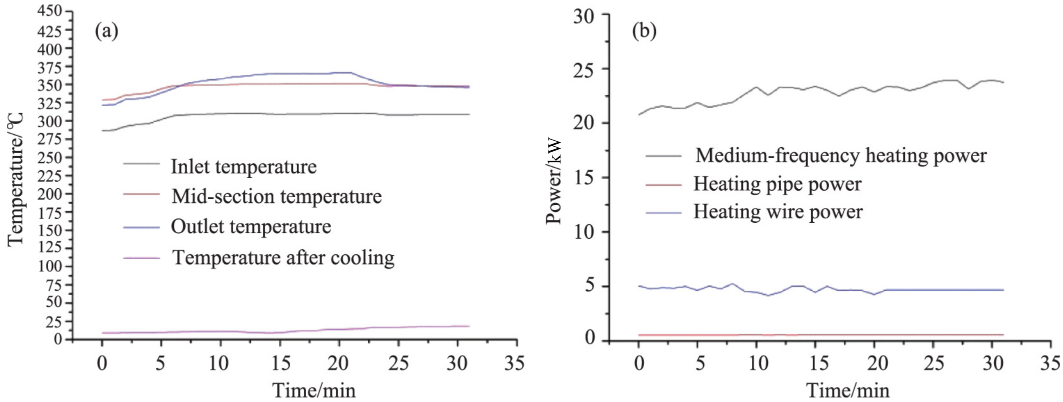

Fig. 4 (color online) Steam temperature(a) and heating power(b) change over time when the flow rate was 8 m/s.

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4 - 4 Vacancy Like Defects in WFeNi Alloys Induced with H Ion Irradiation at 600 ℃

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WFeNi alloys are extensively used in making penetrators against armor plates, balance supporting systems for airplanes and high-speed trains, blocking devices for radioactive- and X-rays, and containers for radioactive materials, *etc.*, due to its advantages such as high density, high strength, good machinability and ductility. The microstructure of WFeNi alloys after the irradiation of ions would change, which may affect the mechanical properties of the material. It is very meaningful to investigate this issue.

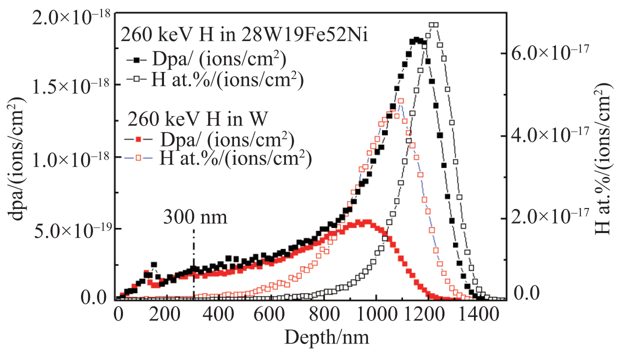

Fig. 1 (color online) The cross section profiles of dpa and H atom distributions in the two areas (*i.e.* pure tungsten area and 28W19Fe52Ni alloy area).

The samples used in the study were 93W4.5Fe2.5Ni (wt.%) alloys, which were consisted of two-phase microstructure of spherically-shaped tungsten particles with bcc structure distributed homogeneously in the W-Ni-Fe matrix (about 28W19Fe52Ni in wt.%) with fcc structure. The samples were irradiated with 260 keV H ions at 600 ℃. The irradiation fluences were 5.0×10^{15}, 1.0×10^{16}, 5.0×10^{16}, 1.0×10^{17} and 3.0×10^{17} ions/cm^2. The cross sections of dpa (displacement per atom) and H atom distributions in the two areas (*i.e.* pure tungsten area and 28W19Fe52Ni alloy area) of the samples were calculated with SRIM and shown in Fig. 1. It can be seen that the dpa cross sections and the H atom concentration cross sections in the two areas are almost the same in the first 800 nm and 500 nm from surface, respectively. The peak dpa cross section of the alloy is about 1.8×10^{-18} dpa/(ions/cm^2), which is higher than the value of pure tungsten (5.4×10^{-19} dpa/(ions/cm^2). The peak H concentration cross section of the alloys is about 6.7×10^{-17} %/(ions/cm^2), which is higher than the value of pure tungsten (4.6×10^{-17} %/(ions/cm^2).

After H irradiation, the slow positron annihilation spectroscopy (SPAS) and coincident doppler broadening (CDB) spectroscopy are completed to investigate the vacancy like defects of the unirradiated and irradiated samples. The detected S and W parameters are fitted with the vepfit program. Fig. 2 (a) gives the detected S parameters as scattered points versus incident positron energies and the corresponding depths, and also the vepfit results as the solid lines. We can see from the figure that the S parameters of irradiated samples are all higher than those of the unirradiated sample, which indicates that vacancy like defects are induced by 260 keV H ions in the first about 280 nm from surface. The $\Delta S/S$ values shown in Fig. 1 (b) of the irradiated samples are calculated with the formula $(S_{\text{irr.}} - S_{\text{unirr.}})/S_{\text{unirr.}}$, which can be used to evaluate the vacancy like defects induced by the irradiation. The $\Delta S/S$ values increase with increasing depth, which indicates that the open volume induced by vacancy like defects increases with increasing depth and is consistent with the SRIM simulated dpa profiles. With increasing fluences, the S and $\Delta S/S$ values show a rising trend. It indicates that the open volumes also increase with fluences. Fig. 2(c) gives the S vs. W plots, from which we see that (S, W) points of different samples are not in one line. In order to identify the types of vacancy like defects, we complete the CDB measurements for the unirradiated WFeNi alloy, pure Fe, pure tungsten and the irradiated samples of 1.0×10^{16}, 1.0×10^{17} and 3.0×10^{17} ions/cm^2. The ratio curves of CDB spectra to the unirriated WFeNi alloy are shown in Fig. 3. The ratio distributions of the irradiated

