New results of wall conditionings from ASIPP

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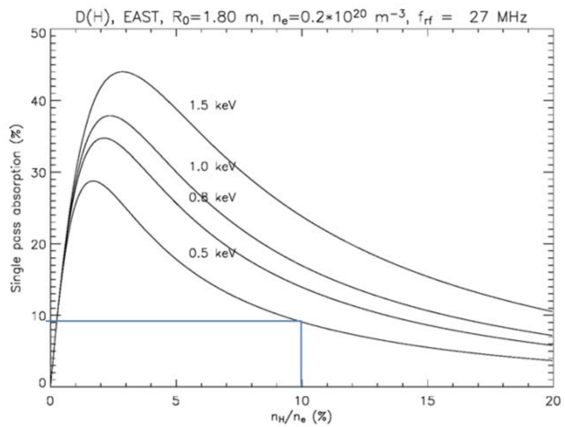
1. Introductions

Motivations

- **Remove or suppress impurities (especially after vent or leak)**
  - For a clean vessel for plasma operation
- **Reduce particle recycling**
  - For the density control, specially for long pulse plasma operation
  - Plasma confinement
- **Removal hydrogen to reduction of the ratio of H/(H+D)**
  - For the improvement of heating efficiency of ICRF
  - To avoid dilution of fusion fuel
- **Reduce tritium inventory for safety**
  - mainly proposed for ITER initial phase for safety
  - carbon deposit layer with high tritium inventory should be removed



Minority fundamental heating of ICRF

- Use H minority in D:
  - Lower H, higher efficiency
    - H/(H+D) <10%

From Dr.X.Z Zhang

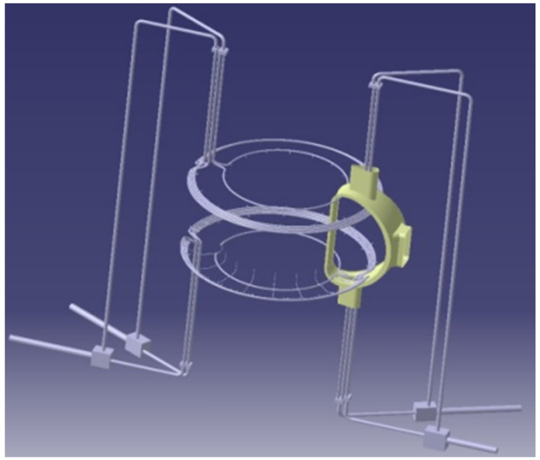
Wall conditionings on EAST with full C walls

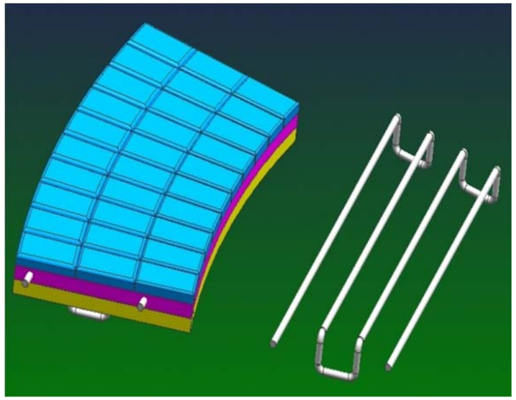
- **Surface cleanings**
  - ✓ Baking
  - ✓ Glow(without BT)
  - ✓ ICRF (with BT)
  - ✓ co-deposits removal by oxygen plasma
  - ◆ New Method 1: High frequency GDC cleaning in the presence of strong Bt
  - ◆ New method 2: Helicon plasma discharge cleaning with Bt
- **Surface coatings**
  - – Boronization
    - ✓ $C_2B_{10}H_{12}$+He,
    - ◆ $C_2B_{10}H_{12}+D_2$
  - – Siliconization
    - ✓ SiH_4+He,
    - ◆ SiD_4+He
  - ◆ Lithium coating!
    - Carried out different techniques, evaporation, GDC, RF
    - Lithium powder injection during plasma discharge
    - Liquid lithium limiter

2. cleanings

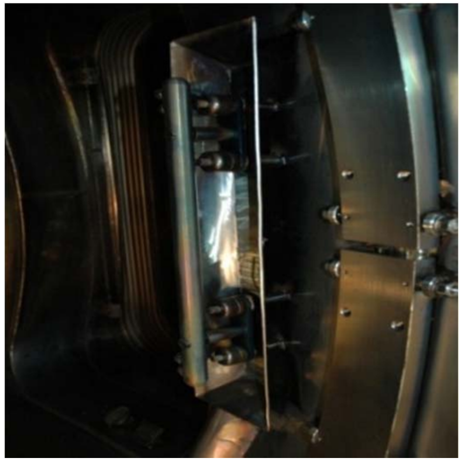
Wall conditioning before plasma operation (Baking+GDC)

- Hot N_2 in heat sinks. Max. Temp for PFCs 350°C. Normal 200~250°C.
- Normal 10 days bake and >60h GDC cleanings by turns of He and D_2.





Baking and cooling tube



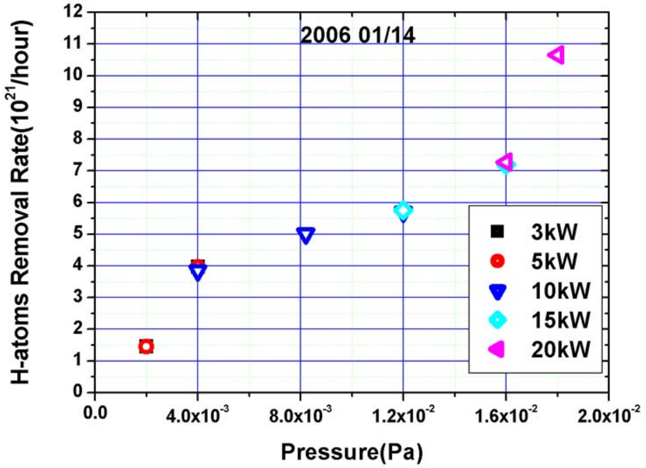
GDC anode(total 4)

- **Best ultimate vacuum, 2.9x10^{-6}Pa in EAST in 2010;**
- **Total rate of release and leaks: 1.1x10^{-5}Pam^3/s;**
- **Release rate of H_2 decreased to 8x10^{-6}Pam^3/s.**
- **H/(H+D)~60%.**

ICRF cleanings

Compatible with Bt !

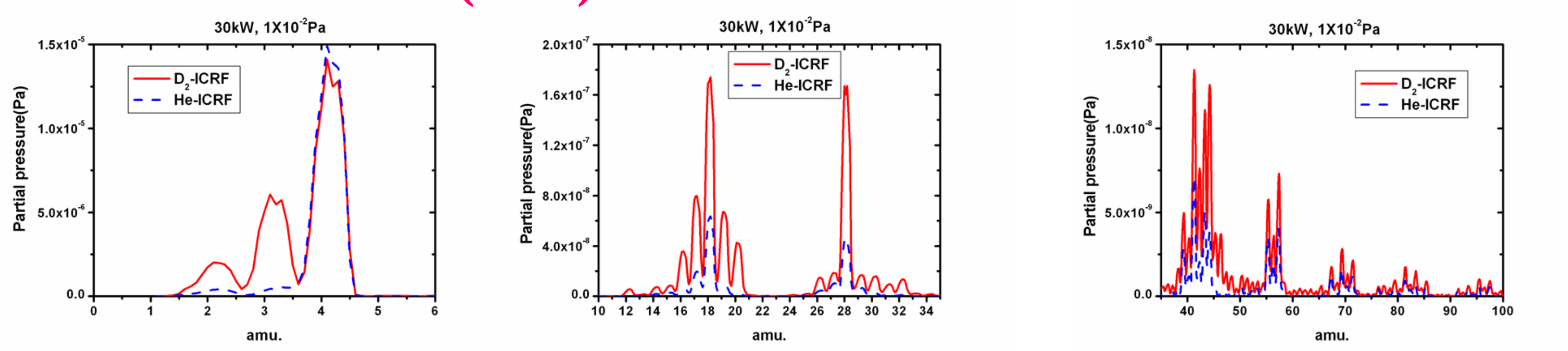
- **Unique dedicated ICRF antenna for wall conditionings**
  - **Power: 3~20kW (Max.300kW, Adjustable)**
  - **Broad Pressure: $4x10^{-3}$Pa~10Pa**
  - **Duty wave time Typical 0.3s on/ 1.2s off**
  - **Frequency: 30MHz**
  - **Toroidal magnetic field: 1~2 T**
  - **Routine cleanings at the interval of plasma discharges.**
  - **Higher power or working pressure is better.**



