Cr-Ta multilayers as a potential coating material for fuel cladding in Gen III and Gen IV nuclear plants

Mamour Sall, Marie Loyer-Prost, Céline Cabet, Alain Billard, Hicham Khodja

Cr-Ta multilayers as a potential coating material for fuel cladding in Gen III and Gen IV nuclear plants

Mamour Sall,[1] Marie Loyer-Prost,[2] Céline Cabet,[2] Alain Billard[3] and Hicham Khodja[1]
[1]LEEL, NIMBE, CEA, CNRS, Université Paris-Saclay, CEA Saclay 91191 Gif-sur-Yvette, France
[2]DEN-Service de Recherches de Métallurgie Physique, CEA, Université Paris-Saclay, F-91191, Gif-sur-Yvette, France
[3]LRC CEA-UTBM LIS-HP, site de Montbéliard, 90010 Belfort cedex, France

The development of nuclear energy is dependent on the elaboration of advanced materials tolerant to irradiation by high energy neutrons and to gas accumulation (He and/or H transmutation products under neutron irradiation) at high temperature [1]. In this context, research focused on nanostructured materials with multiple interfaces (grain and phase boundaries) acting as (i) defect sinks that contribute to reduce the effects of accumulated radiation damage; (ii) and as traps for implanted species such as helium. Multilayer systems allow well-controlled high density of interfaces (i.e. small layer thickness) to reduce the diffusion distance for defects to move from their original location to the nearest sink, thus considerably limiting their transformation into stable aggregates [2]. Previous studies show high tolerance of multilayer systems to helium implantation – the most performant systems can store helium up to 20 at. % [3]. Nevertheless, their behavior under heavy ion irradiation, representative of nuclear reactor neutron irradiation is very less studied.

We combined ion beam analysis techniques (RBS and NRA), Transmission Electron Microscopy (TEM) and X-ray diffraction measurements to study Cr-Ta nanometric multilayer systems submitted to heavy ion irradiation and helium implantation. Though heavy ion irradiation creates mixing layers at the Cr/Ta interfaces, the multilayer character is preserved even at very high irradiation dose (220 dpa) (Fig. 1). Mixing layer formation is strongly limited by the high interface density i.e. small layer thickness. The application of the ballistic thermal spike model indicates a defect healing rate of 80 – 90 % with the 30 nm period-thickness multilayers irradiated with heavy ion. Likewise, this system may contain He at concentrations up to 20 at. % without a noticeable post-implantation diffusion, as He atoms are likely trapped at interfaces.

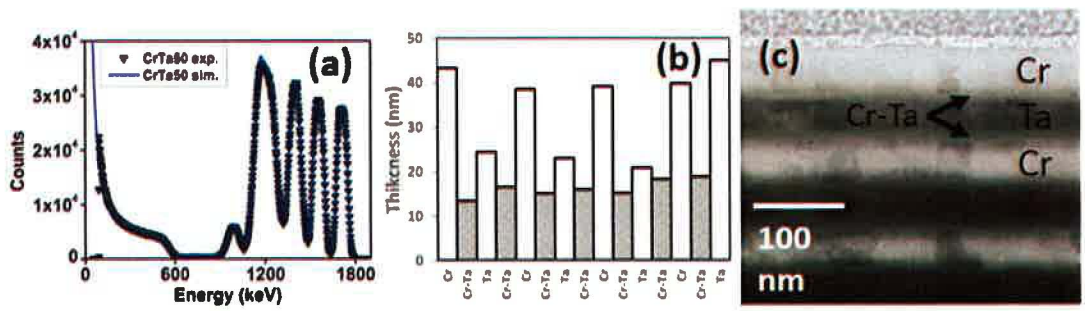

Fig 1: (a) Experimental and simulated RBS spectra of Cr-Ta multilayer (50 nm layer thickness) irradiated with W ions at 220 dpa. (b) Histogram of layer thicknesses used for the RBS simulation: mixing layers are evidenced. (c) TEM image of the corresponding sample confirming the formation of mixing layer upon irradiation.

Keywords: Ion beam mixing, irradiation, Rutherford backscattering spectrometry, multilayer thin films

References

[1] G.R. Odette, M.J. Alinger, B.D. Wirth, Annual Review of Materials Research, 38 (2008) 471-503.
[2] I.J. Beyerlein, A. Caro, M.J. Demkowicz, N.A. Mara, A. Misra, B.P. Uberuaga, Materials Today, 16 (2013) 443-449.
[3] M.J. Demkowicz, Y.Q. Wang, R.G. Hoagland, O. Anderoglu, NIMB, 261 (2007) 524-528.