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Overview on Decade Development of Plasma-Facing Components at ASIPP & Advances in Understanding of High-Z Material Erosion and Re-deposition in Low-Z Wall Environment in DIII-D

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A. The first EAST plasma was ignited in 2006 with non-actively-cooled steel plates as plasma-facing materials and components (PFMC) which was then upgraded into full graphite tiles bolted onto water-cooled copper heat sinks in 2008. And the first wall was changed further into TZM in 2012, while keeping graphite for both of the upper and lower divertors. With rapid increase in H&CD power in EAST, the W/Cu divertor project was launched around the end of 2012, aiming at achieving actively-cooled full W/Cu-PFCs for the upper divertor, with heat removal capability up to 10 MW/mˆ2. The W/Cu upper divertor was finished in the spring of 2014, consisting of about 15000 W monoblocks for 160 vertical targets, and 24000 W flat tiles for 160 baffles and 80 domes, on 80 cassette bodies toroidally assembled. Two different types of W/Cu actively-cooled PFCs for the project have been developed at ASIPP. The monoblock PFCs for vertical targets are manufactured by hot isostatic pressing (HIP) for cladding oxygen free Cu (OFC) to the inner surface of the W monoblocks, and then HIPing for the bonding between the clad monoblocks and CuCrZr cooling tube. The flat-tile PFCs for baffles and domes are manufactured by casting OFC onto the rear side of W tiles firstly, followed by HIPing of the W/OFC tiles onto CuCrZr heat sink plate. The non-destructive testing (NDT) quality control system has been established. In collaboration with IO and CEA teams, we have demonstrated our technology capability to remove heat loads of 5000 cycles at 10MW/mˆ2 and 1000 cycles at 20MW/mˆ2 for the small scale monoblock mockups, and surprisingly over 300 cycles at 20MW/mˆ2 for the flat-tile ones. Commissioning of the EAST upper W/Cu divertor in 2014 failed due mainly to leaks of e-beam welding between cooling tube and manifold box. After the campaign, we examined the leaking PFCs and reviewed the whole process, and then implemented several practical measures to improve connection design, component welding quality and installation welding reliability, which helped us achieve successful commissioning in 2015 campaigns. Key technologies being developed at ASIPP for manufacturing W/Cu-PFCs have shown great performance against HHF testing. The experience and lessons we learned for batch production and commissioning are undoubtedly valuable for ITER engineering validation and tungsten-related plasma physics.

B. Significant advances have recently been made in the understanding of erosion and re-deposition of high-Z plasma facing components in a mixed materials environment, encouraging prospects on control of high-Z material erosion for future reactors. Dedicated DIII-D experiments coupled with modeling reveal that the net erosion rate of high-Z materials is strongly affected by carbon concentration in the plasma and the magnetic pre-sheath, and can be actively controlled with electrical biasing, as well as by local gas puffing. Thin film tungsten (W) and molybdenum (Mo) samples of different diameters were exposed under well-diagnosed divertor plasma conditions in DIII-D using the divertor materials evaluation system (DiMES) to measure the gross and net erosion rates by ion beam analysis. The net erosion rate of high-Z materials is significantly reduced due to the high local re-deposition ratio, which is mainly controlled by the electric field and plasma density within the magnetic pre-sheath. The modeling indicates that decreasing the sheath potential can suppress the net erosion. New experiments have demonstrated the strong correlation of erosion with external biasing voltage. High carbon impurity concentration in the background plasma is also found to reduce the net erosion rate of high-Z materials. Both DIII-D experiments and modeling show that local 13CH4 injection can create a carbon coating on the metal surface. The 13C deposition provides quantitative information on radial transport due to ExB drift and the cross field diffusion. Additionally, new experiments show that local deuterium gas

injection upstream of the W sample not only reduced W net erosion rate by a factor of 2 but also increased the W re-deposition ratio significantly, mainly due to local plasma cooling. High-resolution measurements of the W erosion rate during and between ELM events near the outer strike point (OSP) demonstrate that peak W erosion during ELMs is shifted away from the OSP radius, dramatically broadening the erosion profile at the divertor target. These new findings have significant implications for the understanding and active control of W divertor target operation in ITER with its low-Z beryllium first wall. Work supported in part by the US DOE under DE-AC05-06OR23100, DE-FG02-07ER54917, DE-AC04-94AL85000, DE-AC05-00OR22725, DE-FC02-04ER54698, and DE-AC52007NA27344.

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