D_2-ICRF is better than He-ICR for H_2 and Impuritoes removal

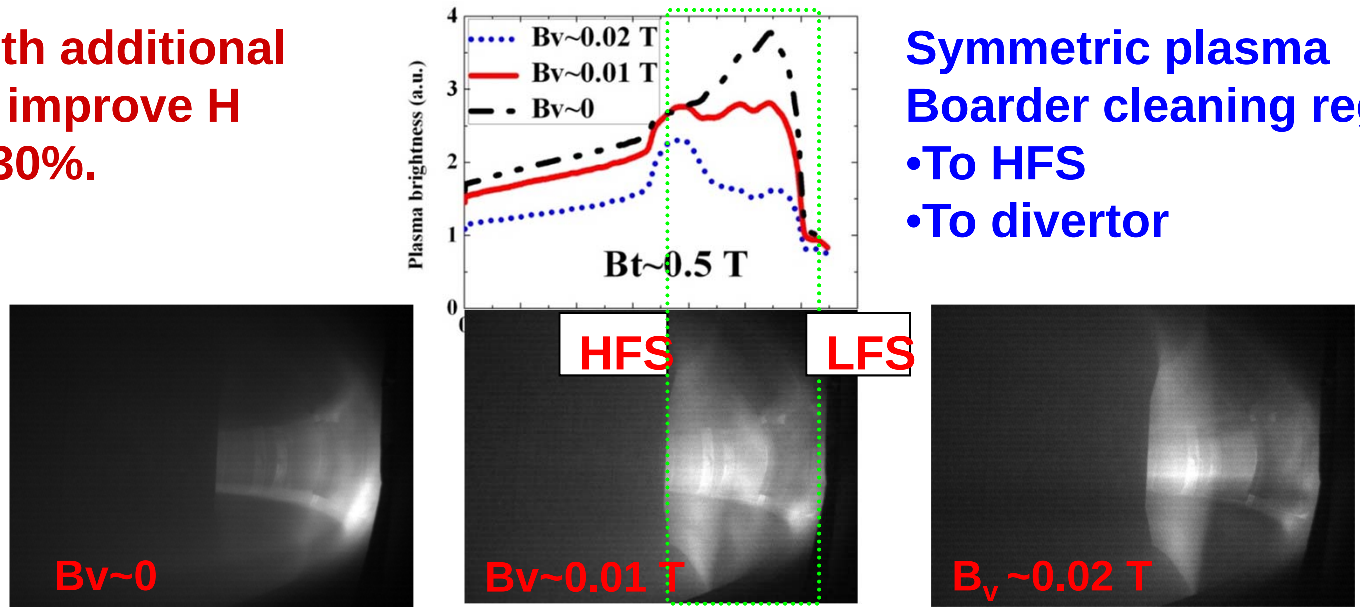
Isotopes(H,D,T) exchanges, D-C reactions

Reduce H/(H+D) due to H removal and D retention



Partial pressure in differentially pumped chamber during ICRF cleanings

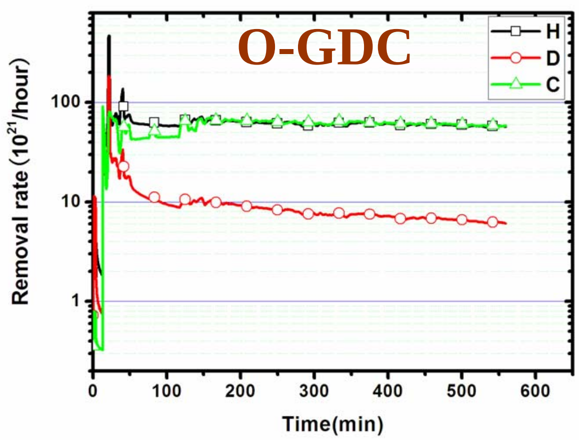
ICRF plasmas with additional vertical filed(Bv) improve H removal rate by 30%.



Symmetric plasma
Boarder cleaning region
- **To HFS**
- **To divertor**

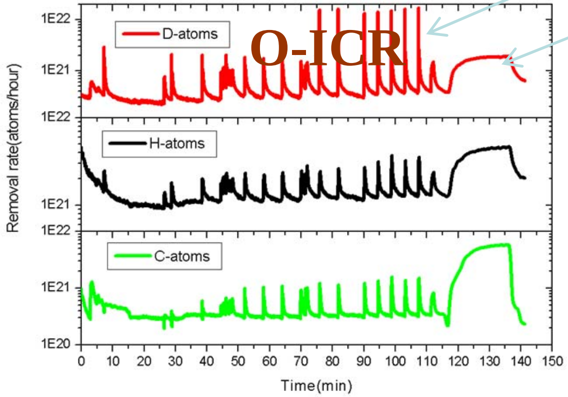
Deposits cleaning by oxygen plasma

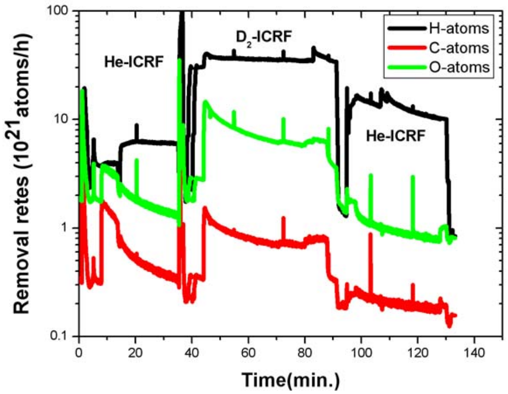
- O-GDC and O-ICR :High removal rate, High pressure and/or power is better.
- D_2-ICR is better methods to remove O.
- Less O retention and boronization helps the plasma recovery.

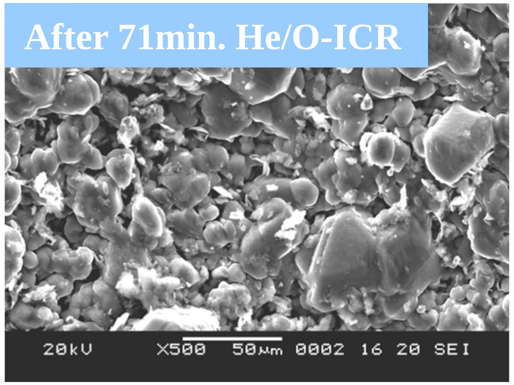


Single ICRF pulse

Pulsed ICRF: 0.3s on/1s off







- By ~71mins O-ICR cleanings,
  - Deposits were effectively removed.
  - H and D retention reduced ~80%.
  - Oxygen content increased <30%.

ICR-WC in HT-7 and EAST

	Gas	Pressure (Pa)	Power (kW)	removal rates ($\times 10^{21}$ atoms/h)			
				H	D	C	O
HT7	He	0.1	40	4		0.08	0.18
	D_2	0.1	40	2.8		0.2	0.5
	O_2	0.1	40	26	8	13	
	He/O(4:1)	0.1	40	4.8		7	
EAST Metal walls	He	0.03	20	17		0.13	
	He/O(1:1)	0.07	20	78		42	
EAST C walls	He	0.05	20	5-40		0.3-1	
	D_2	0.05	20	30-80		0.5-2	
	He/O(1:1)	0.1	20	90		26	

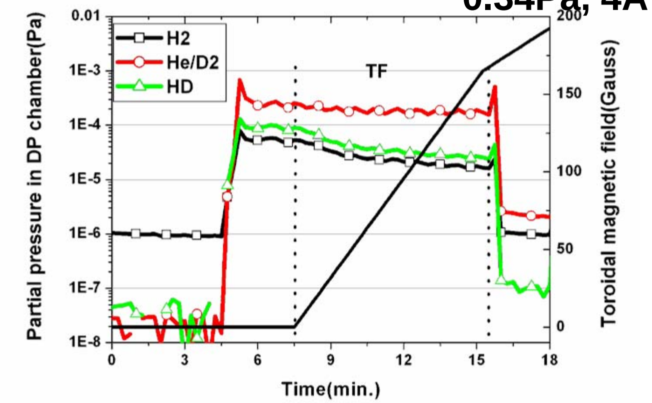
✓Pulse mode (0.3s on/ 1.5s off) is better than CW mode
✓Higher power and pressure are favourable for higher particle removing rates
✓Oxygen plasma is a potential best way for C and H removal for ITER.

New Method 1: HF_GDC cleaning

Compatible with Bt !

