I. INTRODUCTION

Inductively Coupled Plasma (ICP) sources are known to have been widely implemented. Indeed these electrode-less, often rf driven sources require neither high voltages nor high currents. Typically they require a few hundreds of volts at a few tens of amperes, and the used frequency as a rule is below 15 MHz. These plasma sources are capable of producing dense low-noise uniform plasmas in a large volume. The plasma density might vary within a wide range: $10^9 - 10^{12}$ cm$^{-3}$ at electron temperature which could be as low as 1 eV. The plasma size may achieve several tens of cm. Such sources are widely used for many purposes, such as plasma processing (etching, surface cleaning, sputtering), light sources, etc. A distinct family of these ICP sources is Ferromagnetic ICP (FICP) sources. In an ordinary ICP device, plasma exists due to the induced electric field near the inductor-like antenna when rf voltage is applied to its input. The electric field is maximal in the inductor neighborhood and falls down to zero in the center, while the rf magnetic field of the inductor fills the whole volume. In the FICP the antenna appears as a magnetic core with a few turns of winding, which is fully immersed in the plasma. In this case the electric field fills the whole device and does not vanish at the core axis while most of the magnetic field of the winding is inside the magnetic core and does not penetrate into the plasma. Due to the magnetic core, the inductance of the FICP is high. Therefore, it is possible to drive this plasma source with comparatively low frequency and even to work with a relatively long single pulse which significantly simplifies the driver. The FICP device may in general achieve considerably denser plasma due to the greatly increased coupling brought on with the closed magnetic core.

In practice, there are two versions of such FICP device. The first one appears as a single comparatively thin toroidal ferromagnetic core having a large diameter. The opening of this core should exceed the required plasma size. In the second version the FICP consists of a large number (few tens) of small ferromagnetic cores which are properly connected to each other. These cores may be placed in space in various ways: in one plane, on a cylinder surface, etc. Both of these versions have the same advantages, such as very high efficiency (up to 99%) and very low minimal working pressure (about $10^{-4}$ Torr). These parameters are definitely better as compared to ordinary coreless ICP. The FICP devices, being driven by rf current, require a low frequency, typically 240-280 kHz, and with this frequency they show a very high cos $\varphi > 0.9$. The latter means almost pure active loading of the plasma source driver (e.g., an rf oscillator) which is a significant advantage over coreless ICP. For both these versions the driver fitting is very simple: just the number of turns winding should be chosen correctly like in ordinary transformers. The differences between these two FICP versions are the following: the multi-core version is able to produce a more uniform plasma (the non-uniformity could be below 3-4%) as well as it is able to form a required plasma density gradient, but the maximal plasma density usually did not exceed $2 \cdot 10^{12}$ cm$^{-3}$. The single-core FICP forms less uniform plasmas (the non-uniformity is about 7-10%) for the same plasma size (20-30 cm), and there is no option to vary the spatial distribution of the produced plasmas, but it is able to produce denser plasmas, up to $10^{13}$ cm$^{-3}$, with ionization rate above 90%. Another advantage of the single-core device is that its input resistance is often independent of the plasma density.

As we have already mentioned, due to the high initial inductance of the FICP device, it is possible to drive it even by a single pulse, e.g. by discharging a preliminary charged capacitor via the FICP primary windings. However, almost all studies of this device were performed with various rf drivers because of a clear reason: in this case the FICP devices produce stationary plasmas where the plasma exists during the whole operation time of the rf oscillator, including CW regime. On the other hand
these powerful (10-15 kW) oscillators could be rather sophisticated and expensive units. The only single-pulse “exception” was our early work, but even in that work a ballast inductor was connected in series to the primary winding. This was done in order to restrict the primary current, i.e., to eliminate the influence of the produced plasma on the pulse parameters and to expand the pulse. It is obvious that in this case processes of plasma creation and charged particles losses, as well as spatial and temporal plasma evolution, were “externally” disturbed. Advantages of single-pulse drivers are simplicity, low cost and, most importantly, very high pulsed power.

In this paper we present results of experimental study of an FICP plasma source with a single-pulse driver with no ballast and whose output impedance was minimized. Compared to the former experiments, we significantly increased the voltage across the plasma (by a few times) and the current through the plasma (by an order of magnitude), no matter whether they were rf-driven or operated in the single-pulse mode. The power delivered to the FICP could significantly increase the values needed for 100% ionization. Under these conditions the plasma evolution was investigated. This self consistent evolution resulted in drastic changes of the obtained plasma parameters, which significantly differ from those obtained for low power. This, in turn, shows that there is no sense to raise the driving power above a certain limit. These results could be important for optimal design of FICP sources.

