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Beryllium layer response to ITER-like ELM plasma pulses in QSPA-Be

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ABSTRACT

Material migration in ITER is expected to move beryllium (Be) eroded from the first wall primarily to the tungsten (W) divertor region and to magnetically shadowed areas of the wall itself. This paper is concerned with experimental study of Be layer response to ELM-like plasma pulses using the new QSPA-Be plasma gun (SRC RF TRINITI). The Be layers (1 → 50 µm thick) are deposited on special castellated Be and W targets supplied by the ITER Organization using the Thermionic Vacuum Arc technique. Transient deuterium plasma pulses with duration ~0.5 ms were selected to provide absorbed energy densities on the plasma stream axis for a 30° target inclination of 0.2 and 0.5 MJm^{-2}, the first well below and the second near the Be melting point. This latter value is close to the prescribed maximum energy density for controlled ELMs on ITER. At 0.2 MJm^{-2} on W, all Be layer thicknesses tested retain their integrity up to the maximum pulse number, except at local defects (flakes, holes and cracks) and on tile edges. At 0.5 MJm^{-2} on W, Be layer melting and melt layer agglomeration are the main damage processes, they happen immediately in the first plasma impact. Melt layer movement was observed only near plasma facing edges. No significant melt splashing is observed in spite of high plasma pressure (higher than expected in ITER). Be layer of 10 µm thick on Be target has higher resistance to plasma irradiation than 1 and 55 µm, and retain their integrity up to the maximum pulse number at 0.2 MJm^{-2}. For 1 µm and 55 µm thick on Be target significant Be layer losses were observed at 0.2 MJm^{-2}.

1. Introduction

The wall panels of the ITER main chamber will be almost completely armored with beryllium (Be) [1,2]. It is expected that Be eroded from the first wall will migrate to the W divertor plates and deposit there to form layers [3]. This layer may protect the W from a direct plasma action and can decrease the flow of W to the core plasma, but is also expected to be the main source of fuel retention in ITER and can lead to the formation of significant dust sources if the layers disintegrate, for example under transient energy pulses. The redeposited Be layers are expected on the magnetically shadowed areas of the Be first wall (FW) panels also. The experimental data on Be behavior under the expected transient loads are insufficient for assessments of the PFC lifetime and acceptable transient heat loads. Experiments with Be are complicated because of toxicity of Be dust and they require special operating conditions.

To investigate Be erosion under the ITER-like plasma and photonic heat loads, a new QSPA-Be facility was designed in the SRC RF TRINITI and assembled in the Be cell of the Bochvar Institute. This facility is a modernized variant of the QSPA-T plasma gun which was used for the divertor PFC testing under ITER-like transient heat loads [4–8]. Both facilities provide hydrogen (or deuterium) plasma heat loads related to ITER ELMs or disruptions in the range of 0.2–5 MJm^{-2} (pulse duration ~0.5 ms) and photon radiation heat loads relevant to ITER mitigated disruptions up to 1 MJm^{-2} (pulse duration ~0.5 ms) [9]. The first results of Be PFC

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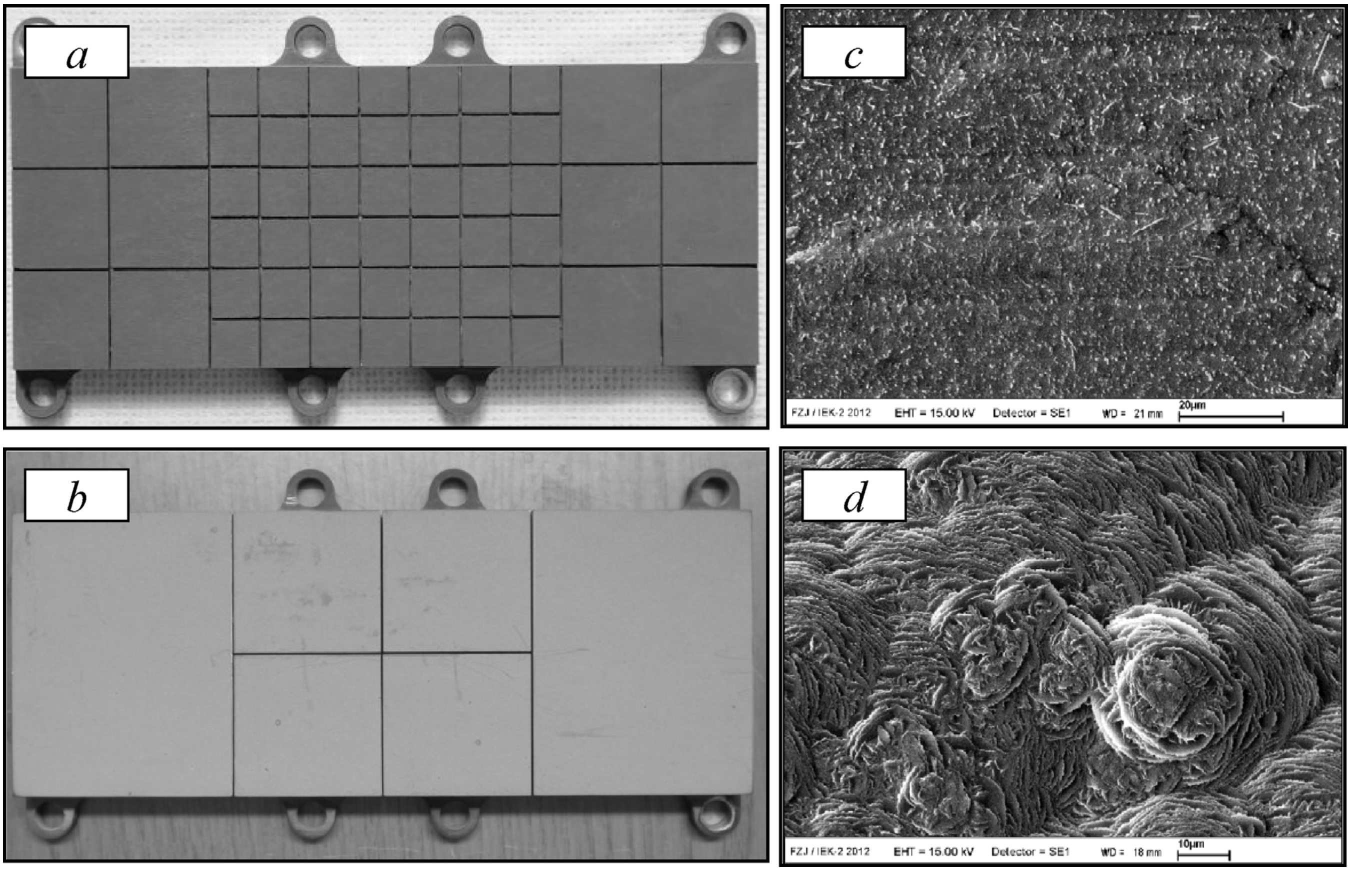

