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LITHIUM WALL CONDITIONING TECHNIQUES IN ADITYA-U TOKAMAK FOR IMPURITY AND FUEL CONTROL

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Importance of Lithium Wall Conditioning in ADITYA-U Tokamak

➢In fusion devices, various techniques of low-Z material coating like Lithium, Boron, and Silicon are performed to generate better plasma discharges.

➢In ADITYA-Upgrade tokamak, different techniques of Lithium wall conditioning are developed to get uniform and sustainable coating of Lithium on Plasma facing components (PFCs) and vessel wall.

➢In current study, two techniques are used to generate Li from source, first Li-rod sputtering by H ion and atoms in H-glow discharge cleaning (H-GDC) and second vaporization from high temperature Li-Evaporator.

➢With Li-evaporator operation, H-glow discharge is also carried out to uniform distribution of Li-vapour in toroidal chamber.

➢Additionally, the Lithium is highly reactive with H ions and atoms compare to H2 gas, thus in H-GDC with Li vapour creates more Lithium Hydride (Li-H) molecules on vessel wall and PFCs.

➢ The melting temperature of Li-H is very high 688.7° C compare to Lithium melting temperature 180.5° C. As result, the Li-H contained, Li wall conditioning effect sustains for long period of plasma operation compare to physically deposited Li atoms.

➢In ADITYA-U, due to high surface area of Graphite PFCs, the major concerns for plasma performance are carbon impurity and Hydrogen recycling.

➢The combination of Li sputtering, Li evaporation, H-GDC, He-GDC, Ar-H mixture GDC are used to get better plasma discharges.

Development of Lithium Wall Conditioning Techniques

(A)Heated Lithium rod (120° C) sputtering by Hydrogen glow discharge

- Location: Installed on 6 Radial Mid-plane on Aditya-U Vacuum Vessel
- Parameters: Lithium Rod Baking max. 120º C using Silicon insulated Heater; Fresh Rod Size: 12.5 Dia, 6 cm Long
- ADITYA-U Glow Discharge Cleaning System: 0.5 to 2.0 A, 400-800 V, H_2 Gas Pressure : 2 - 5 x 10^{-4} Torr, n_e = 10^{12} to 10^{13} /m3, T_e = 1 – 3 eV

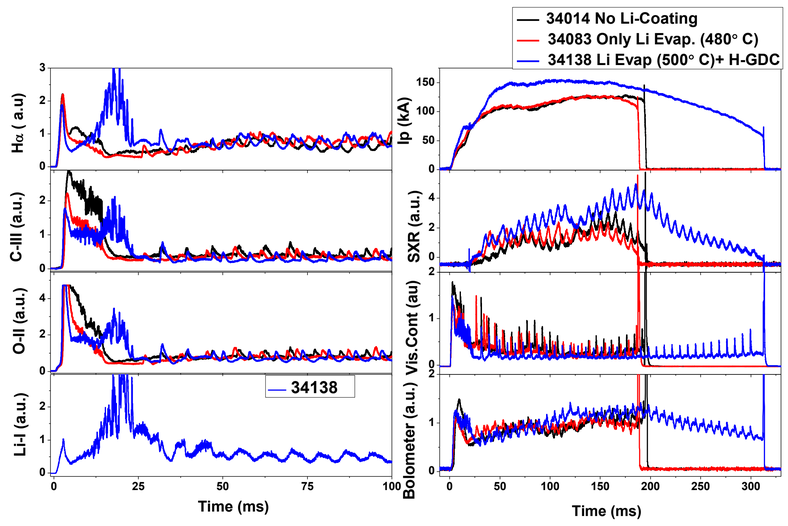
(B) Lithium vaporization by developed Li-Evaporator (600° C)

- Location: Installed on 8 Bottom Middle on Aditya-U Vacuum Vessel
- Parameters: Lithium Evaporator Storage capacity: 10 grams of Li
- Baking Capacity : Upto 600º C using SS Clamp Heaters (3 Nos.); Sensor: k-type Thermocouple
- ADITYA-U Glow Discharge Cleaning System: (As above mentioned parameter)

Using these two Li-Generation systems; various Lithium wall conditioning techniques Studied with following Combinations:

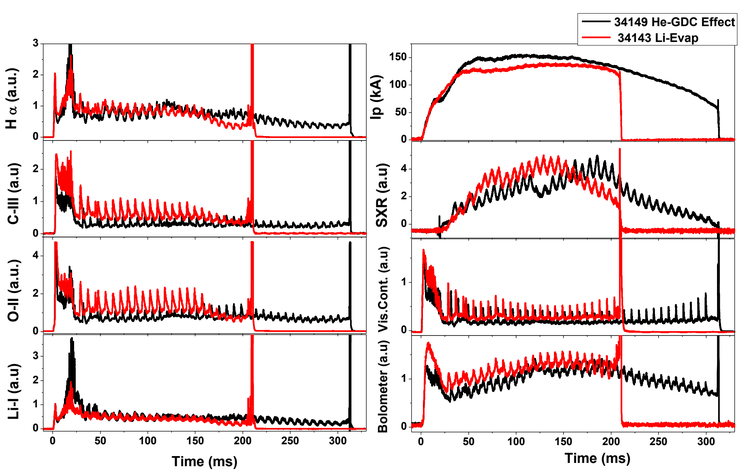
I. Heated Lithium rod with H-GDC
II. Lithium coating by developed Li-evaporator system
III. Combination of Lithium Evaporator operation of different temperature under H-GDC
IV. Effect of Helium GDC with Lithium coating
V. Combination of Ar-H mixture GDC then Lithium coating with H-GDC

