4 - 30 Research Progress of Group of Energy Materials in 2016

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The Group of Energy Materials (GEM) in IMP is engaged in the irradiation response of materials candidate to advanced nuclear energy systems (Gen IV, fusion reactors). The major progress of research in our group in 2016 is in the irradiation hardening/embrittlement of oxide-dispersion-strengthened (ODS) ferritic steels and Vanadium alloys, and in the mechanisms underlying damage production in silicon carbide (SiC) fibers. A brief description is given as follows.

1. Effect of the oxide nano particles on the irradiation hardening of ODS ferritic steels

The influence of oxide nano particles on the irradiation resistance of ODS ferritic steels is a crucial issue for the upgrade of ODS steels. To clarify the mechanisms, we used three ODS ferritic steels which contain oxides with different number density and average size, and carried out irradiation experiment with ^{58}Ni ions with 6.17 MeV/u at the terminal of SFC-T1 of HIRFL. The temperature of the specimens was kept around −80 ℃ during irradiation. A plateau of atomic displacement damage (0.8 dpa) was produced from the near surface to 23 micrometers in depth in the specimens. The hardness was tested with nano indentation technique. The results show that the hardening induced by irradiation decreases with the increase of number density and the decrease of average diameter of oxide particles. The sink strength was used to describe the capacity of oxide interface trapping point defects and making recombination. The data show a strong dependence of the irradiation hardening on the sink strength (Fig. 1). Investigation with transmission electron microscopy (TEM) and modeling with rate equations on the mechanisms of interaction between point defects and oxides are going on. The research will provide a quantitative understanding of impact of structures of nano oxides on irradiation hardening/embrittlement of ODS steels.

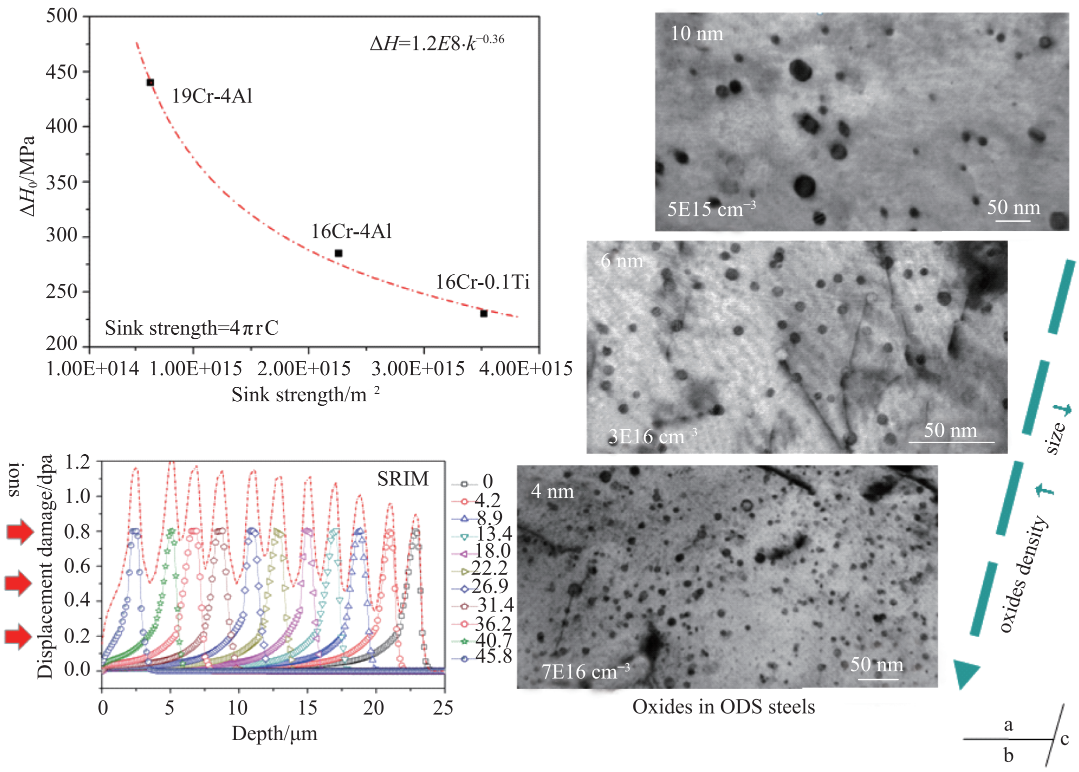

Fig. 1 (a) Dependence of irradiation hardening on sink strength of ODS ferritic steels, (b) Damage profile in specimens by Ni ions (from SRIM simulation), (c) morphology of oxide nano particles in ODS ferritic steels (from TEM observation).