II. APPARATUS DESCRIPTION

The experiments were carried out in a glass vacuum vessel of 32 cm diameter and 50 cm height, similar to our earlier work (see Fig. 1). This vessel was pumped to pressure $p$ of about $2 \cdot 10^{-4}$ Torr and then it was filled with He, Ar, or Xe. The measurements were performed within a pressure range of $10^{-4} - 2.5 \cdot 10^{-2}$ Torr. As a ferromagnetic core we used a Supermendure core having 15 cm outer diameter, 10 cm inner diameter and 5 cm height. The Supermendure core was chosen because of its high saturation level of about 3 T. It was surrounded by three coils, two of which consisted of 10 turns of winding and the third one consisted of just one turn. One of the 10-turn coils (shown in Fig. 1) was used as a primary coil and was connected via an electronic key to the charged capacitor. This $1 \mu$F capacitor could be charged up to 1.5 kV. The primary coil was shunted by a high-current diode to prevent the influence of the driver on the primary current after delivery of the stored energy to the plasma. Such scheme does not perturb the current caused by the plasma self inductance. The second 10-turn coil was used to eliminate the magnetization of the core. We passed through it a 2 A dc current which was sufficient. To prevent the influence of the dc-current source, we used a chock of about 100 mH inductance, which was sufficient as well. The third coil, namely the 1-turn coil, was used for diagnostics: to measure the voltage per turn and to control the absence of core saturation.

To measure the current through the primary winding (primary current $I_{pr}$) we used either a Current View Resistor (CVR) of 0.15 or a Current Transformer (CT), the discrepancy between them never exceeded a very few percent. A thin (about 2 cm) CT having a large (13 cm) diameter was designed, built and calibrated. This CT could be placed directly at the FICP top and it was used to measure the total current $I_{pl}$ induced in the discharge plasma. When the $I_{pr}$ and $I_{pl}$ waveforms were similar and the transformer ratio $I_{pl}/I_{pr}$ was close to 10, i.e., the number of the primary turns, there was no core saturation and the core losses were minimal. A very small discrepancy might be just at the beginning of the driving (primary) current $I_{pr}$ during $0.5-1.5$ μs – the time of the gas breakdown, which increased with the pressure reduction. When there was no discharge there was no demagnetizing current through the plasma and as a consequence the primary current waveform and value became very different. This indicated a minimal pressure $p$ for each sort of gas, namely 0.1 mTorr for Xe, 0.3 mTorr for Ar, and 5 mTorr for He. In all these cases the measurements were started from plasma current $I_{pl} = 200-300$ A, which was actually the maximal current for all former experiments.

In the presented experiments we used a low-power long-pulse hot-cathode discharge for plasma ignition. It is not shown in Fig. 1 but it was described in detail in our recent work. For plasma diagnostics we used combination of two methods: the plasma probing and microwave cut-off methods. To measure the parameters of the dense plasma produced by FICP during a high-current pulse we used a small semi-spherical single probe with collecting area of about 5 mm². This probe was well shielded, its outer diameter was about 4 mm.

FIG. 1. Experimental setup: (1) Supermendure magnetic core; (2) glass vacuum vessel; (3) electronic key; (4) storage capacitor, voltage divider and current transformer; (5) rectifier; (6) movable probe; (7) set of microwave antennas.
This probe mainly worked in the ion saturation current regime, so the area of its holder (4 mm diameter, 100 mm length) was quite sufficient to be used as a base electrode. To prevent parasitic signals this holder as well as the probe bias supply were insulated from the ground. To measure the probe current we also used a small current transformer. This probe was radially and axially movable. For microwave cut-off diagnostics we used 3 sets of transmitters and detectors. One set was for 9.5 GHz (critical plasma density $n_c = 6 \cdot 10^{13} \text{cm}^{-3}$), another one for 22.5 GHz ($n_c = 7 \cdot 10^{12} \text{cm}^{-3}$) and the third one for 70 GHz ($n_c = 6 \cdot 10^{13} \text{cm}^{-3}$). The transmitting antennas were placed above the upper FICP opening and the receiving antennas were placed below the bottom FICP opening, all of them were close to the FICP center.

