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OVERVIEW OF THE RECENT EXPERIMENTAL STUDIES OF PLASMA-FACING COMPONENTS IRRADIATED WITH DIVERTOR RELEVANT PLASMA

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ABSTRACT

Plasma-surface interaction in fusion devices is characterized not only by high energy content, but also by collective effects under the influence of strong turbulence of the near-wall plasma. The stochastic structures of statistical self-similarity have been observed on the material surface irradiated with high heat flux plasma in fusion devices. The problem of the observed surface structures relates to the growth of stochastic interface boundaries under the influence of several competing agglomeration mechanisms of plasma-surface interaction. In fusion devices, this leads to the growth of unique stochastic relief with a self-similar structure and hierarchical granularity of the material with a long-range order in the structure from tens of nanometers to hundreds of micrometers, resulting in high porous structure which needs to be considered in the problem of in-vessel components of fusion reactor.

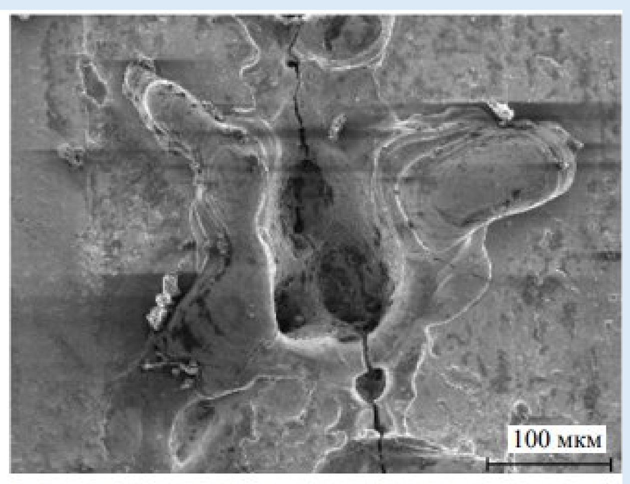
BACKGROUND

Plasma tests of fusion materials (tungsten, graphite, beryllium, steels, liquid metal components etc.) in modern fusion devices revealed a significant change in the surface structure under the high heat plasma loads. The plasma-surface interaction (PSI) in magnetic fusion devices involves several mechanisms including erosion and damage to the surface, melting and recrystallization of surface layers, movement of molten material over the surface, sputtering, evaporation, re-deposition of eroded material on the surface, modification of surface layers on the scales from tens of nanometers to hundreds of micrometers. The conditions corresponding to the plasma load in the fusion reactor cannot be fully achieved in modern tokamaks. To identify the dominant PSI mechanisms expected in fusion reactor, steady-state plasma tests of fusion materials were performed in linear plasma devices (LPD - divertor simulators) NAGDIS-II, PLM, PISCES, MAGNUM-PSI and others, plasma accelerators QSPA-T and QSPA-Be. Experimental studies of plasma-facing components in fusion plasma devices have revealed not only erosion but also surface modification of plasma-facing materials which needs to be analyzed to predict performance of fusion reactor (ITER, FNS, DEMO).

CHALLENGES

- Erosion, cracking and arcking are the problem of plasma-facing materials of in-vessel components in fusion devices.

Tungsten limiter in tokamak T-10



Arc crater on tungsten in tokamak T-10

- Erosion and redeposition of the eroded materials lead to the irregular surface growth on the plasma-facing components (PFC).
- The high porosity and specific area of such a surface leads to the tritium retention problem.

