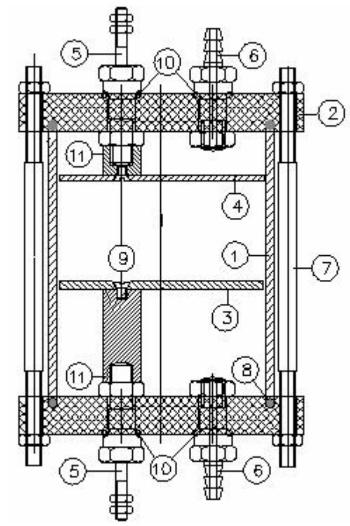


Fig 5. Design of plasma chamber for electron sources, 3 is cathode, 4 is grid anode.

3. Circuit Analysis

The circuit shown in Figure 4, can be drawn in an equivalent circuit [3] as shown by Figure 6, where *C* is capacitor bank, *Lo* is external inductance, diode D has an intrinsic resistance R_D, *Rp* is plasma resistance, and *Lp* is plasma inductance.

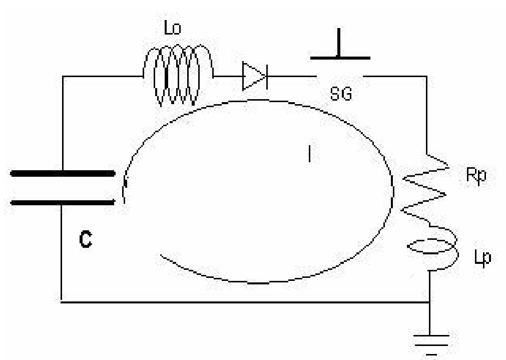


Fig. 6. Equivalent circuit of pulse plasma discharge system.

The equation circuit is

$$V_0 = L_0 \frac{dI}{dt} + IR_p + IR_D + \frac{\int Idt}{C} + L_p \frac{dI}{dt} \qquad (1)$$

The oscillation period T , impendance Z and maximum current I_o are as follows;

$$T = 2\pi\sqrt{L_0 C},\ Z = \sqrt{\frac{L_0}{C}},\ I_0 = \frac{V_0}{Z} \qquad (2)$$

If Equation (1) is arranged into normalized equation, with normalization factors

$$\iota = \frac{I}{I_0}, \quad I_0 = \frac{V_0}{\sqrt{\frac{L_0}{C}}}$$

$$\tau = \frac{t}{t_0}, \; t_0 = \sqrt{L_0 C}, \; \alpha = \frac{R}{\sqrt{\frac{L_0}{C}}}, \; \beta = \frac{L_p}{L_0}, \; \alpha_D = \frac{R_D}{Z} \tag{3}$$

Then, the equation (1) will be

$$I_0\sqrt{\frac{L_0}{C}} - L_0\frac{I_0 d\iota}{t_0 d\tau} - I_0\iota\alpha\sqrt{\frac{L_0}{C}} - I_0\iota\alpha_D\sqrt{\frac{L_0}{C}} - \frac{I_0 t_0\int \iota d\tau}{C} - \beta L_0\frac{I_0 d\iota}{t_0 d\tau} = 0$$

Or

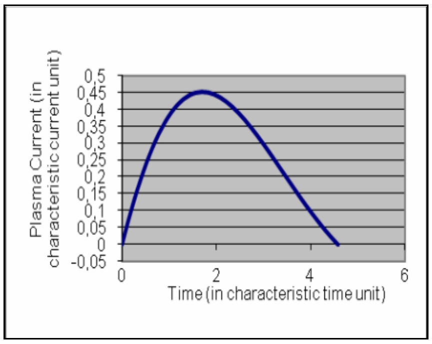
$$1-(1+\beta)\frac{d\iota}{d\tau} - \iota(\alpha+\alpha_D) - \int \iota d\tau = 0 \tag{4}$$

This last equation is a damped oscillation equation and can be solved numerically with any code, with their limit conditions:

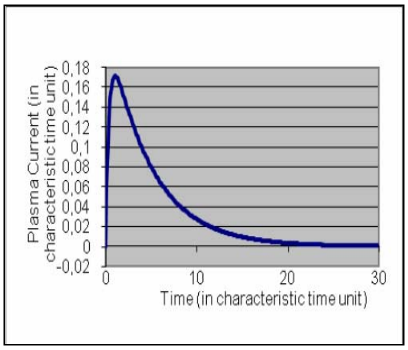
$$\tau = 0, \; \iota = 0, \; \frac{d\iota}{d\tau} = \frac{1}{(1+\beta)}, \int \iota d\tau = 0 \tag{5}$$

4. Discussion

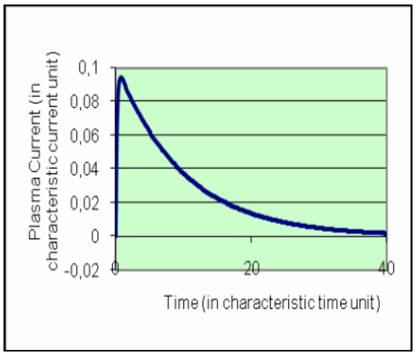
By using Watfor77 code, equation (4) has been solved numerically, and some results are shown in Figure 7 (a), (b), (c) and (d), where only R_D is varied, while *Rp* is constant. Usually, *Rp* is less than Z , while Z is less than R_D.