Fig. 1. Top view of the targets ((a) – W divertor PFCs, (b) – Be FW PFCs) and typical SEM images of the Be coatings ((c) – 1 µm, (d) – 55 µm).

erosion under ELM-like plasma heat loads obtained with QSPA-Be are already published [10–12]. These experiments used Be plates and mock-up of the beryllium ITER first wall PFCs from Russian Be grade TGP-56FW and US Be grade S65-C, which are the candidates for the ITER first wall (FW). The targets were exposed to the plasma heat loads of 0.2 – 1.0 MJm^{-2}, at initial base temperatures in the range 250 – 500 °C and with pulse duration of 0.5 ms.

The present work concerns the next step of these investigations which includes plasma testing of mock-ups of the ITER tungsten divertor target and mock-ups of ITER FW Be panel. The W divertor targets and Be FW panels were preliminary coated with thin Be layers of 1, 10, and 55 µm thickness. Originally manufactured in the EU, under the previous European Fusion Development Agreement, the targets were transferred to Fusion For Energy and finally to IO ownership. The Be coatings were applied in Romania at the National Institute for Laser, Plasma and Radiation Physics in Bucharest.

2. Experimental techniques and conditions of the targets exposure

The targets were specially provided for these experiments by IO. Each tungsten target (Fig. 1a) consist of 3 mm tungsten layer, which were brazed (by 2 mm copper layer) on the supporting stainless steel plate of $60 \times 150\ mm^2$. The tungsten surface were castellated to 42 tungsten elements of $9.5 \times 9.5\ mm^2$ surface area and 12 tungsten elements of $19.5 \times 19.5\ mm^2$ surface area. The gaps between neighbor elements with 0.5 mm.

The tungsten surface of the targets was coated with thin Be layers in Romania using the Thermionic Vacuum Arc technique under the following conditions. Pressure in the vacuum chamber was in the range $(4.5 – 7.5)\cdot 10^{-7}$ torr during deposition. Base substrate temperature was 400 °C. Deposition rate was in the range of 2–5 nm/s. This technique was used for ITER-like wall project at JET [13,14]. Different thickness of Be coating were provided by varying of deposition time. Three targets were provided with Be layer thickness of 1, 10, and 55 µm for the experiments. The one target without Be layer was also used in the experiment for comparison.

The SEM views of deposited Be layer depended on layer thickness and were practically independent of substrate (Be or W). Typical SEM images are presented on the Fig. 1c and d. The Be layers of 10 and 55 µm were faced by rosebud structures with diameter of several micrometers. For 1 µm layer the significantly fine-grained structure was observed. But for all thicknesses the continuous (compact) layer without through pores were performed.

Each Be target (Fig. 1b) consist of 8.5 mm beryllium (S65C) layer, which were brazed (by 2 mm copper layer) on the supporting stainless steel plate of $60 \times 150\ mm^2$. The beryllium surface were castellated to 4 elements of $29.5 \times 29.5\ mm^2$ surface area and 2 elements of $59.5 \times 44.5\ mm^2$ surface area. The gaps between neighbor elements with 0.5 mm. The beryllium surface of the targets was also coated with thin Be layer. Three targets were used with Be layer thickness of 1, 10, and 55 µm.

The general schemes of target plasma exposure at the QSPA-Be facility are presented in Fig. 2a. The exposed target with infrared heater is placed under direct plasma action at the distance of 60 cm from the plasma gun. The incidence angle of the plasma flow can be varied from 0 up to 80° (60° in present experiments). The results of some previous experiments performed using this loading scheme are described in the [4–8,10–12].

The infrared heater which provides the target preheating before the plasma exposure and maintains the target surface temperature before each plasma pulse at a fixed level in the range 20 – 500 °C. In all cases of present work, the target heater was used to set a