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Effects of partially installed tungsten coated divertor tiles on the LHD plasma and plasma-wall interactions

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ABSTRACT

What has been done

- ✓ Tungsten (W)-coated divertor tiles were installed in a wide range of the divertor of one inner- and outer-toroidal sections out of 10 toroidal sections in the Large Helical Device (LHD).

Any impact on operation

- ✓ The erosion of coated-W is partially observed through two experimental campaigns.
- ✓ The impact of eroded-W on the plasma performance is being analyzed. A serious degradation of plasma performance due to eroded W has not been clearly observed.

Physics results

- ✓ The divertor visible spectroscopy shows the neutral W emission from sputtered W divertor tiles in divertor region. However, the increase of radiation by the accumulation of W into core plasma is not observed. Core W intensity is analyzed by EUV spectroscopy.
- ✓ W-coated divertor reduced the carbon flake. The surface analysis shows that the coated tungsten near the strike point was eroded in some divertor tiles. The erosion could be caused by low-Z impurities such as carbon.

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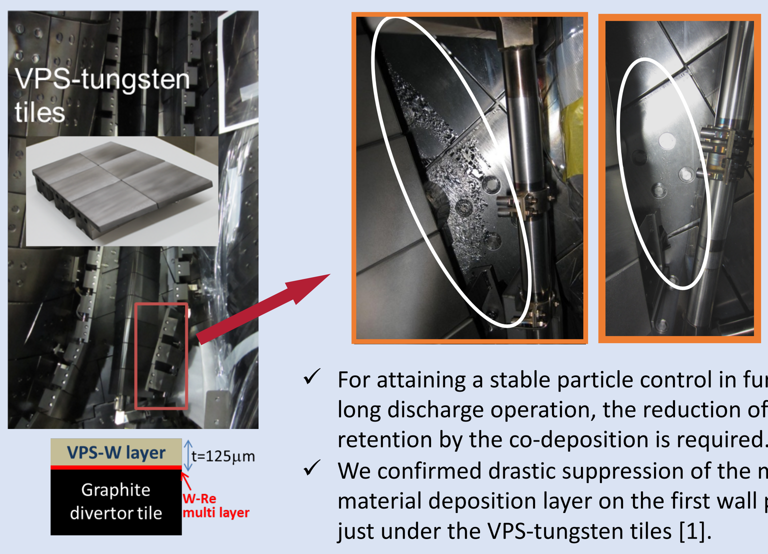
BACKGROUND

Three VPS-tungsten tiles installed earlier

Drastically improved "No deposition"

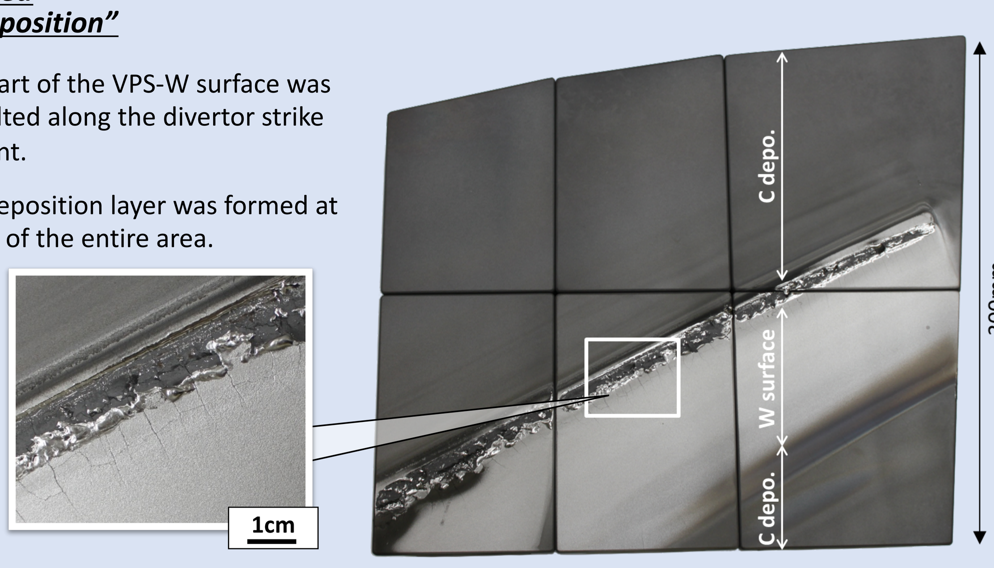


- ✓ For attaining a stable particle control in further long discharge operation, the reduction of wall retention by the co-deposition is required.
- ✓ We confirmed drastic suppression of the mixed-material deposition layer on the first wall panels just under the VPS-tungsten tiles [1].

