Investigation of Oxygen-Induced-Arcing in Cs-Seeded Negative Ion Source*)

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High-power and long-pulse arc discharges of 150 kW for 100 s have been achieved for the first time by suppressing oxygen-induced-arcing which was one of the critical issues on JT-60SA negative ion source. Toward the realization of such arc discharge, the suppression of recycling of oxygen from the arc chamber wall was found to be a key issue in the large-size arc-driven negative ion source. Because the experimental results showed that this oxygen was derived from release of water due to high temperature chamber wall of heated by an arc discharge, the baking of the arc chamber was tried to reduce water adsorbing to the chamber before the long-pulse discharge. After the baking at 80 °C for 8 hours, since the oxygen level was reduced to half of that before baking, the available pulse duration became twice longer. By combining this baking and long-pulse conditioning shots, the stable long-pulse arc discharge has been obtained. This result contributes to the improvement of availability of the large-size negative ion sources which require long-conditioning time.

Keywords: ion source, arcing, JT-60SA, N-NBI

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1. Introduction

Reliable long-pulse injections of 500 keV 10 MW D^0 beam are required on the negative-ion-based neutral beam injector (NBI) for JT-60 Super Advanced (JT-60SA) [1,2]. For this purpose, a large negative ion source has been developed to achieve negative ion current of 22 A for 100 s [3–5].

In the past experiment of high-power long-pulse operations, the achievable beam current and pulse width had been limited by unstable arc discharge, so-called, arcing, which is an abnormal localized discharge. Because this arcing not only limits the available arc power and pulse width but also shortens life of filaments, the suppression of the arcing is one of critical issues in order to realize JT-60SA negative ion source. However, because causes of the arcing has not been fully clarified yet even in the case of without cesium (hereinafter Cs), there was no available technique to suppress arcing.

In the previous experiment, before arcing terminated the long-pulse discharge, a rapid increase of oxygen was typically observed. Therefore, in this paper, oxygen-induced-arcing is investigated as one of the cause of the arcing in the long-pulse discharge. And based on understanding of the cause of arcing, a countermeasure to extend the pulse width is discussed.

2. JT-60SA Negative Ion Source

JT-60SA negative ion source, which is under development by improvement of ion source used in JT-60U [6–8], is shown in Fig. 1. This ion source has semi-cylindrical arc chamber, called KAMABOKO shape. This is the world largest one, having 600 mm of diameter and 1200 mm of length. In this ion source, arc discharge is driven by 48 tungsten filaments divided into 8 series. Produced arc discharge plasma is confined by cusp magnetic field made by permanent magnets arranged around the arc chamber and external magnetic filter field above a plasma grid.

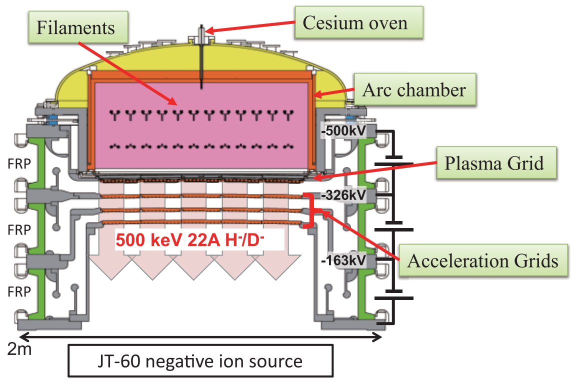

Fig. 1 Schematic view of JT-60SA N-NBI ion source.

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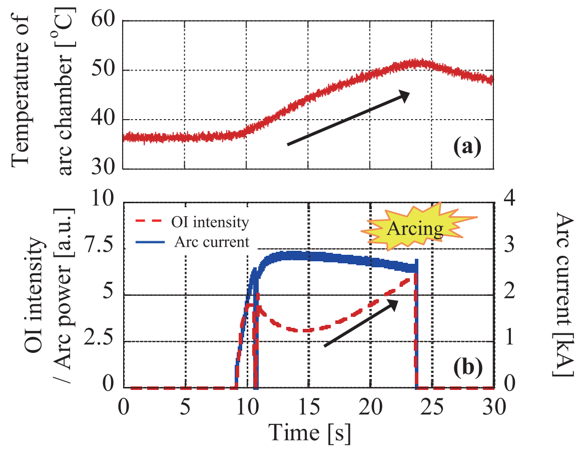

Fig. 2 (a) Increase of Temperature of the arc chamber with pulse width. (b) Variation of oxygen intensity and arc current with pulse width.

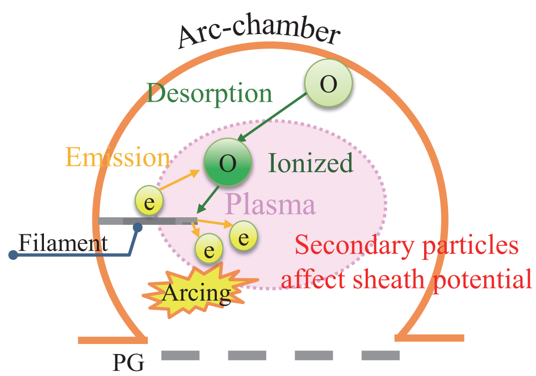

Fig. 3 Schematic model of putative arcing mechanism.

