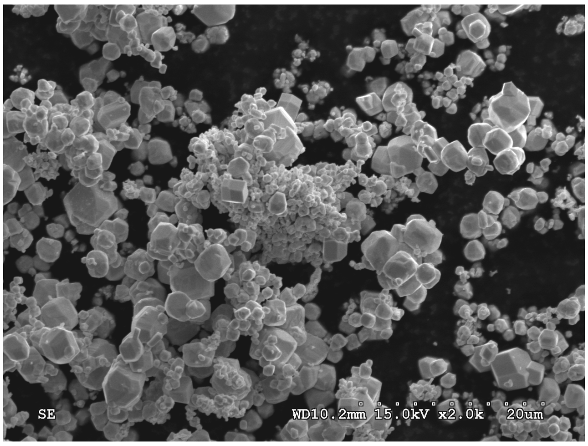
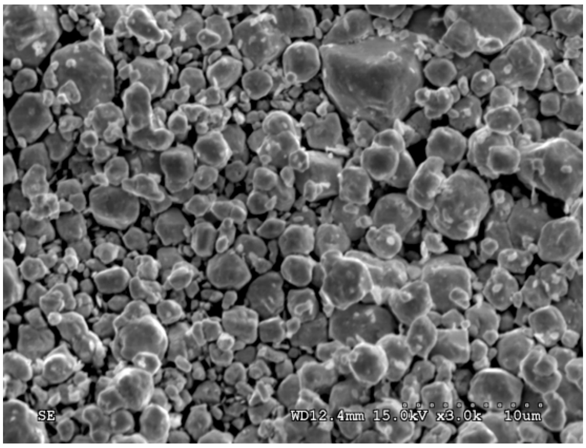
1. Underlying Technology

The underlying technology activity includes two tasks:

- Application of pulsed laser light for the removal of co-deposited deuterium/tritium from in vessel components
- W-Cu composites fabrication route based on powder metallurgy, high current electric impulse sintering, plasma spaying and electrocrystallization methods



a)



b)

Selected illustration Tungsten powder a) before milling process, b) after milling process (see section 3.2 for details)

1.1. Application of pulsed laser light for the removal of co-deposited deuterium/tritium from in vessel components

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Abstract

Among other methods of detritiation of in-vessel tokamak components the application of lasers for removal of fuel trapped in co-deposited layers is under investigation. The research conducted at IPPLM includes preparation, completion and testing of the experimental arrangement (interaction chamber, laser, diagnostics, etc.) for the ablation tests performed on commercial graphite and polyethylene samples and optimization of hydrogen/deuterium removal from the graphite targets from the main toroidal limiter of the TEXTOR tokamak. For removal of the surface layer from the graphite target (plate) we used a new repetitive Nd:YAG laser system with the following parameters: $E_L \leq 5$ J, $\lambda_L = 1.06$ µm, $\tau_L \sim 1$ ns, $I_L \leq 10^{13}$ W/cm^2 and repetition rate up to 10 Hz. Determination of the characteristics of ions emitted from the laser-illuminated targets was performed with the use of ion collectors and an electrostatic ion-energy analyzer. The main ion stream parameters were measured in dependences on number of laser shots and the laser power density on the target surface. The results obtained with the use of the electrostatic ion-energy analyzer were confirmed by the means of Quadrupled Mass Spectroscopy performed at collaborating laboratory at FZJ Juelich. The properties of modified carbon sample surface were determined with the use of optical and profilometry methods and compared with the results of the ion measurements.

Summary

The present choice of plasma facing materials (PFM) for ITER comprises beryllium for the main chamber wall and port limiter, tungsten for the upper vertical divertor target and dome, and carbon fibre composites (CFC) for the lower vertical target, i.e. for the strike point zone. The use of carbon is related to good thermo-mechanical properties of CFC although the presence of this element can lead to the fuel accumulation by co-deposition. The most significant inventory may be expected in remote areas shadowed from the direct plasma impact, as observed at JET. Such massive accumulation of fuel would have a serious impact on the safety and economy of the ITER operation. Based on the experience gathered following the full deuterium-tritium campaigns in carbon-wall devices, e.g. TFTR and JET, a development of reliable and efficient methods of fuel removal is indispensable. Until now, several *in-situ* and *ex-situ* techniques have been tested. The first group of methods is based on tokamak discharges in D_2 fuelled plasma, H and He glow discharge in order to induce the isotope exchange. Venting with oxygen aims at the conversion of fuel into tritiated water, which – on the other hand – is difficult to handle. Several *ex-situ* methods are being developed and tested in laboratories. They rely mainly on cleaning PFM by photons (laser or flash-lamp light) or plasma torches. Laser-induced ablation is used for removal of the whole co-deposit. The fuel removal efficiency is usually satisfactory, but the composition of products formed under power deposition and the surface state of the irradiated target is also important.