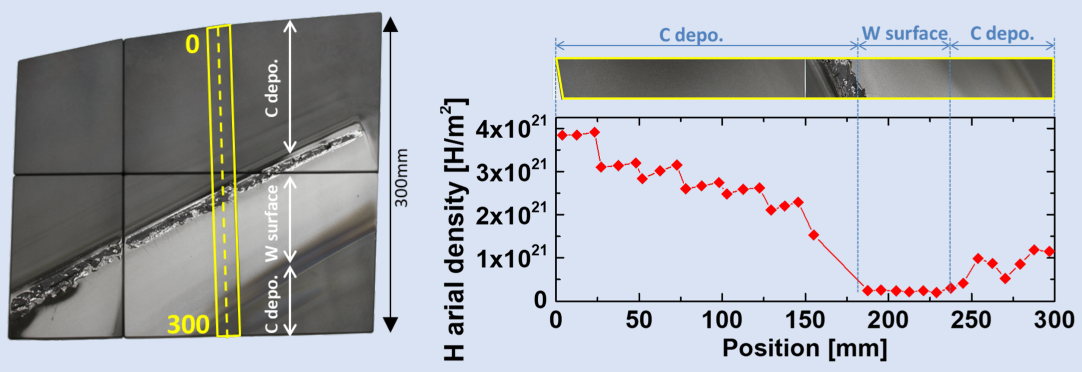
[1] M. Tokitani et al., NME, 18 (2019) 23.

Melting and crack formation

- ➢ A part of the VPS-W surface was melted along the divertor strike point.
- ➢ C deposition layer was formed at 2/3 of the entire area.



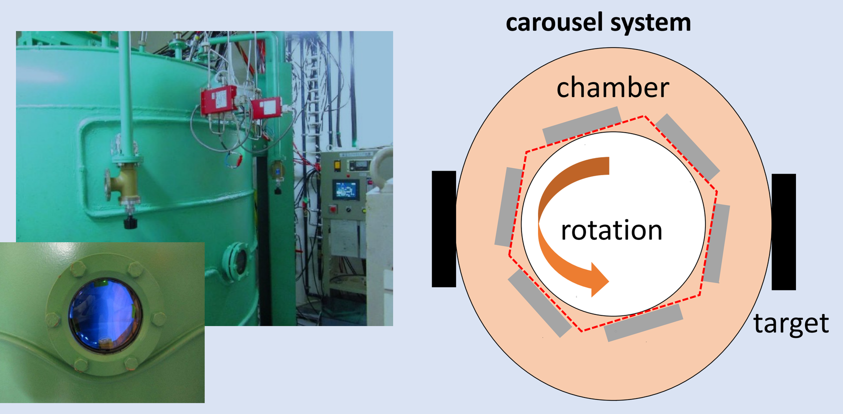
Line distribution of the retained H measured by ERD



- ➢ Original VPS-W surface showed the lowest retention.
- ➢ C deposition layer acts as a large trapping sink for H.

METHODS/Applied W coated divertor tiles

Tungsten is coated by magnetron sputtering

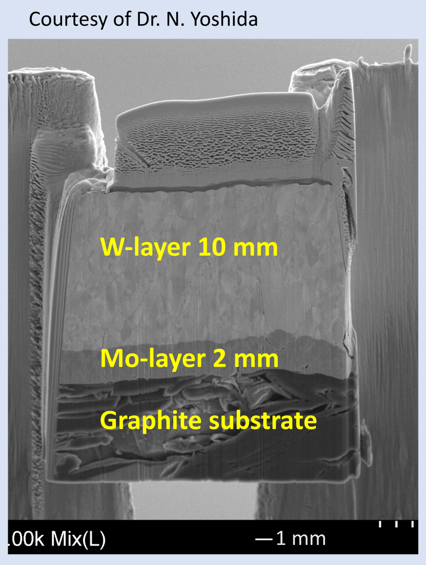


- ➢ A large area of coating is possible in one patch. 14 plates (300 × 500 mm) can be coated in one patch.
- ➢ Deposition rate is 250 nm/s.

