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The Preliminary Results of the DC-Toroidal Discharge Plasma with Axial Electric Field in the Batorm

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Abstract- A toroidal plasma system (Batorm) were designed, constructed and developed in Egyptian Atomic Energy Authority (EAEA) since 1998. The plasma parameters of this device have been studied and obtained for the first dimensions during PhD thesis 2003. The word "BATORM" is an abbreviation to "Baby Toroidal of Masoud". The main feature of the system is a low-cost machine which can be operated as a small toroidal plasma device. In this system, the plasma is initiated by linear axial discharge between two plates which create an applied axial field all over the discharge device. This system could be provided rich information on toroidal discharge physics which includes small impurities. The design of the Batorm is upgraded by change its dimensions, according that, the turns number of toroidal, ohmic and vertical coils are increased. The discharge current I_{dis} and total inductance of these three coils were (2 A) and (934.4 μH) respectively. The experimental results have been preliminary taken depending on measurment of electron temperature (KT_e) and ion density (n_i) at each one cm from the outer wall to the inner wall of the chamber. From these results, it is found that the highest values of (KT_e) and (n_i) arrived to 10 eV and 1.52 $x10^{-9}cm^{-3}$ (respectivelely) at distance 7 cm. Besides, it has been seen that there are no plasma arrived to the inner wall according to the toroidal confienment.

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Strictly as per the compliance and regulations of:

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A. A. Talab [α] & M. M. Masoud [σ]

Abstract- A toroidal plasma system (Batorm) were designed, constructed and developed in Egyptian Atomic Energy Authority (EAEA) since 1998. The plasma parameters of this device have been studied and obtained for the first dimensions during PhD thesis 2003. The word "BATORM" is an abbreviation to "Baby Toroidal of Masoud". The main feature of the system is a low-cost machine which can be operated as a small toroidal plasma device. In this system, the plasma is initiated by linear axial discharge between two plates which create an applied axial field all over the discharge device. This system could be provided rich information on toroidal discharge physics which includes small impurities. The design of the Batorm is upgraded by change its dimensions, according that, the turns number of toroidal, ohmic and vertical coils are increased. The discharge current I_{dis} and total inductance of these three coils were (2 A) and (934.4 μH) respectively. The experimental results have been preliminary taken depending on measurment of electron temperature (KT_e) and ion density (n_i) at each one cm from the outer wall to the inner wall of the chamber. From these results, it is found that the highest values of (KT_e) and (n_i) arrived to 10 eV and 1.52 $x10^{-9}cm^{-3}$ (respectivelely) at distance 7 cm. Besides, it has been seen that there are no plasma arrived to the inner wall according to the toroidal confinement.

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I. Introduction

BATORM is the first toroidal plasma machine designed and operated in our lab at EAEA [1]. It was designed and built in 1998 depending on an idea to produced plasma in two ranges. In beginning, a low pressure DC glow plasma discharge is produced. After that, the excited magnetic trap in toroidal chamber are used to confine the energy and charged particles of the plasma to produce toroidal plasma confinement (as in the to kamaks devices [2]).

In this work, we are going to study and investigate experimentally the different parameters of the plasma of low pressure toroidal glow discharge in radial magnetic field [3]. The magnetic field has two orthogonal components: one that is created by a system of current-carrying coils around the plasma (toroidal magnetic field (TF)) and the other is created by a current that is induced in the plasma (poloidal magnetic field (PF)). The resulting magnetic field lines spiral around a set of nested toroidal flux surfaces, providing an effective plasma-confinement system, which can heat the plasma [4]. There is a weak vertical field is added by two separate set of external coils parallel to the Ohmic coil [5-7] provides additional stabilizing forces which required to prevent the radial expansion of the plasma column.

The Batorm is considered as one of the small and low cost devices. The first one (from 1998 to 2003) had aspect ratio (R/a) 1.68 with R = 6.125 cm and a = 3.625 cm. The toroidal coil consisted of 48 turns while the Ohmic coil had 22 turns and the vertical coil had 5 turns. In that work, there are four electrical circuits was designed and demonstrated to produce toroidal plasma inside the vacuum and magnetic vessel. The discharge energy was in the range between 45 J to around 384 J. It was during discharge time around 0.68 msec to 1.6 msec. The plasma current was between 3.4 KA to 12.75 KA with electron temperature from 2.25 eV to 9 eV by double electric probe [1].