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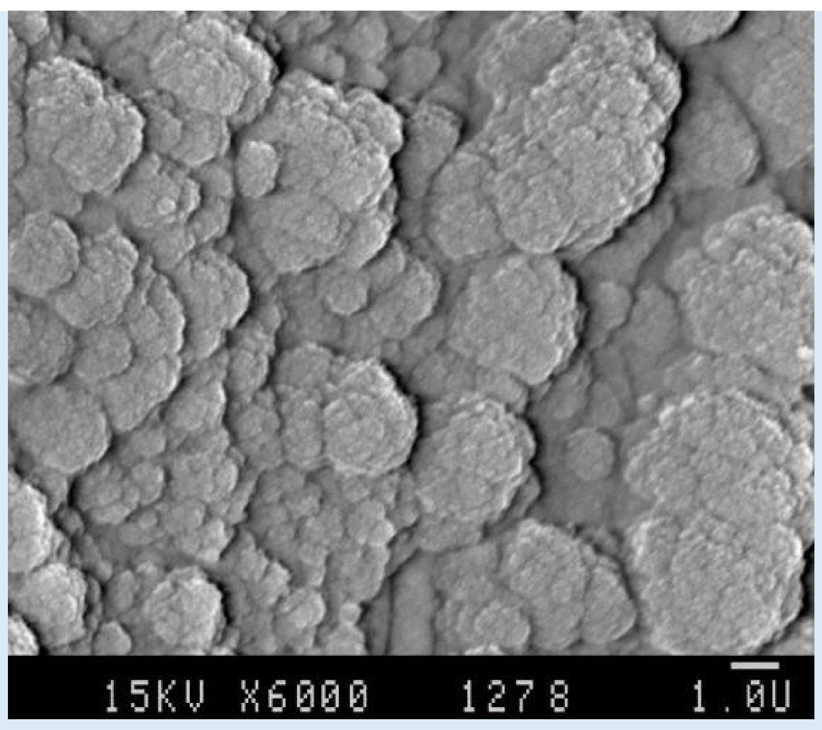
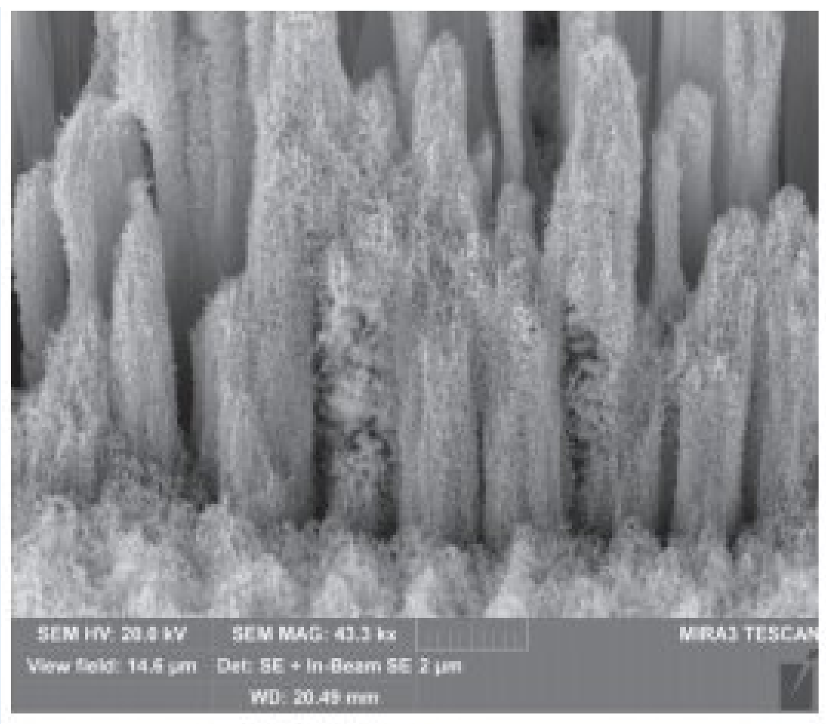
OVERVIEW OF RECENT STUDIES