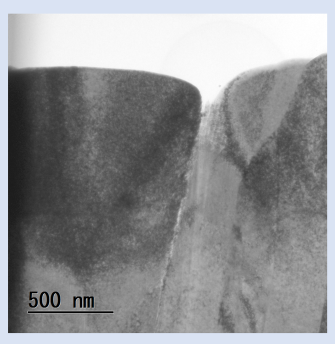
- ✓ Coated by KYODO-INTERNATIONAL, INC. in Japan
- ✓ Tungsten is coated on the graphite divertor tile.
- ✓ On the coating, the substrate temperature is not controlled. Heat treatment after the coating is not conducted.

TEM images of W-coated divertor

Courtesy of Dr. N. Yoshida



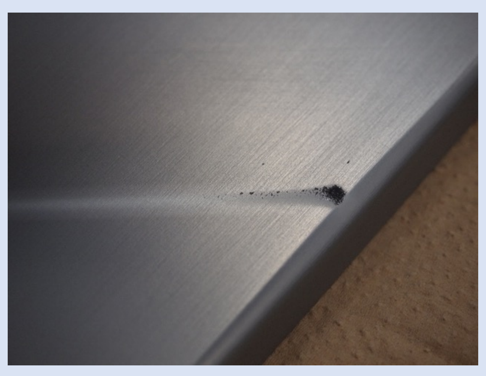
- ✓ Crystal grains grow in the vertical direction
- ✓ Cracks are induced on the grain boundaries.
- ✓ The black dots are the dislocation loops that were generated during FIB processing.



