# §27. Development of Plasma-Spray Technique and Evaluation of Coating Properties for LHD

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Low pressure plasma spraying (LPS, also known as vacuum plasma spraying VPS) is an attractive technique to prepare W armor layers on substrate materials. The objective of this study is to optimize the fabrication conditions of W coating on the LHD divertor tiles made of graphite from various viewpoints including microstructures, heat load resistance, and tritium (T) retention and desorption. In 2014, it was found that 25–38 μm is the optimum size of W powder particles under the present conditions of arc plasma used in spraying and geometrical configuration between plasma and substrate. In 2015, the influence of substrate temperature was examined.

E-type tiles made of isotropic graphite (IG-430U) used in LHD were employed as substrates. After roughening the substrate surface using a conventional sand blast technique, LPS-W coatings were prepared at 1130–1220 K and 1230–1320 K. The substrate was heated solely by the heat flux from the plasma in the former case, while a carbon-fiber reinforced composite heater set on the back of the substrate was used for additional heating in the latter case. The fluctuation of substrate temperature was due to scanning of plasma gun in front of the substrate surface. The diameter of powder particles used was 25–38 μm. The cross sectional observation of the coatings and micro-crystallography were performed using a scanning electron microscope (SEM) and an electron back scatter diffraction (EBSD) technique. An electron beam heating device (ACT2) was used for heat load tests. The energy of electron beam was adjusted to 40 keV, and the beam was scanned in the areas of 50×50 mm or 10×10 mm. Tritium (T) retention after implantation of 0.5 keV DT ions at room temperature was also examined using an imaging plate technique. Retention of T in uncoated graphite tiles and bulk W specimens with mirror-like surfaces was also measured for comparison. The LPS-W prepared at 1130–1220 K and 1230–1320 K are hereafter denoted as LPS-W-LT and LPS-W-HT, respectively.

The mass densities of LPS-W-LT and LPS-W-HT were 95.3 and 95.6% of the theoretical density of W; there was not significant difference in the mass density. EBSD images of cross sections of prepared coatings are show in Fig. 1. Growth of columnar grains along the coating direction was observed for both coatings, indicating sufficient melting of tungsten particles in the plasma. The grain size in LPS-W-HT was significantly larger that in LPS-W-LT. These observations showed that the substrate temperature has strong influence on the rate of grain growth.

The heat load tests were performed in a pulsed mode (typically 2 s×20 pulses) and a steady state mode (longer than 1500 s). The maximum heat loads given to the specimens were 0.9 MW/m$^2$ in the steady state mode and 3 MW/m$^2$ in the pulsed mode at 50×50 mm, and 2 MW/m$^2$ in the steady state mode and 20 MW/m$^2$ in the pulsed mode at 10×10 mm. Those values are comparable with the heat loads on the divertor tiles in LHD. Tests at higher heat loads were difficult due to various reasons including increase in the temperature of vacuum chamber and the pressure of residual gases. No visible damage and modification were observed on the surface and in the cross sections of LPS-W-HT and LPS-W-LT after the heat load tests. It was concluded the coatings prepared in this study had sufficiently high heat load resistance.

T retentions in LPS-W-HT and LPS-W-LT were clearly lower than that in the uncoated tile but higher than that in the bulk W by a factor of 8. SEM observations showed that LPS-W-HT and LPS-W-LT had fine W grains on the surfaces, as shown in Fig. 2 left. The origin of these fine grains was considered to be the condensation of W fume in the vacuum chamber after the last scan of plasma gun in the LPS processes. These fine grains could be removed easily by polishing the specimen surfaces with abrasive papers, as shown in Fig. 2 right. The implantation of T and retention measurements were repeated again after the surface polishing. T retentions in the polished LPS-W-HT and LPS-W-LT were comparable with that in the bulk W.

The results obtained in 2015 indicated that the substrate temperature during the preparation of coatings has significant effects on the size of columnar grains. Nevertheless, even the LPS-W coating prepared at lower temperature showed sufficiently high heat load resistance and low T retention under the test conditions employed in this year.

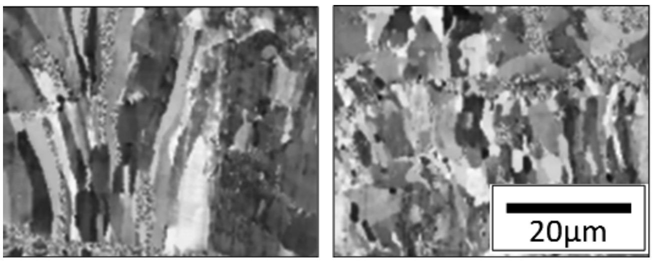


Fig. 1. EBSD images of cross sections of prepared coatings.

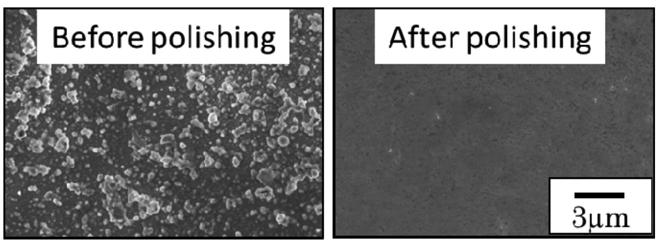


Fig. 2. SEM image of surfaces of LPS-W-LT before and after mechanical polishing.