Normal GDC in HT-7

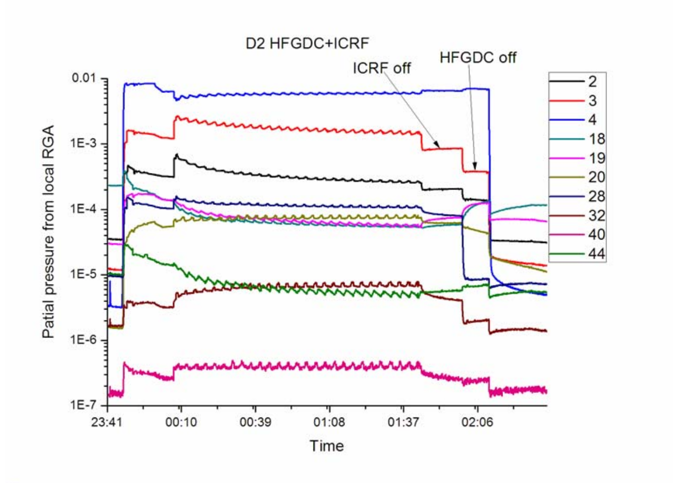
0.34Pa, 4A

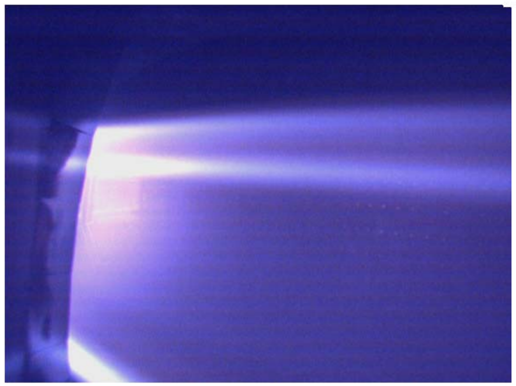


only could be operated whit a weak Bt. Increasing Bt, removal rates for H and D decreased.

HF-GDC :

- Power Supply : U=1.0KV , f=20/100KHz , I~0.5-1.0A
- Work Gas : Ar , He , H2.
- Normal GDC electrode
- HT-7: 5x10-4Pa-0.5Pa, Bt=0.5-2





Bt=1.5T,P=5Pa in EAST

HF_GDC has a comparable removal rates for H and impurities with ICRF

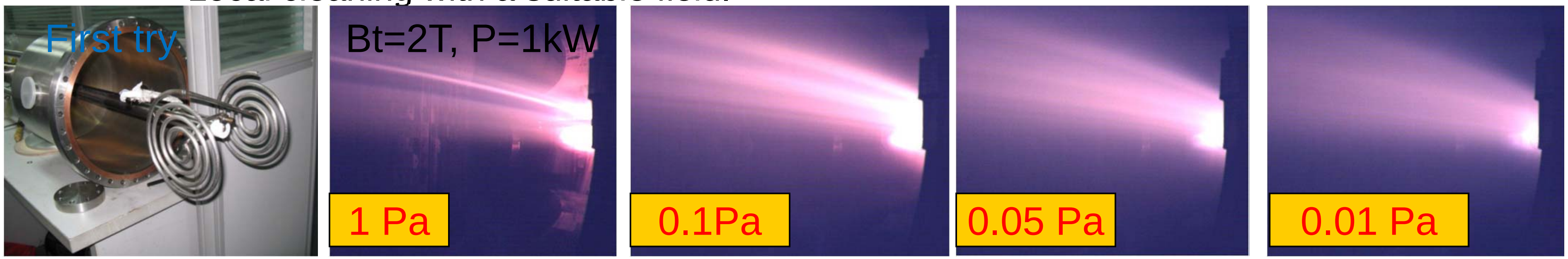
Presented by Dr.X. Gong

New method 2: Helicon wave plasma cleaning

Compatible with Bt !

- Potential Advantage of HWP cleaning[Prof. X.M Wu, Suzhou Univ.)
  - ◆ Higher Cleaning Efficiency
    - ✓ High plasma density: $10^{13}/cm^{-3}$
  - ◆ Wider Operational Region
    - ✓ Working pressure: 10^{-2}-10Pa,
    - ✓ Power: 10W- a few kW,
    - ✓ Frequency: 6-144MHz
    - ✓ Magnetic field: hundreds Gs-Tesla
  - ◆ HWP Spread Along the Direction of B fields
    - ✓ Local cleaning with a suitable field.

Three type HWP antennas;
Movable antenna will be transferred to the center of plasma vessel;
Bt is perpendicular to the circle of antenna.



✓Simper system;
✓Easily to get HWP plasma;
✓Compatible with Bt: 1~2T;
✓Broader working pressure;

➢Strong confinement by Bt;
➢Lower power <2kW;

⇨

Lower removal efficiency.
●Increase power;
●Optimize antenna;
●Bv?

3. Surface coating

3.1 Boronization in EAST

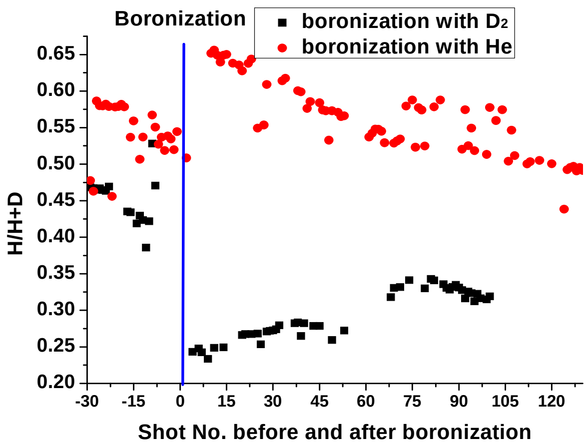
- **ICRF:8-15kW, 30 MHz, 0.3 s on and 1.2 s off.**
- **Bt= 1~2 T**
- **Feedback controlled P~1E-2Pa**
- **PFCs to 120℃**
- **10g for EAST, 3g for HT-7**
- **More than 100nm**

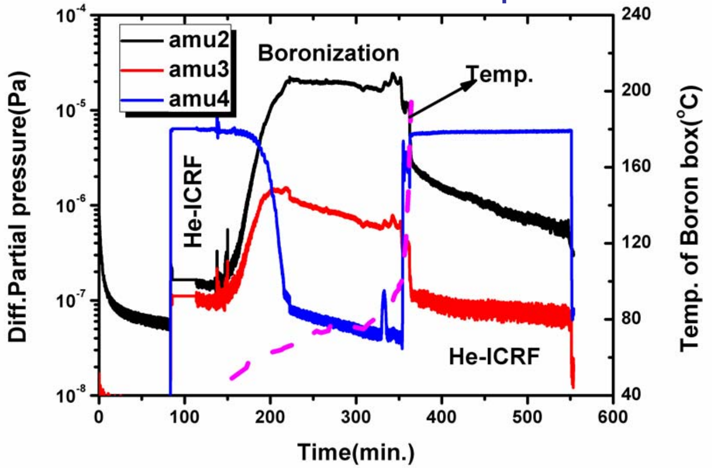
➢ICRF would effectively disassociate and ionize the boron material, and lots of H released.

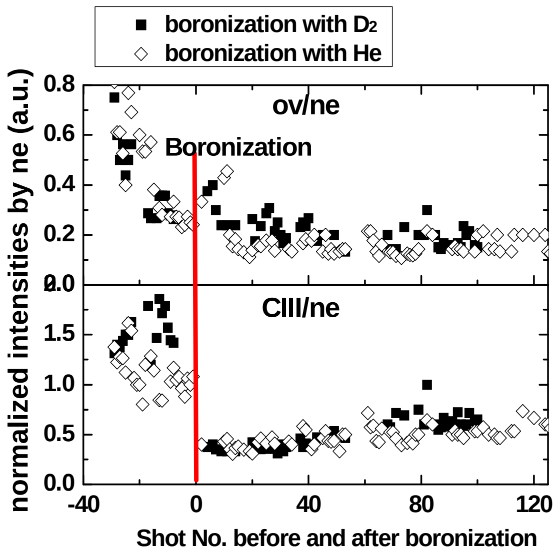
➢After boronization, He-ICR is effectively remove H.

➢Suppressed impurities in plasmas

➢Using D_2 as additional gas, H/(H+D) decreased , but higher than 20% is still not acceptable.