Further optimization of coating technique is expected

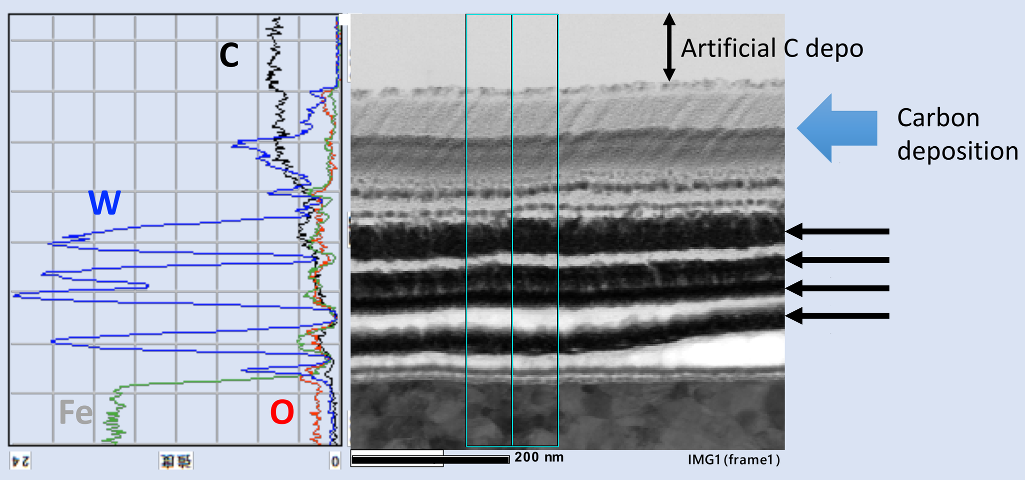
High heat flux test facility of ACT2

~ 12.5 MW/m²

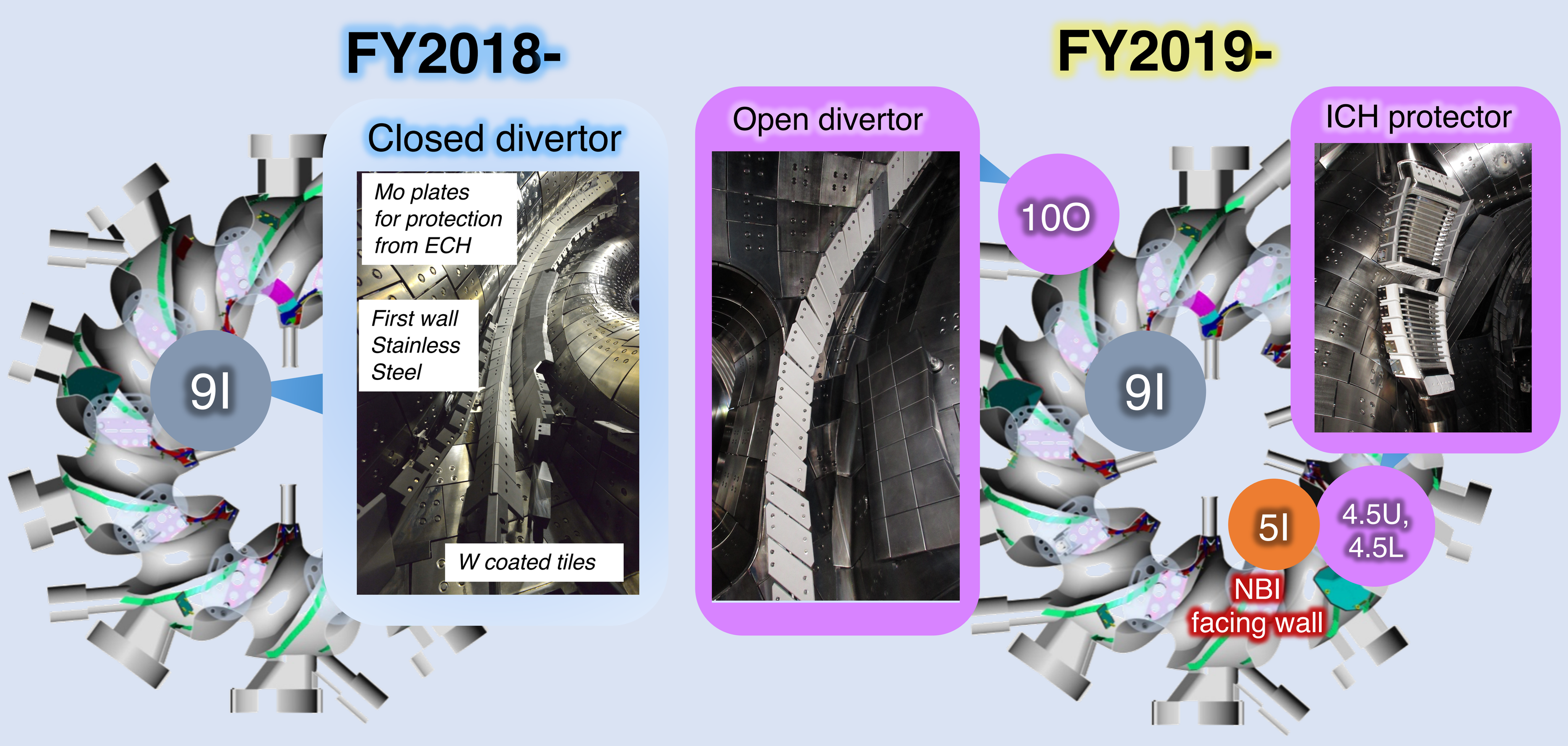


W-coating survived without delamination up to 10 MW/m² for 3 s.