The main focus of the research conducted at IPPLM was on the drawing up the schema for the viable and feasible process (based on the means of laser ablation phenomenon) of deuterium containing co-deposite removal from in vessel tokamak components. After the preliminary experiments, the key effort was made for the surface layer characterization by the diagnosis of ionic species emitted from the laser-irradiated co-deposits on a limiter tile from the TEXTOR tokamak. Obtained results were to be confirmed at the collaborating laboratories (by the means of optical microscopy, profilometry and QMS) and allowed to optimize the crucial parameters of the investigated process (number of shots in series, power density, etc.).

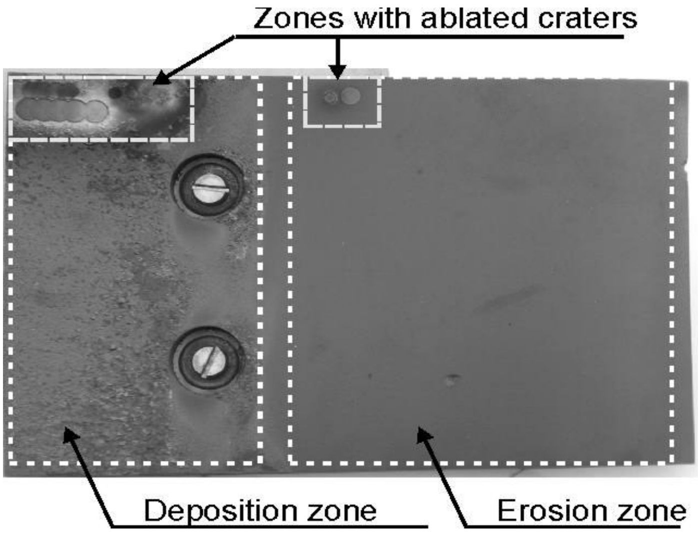

Figure 1 The tile from the toroidal belt pump limiter of TEXTOR

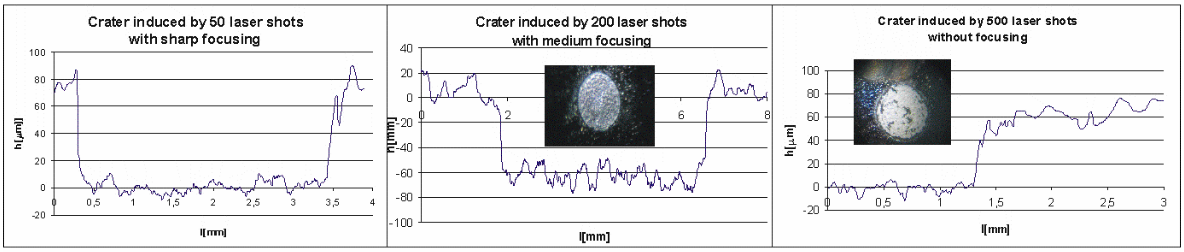

Figure 2 Depth profiles and pictures of craters induced for different focusing set-ups (*l* – length along crater diameter, *h* – depth of the crater)

Conclusions

The investigation conducted at IPPLM and FZJ Julich has proved that laser ablative method can be interesting one for removing the deuterium/tritium containing co-deposited layers from the PFCs.

The results obtained at both laboratories are consistent and complement so they can give good information about the surface of samples being investigated and the effects of laser ablation method as well. Future experiments are needed, especially for development of technical aspects of the method such as scanning schemas, energy delivering systems, etc.

Collaboration

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Association EURATOM–VR, Alfvén Laboratory, KTH, Stockholm, Sweden

1.2. W-Cu composites fabrication route based on powder metallurgy, high current electric impulse sintering, plasma spraying and electrocrystallization methods (composite manufacturing, characterization and mechanical testing)

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Abstract

W-Cu composites were produced via: (a) powder metallurgy route, (b) high current electric impulse sintering, (c) plasma spraying and (d) electrocrystallization method. The materials and coatings were described and characterized. Microstructure of powders and composites as well as theirs chemical composition were investigated. Mechanical tests for characterizing of mechanical properties of the materials as well measurements of coefficients of thermal expansion and coefficients of thermal conductivity were carried out.