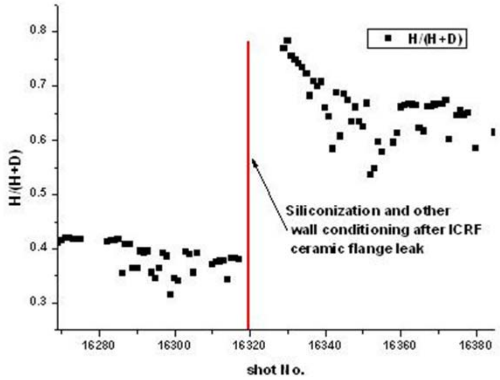


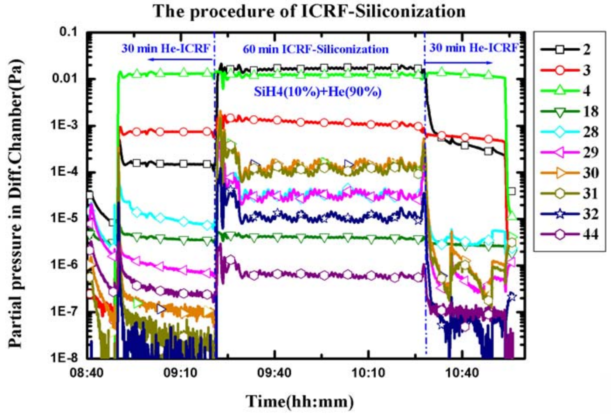


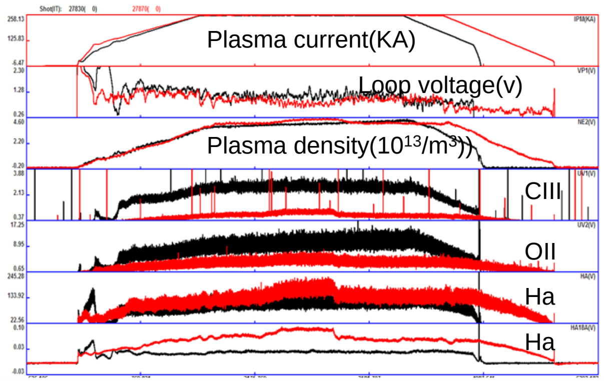


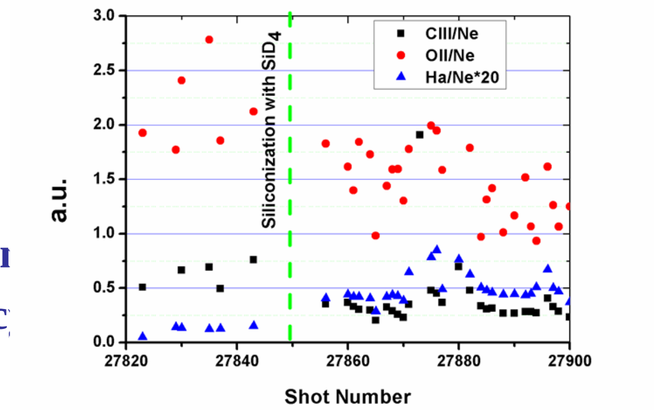
3.2 Si coating with ICRF

SiH_4:He = 10:90

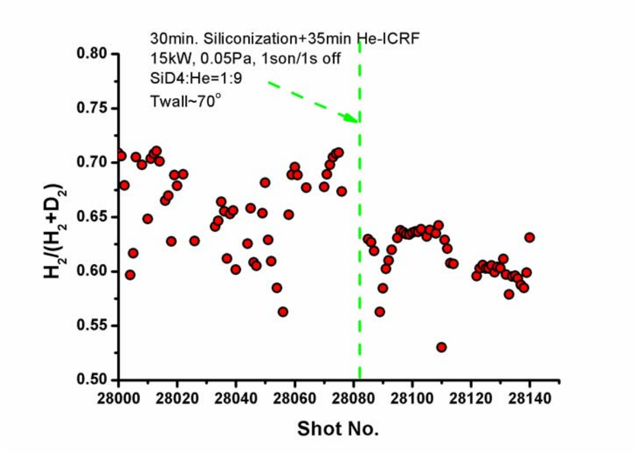








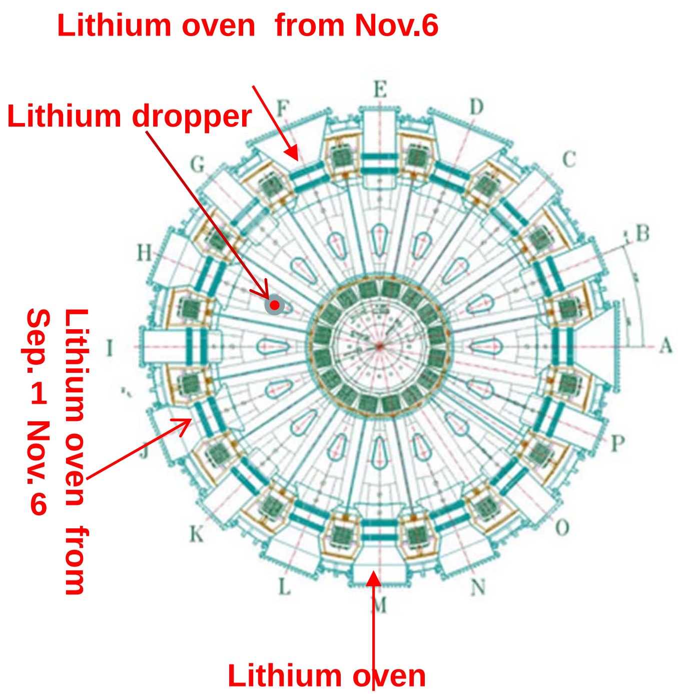
SiD_4:He=10:90

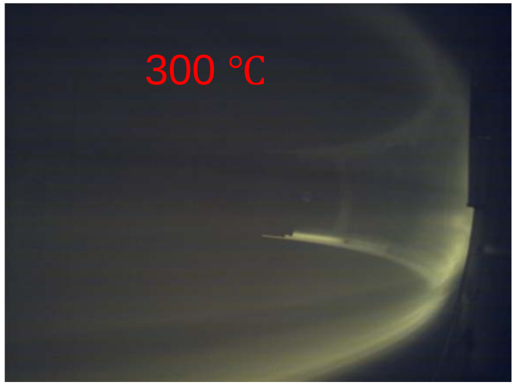


- **P_{RF} =15kW, B_T=1.5~2.0T,**
- **Pv=0.5~2x10^{-2} Pa,**
- **30~60 minutes,**
- **Film thickness is about 20-60n**
- **Easy control of density and rec compared with boronization.**
- Useful for the suppression of impurities
- Siliconiztion using SiD_4:He=10:90 has a small effective on the reduction of the ratio of H/(H+D)

3.3 Lithium coating

Lithium coating by oven for EAST



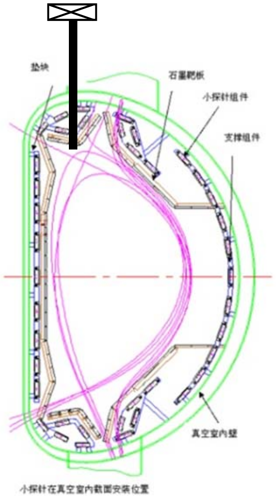


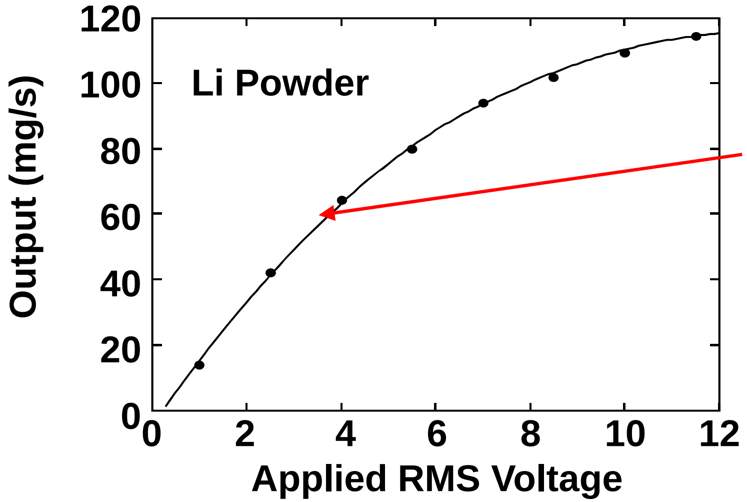
ICRF lithium coating

- Two ovens;
- Evaporated at 500~550^{o}C; 1~2Hr
- **Only by evaporation, or associated by GDC or ICRF discharge**
- 10~30g/coating;
- 1~2 coating/day(~100shots);
- He used as axially working gas