Recently, updating Batorm configuration is beginning to increase the plasma properties (current, temperature and magnetic field). The new updating one will be explained in details in next section. Our study gives some preliminary results and makes complete survey to the plasma properties from this system. Also, it is considered as the first step to make use this plasma in different industry applications in future plan.

II. Design and Operation of the Batorm

The BATORM consists mainly of vacuum chamber, vacuum system, magnetic vessel and electric circuit [1]. The photographic view of the new Batorm is illustrated in figure (1). The vacuum chamber consists of two parallel aluminum plate electrodes, which is fixed at Pyrex glass discharge chamber of 15 cm length, and 32 cm inner diameter. At the center of it there is another glass tube of 15 cm length, and 10 cm outer diameter. So, the aspect ratio of this device R/a = 2. The working gas pressure of helium is 9 x 10^{-2}Torr.

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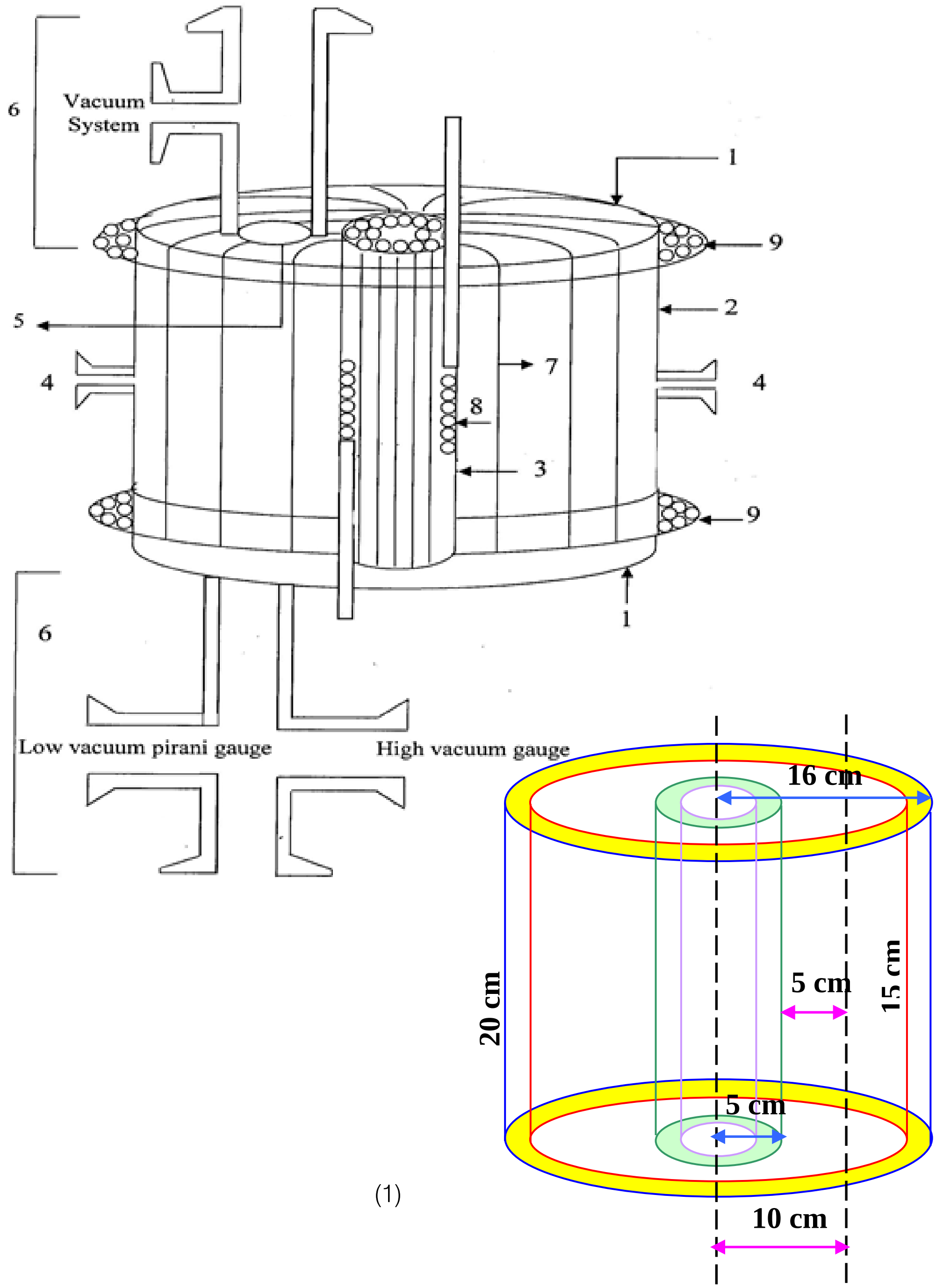
A magnetic vessel is used to contain and stabilize the plasma by Toroidal, Ohmic and Vertical coils. The toroidal magnetic field (TF) is produced by an external coil consisting of 75 turns wound directly on the discharge chamber after insulating the two electrodes. And the poloidal magnetic field is produced by 30 turns which generates large plasma current. These turns form the cylindrical air solenoid for the OH transformer. The weak vertical field is generated by two coils parallel to the OH-coil, each coil has 6 turns. The schematic diagram of the vacuum chamber and magnetic vessel is shown in figure (2).

