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

Yang Yitao and Zhang Chonghong

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.

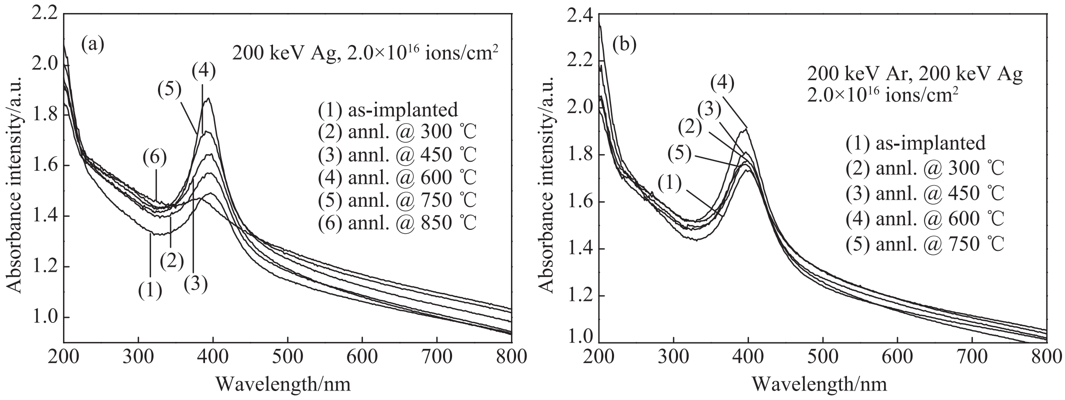

Fig. 1 Absorbance spectra for the Ag ion implanted silica (a) without and (b) with pre-irradiation annealed at different temperature for 1 h in vacuum condition.

This indicates that defects could accelerate the decomposition of Ag nanoparticles at higher temperature. The size evolution shown in Fig. 2 obtained from TEM observation indicates that Ag nanoparticles with defects have a lower growth rate than Ag nanoparticles without defects at temperature lower than 750 ℃.

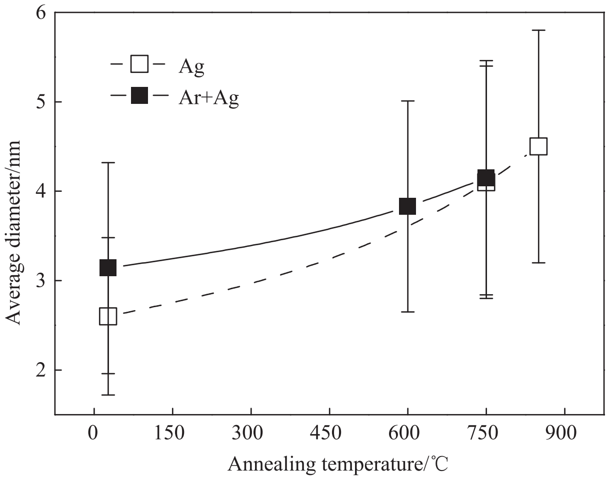

Fig. 2 The evolution of average diameter of Ag nanoparticles with annealing temperature.

4 - 32 Damage Effects of Mechanical Properties of Silicon Carbide Fiber Irradiated by Electron Beams*

Zhang Liqing, Zhang Chonghong, Chen Yuguang, Yan Tingxing, Xiao Rongqing and Zhang Zimin

Continuous silicon carbide fiber reinforced silicon carbide (SiC_f/SiC) composites have been considered to be candidate materials of high temperature structural application in aerospace, energy conservation and power generation due to the excellent high temperature mechanical properties, good fracture resistance, corrosion resistance and thermodynamic stability. Furthermore, due to the high thermal stability, low induced radioactivity, quick decay of activity and low afterheat, SiC_f/SiC composites have been recognized as the promising materials of fission and future fusion reactors. SiC_f/SiC composites are composed of SiC fiber and SiC marix materials. Radiation resistance, oxidation tolerance, fracture toughness and tensile strength of SiC fiber have a direct impact on the SiC_f/SiC composites performance.

In the present work, we have investigated the diameter, tensile strength and elastic modulus of SiC fiber irradiated by 1.2 MeV-electron beams with a beam intensity of 5 mA to different irradiation times at a water-cooled sample stage in the air atmosphere. The 10 μm-diameter SiC fibers, mounted on a copper substrate, were irradiated to different times ranging from 18 to 40 h, corresponding to fluences from 8.1×10^{18} to 1.8×10^{19} e/cm^2. After irradiation, their diameter and mechanical properties were characterized by the electronic vernier caliper and electronic tensile machine, respectively. The mode of the electronic tensile machine is Textechno FAVIMAT$^+$. The span is 25 mm and tensile rate is 1 mm/min.

Results from experiments reveal with increasing irradiation time (electron fluence), the SiC fibers' tensile strength and their elastic modulus first decrease and then increase, while their diameters first show little change and decrease (Figs. 1 and 2). This phenomenon is attributed to the competition between the decomposition and release of pyrolysis products (organic gases) and carbon in SiC fiber and the surface oxidative degradation during irradiation. At lower fluence (18 h) irradiation, the release of pyrolysis gases is predominated, resulting in a slight decrease in fiber' diameter. As the electron fluence (irradiation time) increases, surface oxygen absorption and oxidative degradation govern the mechanical properties and diameters changes, leading to a slight increase in fibers' diameter and a significant decrease in their tensile strength and elastic modulus (Figs. 1 and 2). With the electron fluence further increase, the carbon which is precipitated and segregated from SiC fiber reacts with the pyrolysis products and takes away the partial oxygen on fiber surface, resulting in a rapid reduction in fiber diameter and a remarkable increase in their tensile strength and elastic modulus (Figs. 1 and 2). Author are grateful to staff members for running the electron accelerator in Institute of Modern Physics, Chinese Academy of Sciences for their collaboration.