III. EXPERIMENTAL RESULTS

When the negative bias applied to the probe exceeded a certain value (35 V for Xe, 45 V for Ar and 70 V for He) the ion probe current $I_p$ reached saturation. As a rule we worked with probe bias above these values. If the current induced in the plasma $I_{pl}$ during the discharge pulse did not exceed a certain value (200-400 A), the waveform of probe current $I_p$ was similar to the waveforms of the primary winding current $I_{pr}$ and to the induced current $I_{pl}$ (Fig. 2a). In the experiments described in Ref.4 the plasma current never exceeded this value. However, with the increase of $I_{pl}$ the $I_p$ waveform changed gradually. Above a certain threshold value of $I_{pl}$ the maximal value of $I_p$ increased significantly and its waveform became narrow and sharp (Fig. 2b). The dependence of the $I_p$ maximum on $I_{pl}$ is shown in Fig. 2c. It is seen there that the maximal value of the probe current $I_p$ increases abruptly starting from a certain threshold value $I_{th}$ of the plasma current $I_{pl}$. As it is seen in Fig. 2c, for $p = 1$ mTorr of Ar, $I_{th} = 950$ A. Very similar results were obtained with He and Xe, just the values of the maximal probe current $I_p$ and plasma threshold current $I_{th}$ were different for various gases and pressures. For each gas the threshold current $I_{th}$ increased slowly but monotonically with the increase of $p$: from 1050 A at $p = 0.1$ mTorr to 2050 A at $p = 1$ mTorr for Xe, and from 650 A at 5 mTorr to 1150 A at 25 mTorr for He.

The increase of the plasma current $I_{pl}$ caused not only the decrease of the probe current $I_p$ but also its strong dependence on the probe position. Two examples of this dependence in the middle cross sectional area of the FICP core are shown in Fig. 3a,b in the case when $I_{pl} < I_{th}$. They are comparatively smooth and very similar to those obtained in Refs. 6–9. Above the threshold, when $I_{pl} > I_{th}$, a narrow “filament” of $I_p$ appears in parallel to the core axis somewhat off center (Fig. 3c,d). The probe currents $I_p$ in the core openings (top and bottom) were approximately the same and just 20-25% less than in the middle core cross sectional area. It should be noted that the resolution of these measurements could not be better than the shielded probe diameter, i.e. 4 mm. A typical evolution of the filament location and its width vs the plasma current $I_{pl}$ is shown in Fig. 4a. The smallest measured filament width was never less than 5 mm, probably because of the probe resolution. Although for various gases and pressures there were different values of $I_{th}$, the location of the $I_p$ maximum was the same. It is also interesting to note that multiplying the measured pressure of Xe by 10 and dividing the measured pressure of He by 5, all dependencies of $I_{th}$ on $p$ for He, Ar, and Xe may be put together on the same curve, as it is shown in Fig. 4b. These factors of 10 and 5 are close to the ratios of the corresponding ionization cross sections within an order of magnitude.

To connect the measured ion probe currents to the plasma densities we used the microwave cut-off method (see e.g. 4 and refs. therein). Scope traces for a typi-
cal microwave cut-off signal for 70 GHz (critical density $n_c = 6 \cdot 10^{13} \text{cm}^{-3}$) and the plasma current $I_{pl}$ are shown in Fig. 3 for Ar at $p = 1 \text{ mTorr}$. The ion probe current $I_p$ and the plasma current $I_{pl}$ for the same case are shown in Fig. 3b. Similar waveforms were also obtained for He and Xe. For all sorts of gas and pressures the microwave cut-off appeared if the plasma current $I_{pl}$ was high enough and the cut-off existed just within a certain range of this plasma current. Strictly speaking, at the moments when the cut-off starts and ends, the corresponding plasma currents might not be equal to each other. Despite the fact that the maximal $I_{pl}$ could exceed 2.5 kA, these currents could usually be found within the range of 600-1400 A for Ar and 300-700 A for Xe. Typically $I_{pl}$ is larger in the beginning. These plasma currents tend to be smaller at higher pressures and for heavy gas. For Xe at $p = 1 \text{ mTorr}$ and $I_{pl} = 2.6 \text{ kA}$, the minimal cut-off holding current $I_{pl}$ is about 100 A (Fig. 3c). Note, that at the end of the pulse the plasma current exists due to the plasma self inductance, which is clear from the waveform of the voltage across the primary winding (Fig. 3d). Indeed, this voltage changes polarity during the pulse while the plasma current does not. When the cut-off appeared with the heavier gases, Ar and Xe, the value of the probe current $I_p$ at the cut-off moment depended on the sort of gas but was almost independent of $p$ and $I_{pl}$. For Ar $I_p = 49 \pm 2$ mA (averaged over 16 measurements) and for Xe $I_p = 23 \pm 1.6$ mA (averaged over 10 measurements). Also, when the cut-off appeared, its duration $t_{cut}$ increased very fast with the increase of $I_{pl}$ and then saturated as it is seen in Fig. 3d. It is also seen there that if the plasma current is kept constant ($I_{pl} = \text{const}$), the cut-off duration $t_{cut}$ tends to become higher with the increase of $p$: for Ar in the pressure range $p = 0.63 \text{ mTorr}$, $t_{cut}$ increased from 9 $\mu$s to 18 $\mu$s. Also $t_{cut}$ increased with the atomic weight of the gas. However, we never obtained $t_{cut}$ above 30 $\mu$s (for Xe at $p = 1 \text{ mTorr}$ and maximal $I_{pl} = 2.6 \text{ kA}$). This corresponds to the mentioned above minimal $I_{pl}$ where the cut-off stops at the end of the current pulse (Fig. 3d).