EDX analysis of deposition layer near W coated divertor

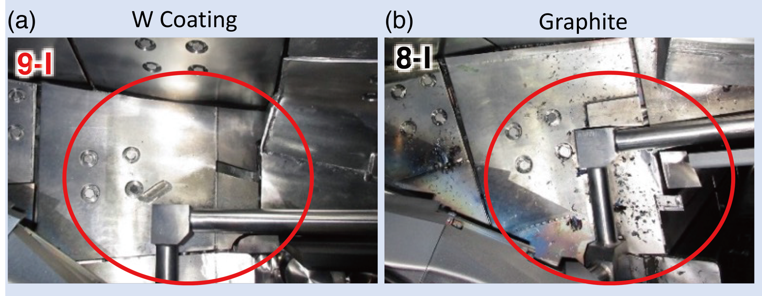


Tungsten coated plates widely installed



RESULTS/Erosion of W and W spectroscopy

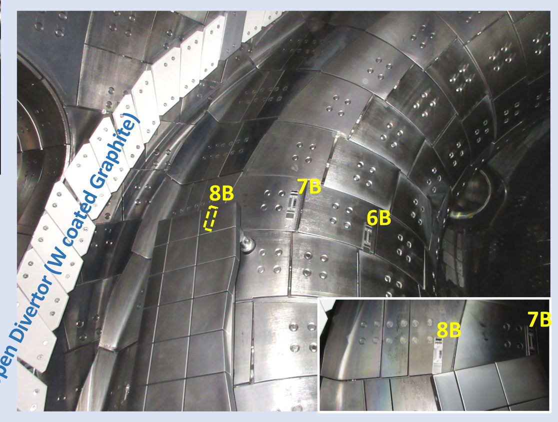
Reduction of the carbon flakes

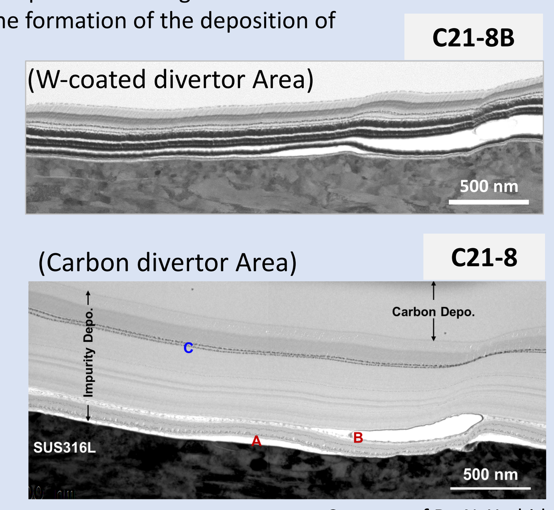


- ✓ Drastic suppression of the carbon flakes on the first wall panels behind the closed divertor system is confirmed.
- ✓ A carbon flake often causes undesirable impact for maintaining a long pulse discharge in LHD. The results suggest that W-coating is effective for the particle control.

Comparison of specimens installed near W-coated and Graphite divertors

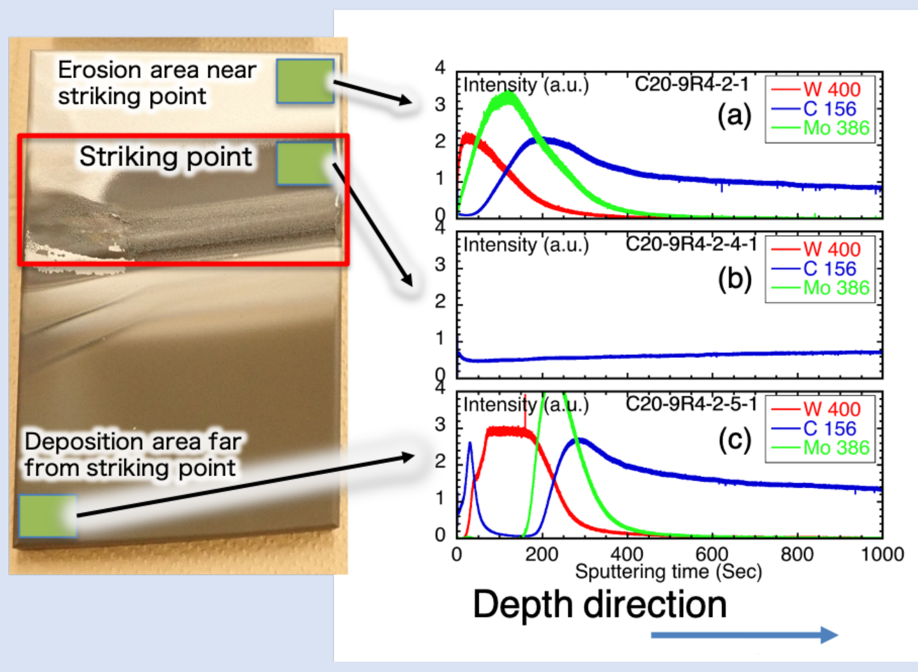
- ✓ Reduction of deposition layer is observed in the specimen near W-coated divertor
- ✓ In initial phase of the experimental campaign, the deposition of tungsten is observed.
- ✓ In the end phase of the experimental campaign, the formation of the deposition of carbon is similar.