Li- Evaporator Performance



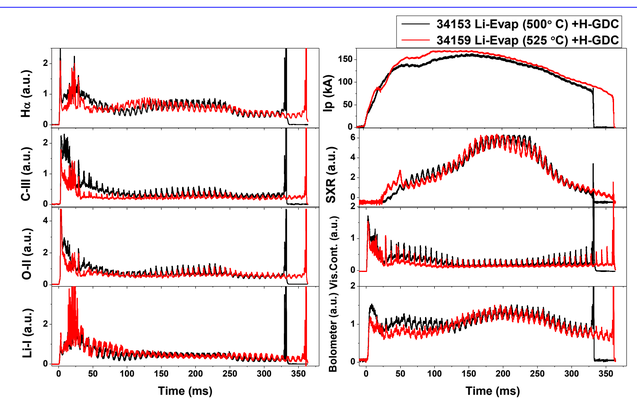
❖ plasma discharge shots as 34014 –No Li Coating, 34083- Only Li evaporator operation at 480° C for 2 Hours., 34138- Li-Evaporator operation at temperature 500° C and under Hydrogen glow discharge conditioning (H-GDC) for 2 Hrs
❖ The C-III and O-II impurity line radiation and visible continuum in 34083 and 34138 are reduced 30- 50 % compare to no Lithium coating shot 34014
❖ plasma current, duration, soft x-ray, less impurities with low recycling has been observed in 34138 as effect of Li- evaporator with H-GDC. While in 34083 has marginal improvement compare to 34014

Effect of Helium Pulsed Glow discharge on Lithium coating



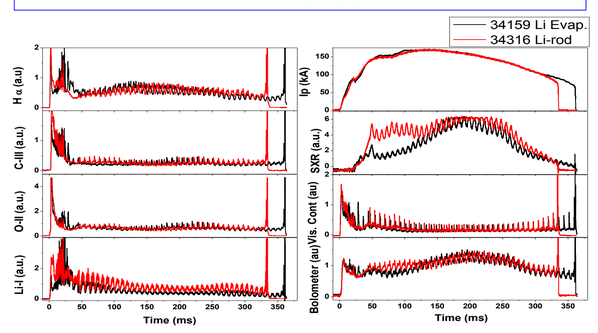
❖ Before shot 34149, Helium Pulsed GDC was carried out for 10 minutes active operation window (10 pulses of 1 min Glow On and 2 min Pump down) to control H retention by Helium sputter cleaning
❖ Li coating by evaporator is performed under H-GDC for 2 Hrs. Thus the resultant effect is not only coating of Li in form of Li-H but also increasing H monolayers on Li coating.
❖ As shown in fig, the shot 34149 is better in terms of all parameters of plasma performance

Effect of Li Evaporation rate increased by Temperature Ramp-Up



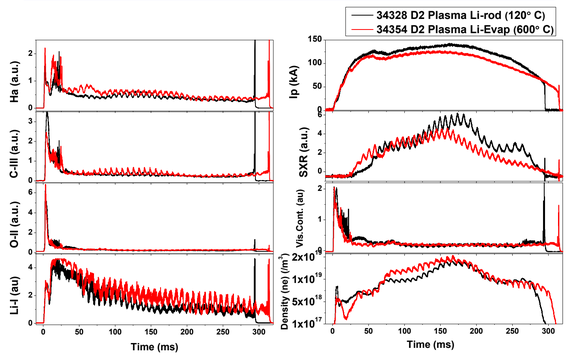
❖ Plasma shot No. 34159 in fig., the C-III and O-II impurity are reduced in factor more than 1.5 compare to 34153.
❖ the plasma core temperature was increased 30-50 eV in shot 34159 as 300 eV

Li-Wall conditioning using Fresh Li-Rod Insertion



❖ The Lithium sputtering was carried out by Hydrogen glow discharge plasma for 2 Hrs on first day and 1 Hr. on second day.
❖ In 34159, marginally less impurities during plasma formation, high core temperature, less hard x-ray as same all applied parameter of TF, OT, BV, fill pressure in both shots
❖ observed the fresh Lithium rod is highly active to generate strong coating with very less Lithium consumption