The results obtained with the lightest gas we used (He) were qualitatively similar but with one exception. Namely, when $I_{pl}$ reached the value needed for microwave cut-off, even a small overlap was enough for $t_{cut}$ to saturate. When it happened, the probe current $I_p$ in the cut-off beginning differed from $I_p$ at the cut-off end. Thus, the cut-off started with probe current $I_p = 120 \pm 8$ mA and ended with $I_p = 250 \pm 17$ mA. This result is correct for the whole pressure and plasma current ranges, 5-25 mTorr and 200-2000 A, respectively. At the minimal pressure for each sort of gas the collected probe current $I_p$ became unstable and the cut-off signal waveform became irregular.

These measurements were carried out with a 70 GHz microwave signal. The results allows one to estimate.

FIG. 3. Spatial distribution of ion probe current in the middle cross sectional area of the magnetic core for Xe at various pressures $p$ and plasma currents $I_{pl}$. a- $p = 0.1 \text{ mTorr}$, $I_{pl} = 430 \text{ A}$; b- $p = 1 \text{ mTorr}$, $I_{pl} = 480 \text{ A}$; c- $p = 0.1 \text{ mTorr}$, $I_{pl} = 1100 \text{ A}$; d- $p = 1 \text{ mTorr}$, $I_{pl} = 2700 \text{ A}$

FIG. 4. a- location of maximal $I_p$ vs plasma current $I_{pl}$ (upper curve) and its width at 70% of its maximum; b- plasma compression threshold current vs pressure $p$ for He (circles), Ar (triangle) and Xe (squares). Here the true pressure for Xe has been multiplied by 10 and for He it has been divided by 5.
the probe current became very sensitive to the voltage typically present in such plasma sources: beams, related to the voltage induced in the plasma and tens of volts, as needed for ion current saturation, the relevant in our case. When the probe bias was below a few electron temperature was not reliable in the plasma source. So, derivation of the plasma parameters from probe characteristics became problematic, in particular taking into account that in the present experiments the induced voltages and currents are definitely higher than even those in Ref. Oppositely, when the probe bias is sufficiently high, the ion saturation current $I_p$ is proportional to the plasma density $n$ and almost insensitive to the above mentioned factors. Comparing the voltage required to get the saturation and the evaluated values of $T_{\text{eff}}$ (tens of volt $\text{v} \text{s}$ volts), one might expect that intensive electron beams exist in the “cold” bulk plasma. The evaluated $T_{\text{eff}}$ was about 2-3 times smaller than the one obtained formerly in these plasma sources. To verify this point we compared the decay time of the afterglow plasma $t_{\text{dec}}$ at high and low plasma current $I_{\text{pl}}$. To do this, we used microwave oscillators for 9.5 GHz ($n_\text{c} = 1.2 \cdot 10^{12}\text{cm}^{-3}$) and for 24.6 GHz ($n_\text{c} = 7.7 \cdot 10^{12}\text{cm}^{-3}$) because for low $I_{\text{pl}}$ the plasma density is definitely smaller. Thus, with $p = 3$ mTorr of Ar and $I_{\text{pl}} = 300$ A, we obtained the microwave cut-off at 24.6 GHz a bit after the $I_{\text{pl}}$ pulse and the cut-off at 9.5 GHz at about 250 $\mu$s later. Taking into account the corresponding densities ratio (about 6 times), one might easily derive the plasma decay time $t_{\text{dec}} = 120\mu$s. The same measurements done with $I_{\text{pl}} = 1800$ A showed for the microwave frequency of 24.6 GHz a cut-off delay of about 300 $\mu$s and for the 9.5 GHz – about 800 $\mu$s. The difference was about 500 $\mu$s and, consequently, $t_{\text{dec}} = 270\mu$s. This decay time is more than twice longer than in the “low current” case, which at least indirectly confirmed our considerations concerning low $T_{\text{eff}}$. This could be qualitatively understood taking into account that the high-energy fraction of plasma electrons contains more energy in the “high current” case and this fraction disappears very fast during decay processes, in the absence of induced electric and magnetic fields.