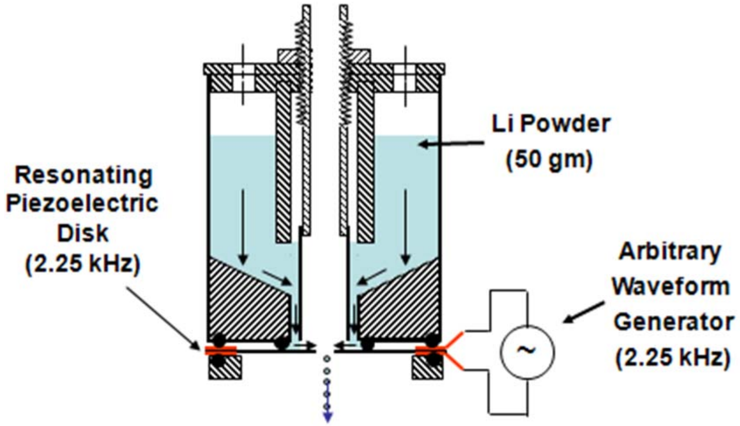
Active Li coating by dropper from PPPL

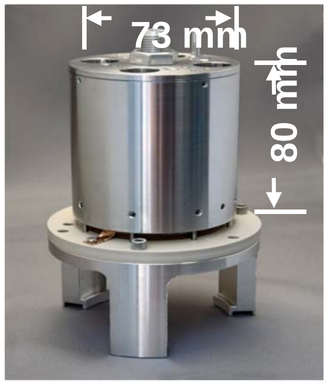
dropper

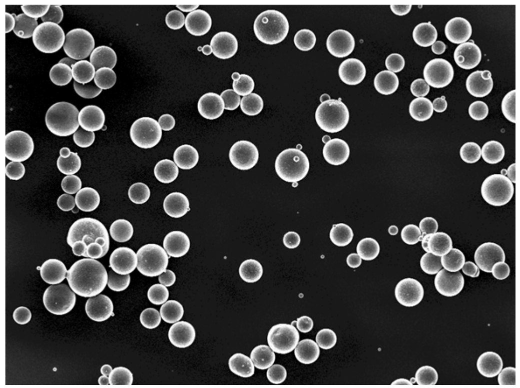




- 50mg/s for EAST
- 3 x10^6 Li Spheres/s
- ~2 x D influx EAST
- 14 x Evaporator Rate







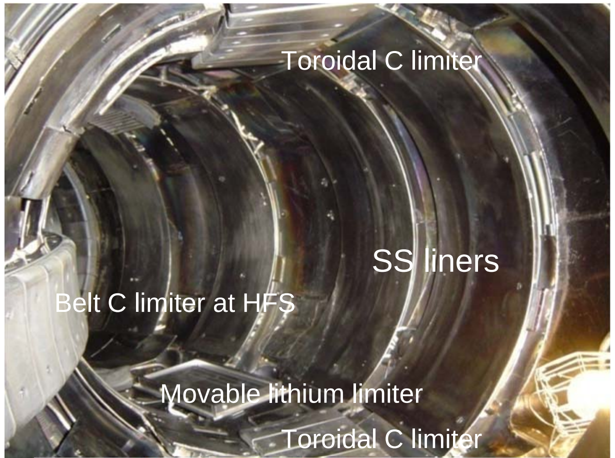
Lithium powder
44 μm dia.
30 nm Li_2CO_3
99.9% Li
0.1% Li_2CO_3

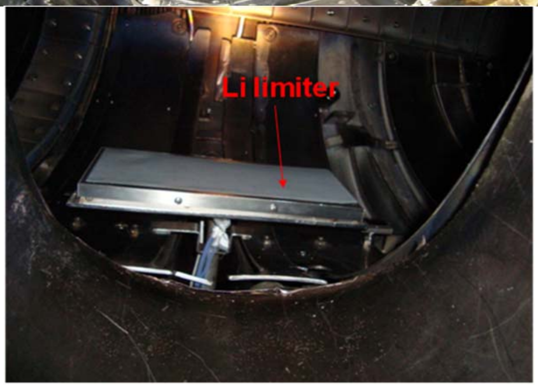
D. Mansfield, PPPL, USA

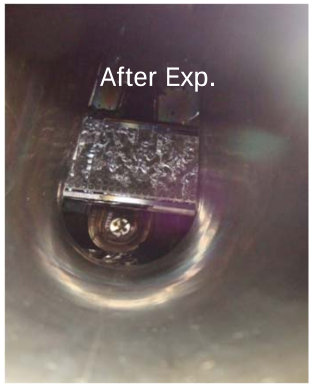
(Active Li coating by) liquid Li limiter

HT-7 liquid lithium limiter (2008-2009)

- ✓ SS dish has Mo protection at each side.
- ✓ Lithium plate with plasma facing area ~377cm^2 .
- ✓ The lithium is 3mm in thickness.
- ✓ Set at 230^{o}C during plasma dischare.
- ✓ Capillary Pore Structure was tested.

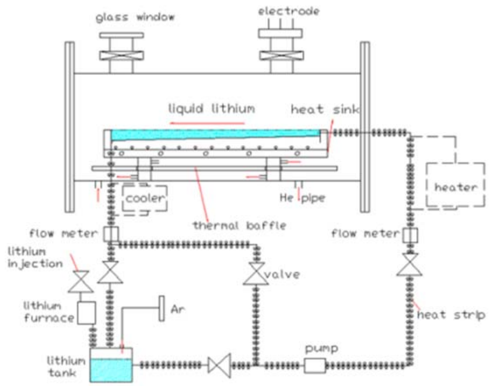


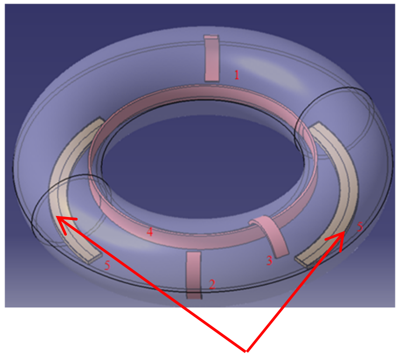




Flowing liquid lithium limiter project(FLLL):

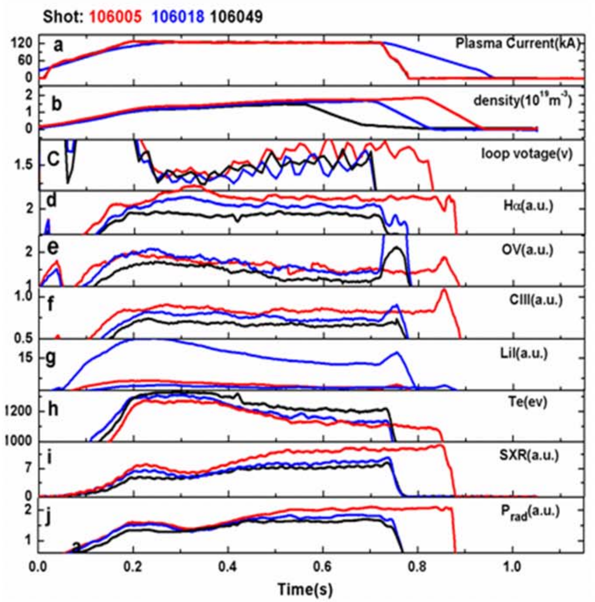
- ➢Modified all PFCs to Mo in HT-7, 2010
- ➢Design a test bench for flowing liquid limiter,2011
- ➢Design HT-7 flowing liquid limiter, possibly 2012
- ➢Modified PFCs to W in EAST, 2014
- ➢Design flowing lithium divertor for EAST, after 2014

