4 - 7 Positron Annihilation Doppler Broadening Spectroscopy Study on SIMP Steels Irradiated with He and H Individually and Sequentially at Room Temperature

Jin Peng[1,2], Wang Zhiguang [1] and Shen Tielong[1]

([1] Institute of Modern Physics,Chinese Academy of Sciences, Lanzhou 730070, China;
[2] Graduate University of Chinese Academy of Sciences, Beijing 100049, China)

To investigate that synergistic effect of hydrogen and helium on bubble nucleation and growth, vacancy-type defects induced by H-implantation, He-implantation and co-implantation of H and He in SIMP steels respectively were detected by positron annihilation Doppler broadening spectroscopy. Through comparing their S values, it is found that an increase of S parameter induced by H-implantation is more remarkable than that induced by He-implantation due to H atoms essentially do not occupy substitutional vacant sites in small vacancy clusters but He prefer. Another interesting finding is that the S values of He+H sample were smaller than those of H sample. This indicated that the formation of H-V complexes were suppressed by pre-implantation of He.

The SIMP steel is a type of reduced activation martensitic steel. Due to their excellent properties, such as high heat resistance, high radiation resistance, high oxidation resistance and liquid metal corrosion resistance, the SIMP steel is much potential as a candidate structural material for the spallation target in ADS system.

In addition to the high displacement damage rate (100 dpa/year for steels), the He and H gas produced by nuclear reaction transmutation will be 100 appm/dpa and 800 appm/dpa for steels in ADS system, respectively. What effects of such high yielding gas (hydrogen and helium) on the structural material is not yet clear.

The material used in this experiment is 1t grade SIMP steel and its chemical composition is shown in Table 1. The Samples were implanted with using a terminal chamber of the 320 kV multi-discipline research platform for highly charged ions at the Institute of Modern Physics (IMP) in Lanzhou, China. The irradiations were performed with 130 keV He+ and 160 keV H_2^+ ions. The beam-current density of He and H ions was 4.8 μA/cm^2 and 6.7 μA/cm^2, respectively. The samples were implanted with He^+-only (*i.e.* He), H_2^+ -only (*i.e.* H) and He^+ +H_2^+ sequentially (He ions were implanted before H, *i.e.* He+H), respectively. The detailed fluences of implantation are shown in Table 2.

Table 1 Chemical composition of 1t grade SIMP steels. (mass fraction %)

Material	C	Si	Cr	Mn	W	Ta	V	S	P	Fe
SIMP	0.22	1.22	10.24	0.52	1.45	0.12	0.18	0.004 3	0.004	Bal.

Table 2 Fluences of co-implantation at room temperature.

Sample number	Ion		Fluence/cm^{-2}	Peak dpa value	Peak appm value	C_H:C_{He}
1#	H		2.78×10^{16}	0.07	25 000	
2#	H		5.56×10^{16}	0.14	50 000	
3#	H		5.56×10^{17}	1.4	500 000	
4#	He		7.14×10^{15}	0.18	5 000	
5#	He+H	He	7.14×10^{15}	0.18	5 000	5:1
		H	2.78×10^{16}	0.07	25 000	
6#	He+H	He	7.14×10^{15}	0.18	5 000	10:1
		H	5.56×10^{16}	0.14	50 000	
7#	He+H	He	7.14×10^{15}	0.18	5 000	100:1
		H	5.56×10^{17}	1.4	500 000	

* C_H represents the implanted H concentrations; C_{He} represents the implanted He concentrations.

Before irradiation, SRIM calculation was carried out, and the results are given in Fig. 1. In order to investigate interaction among H, He and vacancy- type defects when the samples were implanted with He and H sequentially, we have designed the peaks of dpa (concentration) for H and He in the He+H samples were overlapped at about 370 nm (400 nm) by implanting with 130 keV He^+ followed by 160 keV H_2^+ according to the SRIM calculation.