Fig. 1: Photographic view of the BATORM device

The inductances of the toroidal, ohmic and vertical coils are calculated from the following equations (1) and (2) as [8]:

$$L_{toroidal} = \frac{\mu_o N^2 h}{2\pi} \ln\left(\frac{b}{a}\right) \quad (1)$$

$$L_{Solinoid} = \mu_o n^2 hA \quad (2)$$



(1)

Fig. 2: Schematic diagram of the plasma discharge chamber and magnetic vessel

1- Two parallel aluminum plate electrodes	6- Two (T) connections
2- Pyrex glass discharge chamber	7- Toroidal Coil
3- Glass tube	8- Ohmic coil
4- Three small ports	9- Vertical coil
5- Two large ports	

Where; μ_o is the permeability constant, n is the number of turns per unit length and A is the area of one turn. Therefore,

$$L_{toroidal} = 785\ \mu H,\ L_{Ohmic} = 28.4\ \mu H \text{ and } L_{vertical} = 121\ \mu H$$

So, the total inductance of the all coils: 934.4 μH.

III. Evaluation of Plasma Parameters

a) The Electrical Circuit and Operation Conditions

In this section, the electrical Circuit in our system has been investigated in figure (3). The plasma is initiated by linear axial discharge between the two plates which will apply an axial electric field all over the discharge. So, first make pre ionization by connected the two electrodes in series with DC power supply has 7 kV and 125 mA to get glow discharge plasma at 300 volts. Then to confine the plasma connected the Torodia, Ohmic and Vertical coils with the electric circuit which is illustrated in figure (3). It consists of three phase electric tap has a neutral point, three diodes as rectifier, three heater wire with different power values connected in series with the tree coils To, Oh, V during an overload 150 A.