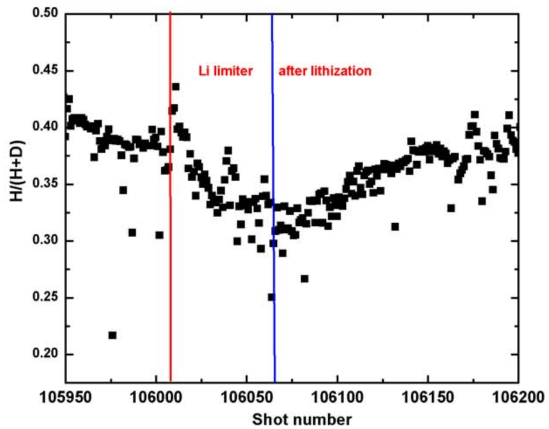


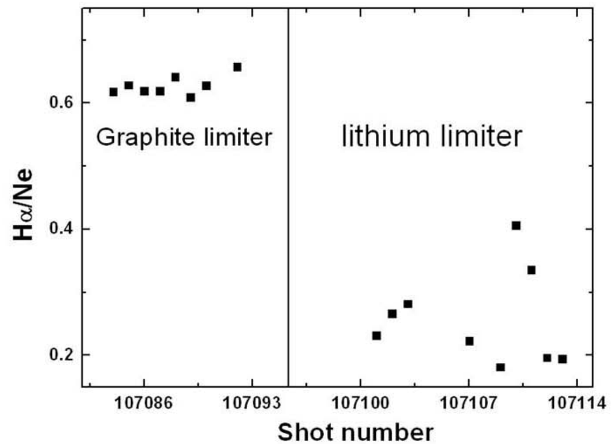


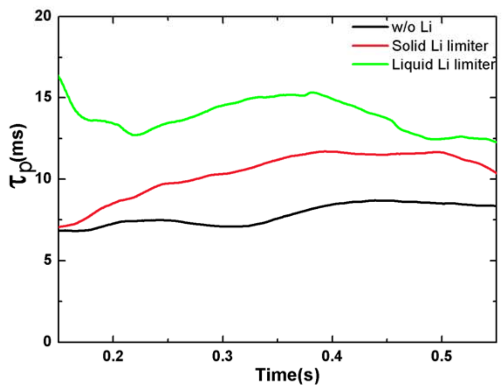
Long FLLL will be in HT-7

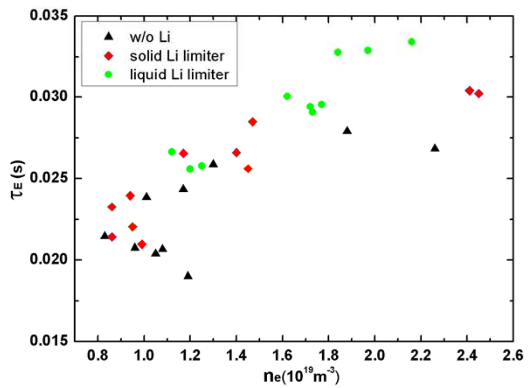
Results of liquid lithium limiter in HT-7







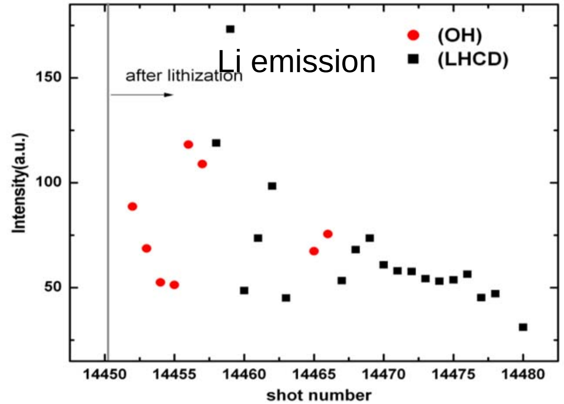


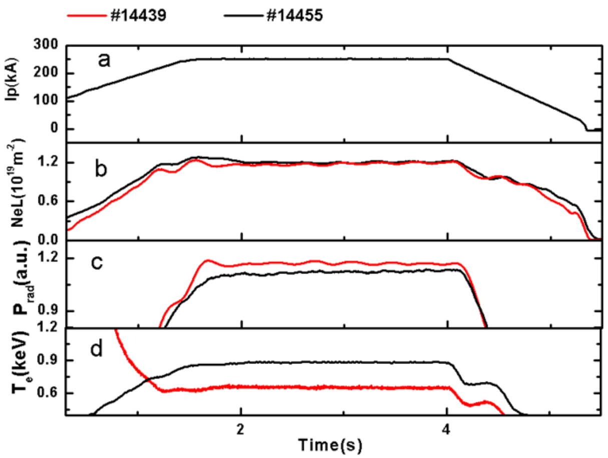


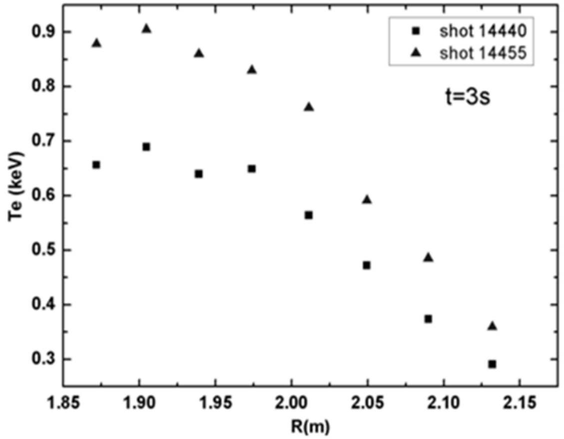
- ✓H recycling decreased;
- ✓C, O emission decreased;
- ✓Loop voltage had a slight decline;
- ✓Core electron temperature slightly increased;
- ✓Particle confinement time and energy confinement time increased.

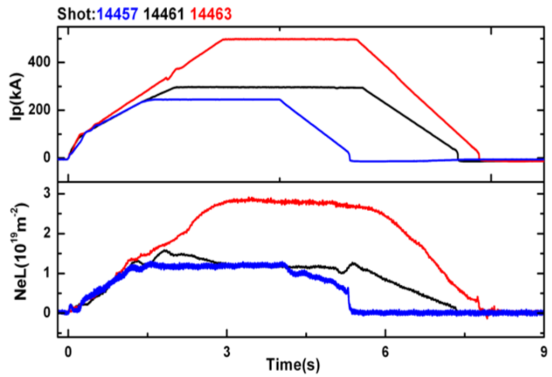
First Li coating on EAST by ICRF in 2009

- Only 2g lithium evaporated at a single position
  - very thin and not uniformed lithium coat
  - the lifetime of the film is very short, only for 40 plasma discharges.
- Plasma performances were improved
  - a lower impurity radiation
  - higher electron temperature
  - reproducible plasma discharges with high parameters, such as higher plasma current and density





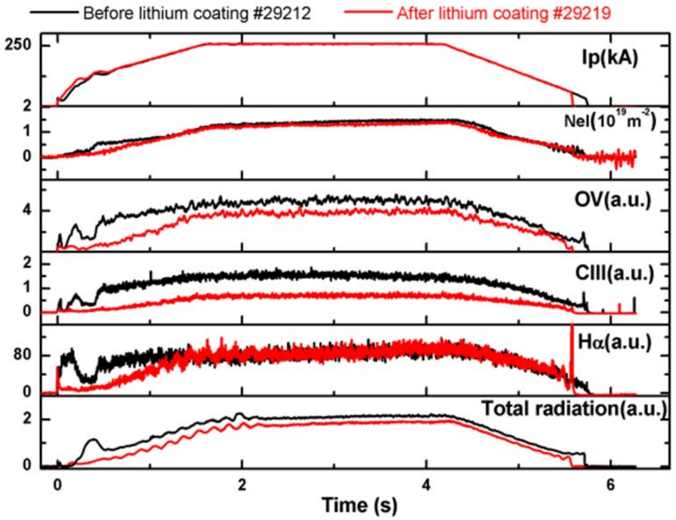




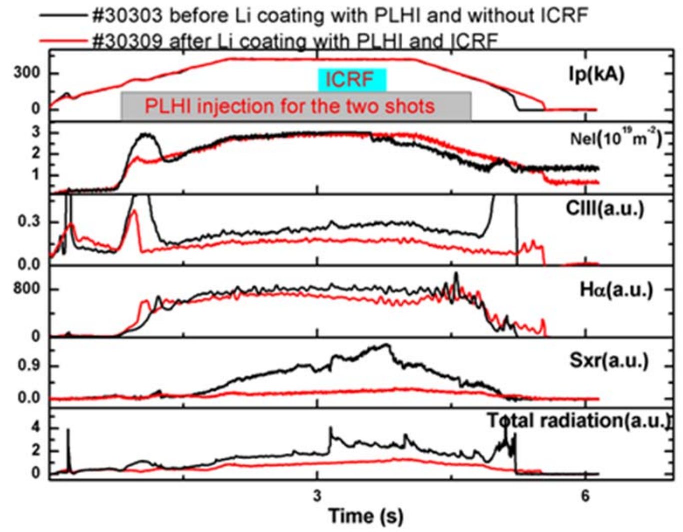
Development of Li coating by oven in 2010

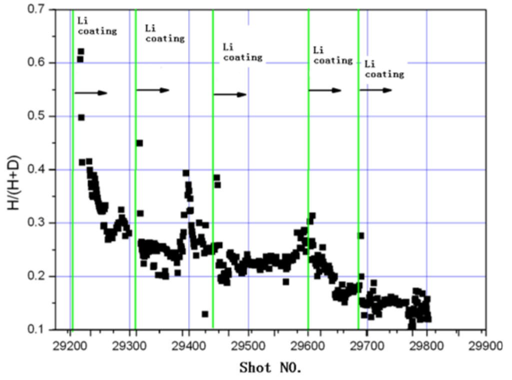
- Upgrade lithium oven
  - 15g/oven,10-30g/coating, 1~2hr.
  - Two ovens at symmetrical positions
- Great improvement of plasma performance
  - Reduce impurity radiation
  - Lower H recycling;
  - Low Zeff=1.5~2.5
  - Reduce H/(H+D);
  - Suppress MHD activity;
    - Improve plasma confinement;
    - increase plasma stored energy;
    - Beneficial for high parameters plasma operation.
    - Decrease L-H transition threshold , Beneficial for H-mode achievement.