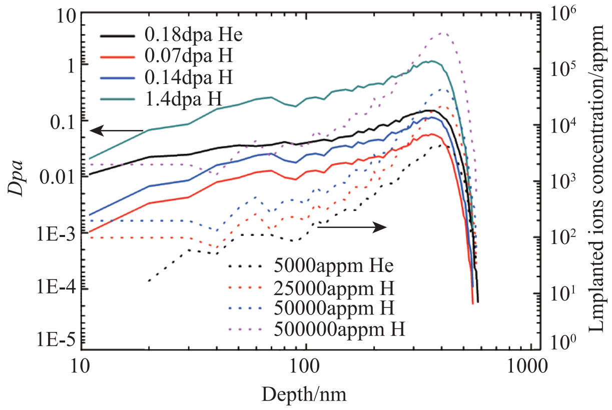

Fig. 1 (color online) SRIM calculation of defect profile of samples 1#∼4 #only implanted with H (80 keV) or He (130 keV) ions and 5#∼7# implanted with He and H ions sequentially.

In this work, we have defined the ΔS to reflect the change of S parameter caused by irradiation.

$$\Delta S = \frac{S - S_{\text{unirradiated}}}{S_{\text{unirradiated}}}.$$

Where S is the S parameter of the irradiated samples, $S_{\text{unirradiated}}$ is the S parameter of the unirradiated samples.

Figure 2 shows ΔS parameter as a function of mean depth from surface (converted from incident positron energy), respectively. At depth from 150 to 500 nm (including track and bragg region):

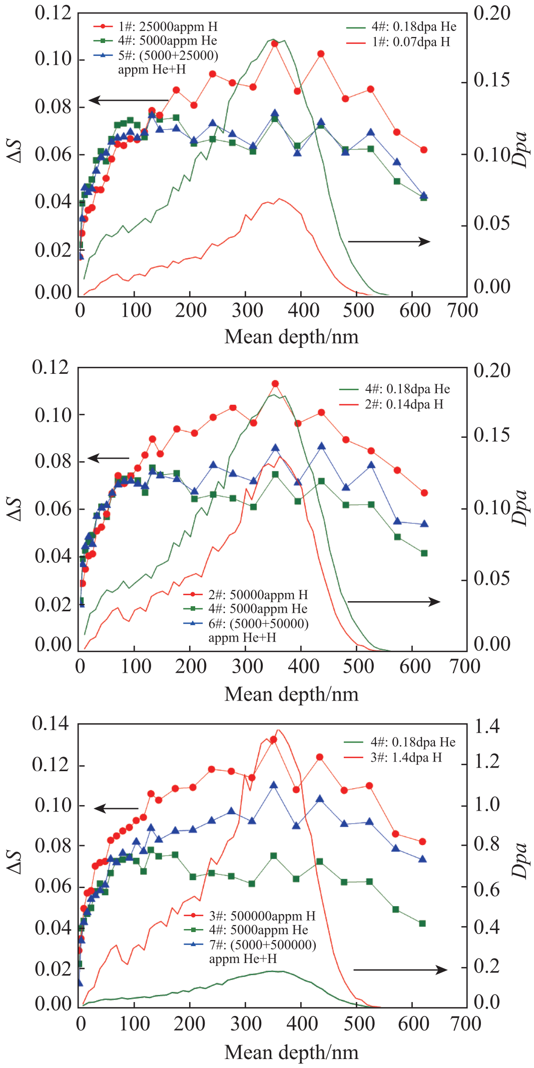

Fig. 2 (color online) ΔS parameter of samples implanted with H, He and He+H respectively. Peak conentration of He is 5 000 appm and that of H is from 25 000 to 500 000 appm.

(1) The tendencies and peaks of ΔS parameter plots are consistent with those of dpa according to SRIM calculation for all samples.

(2) The ΔS values for both the sample 1# and 2# only implanted by H ions with higher peak concentration and lower dpa are larger than sample 4# only implanted with He ions.