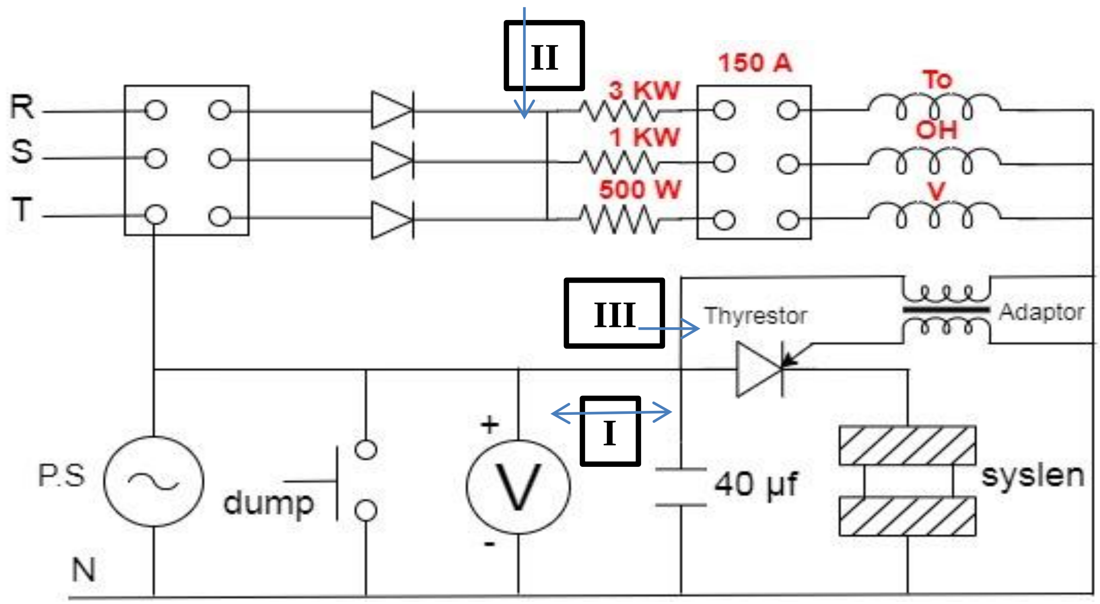


Fig. 3: Schematic diagram of the plasma discharge circuit. It has three parts (I) to produce plasma, (II) to prepare the coils to confinement the plasma and (III) as a trigger circuit to confinement the plasma.

The discharge period τ and the discharge current I_{dis} can be calculated from equations (3) and (4) as follows [1]:

$$\tau = 2\pi\sqrt{L_{total}C} \quad (3)$$

$$I_{dis} = \frac{2\pi CV}{\tau} \quad (4)$$

Where, *C* is the capacity of the capacitor bank. Therefore, I_{dis} = 2 A.

b) Double Probe Method

The double electric probe is a diagnostic tool to measure the electron plasma temperature and ion density. It consists of two identical probes, normally cylindrical configuration, biased with respect to each other by an external source voltage (V_{probe}) with an associated current (i_d), but the entire system floats with the plasma potential. Its technical data is illustrated in table (1). The double probe has an advantage that it can be used in plasma, with high space potential and it could disturb the plasma only at its location [9, 10].

If the potential difference between the probes is increased, then the relatively positive probe collects more electrons, until at a certain potential it reaches saturation.

Table 1: The technical Data for Probe Designing

Probe material	Tungsten
Tip length	4mm
Tip diameter	1.5 mm
Tip area	9.87 mm^2
Insulating material	Glass
DC power supply	From 0 V to 27 V

IV. The Experimental Results and Discusion

The (I-V) characteristics of double Langmuir probe at each cm of the length of the plasma inside the BATORM are shown in figure (4). In this figure the (I-V) characteristics for glow discharge drown by black points, while for toroidal confinement by red points. This figure illustrated that the confinement success to move the plasma far from the inner wall of the BAtorm (r = 11 cm) more than the outer wall (r = 0 cm).

