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STUDIES ON IMPURITY CONTROL AND HYDROGEN PUMPING WITH CHROMIUM GETTERING IN ISX-B *

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1. Introduction

Gettering inside the vacuum vessel has been employed in many tokamaks [1-3] and has led to strongly reduced impurity radiation and expansion of the operating space. Except for one brief test with chromium [4], titanium has been used until now as getter material, mostly because sources for large-scale applications are commercially available. One of the characteristics of titanium is that it pumps large amounts of hydrogen by bulk diffusion even at room temperature. As a consequence, titanium gettering requires increased gas flow rates and entails large hydrogen inventories. In contrast, chromium pumps hydrogen only in monolayer quantities on the surface without subsequent bulk diffusion. Therefore, chromium gettering allows the control of impurities without increased gas flow rates or hydrogen retention at the wall. This has the added advantage of minimizing the tritium inventory in DT-burning fusion devices.

2. Physics data base and gettering technique

A comparison of the gettering characteristics of chromium and titanium has been reported in a previous paper [5]. It was found that pumping of impurity gases like oxygen and nitrogen is very similar for titanium and chromium. Hydrogen pumping on the other hand, is different for these two getter materials: chromium pumps hydrogen isotopes by surface adsorption only, whereas titanium absorbs large amounts of hydrogen by

surface adsorption followed by bulk diffusion.

To cover many square meters of surface area with the getter material, large scale chromium sublimation sources have been developed which are similar to the widely used VARIAN Ti-Balls™ [6]. Since the vapor pressure of chromium is higher than that of titanium at a given temperature, chromium gettering requires lower temperatures for given sublimation rates.

3. Gettering procedure

To test chromium gettering in ISX, two getter sources, separated toroidally about 180°, were installed in the torus. The sublimation rate was chosen to be 0.1 g/h for each source. A typical getter cycle lasted for 30 min. This procedure was identical to the usual titanium getter cycle in ISX to facilitate comparison between chromium

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Fig. 1. Total radiated power from the plasma normalized to line-average density as a function of shot number before and after chromium gettering.

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and titanium. The gettered area in the torus is estimated to be 70% with a film thickness of 1–10 monolayers and about 5% with a coverage of 10–100 monolayers. From an operational viewpoint, chromium gettering was very convenient. While titanium sources have to be outgassed and conditioned, sometimes for several hours, outgassing of the chromium balls was negligible. After only 5 min into the getter cycle all impurity gases (H_2O , N_2 , CO etc.) in the residual gas were reduced by factors of 3–5. And after a full getter cycle of 30 min all impurities were down by almost an order of magnitude.

4. Impurity control

After chromium gettering the total radiation from the plasma was strongly reduced. The content of individual impurities – as measured spectroscopically was reduced by factors of 3–5. Fig. 1 shows the total radiated power from the plasma, normalized to the line-average density, before and after chromium gettering. In addition to reduction of total radiated power from the plasma, the discharges display high reproducibility after gettering, i.e. normalized radiated power was monitored for up to 50 discharges after the getter cycle and no exhaustion of the impurity pumping capability was observed.

5. Hydrogen pumping

Titanium gettering entails large pumping speeds and capacities for hydrogen species. To obtain reproducible discharges without tedious adjustments of the gas puff

between shots, a procedure has been established in ISX that is referred to as "ungettering". It involves puffing a large amount of hydrogen into the torus to saturate the titanium, thus reducing the hydrogen pumping speed to a tolerably small value. This procedure does not affect the impurity pumping capability, because hydrogen on the getter surface is continually replaced by the more reactive gases like oxygen. In contrast to this behaviour, chromium gettering does not significantly change the pumping speed or capacity of the walls for hydrogen isotopes. To demonstrate this, fig. 2 shows the line-average gas flow rate as function of shot number before and after gettering. It appears that the required gas flow rate for a given density is affected for only 2 shots after the getter cycle, and in subsequent discharges the effect becomes negligible. The same effect is observed if we merely interrupt tokamak operation for about 30 min. It is assumed, therefore, that an increased gas flow rate is necessary to establish an equilibrium wall loading. Comparing individual shots before and after chromium-gettering, the same line-average density is obtained for a given gas flow rate. After titanium gettering, on the other hand, gas flow rates have to be increased by factors of 2–3 to maintain a given density.

6. Operating space

Finally, it is worth mentioning that the operating space has been increased significantly after chromium gettering. A maximum line-average density of $1.5 \times 10^{14} \text{ cm}^{-3}$ has been achieved. This is the highest density observed in ISX. It corresponds to a Murakami parameter of 11 at $q_0 = 0$. Thus, the expansion of the operating space after chromium gettering is similar to that after titanium gettering without the disadvantage of increased gas flow.

7. Conclusions

Chromium gettering has been proven to be a trouble-free and efficient method of surface pumping in tokamaks. The impurity control capabilities are excellent and comparable to that of titanium. The hydrogen uptake is reduced to monolayer quantities on the surface. The expansion of the operating space is similar to that seen with titanium without the disadvantage of strongly increased hydrogen fluxes. Possible applications of chromium gettering are: impurity control in contemporary tokamaks; surface pumping in short pulse DT-burning devices to minimize tritium inventory, and

Fig. 2. Line-averaged density normalized to gas flow (ϕ is the gas flow rate) as a function of shot number before and after chromium gettering.

wall-conditioning of future large machines prior to operation.

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