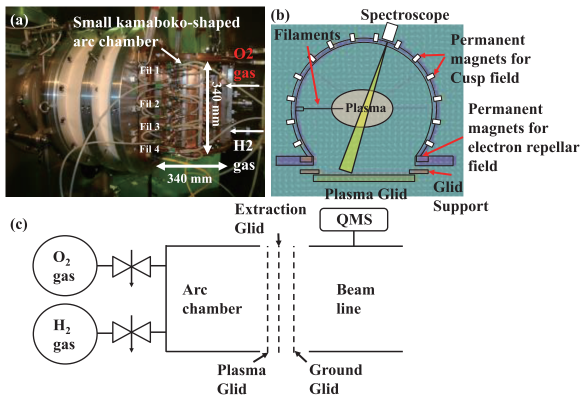

Fig. 4 (a) Photo of the test stand. (b) Schematic view of cross section of the ion source. (c) Schematic view of test stand beam line.

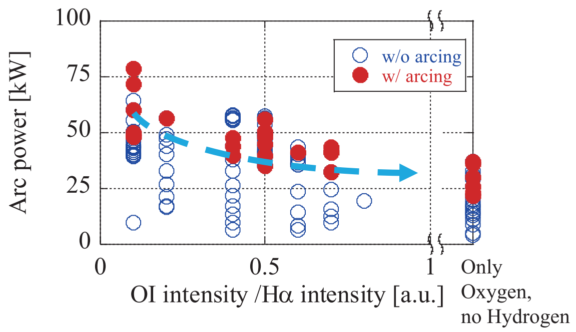

Fig. 5 Critical arc power of each amount of Oxygen. Dashed line means 70 % line, above this line arcing occurred in 70 % or more probability.

The previous results was obtained in the long-pulse experiment as shown in Fig. 2. As shown in Fig. 2 (a), the temperature of the arc chamber increased with pulse width. At the same time, as shown in Fig. 2 (b), intensity of oxygen in plasma also increased. Before the arcing occurred, intensity of oxygen rapidly increased. This fact implied that arcing was induced by oxygen.

Based on this consideration, following model of arcing is considered as shown in Fig. 3. In this model, desorbed oxygen molecule is ionized by fast electron emitted from filaments, and oxygen ions are accelerated to a filament by plasma sheath potential. Due to large mass of oxygen ion, more secondary particles is produced through the sputtering process than that for hydrogen ions. This secondary particle production affects plasma sheath potential locally. This local potential variation can causes unipolar arcing [9].

3. Experimental Set Up

In order to investigate the oxygen-induced-arcing, the half scale ion source of JT-60SA negative ion source was employed as shown in Fig. 4 (a). Because this half scale ion source has same magnetic configuration, which is shown in Fig. 4 (b), as JT-60SA negative ion source, same physical mechanism as JT-60SA negative ion source in arc chamber can be simulated.

This ion source has KAMABOKO shape [10] with 340 mm of diameter and 340 mm of length. Arc discharge is driven by 4 filaments made from tungsten in this ion source.

This time, in order to simulate the oxygen-rich situation as in long-pulse operation, as shown in Fig. 4 (c), O_2 gas was injected into the arc chamber artificially as well as hydrogen gas. Amount of oxygen in plasma was controlled by flow rate of O_2 gas injected into the arc chamber and measured with a spectroscope through an optical system installed on the arc chamber. Residual gas flow into beam line was measured by quadrupole mass spectrometer (hereinafter QMS).

Arcing was detected as unintended rapid increase of arc current. When arcing is detected, an interlock system cut off a power source to prevent severe damage on filaments.

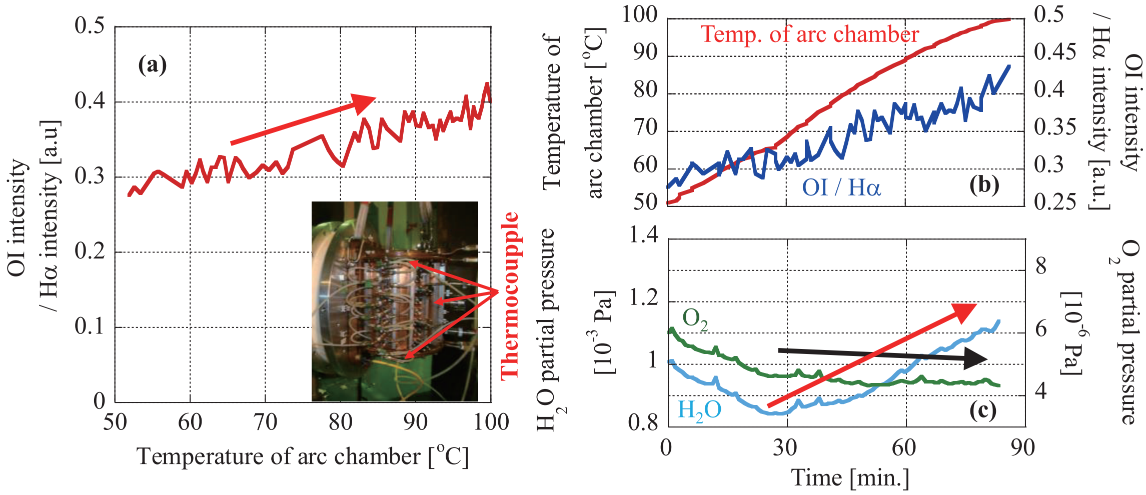

Fig. 6 (a) OI intensity against Temperature of the arc chamber. (b) Temperature of the arc chamber and OI intensity against time. (c) Partial pressure of H_2O and O_2 against time.