(3) With increase of H ion irradiation dose, the ΔS values of the He+H samples increase as well as those of the H samples.

(4) The ΔS values of the He+H samples are larger than thode of the He samples but smaller than those of the H samples.

The profiles of vacancy-type defects in the SIMP steels implanted with H , He and He+H (pre-implanted He followed by H) respectively were characterized by positron annihilation Doppler broadening spectroscopy. It is found that the increase of S parameter induced by H-implantation is more remarkable than that induced by He-implantation. Another interesting finding is that the S values of He+H sample were smaller than those of H sample, This indicated that the information of H-V complexes were suppressed by pre-implanted He.

References

[1] K. Yang, W. Yan, Z. G. Wang, et al., Jinshu Xuebao/Acta Metallurgica Sinica, 52(10)(2016)1207.
[2] Y. E. Kupriiyanova, V. V. Bryk, O. V. Borodin, et al., Journal of Nuclear Materials, 468(2016)264.
[3] P. Vladimirov, A. Möslang., Journal of Nuclear Materials, 329–333(1–3 PART A)(2004)233.
[4] J. Marian, T. Hoang, M. Fluss, et al., Journal of Nuclear Materials, 462(2015)409.
[5] G. D. Tolstolutskaya, V. V. Ruzhytskiy, I. E. Kopanets, et al., Journal of Nuclear Materials, 356(1–3)136.
[6] T. Tanaka, K. Oka, S. Ohnuki, S. Yamashita, Journal of Nuclear Materials, 329–333(1–3 PART A), (2004) 294.
[7] E. H. Lee, J. D. Hunn, G. R. Rao, et al., Journal of Nuclear Materials, 271–272(3791)(1999)385.
[8] Z. Shen, Z. Zheng, F. Luo, et al., Fusion Engineering and Design, 115(2017)80.
[9] E. Wakai, T. Sawai, K. Furuya, et al., Journal of Nuclear Materials, 311(2002)278.
[10] A. Hasegawa, S. Miwa, S. Nogami, et al., Journal of Nuclear Materials, 329–333(1–3 PART A)(2004)582.

4 - 8 Study on the Radiation Effect of SiC Fiber

Niu Lijuan[1,2], Wang Zhiguang[1] and Sun Jianrong[1]
([1] Institute of Modern Physics,Chinese Academy of Sciences, Lanzhou 730070, China;
[2] Graduate University of Chinese Academy of Sciences, Beijing 100049, China)

SiC fibers can significantly improve the properties of SiC_f/SiC_m ceramic matrix composites which are considered as advanced materials for nuclear system. These materials exhibit interesting features such as a low activation level and a higher operating temperature in comparison to ferritic steels and vanadium alloys[1]. Such properties make them promising candidates for use as fuel cladding, structural components or flow channel inserts. However, their performances strongly depend on their complex microstructure which undergoes significant changes when they are irradiated. It is necessary to study the performance of SiC fiber under irradiation.

The experimental object is the KD-II SiC fiber, which is independently developed and produced by National University of Defense Technology. Table 1 shows the basic properties of silicon carbide fiber[2]. Figure 1 shows SAED pattern from the unirradiated fibers. The circular ring pattern is indicative of nanostructured material, and indexing of the rings reveals a consistent 3C SiC polytype. The SRIM 2010 code was used to assess the damage induced in the material. The displacement threshold energies for C and Si sublattices were, equal to 20 and 35 eV[3], respectively. Calculations show that 246.8 MeV Ar^{12+} ions have a projected range of about 52.8 μm in SiC fiber which is greater than the fiber diameter.

Table 1 The properties of the KD-II SiC fiber.

Properties	KD-II
Fiber diameter/μm	11
Tensile strength/GPa	3.0
Young's modulid/GPa	300
Elongation/%	1.5
Density/(g/cm^3)	2.76