2. Effects of helium and displacement damage on irradiation hardening of vanadium alloys

Vanadium alloys have superior low activation property and good high-temperature creep rapture strength. Influence of atomic displacement and nuclear reaction products including helium on the mechanical properties of vanadium alloys is a serious concern. In 2016 we carried out experiments using He, Sn ion beams, respectively, to clarify the effects of helium implantation and atomic displacement damage on the irradiation hardening. Two kinds of state-made vanadium alloys (V-5Cr-5Ti, V-4Cr-4Ti) were used. The hardness was tested with nano indentation technique. The results show that the helium implantation causes more significant hardening than the irradiation with heavy ions to the same atomic displacement damage level. It is understood in the way that strong interaction of helium atoms with point defects can enhance defect clusters growth. A numerical simulation with rate equations shows that both dislocation loops and helium bubbles may contribute to the irradiation hardening. Details of the research is described in the present volume of Annual Report.

3. Evolution of micro-structures of SiC fibers and its impact on tensile strength under irradiation with swift heavy ions

Silicon carbide (SiC) fibers as the basic skeleton of the SiC_f/SiC_m composites can strongly influence the performance of the materials. The behavior of SiC fibers under irradiation is therefore of practical importance for the use of SiC_f/SiC_m composites in nuclear energy systems. In 2016, we investigate the damage production and its impact on tensile tests of SiC fibers by using swift heavy ions (Ar, Fe and Sn) at HIRFL. The results show an increase of the tensile strength of single SiC fibers when the Ar ion fluence is lower than 5×10^{14} ions/cm^2, and show a subsequent decrease on further irradiation to higher doses. The observation with transmission electron microscopy showed that the microstructures were recovered at low doses while new damaged regions were produced on irradiation to higher doses. Part of the research is described in the present volume of Annual Report.

Besides, there is progress in our group with the synthesis of metallic nano-particles in silica substrate by using energetic heavy ion irradiation. Details of the research is described in the present volume of Annual Report.

In 2016, our group (GEM) got involved in more domestic nuclear energy projects, and provided several reports on the evaluation of irradiation resistance of candidate materials for fuel cladding and blankets, by using high energy ion beams to simulate damage production by energetic neutrons in nuclear reactors.

4 - 31 Annealing Behavior of Ag Nanoparticles in Silica with and without Defects

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The annealing behavior of Ag nanoparticles in silica with and without defects was investigated in this study. Silica samples with and without Ar ion pre-irradiation were implanted with Ag ions and then annealed at temperature from 300 to 850 ℃. UV-VIS spectroscopy and TEM were used to characterize the optical absorbance property and size distribution of Ag nanoparticles, respectively. Optical absorbance results show that the absorbance intensity of SPR (Surface Plasmon Resonance, SPR) peak from Ag nanoparticles in the sample with pre-irradiation is stronger than in the sample without pre-irradiation, which indicates that the defects produced by pre-irradiation prompt the nucleation of Ag nanoparticles. During annealing, the SPR peak shifts to short wave length direction, as shown in Fig.1. Compared to the sample without pre-irradiation, the normalized absorbance intensity of SPR peak fluctuates in a smaller range with temperature for the sample with pre-irradiation. This indicates that defects produced by pre-irradiation prevent Ag nanoparticles from a rapid growth during annealing, namely have a stabilizing effect on Ag nanoparticles. However, in contrast to the sample without pre-irradiation, the SPR peak starts to became broad and weak at a relative low temperature and fully disappears after annealing at 850 ℃ for the sample with pre-irradiation.

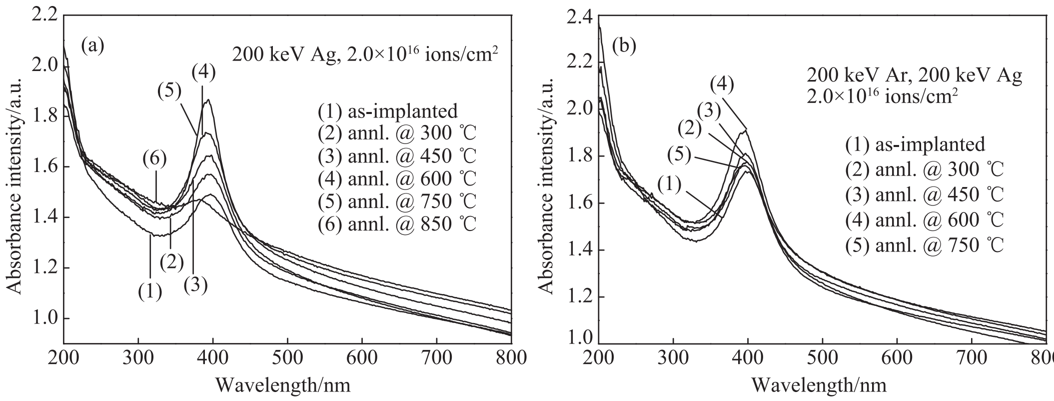

Fig. 1 Absorbance spectra for the Ag ion implanted silica (a) without and (b) with pre-irradiation annealed at different temperature for 1 h in vacuum condition.