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Mirrors for plasma plasma diagnosis in reactors of controlled thermonuclear fusion: Ion-induced damage and ion beam analyses

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Optical spectroscopy and imaging diagnostics in next-step fusion devices, ITER and DEMO, will rely on metallic mirrors. The performance of mirrors is studied in present-day tokamaks and in laboratory systems. This work deals with comprehensive tests of mirrors: (a) exposed in JET with the ITER-Like Wall (JET-ILW); (b) irradiation by H^+, He^+ (1-2 keV) and $^{98}Mo^+$, $^{93}Zr^+$, $^{90}Nb^+$ (30 keV) to simulate transmutation effects and damage which may be induced by neutrons under reactor conditions in the optically active layer of mirrors: 15-30 nm.

Material studies performed with a wide range of ion beam (standard and μ-beam NRA with $^3He^+$, PIXE, RBS and HIERDA with $^{127}I^{9+}$), microscopy methods (including STEM, FIB) and spectro-photometry techniques have led to results summarised briefly in the following.

First Mirror Test at JET for ITER has been for Mo mirrors placed in the main chamber wall and in the divertor during a single campaign and during all three ILW campaigns , ~62 h of fusion plasma operation:

- In the main chamber only mirrors located at the entrance to the cassette lost reflectivity Be deposition from the eroded limiters), while those in the channels were only lightly affected.
- The performance of all divertor mirrors was strongly degraded by deposition of beryllium, tungsten and other species.
- Splashing of metal droplets from molten limiters on mirrors also occurred. It should be stressed, that solid Mo test mirrors were not damaged by arcing.

Work towards DEMO: radiation damage in mirrors: To induce changes predominantly in the optically ative layer the conditions for the irradiation with were based on SRIM simulations. The selection of ion type and dose was based on the FISPACT-II and TENDL-2014 predictions. Studies were done both for mirrors irradiated with a single species and with several types of ions, e.g. H^+, He^+ and Zr^+.

- The stepwise irradiation up to 30 dpa by heavy ions (Mo, Zr or Nb) caused only small changes in the optical performance. In some cases even improving even reflectivity due to the removal of surface layer with Mo oxides.
- Much stronger effects have been produced by helium because of bubble formation which led to the reflectivity decrease by more than 20%. Helium retention studies revealed that only 7-9% of the implanted He was retained mainly in two types of bubbles as detected by STEM. Helium residence time in Mo mirrors is long, as proven by HIERDA immediately after the irradiation and one year later.