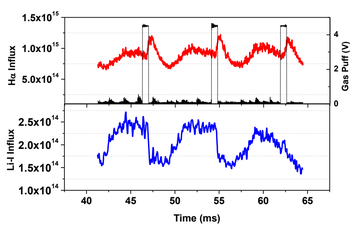
D2 Plasma Operation



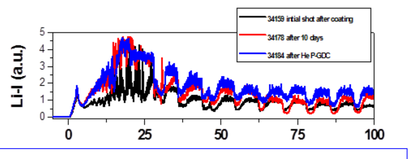
❖ A strong lithium coating was carried out during D2 fuel plasma operation using Li-Evaporator Operation upto 600° C with H-GDC for 2.5 Hrs.
❖ The core temperature is high in 34354 as 290 eV compare to 34328 as 240 eV
❖ Lithium coating by evaporator +H-GDC is more effective compare to Li-rod + H-GDC

LI-H FORMATION AND LONG RETENTION OF LITHIUM EFFECT

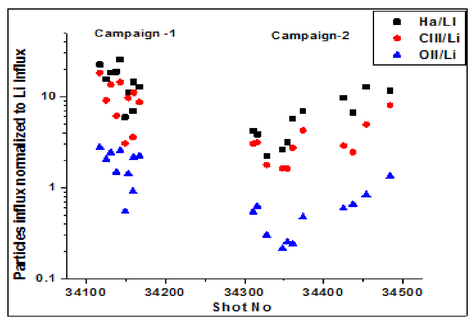
Plasma Shot	Type of Li-H Coating	Li particle influx to plasma at Flat top	Hα Particle Influx to plasma at Flat Top	Hα/Li
34311	Fresh Li rod 120 C + H-GDC 2 Hrs.	8.1 x 10^{13}	2.6 x 10^{14}	3.3
34348	Li-Evaporator 600 C + H GDC 2 Hrs. (D2 Plasma)	8.0 x 10^{13}	3.4 x 10^{14}	4.3
34149	Li-Evaporator 500 C & H-GDC 2 Hrs + 2nd day Only He Pulsed GDC (10 mins) + 45 min H-GDC	6.8 x 10^{13}	1.8 x 10^{14}	2.6



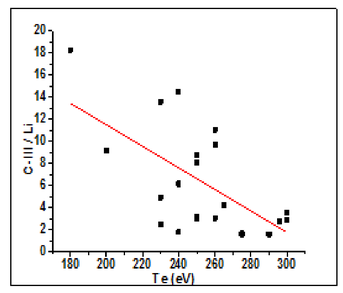
➢The evidence of Li-H is observed in visible line radiation spectroscopy as simultaneously detection of Li line intensity with H-α line intensity in different plasma states
➢The 525 C Li evaporation + H-GDC effect still observed with high Li-I counts after 10 days in Shot No.34178. After this shot, the Li-I counts increased more due to short He-P-GDC in between plasma discharges

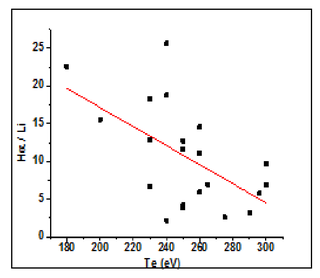


IMPURITY AND HYDROGEN RELATION WITH LITHIUM CONDITIONING



Plasma Temperature and Carbon and Hydrogen Influx





❖ the carbon impurity influx (normalized to Li) was decreased more than 5 time from first operation of Li- Evaporator of 450° C to final operation of 525° C. the plasma core temperature rise has been observed 50 – 65 % compare to plasma shots of non Li- coated wall
❖ With Li-Evaporator 600° C operation, the Carbon, Oxygen, Hydrogen influx with respect to Lithium reduced lowest level in both campaigns
❖ the plasma core temperature has been achieved as 290 eV in D2 Plasma as effect of Li-Evaporator 600° C compare to 240 eV as effect of Li-rod.

❖ The Carbon impurity and Hydrogen recycling are important for high performance plasma discharges.
❖ The plasma core temperature are increased significantly high as more than 50-65 % in compare to less lithium coating shots

Summary

- The developed Li wall conditioning techniques are implemented successfully in ADITYA-U tokamak.
- The Fresh Lithium rod sputtering in H-GDC is more effective for better wall conditioning compare to old Li-rod.
- The comparison of Li-rod and Li-evaporation in H-GDC techniques, there is marginally better performance has been observed in Li-evaporation techniques due to more Lithium consumption in evaporation.
- The evidence of Li-H on PFCs and vessel wall has been observed in the relation of Hα and Li-I particles influx to plasma spectroscopic study.
- With reduction of neutral hydrogen from wall using pulsed He-GDC, the ratio Hα/Li-I reduction indicates more Li-H concentration. As result, the plasma performance was improved in short Helium GDC + H-GDC on lithiated wall.
- First time we have operated full D2 plasma in tokamak. With support of high temperature Li-Evaporator operation (600° C), the high temperature 290 eV and long duration D2 plasma discharges were generated.
- The control of Carbon influx and Hydrogen recycling has been observed in term of core temperature rise, duration, density control by various Li wall conditioning techniques.
- The initial study of Ar-H mixture GDC before Li wall conditioning is carried out. Further study of this technique will be carried out to control more impurities.