Mirrors for plasma diagnosis in fusion reactors. Overview of tests under fusion and laboratory conditions

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Optical systems for plasma diagnosis and imaging in a fusion reactor operated with a deuterium-tritium fuel will be based on metallic so-called first mirrors. The test programme has been carried out since 2003 [1] in carbon [2] and metal wall [3] machines. Results from current tokamaks have consistently shown that co-deposition processes of carbon and beryllium are responsible for the degradation (loss) of optical performance, especially of mirrors facing the divertor plasma. Main chamber mirrors have been modified mainly by co-implantation of neutral species. However, in the D-T reactor (e.g. ITER, DEMO) factors associated with tungsten (W) and boron (B) deposition, implantation of ^{4}He and charge exchange hydrogen isotopes (H,D,T), and neutron-induced effects are to be considered. Their impact cannot be studied in present-day fusion machines; therefore, the test program has been extended and complemented by laboratory works involving a range of accelerators [4,5].

The focus is on molybdenum (Mo) poly- and mono-crystalline mirrors. The neutron impact is simulated by self-irradiation of the polycrystalline Mo mirrors with 30 keV $^{98}Mo^{+}$ ions at three fluences, $1.5\cdot10^{14}$ cm^{-2}, $1.5\cdot10^{15}$ cm^{-2}, and $4.5\cdot10^{15}$ cm^{-2}. These values relate in order of magnitude to the estimated yearly radiation damages in DEMO. To include the effect of transmutation products, irradiation with 30 keV zirconium (^{93}Zr) and niobium (^{90}Nb) ions was performed. Protium (^{1}H) and ^{4}He irradiation at 2 keV simulates the remaining transmutation products and the impact of plasma species. The irradiation procedure was repeated on Mo mirrors with thin B and W deposits. Effects of erosion and deposition on monocrystalline Mo mirrors were investigated by repeated deposition and plasma cleaning of the mirrors. Additionally, a set of Mo-poly mirrors pre-damaged to 2 dpa and 20 dpa (1.5 MeV ^{98}Mo) has been installed in the main chamber of JET to examine the impact of damage on fuel retention (particularly tritium) during the D-T operation.

The reflectivity of the mirrors was measured before and after the irradiation steps using a photo-spectometer in the 250 – 2500 nm. Elastic Recoil Detection Analysis (ERDA) monitored the ^{4}He content close to the mirror surface. Focused ion beam (FIB) with subsequent scanning transmission electron microscopy (STEM) analysis was used to examine structural changes. The main results are:

a) The irradiation of the mirrors decreased their specular reflectivity, whereby the observed effects after ^{1}H and ^{4}He irradiation are stronger than after self-irradiation with ^{98}Mo. The reflectivity changes after irradiation are small compared to those caused by thin W deposits on the mirrors.
b) Deposition of B strongly leads to a significant loss of reflectivity.
c) Low amounts of ^{4}He were retained, i.e. 7% of the irradiated amount. The retained ^{4}He was located as expected in the top 50 nm of the mirrors. Over a timescale of 2 years, ^{4}He diffusion into the bulk Mo is observed.
d) Self-irradiation with ^{98}Mo and subsequent irradiation with H and ^{4}He lead to blister formation.

The irradiation program for testing other types of mirrors used in fusion machines will also be presented and discussed.

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ToF-ERDA Characterization of the Effect of Sputtering Power Density on Low Concentration Impurities in Binary Oxides for Semiconductor Applications

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The performance of semiconductors is critically influenced by the concentration of impurities, where the power density during the magnetron sputtering process has a non-negligible effect on their volume. Increasing power density leads to a decrease of contaminant concentration in the resulting thin layer. Investigation of this effect need to be executed in greater detail, particularly in oxides. This study investigates the effect of the power density in magnetron sputtering on the amount of hydrogen, carbon and other impurities in silicon, titanium, copper, silver and palladium binary Oxides, commonly used in the semiconductor industry. We have focused on a very narrow power density region of DC reactive magnetron sputtering in the range of 4,4-6,6 W/cm^{-2} (200-300W/3 inch target). Six samples of each material were prepared at fixed parameters of 5*10^{-3} mbar pressure, Argon and Oxygen atmosphere with flow rate 40/10 sccm. The analysis data were obtained from the same film thickness omitting surface of both substrate and the film. Detection limits of Time of Flight Elastic Recoil Detection Analysis allow us to point out even the very low, but important, concentration changes and characterize the correlation between the investigated parameters. This detailed investigation into such low concentrations has not been previously explored to this extent. The results provide more specific insides into importance of optimizing deposition parameters for further enhancing film purity and performance.

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Sputtering and structural modifications induced in Hafnium dioxide (HfO_2) thin films under (40-120) keV Kr^+ ion bombardment

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Research on the effects induced by energetic heavy ions interacting with solid materials, including atomic defects, sputtering due surface erosion and structural modifications, has received a considerable attention in various fields of nuclear physics and materials science [1]. The main interest was often focused on the study of the induced behavior of the solid material under keV to MeV heavy ion irradiation. In the keV energy region of our interest, the incident ion penetrates weakly into the target material and deposits a great amount of its kinetic energy essentially via nuclear elastic collisions until comes to rest near the target surface by ion implantation. It results on induced atomic damages in volume and surface sputtering with structural modifications [2]. In the present contribution, we report an experimental and numerical investigation on the induced sputtering yields and the structural modification on hafnium dioxide thin films (HfO_2/Si) deposited onto silicon substrate and then implanted by (40-120) keV Kr^+ heavy ions with different incident fluences ranging from 0.2 to 1.8×10^{16} cm^{-2}. This target material has recently gained much attention due its high-dielectric properties that can potentially replace silicon dioxide (SiO_2) in various technological applications, including devices for radiation [3]. The implanted HfO_2/Si samples were then analyzed using four different experimental techniques: Rutherford backscattering (RBS) spectrometry and Particle induced X-Ray Emission (PIXE) [4], Nuclear Reaction Analysis (NRA) and X-Ray Diffraction (XRD). The obtained experimental results in terms of sputtering yields, stoichiometry and microstructural changes were discussed and then compared to corresponding numerical ones derived by different predicted models [1, 3], including computer simulations tools (i.e., SRIM code [5]). Finally, a close correlation was observed between the measured sputtering yields and the structural modifications in terms of grain growth and lattice strain.

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