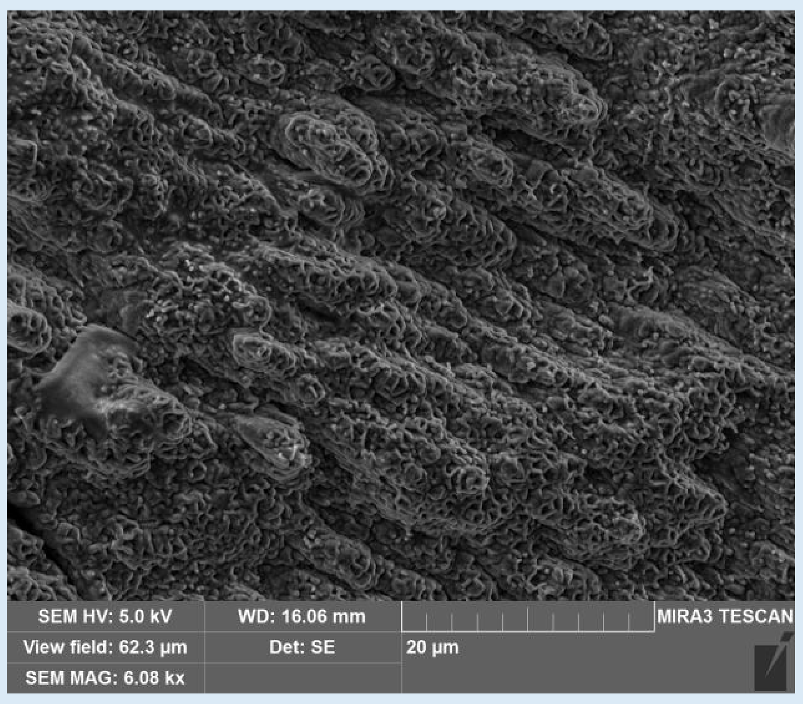
- In tokamaks, plasma accelerators QSPA, LPDs, irradiation with high heat plasma leads to a formation of irregular surface structures on PFC.
- Various types of stochastic topographic surfaces have been observed like "cauliflower", "fuzz', stratified, columnar micro- and nanostructures on W, graphite, Mo, Be, Ti, steels and others.
- The growth depends on intensity of plasma load, PFC material surface temperature, duration of plasma irradiation.



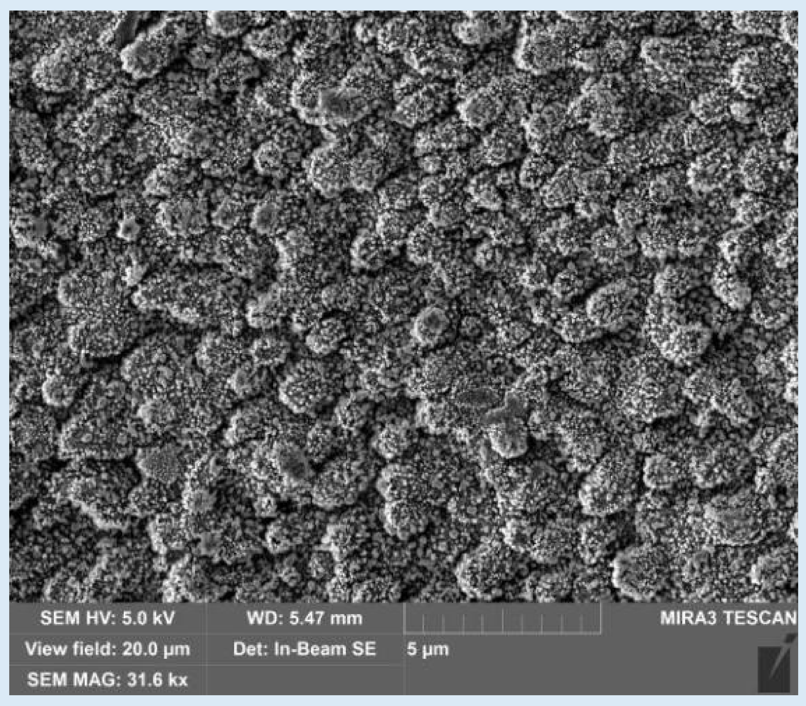
W cauliflower-like, QSPA



W "fuzz", He plasma PLM



Li in tokamak T-10 + PLM



Ti, He plasma PLM

OUTCOME

- Experimental results show that multiple processes of erosion and redeposition of the eroded material, surface melting and motion of the surface layers lead to a stochastic surface growth with a self-similar structure and hierarchical granularity on the scales from tens of nanometers to hundreds of micrometers.
- The specific property of the near-wall plasma in fusion devices is the strong plasma turbulence generating electric field fluctuations with long-range correlations effecting the surface modification and agglomeration.

CONCLUSION

- Stochastic clustering with hierarchical granularity has been found on the material surface (W, Mo, Li, Ti) irradiated with high heat plasma fluxes in fusion devices.
- The dominant factor in such process is the collective effect during stochastic clustering rather than the chemical element composition.
- To identify the dominant PSI mechanisms generating the stochastic clustering and porosity, steady-state plasma tests of fusion materials are needed to be continued in divertor simulators in support of fusion reactor technology.

ACKNOWLEDGEMENTS

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