IV. DISCUSSION

A remarkable result which is clear from the present measurements is the fact that at low pressures the neutral atoms density $N$ is more than an order of magnitude below the critical plasma density of $n_\text{c} = 6 \cdot 10^{13}\text{cm}^{-3}$ required for microwave cut-off at 70 GHz. Indeed, for Xe at $p = 0.1$ mTorr we have $N = 3.6 \cdot 10^{12}\text{cm}^{-3}$. The reason is the plasma compression instead of more or less evenly distributed plasma inside the magnetic core at low $I_{\text{pl}}$, a thin cylinder of dense plasma appears somewhat aside of the core axis (Fig. 3b). Considering the total ionization of the neutral gas inside the core, which was quite reasonable even with $I_{\text{pl}} = 200-300 \text{A}^\text{2}$, it is easy to estimate the level of such compression. For the minimal pressure of Xe and total ionization, the density of the uniformly distributed plasma is $n = 3.6 \cdot 10^{13}\text{cm}^{-3}$. Taking into account that the probe current is $I_p = 23$ mA for Xe and critical plasma density

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\text{falls and currents in the plasma, i.e. to the regime of the plasma source. So, derivation of the plasma parameters from probe characteristics became problematic, in particular taking into account that in the present experiments the induced voltages and currents are definitely higher than even those in Ref. Oppositely, when the probe bias is sufficiently high, the ion saturation current $I_p$ is proportional to the plasma density $n$ and almost insensitive to the above mentioned factors. Comparing the voltage required to get the saturation and the evaluated values of $T_{\text{eff}}$ (tens of volt $\text{v} \text{s}$ volts), one might expect that intensive electron beams exist in the “cold” bulk plasma. The evaluated $T_{\text{eff}}$ was about 2-3 times smaller than the one obtained formerly in these plasma sources. To verify this point we compared the decay time of the afterglow plasma $t_{\text{dec}}$ at high and low plasma current $I_{\text{pl}}$. To do this, we used microwave oscillators for 9.5 GHz ($n_\text{c} = 1.2 \cdot 10^{12}\text{cm}^{-3}$) and for 24.6 GHz ($n_\text{c} = 7.7 \cdot 10^{12}\text{cm}^{-3}$) because for low $I_{\text{pl}}$ the plasma density is definitely smaller. Thus, with $p = 3$ mTorr of Ar and $I_{\text{pl}} = 300$ A, we obtained the microwave cut-off at 24.6 GHz a bit after the $I_{\text{pl}}$ pulse and the cut-off at 9.5 GHz at about 250 $\mu$s later. Taking into account the corresponding densities ratio (about 6 times), one might easily derive the plasma decay time $t_{\text{dec}} = 120\mu$s. The same measurements done with $I_{\text{pl}} = 1800$ A showed for the microwave frequency of 24.6 GHz a cut-off delay of about 300 $\mu$s and for the 9.5 GHz – about 800 $\mu$s. The difference was about 500 $\mu$s and, consequently, $t_{\text{dec}} = 270\mu$s. This decay time is more than twice longer than in the “low current” case, which at least indirectly confirmed our considerations concerning low $T_{\text{eff}}$. This could be qualitatively understood taking into account that the high-energy fraction of plasma electrons contains more energy in the “high current” case and this fraction disappears very fast during decay processes, in the absence of induced electric and magnetic fields.