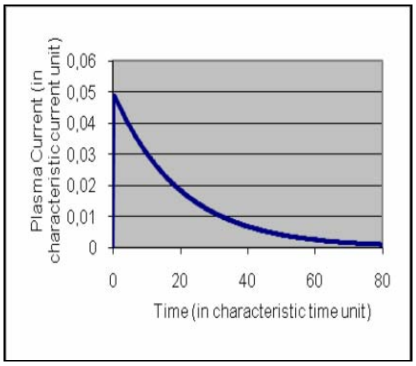
(a)



(b)



(b)

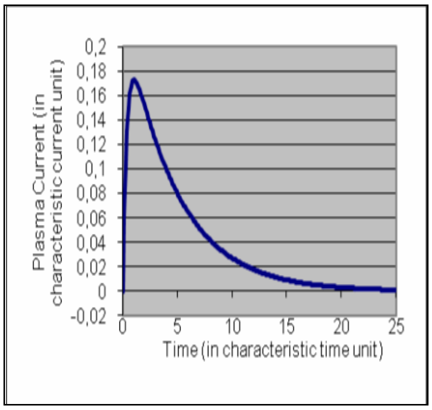


(d)

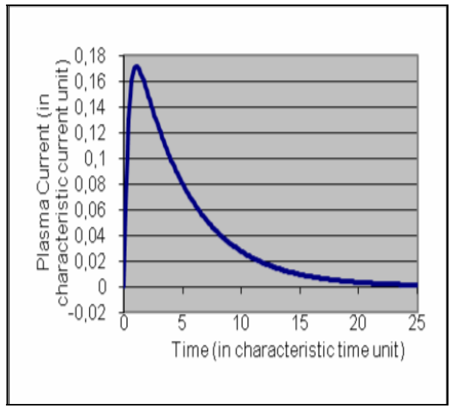
Fig 7. Plasma current as function of time for R_D =1, 5, 10, 20 Ω.

As shown in Figure 7, for bigger R_D, the rise time of plasma current will be faster, their decaying time is slower and peak current is smaller. These data will be important in designing such machine. From this figure, in order to get high current, it is recommended that R_D should be 3-5 times higher than characteristic impedance Z. For higher R_D, it seems that the electron sources will be inefficient, because its plasma current is too low.

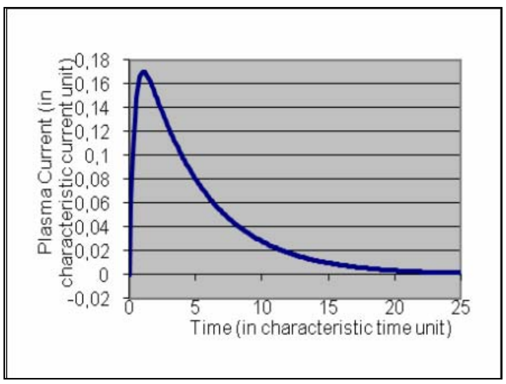
By choosing R_D as constant, and R_P is varied for 0.01, 0.005, 0.1 and 0.5, their responses are shown in Figure 8 (a), (b), (c) and (d).



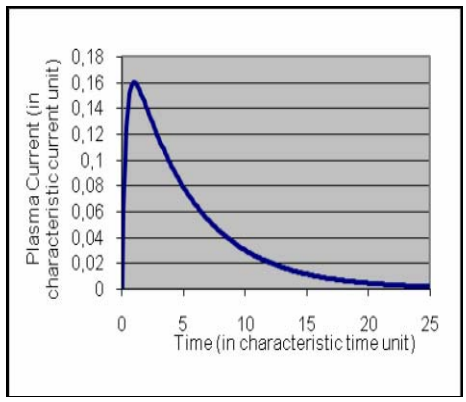
(a)



(b)



(c)



(d)

Fig. 8.Plasma current as function of time for R_P = 0.01, 0.05, 0.1, 0.5 Ω.

It seems that for higher R_P, the plasma current will be decreased, decaying time will be longer, and rise time will be slower. So, it is resumed that for R_P is smaller will increase the plasma current.

The computational results shown above are useful as basic understanding in designing the machine [4].

5. Conclusions

It has been shown the concept of electron source based on pulsed plasma discharge. Using simple equations, it is shown that by varying some parameters like diode resistance and plasma resistance, some plasma characteristics like plasma current, rise time, and decaying time will be understood. Higher plasma current will impact in achieving higher electron beam current in electron source based on pulsed plasma discharge.

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