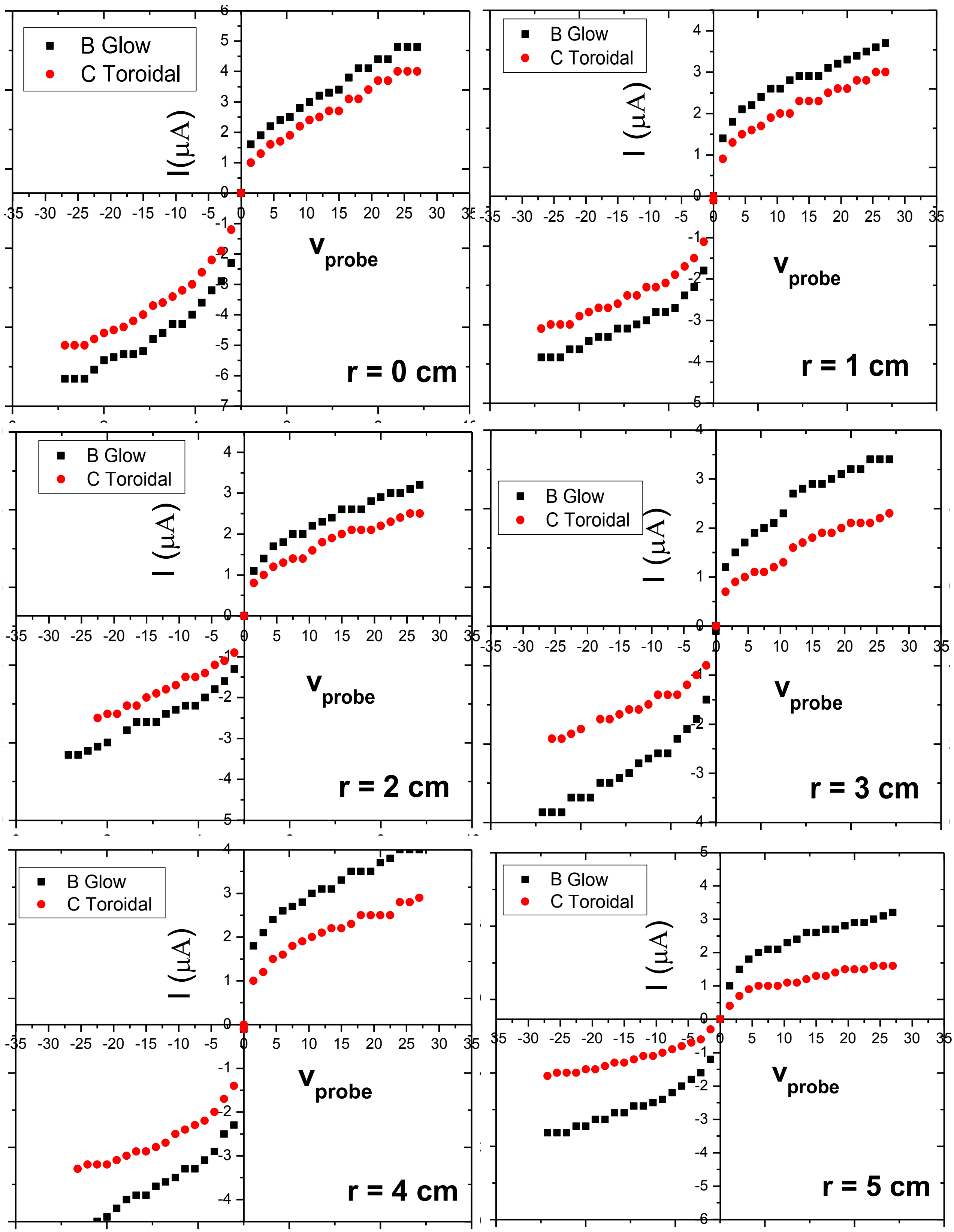
Table 2: The different values of electron temperature (KT_e), ion density (n_i) and energy density at different distances

r (cm)	KT_e (ev)	n_i (cm^{-3}) x 10^9	(KT_e x n_i) x 10^9
0	2.5	1.6	3.99
1	2.5	1.89	4.7
2	3.5	1.28	4.48
3	5.5	1.02	5.61
4	6.25	1.44	8.98
5	6.25	0.72	4.5
6	8.75	0.81	7.1
7	10	1.52	15.2
8	7.5	1.75	13.1
9	2.5	1.06	2.7
10	2.5	0.38	0.947
11	0	0	0

Figure (5) shows the variation of plasma temperature, plasma density and plasma energy density at deferent distances from 0 to 11 cm. From the results, it is clear that, the plasma has maximum temperature and density at distance 7 cm from the outer wall. Plasma is found around the minor axis but there are run away electrons which escape in direction of the outer wall. From knowing the energy density, the biggest value of plasma kinetic pressure is 15.2 x 10^9eV/cm^3; at 7 cm from the outer wall.

V. Conclusion

BATORM is the first toroidal plasma machine designed and operated in our lab at EAEA. This device is the first step to build small and not expensive plasma toroidal devices. The aim from them is to produce plasma in different properties by using available equipment and facilities. On condition, this plasma is in high accuracy to useful in different applications. By this way our lab will open contacts with the universities to explain experimentally and simply the plasma technology for students. Adding to contact with any destination need to use these sources of plasma in different applications such as industry, archeology, petroleum, medicine, agriculture, environment and etc. according to plan will stomach for each application.