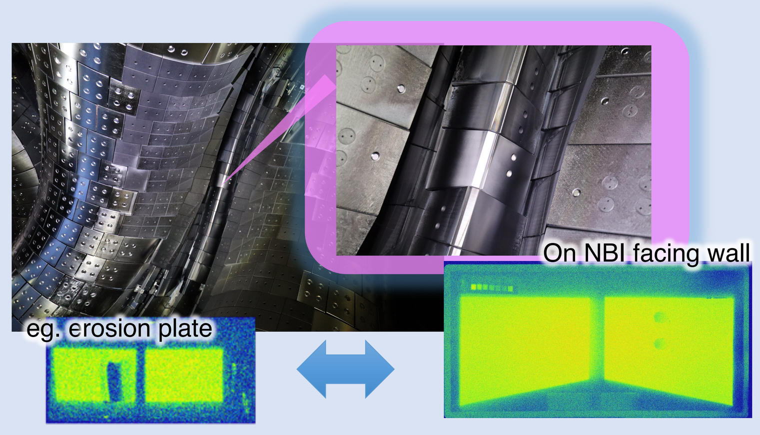
Courtesy of Dr. N. Yoshida

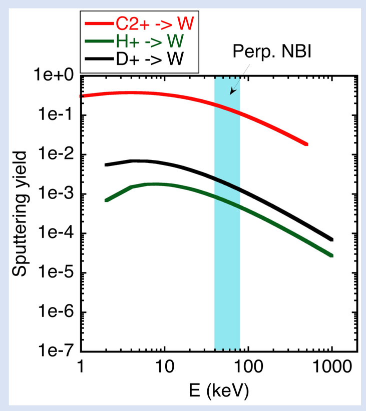
Surface analysis of the tile after the experiments by GD-OES



- ✓ We confirmed some black colored regions on the surface. In these areas, near the surface of the striking point, the bulk carbon is seen due to the erosion of coated-W.
- ✓ In other areas, the carbon is deposited, indicating that the carbon coming from other positions is probably transported. These carbon impurities might sputter W.

Tungsten coated tiles on NBI facing wall

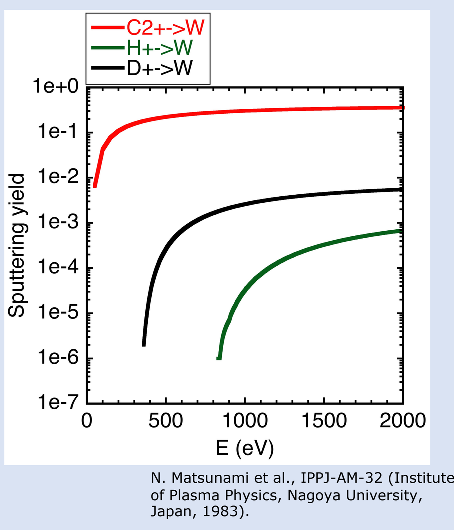




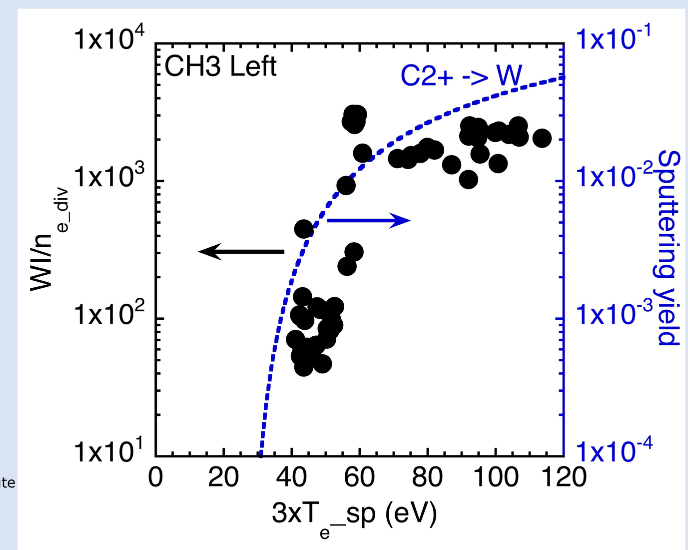
- ✓ No erosion was visually observed. Also, imaging plate shows no erosion.
- ✓ The sputtering rate of the W on high energy particles decreases, suggesting that the effect of W sputtering is small.