Summary

One of the main problems in the development of W/Cu joints is large difference in the coefficients of thermal expansion (CTE) ($\alpha_{Cu} \approx 4\alpha_W$) and elastic modulae ($E_{Cu} \approx 0.2E_W$) of Cu and W. These differences generate large stresses at the W/Cu interfaces during manufacturing and/or during operation of plasma facing components. Such stresses may lead to cracking, delamination and reduced lifetime of the components. Possible solution to these problems is the use of a W-Cu functionally graded material incorporated between W armour and Cu-based heat sink material.

The main objective of the project is to develop alternative technology for W-Cu composites in the form of a functionally graded material (FGM) by improving the techniques currently used for manufacturing of tungsten heavy alloys. Possibility of employing novel methods, such as current electric impulse sintering, plasma spraying and electro-crystallization is also investigated. Application of these different techniques aims at selection of optimal production technology based on recognition of advantages and drawbacks of individual processes. During 2005 the studies were directed towards development of W-Cu composites of specific W:Cu ratios.

The short description of the results obtained using the fabrication technologies scheduled in the project is presented below.

<ins>High current electric impulse sintering</ins>
W-Cu composites were consolidated using the device for Pulse Plasma Sintering (PPS) at the Faculty of Materials Science and Engineering at Warsaw University of Technology. The most important results of the present research can be summarized as follows:

1. Parameters of the milling process of the tungsten powder were established (to de-agglomerate the particles)
2. Parameters of the mixing process of tungsten and copper powders were determined. It was confirmed that mixing process has an essential influence on the homogeneity of the sinters.
3. The annealing of powder mixture before sintering (in dry hydrogen in order to remove oxides) reduces sinters porosity.

4. For the rate of heating of the order of 1500 °C/min one can obtain W-50wt.%Cu and W-75%Cu sinters at temperature of 900 °C, with 99% of theoretical density during 300s.

Powder metallurgy route

W-Cu composites were produced by mixing, pressing and sintering of pre-selected powders. The powders used for the composites fabrication were tungsten FSSS 2.95 μm and dendritic copper (particle size <40 μm). The tungsten powder was sieved by the screen of a 28 μm mesh.

The powders were mixed in a two-conical mixer with WC balls for the time 10-14h. The powder mixtures before sintering were reduced in the dry hydrogen (in order to remove surface oxides) and pressed under the pressure of 300 MPa. The preliminary experiments with iso-static pressing (200 MPa) were also performed.

The compacts were sintered in a furnace with two zones (840 and 1170^{o}C – liquid phase sintering) in a dry hydrogen (-50^{o}C dew point). The experiment with solid state sintering was also carried out.

The W-Cu compacts with a pure copper on one side showed a very good bonding between the two components (neither pores nor the oxides at the interface).

Electrocrystallization method

Cu-W composite layers were produced by electrocrystalization. The deposition of composite layers was realized by the direct current with various current densities. The composite layers were deposited at ambient temperature, in an electrolytic bath containing dispersed tungsten powders. Such process parameters as: current density, concentration of bath components as well as the time and velocity of the electrolyte mixing were optimised. The investigations made possible to produce the composite layers with various thickness and different content of the tungsten. This content varied in the range of 5–30 % at. The Cu-W composite layers were investigated by the electron scanning microscopy. The distribution of the tungsten particles within the volume of the composites was examined by computer image analysis technique. The results of examinations showed that the tungsten particles were distributed homogenously in the entire volume of the composites.

Plasma spraying

The process of the plasma spraying was conducted at the atmospheric pressure. Experiments were performed using plasmotron PN 120. In the first step Cu and W coatings were deposited on the copper and steel substrates. In the second, the composite layers were manufactured. The coatings from powder mixtures of the composition of W+10%Cu, W+30%Cu, W+50%Cu were obtained.

The mechanical tests of composites produced by PPS and powder metallurgy were carried out (tensile tests of small samples at room temperature, hardness measurements). Additionally the coefficients of the thermal expansion of the samples produced by PPS were evaluated.