B Glow
C Toroidal
I(μA)
V probe
r = 0 cm
r = 1 cm
r = 2 cm
r = 3 cm
r = 4 cm
r = 5 cm

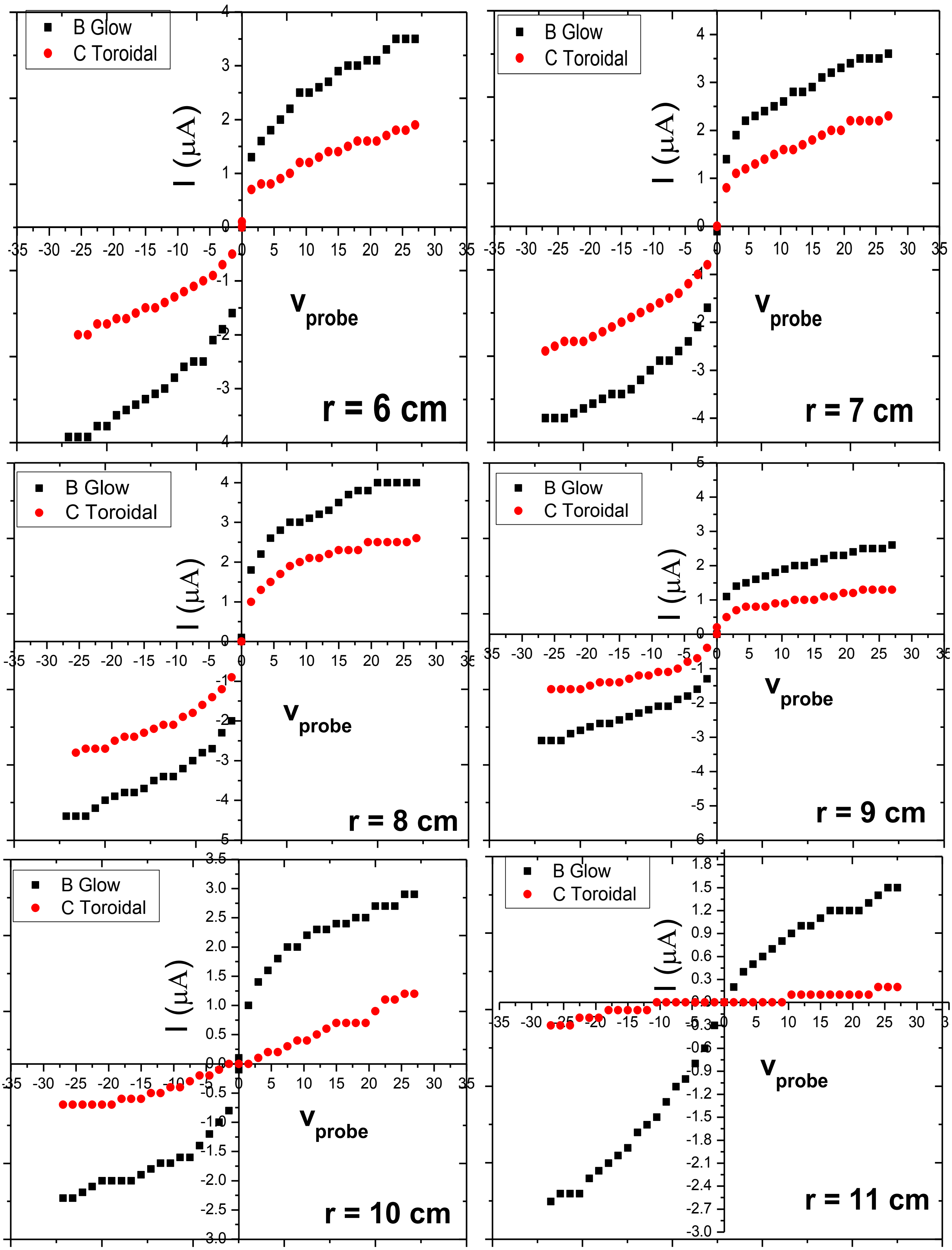


Fig. 4: The variation of plasma temperature, plasma density and plasma energy density at deferent distances from 0 to 11 cm