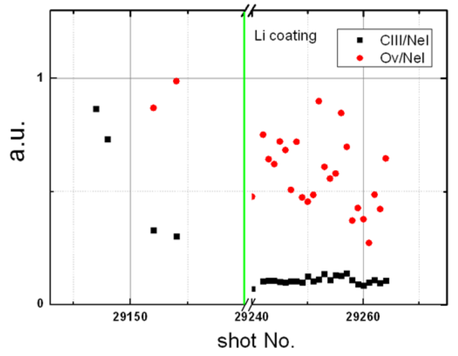
Circular plasmas



Divertor plasmas with double null

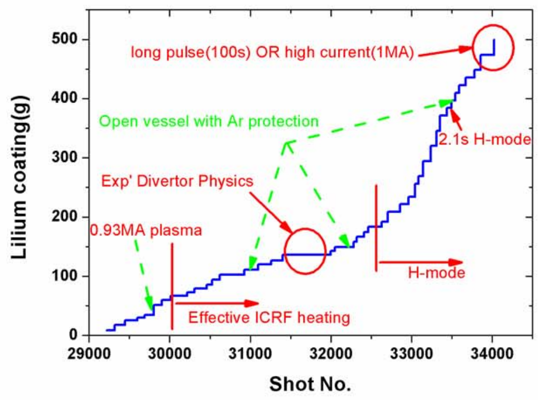


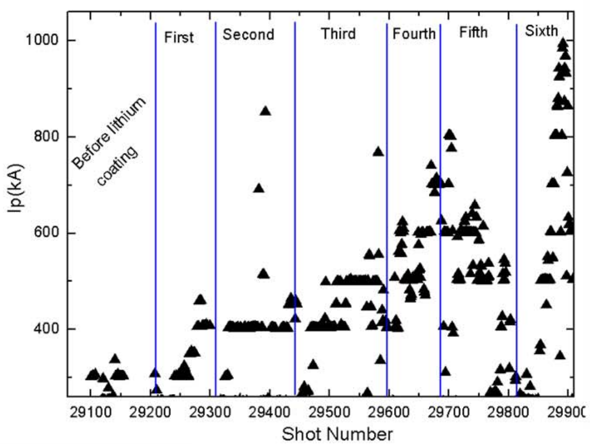


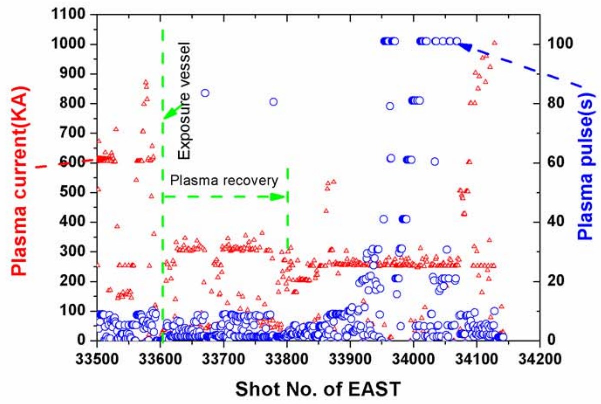


Spectroscopy From Dr. J. Fu

Plasma parameters Improved by long term Li coating
(A few new milestones of EAST achieved)

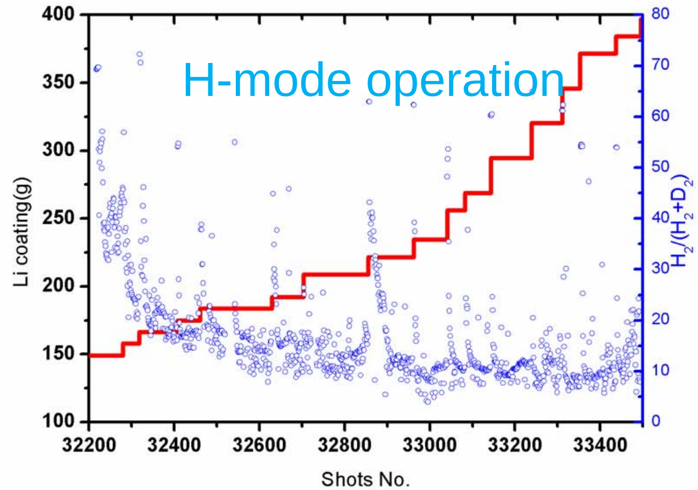






First effective heating of ICRH：No.30294

Long pulse and high current operation

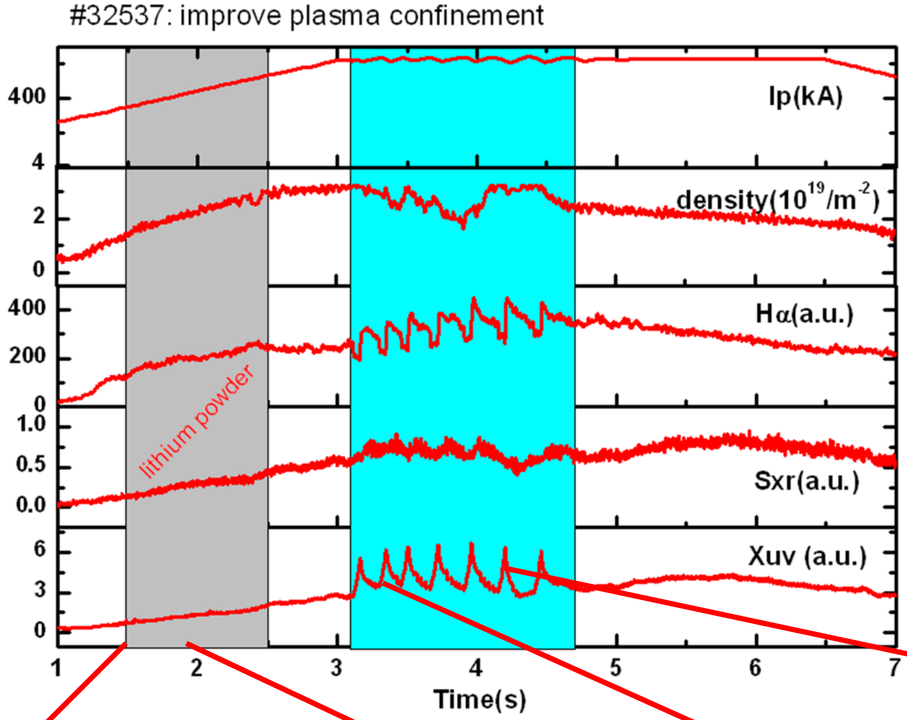


From RGA data in release gases

No.32525-33590:

- First H-mode plasma No.32525
- Total H-mode plasma: 141 shots;
- In H-mode plasmas, lithium powder injection:61 shots, 43.3 %.
- No.33473, 2.1s H-mod plasma

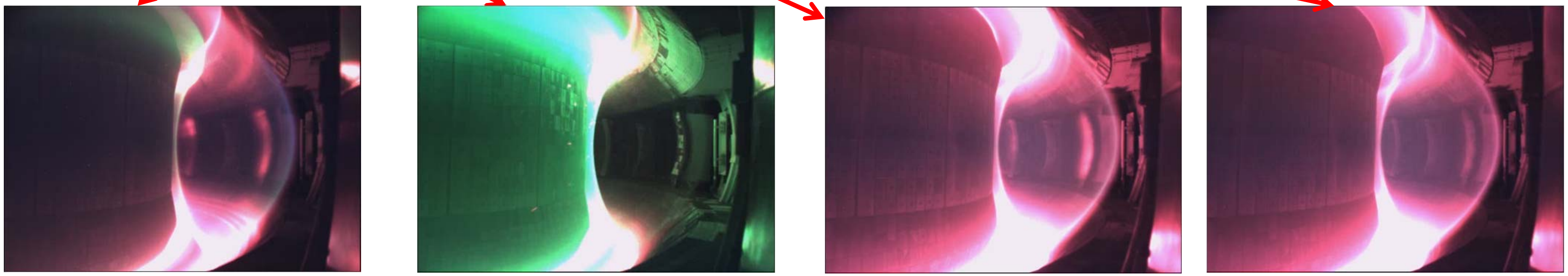
H mode plasma of EAST easily obtained either by Li coating by oven or by active Li powder injection!