4. Experimental Results

4.1 Simulated experiment of oxygen desorption as long-pulse operation

In order to investigate an influence of oxygen on arcing and resultant arc power, the critical arc power, above which arcing occurs, was examined against amount of oxygen in plasma as shown in Fig. 5. The amount of oxygen was relatively evaluated as a ratio between an emission intensity of OI (777 nm) and Hα (656.3 nm). This oxygen level is controlled by increasing the flow rate of oxygen with keeping the flow rate of hydrogen. The flow rate of oxygen was kept lower than 1 % of that of hydrogen and pressure change caused by adding oxygen was negligible. At each oxygen level, probabilities of arcing against arc power were measured and the critical arc power is defined to be the power where arcing occurs over the possibility of 70 %.

At the normal operational condition, the oxygen level is around 0.1, where the critical arc power is 60 kW. By increasing the oxygen level up to 0.2, the critical arc power become less than 50 kW. Finally, the critical arc power is decreased to half of the normal condition at an almost oxygen plasma without hydrogen gas flow.

This result suggested that increase of oxygen in plasma certainly induced arcing. In other words, increase of oxygen in plasma is one of the cause of arcing occurrence in high-power long-pulse operation.

4.2 Origin of the increasing of oxygen in plasma

The origin of the increase of oxygen in long-pulse operation was investigated to consider an available techniques to suppress oxygen-induced-arcing.

In order to investigate the origin of oxygen, temperature increase of arc chamber in long-pulse operation was simulated by heating arc chamber artificially. By using heaters and radiation heat from filaments, the temperature of the arc chamber was increased up to 100 °C in 90 minutes as shown in Fig. 6 (b). As a result shown in Fig. 6 (a), oxygen level increased with temperature increase of the arc chamber wall as well as long-pulse operation. At 50 °C oxygen level was around 0.3. By increasing the temperature of the arc chamber up to 100 °C, the oxygen level increase to about 0.4.

At the same time, as shown in Fig. 6 (c), while partial pressure of water measured by QMS was increased, increase of oxygen gas did not measured. This result suggested that increase of oxygen level in plasma was derived from water which was desorbed from the wall due to the temperature increase. Therefore, baking of chamber wall was found to be one of the available techniques to reduce water on the wall, which had not been used previously because the temperature of the permanent magnets was limited below 150 °C.

In order to confirm the availability of baking on suppression of oxygen-induced-arcing, baking of over 60 °C and 2.5 hour was applied. As a result shown in Fig. 5, oxygen level was reduced from 0.4 to 0.1, and achievable arc power was improved. Therefore, it is confirmed that reducing absorption water using baking was effective to suppress oxygen-induced-arcing.

5. Application of JT-60SA Negative Ion Source

Based on the experimental results, the baking of chamber wall was also applied to JT-60SA negative ion source by circulating hot water of 80 °C in the cooling channels of the arc chamber for 6 hours.

After this baking, as shown in Fig. 7, oxygen level in plasma was reduced to half of that before the baking. In the operation before baking, oxygen level rapidly increased within 20 s and the arcing prevent longer pulse operation

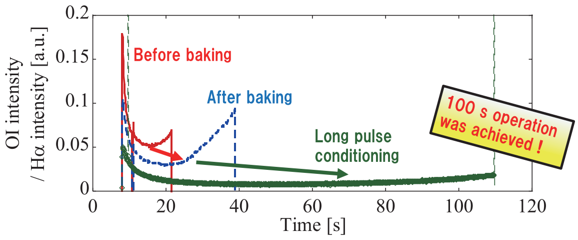

Fig. 7 Extension of achievable pulse width in JT-60 SA negative ion source operation with baking.

longer than 20 s. On the other hand, in the operation after baking, oxygen level increase was suppressed at low level even in 100 s long-pulse operation. Thanks to this reduction of oxygen level in the plasma, achievable pulse width was extended and finally 150 kW, 100 s operation was achieved.

6. Summary

Oxygen-induced-arcing was investigated to extend the pulse width of the high-power arc discharge. As a result, it was found that increase of oxygen level during long-pulse operation is derived by water desorbed from the heated arc chamber wall, which is one of the cause of arcing. Therefore, one of available techniques to suppress oxygen-induced-arcing is found to be the baking of the arc chamber.

Appling this result to JT-60SA negative ion source, 150 kW and 100 s operation was achieved by reducing the oxygen level after baking.

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