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of \( n_e = 6 \cdot 10^{13} \text{ cm}^{-3} \) a probe current of \( I_p = 1000 \text{ mA} \) (maximal \( I_p \) at \( p = 0.1 \text{ mTorr} \)) corresponds to a plasma density of \( n = 2.5 \cdot 10^{15} \text{ cm}^{-3} \). Therefore the compression ratio is about 670. This means that the initially uniform plasma for an inner FICP diameter of, say, 10 cm should be reduced by approximately 26 times (sq. root of 670) to a diameter of about 3.8 mm. This is close to the minimal size of the plasma that we measured, i.e., close to the spatial resolution of the probe. It seems likely that plasma compression was caused by the magnetic field, which, in turn, was caused by the high current \( I_{pl} \) induced in the plasma.

For example, suppose that at low gas pressure the plasma compression started from a plasma current of about 500 A and the corresponding plasma diameter was about 6 cm (Fig. 3a). Then one could easily derive that the magnetic field \( H \) at the plasma boundary was approximately 30 Gauss. Considering an electron temperature of, say 3 eV, it is easily seen that the equality \( H^2/8\pi = nT_e \) leads to a plasma density of \( n = 1.5 \cdot 10^{13} \text{ cm}^{-3} \). This was sufficient for plasma compression because at low gas pressures (0.1-0.3 mTorr) and total ionization, the plasma density should be within the range of \( 3.5 \cdot 10^{12} - 10^{13} \text{ cm}^{-3} \).

A more or less exact description of the plasma dynamics during the comparatively short pulse is a very sophisticated problem. On one hand, many parameters and processes should be taken into account, such as ionization and charged particles losses, self consistent influence of the induced electric fields and currents, etc. On the other hand, it is quite clear that at low gas pressures just plasma compression may provide a microwave cut-off for 70 GHz. Note, that at low pressures all the mean free paths of the charged particles do exceed the core size and just a magnetic field may hold the plasma inside the device volume, reducing the wall losses. The fact that at least at low pressures the cut-off starts and ends when the plasma current is quite large, confirms this statement. On the contrary, when the gas pressure is high, a high ionization rate is not needed to get the cut-off and the mean free paths are small compared the device size. In this case collisions should impede the charged particle losses, i.e. there is a certain sense that the diffusion processes play a role of plasma confinement. As a consequence, a high plasma current is not needed for the microwave cut-off at high gas pressures which is also the experimental result: the microwave cut-off duration \( t_{cm} \) increased slowly but monotonically with the pressure increase (Fig. 5d), and could be comparable to the duration of the whole current pulse in the case of Xe (Fig. 5c). In the latter case the plasma current does not exceed 100 A at the cut-off end.

It is interesting to note, that if the plasma current pulse was strong enough, near its top the microwave detector received a weak microwave signal for a short time (Fig. 5b). This is understood because at the highest \( I_{pl} \) the compressed plasma “string” might be too thin, even less than the measured 4 mm. Taking into account that the microwave wavelength was just 4.3 mm and a certain displacement of the plasma string from the axis took place (Fig. 5b), microwave “leakage” was possible. It should also be noted that at the highest pressures we worked with (5-25 mTorr of He) even the fast fraction of plasma electrons might have enough collisions to stay longer inside the core and, as a consequence, to further heat the bulk plasma electrons (in our case from 1.5 to 6 eV).

V. CONCLUSION

We have shown that a number of advantages of FICP sources, such as plasma uniformity, high ionization rate, absence of magnetic field etc., are naturally limited. These limitations are not connected to the ferromagnetic core saturation or other design-related reasons. With the increase of the plasma driving power, the initially uniform plasma becomes strongly compressed from the periphery inwards and evolves into a thin string somewhat near the center. This compression (pinch) might be associated with the full ionization of neutral gas in the inner core volume. The reason of this plasma pinch is the self consistent magnetic field which appears in the plasma due to the induced electric current. This phenomenon is related to the basic principle of this device operation (actually this is a transformer) and could not be eliminated. This plasma compression is accompanied with a certain reduction of the bulk plasma electron temperature.

Consequently, if the aim is a large volume of uniform plasma, the power delivered to the device should not exceed a certain value, which could be simply estimated. We believe that this restriction is valid not only for a single-pulse driven FICP but also for rf-driven versions of such device. On the other hand, if the aim is a long-lasting dense afterglow plasma, it should be reasonable to exceed this threshold value needed for plasma compression.

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