No. 32537:

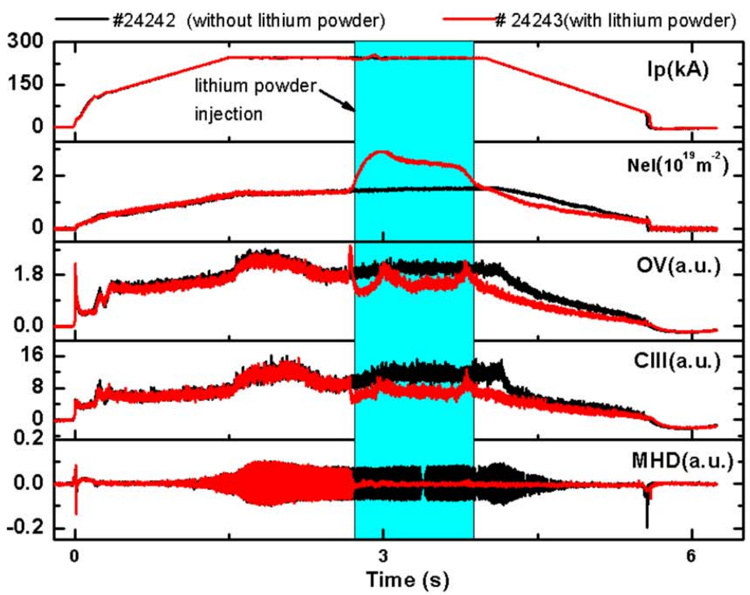
- ◆IT ~ 6000A,
- ◆IP ~ 600kA ,
- ◆ne ~ 2.1 ,
- ◆P_{LHCD}~1MW,
- ◆H/(H+D)~10%,
- ◆Zeff~2.

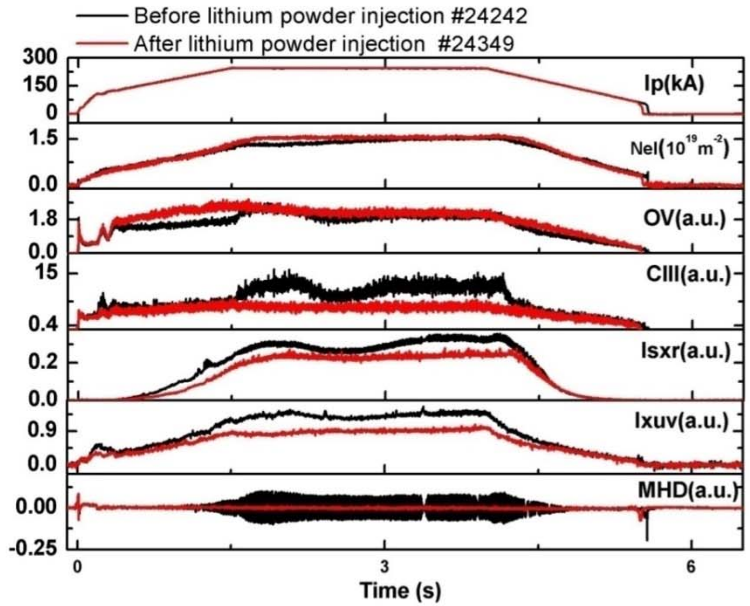
- ➢lithium powder injection from 1.9s to 2.9s;
- ➢Before this shot
  - ➢ ~150g lithium coated by oven;
  - ➢about 20 shots lithium injected.

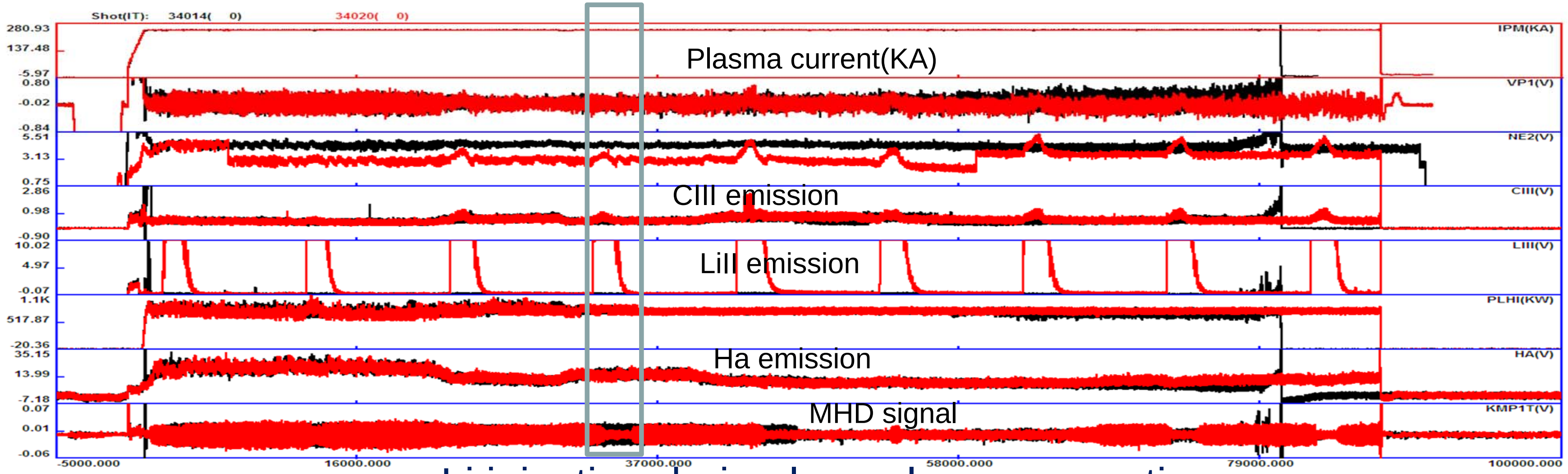


EAST

MHD suppressed by active Li powder injection







Li injection during long plasma operation

Summary

- ✓ Baking, He-GDC(no Bt) and He-ICRF(with Bt) cleanings are effectively remove H isotopes. The D_2-ICRF (GDC) is much better than by He to clean H_2. During ICRF cleaning, an additional Bv would improve H removal.
- ✓ Oxidation is an effective method to removal C deposits and release H isotopes.
- ✓ Boronization ($C_2B_{10}H_{12}$) and siliconization(SiH_4) are beneficial for plasma operation, but it introduce a lot of H and lead high particles recycling and high H/(H+D). Changed the axially gas from He to D_2 or change SiH_4 to SiD_4, H/(H+D) would decrease, but recycling is still high.
- ✓ Lithium coating is very useful to reduce particles recycling to improve plasma performance. Specially, lithium coating became a routine wall conditioning in the 2010 campaigns.
- ✓ New techniques, such as HF-GDC and HWP cleanings, were successfully carried out with Bt.
- Further researches
  - ➢ To develop HF_GDC cleanings and HWP cleanings
  - ➢ The materials for coating will be changed to one without H, e.g., B_2D_6.
  - ➢ Wall conditioning studied for Higher Parameters, Higher Power, Higher Confinement under steady state plasmas.

- **Impurities suppression**
  - ✓ Bake
  - ✓ Cleanings
  - ✓ Boronization
  - ✓ Siliconization
  - ✓ Lithium coating!
  - × Oxygen cleaning
- **Reduce particles recycling**
  - ✓ Bake
  - ✓ He-Cleaning
  - ✓ Oxygen cleaning
  - ✓ Lithium coating!
  - ×Boronization
  - ×Siliconization
- **Reduce the H/(H+D)**
  - ✓ Bake
  - ✓ D_2-cleaning
  - ✓ $C_2B_{10}H_{12}+D_2$
  - ✓ SiD_4+He
  - ✓ Lithium coating!
  - ×$C_2B_{10}H_{12}$+He,
  - ×SiH_4+He,
- **Deposits removal**
  - ✓ D_2 cleanings
  - ✓ Oxygen cleaning

Thank you for your attention!!