The erosion seems to be dominated by low-Z impurities of carbon

If the full W-coated tiles are installed in future, the sputtering of W will be significantly reduced.

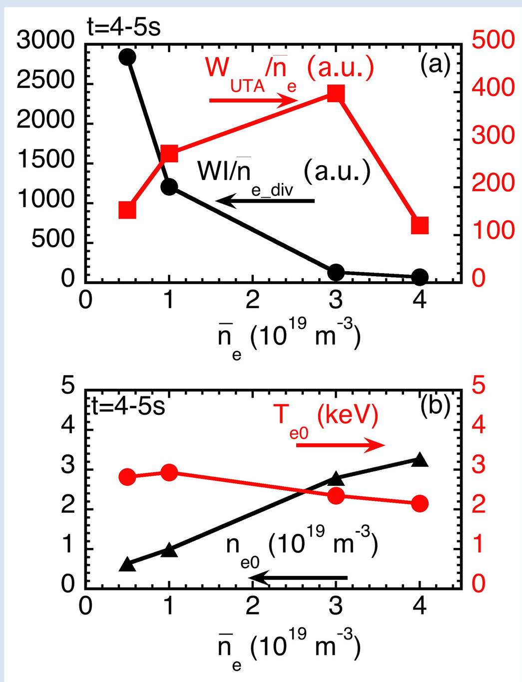


N. Matsunami et al., IPPJ-AM-32 (Institute of Plasma Physics, Nagoya University, Japan, 1983).



The sputtering yield of W from carbon impurity qualitatively coincides with the dependence of the intensity, indicating that carbon impurities can be a cause for the sputtering of W.

W behavior investigated by EUV and divertor spectroscopies



- ✓7.8 MW of NBI
- ✓W source evaluated in the intensity of WI by divertor spectroscopy. The intensity of WI decreases with electron density.
- ✓W behavior evaluated in UTA (W^{24+}~W^{29+}, 50-51Å) by EUV spectroscopy. UTA intensity is maximum at $3x10^{19}$ m^{-3}, and the intensity decreases with further high density. →suggesting in the change of the transport of W.
- ✓Impurity shielding effect of the ergodic layer. The impurity shielding effect of high Z impurities (Fe) also increases with increasing density. S. Morita+, NF 2013

CONCLUSION

- ✓ Tungsten (W)-coated divertor tiles were installed in the wide area of the divertor of one toroidal section out of the ten toroidal sections in the Large Helical Device (LHD). The visible and extreme ultraviolet (EUV) spectroscopic measurements show the different dependence of emission intensity of neutral W atoms and highly ionized W ions (W^{24+}~W^{29+}) on the line-averaged electron density in NBI plasmas. The different dependence suggests that an intrinsic mechanism to reduce core W concentration is observed in helical systems.
- ✓ The suppression of the carbon flakes, which is generated by the exfoliation of a deposition layer formed by eroded carbon divertor tiles is confirmed at the W-coated divertor section. A carbon flake often causes undesirable impact on the particle control in a long pulse discharge in LHD. The results suggest that W-coating is effective for the particle control. The surface analysis shows that the coated W at the strike point was eroded on some divertor tiles.
- ✓ Based on the analysis of divertor plasma parameters and spectroscopy data, the erosion is considered due to carbon bombardment originating from graphite divertor tiles of which much larger number than W-coated tiles in the vacuum vessel. The results suggest that understanding of role of low-Z impurity is important to predict a lifetime of W divertor in future devices, where the low to medium Z impurity exist as auxiliary impurity to aid divertor heat load mitigation.