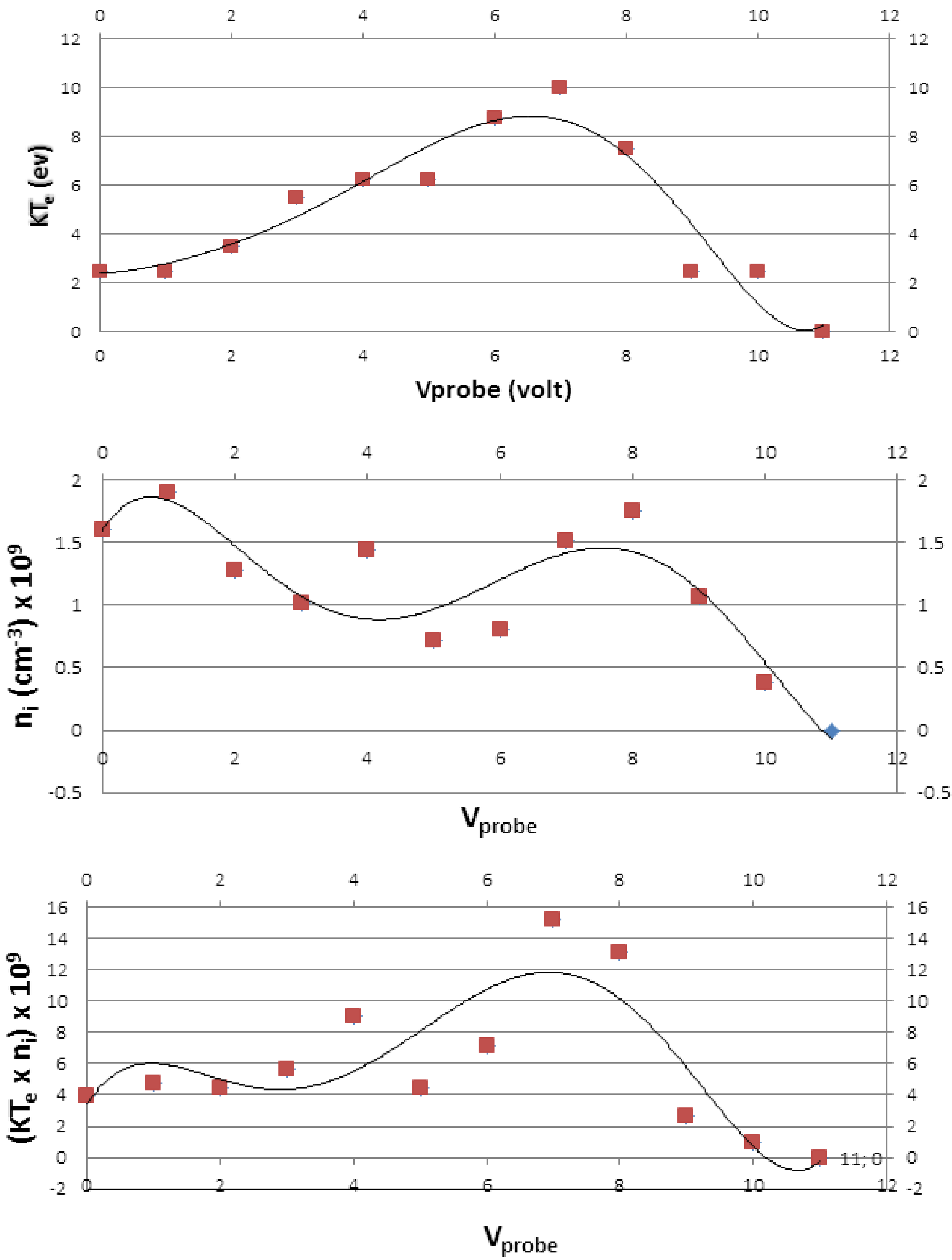


Fig. 5: The variation of plasma temperature, plasma density and plasma energy density at deferent distances from 0 to 11 cm

The BATORM device consists mainly of vacuum chamber & vacuum system, Toroidal, Ohmic & Vertical coils and electrical circuit. The vacuum chamber consists of two parallel aluminum plate electrodes, which is fixed at Pyrex glass discharge chamber of 15 cm length, and 32 cm inner diameter. At the center of this chamber there is another glass tube of 15 cm length, and 10 cm outer diameter. From that, the aspect ratio for this device is R/a = 2.

This is the first attempt to obtain DC plasma in BATORM device. The double electric probe estimates the electron temperature. The peak electron temperature is 10 eV and peak ion density is 1.5 x 10^9 cm^{-3}at 7 cm from the outer wall of the device.

It is clear that from the values of ion density, it could be increased the dc glow discharge voltage in future to give maximum values for n_i. Besides, it is possible to connect more capacitor banks with ohmic coil circuit to increase poloidal magnetic field. This work has be considered as the first step to produce a good view for Batorm system. This will be used as a sourse of toroidal plasma machien which very useful in different applications related to material science.

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