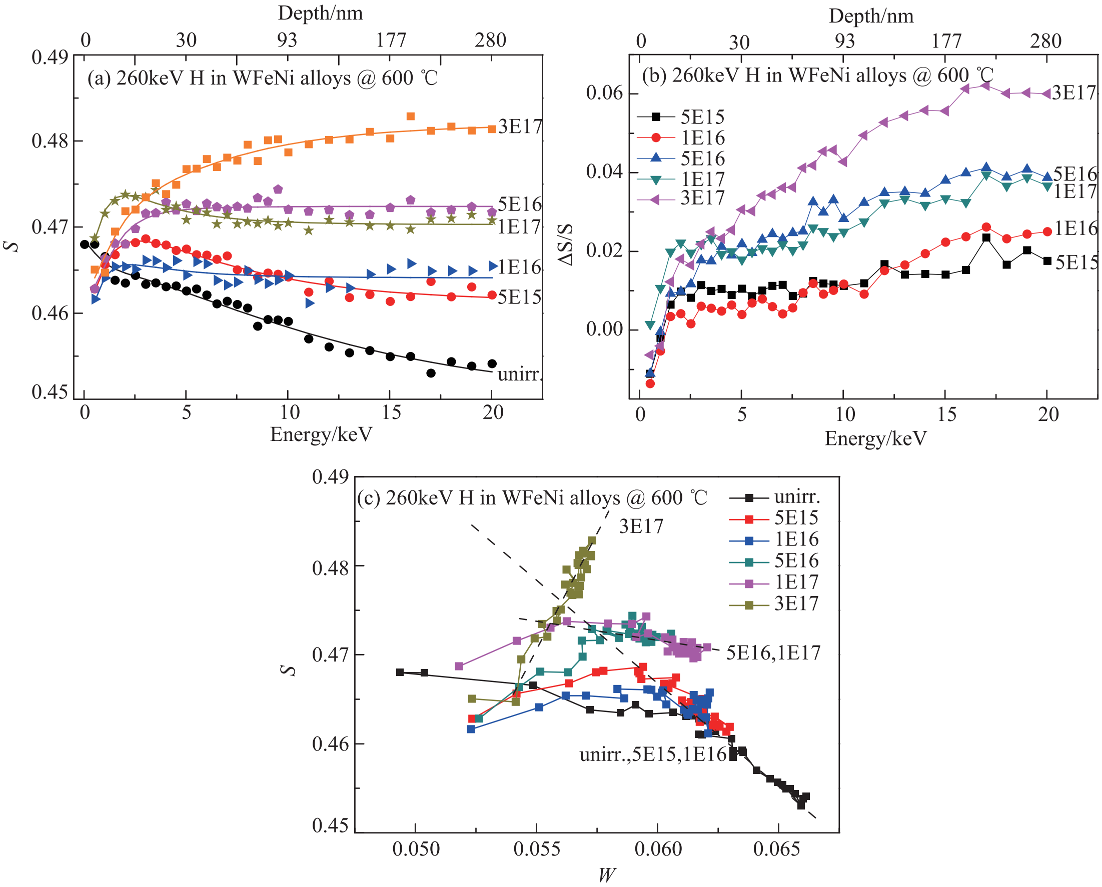

Fig. 2 (color online) (a) S parameters and their vepfit profiles and (b) S/S distributions with indicent positron energy and the corresponding depths, and (c) S versus W plots in different WFeNi alloys.

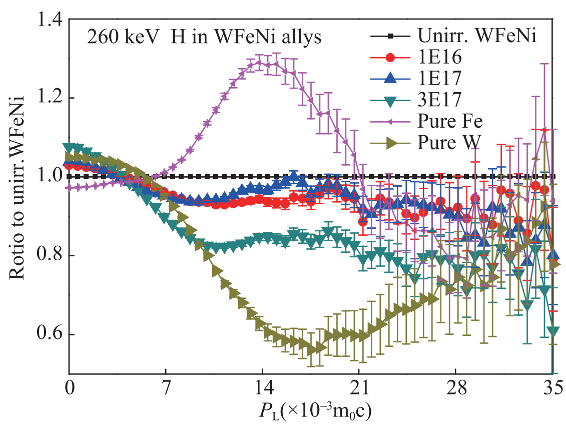

Fig. 3 (color online) Ratio curves of the CDB spectra, including unirradiated WFeNi alloy, pure Fe, pure tungsten,and irradiated WFeNi alloys to 1.0×10^{16}, 1.0×10^{17} and 3.0×10^{17} ions/cm^2 with respect to that of the unirradiated WFeNi.

samples are similar with the pure tungsten, which suggest that the irradiation induced vacancy like defects are mainly tungsten vacancy. The differences of (S, W) plots originate from the different surface defects and size of vacancy like defects. Therefore we conclude that the increasing S parameters with increasing fluences are mainly caused by the increasing size of vacancy like defects.

In summary, WFeNi alloys were irradiated with 260 keV H ions at 600 ℃ to flucens of 5.0×10^{15} $\sim3.0\times10^{17}$ ions/cm^2. The SPAS and CDB measurements show that H irradiation induced vacancy like defects in WFeNi alloys. The open volume induced by vacancy like defects showed an increasing trend with increasing depths and increasing fluences. The size of vacancy like defects increases with increasing fluences.

4 - 5 EBSD Analysis on Static LBE Corrosion of SIMP and T91 Steels

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Due to its favorable thermal-physical and chemical properties, lead-bismuth eutectic (LBE) is one of primary candidate materials for coolant in advanced nuclear reactors. However, severe corrosion of structural materials occurs in the presence of LBE in advanced nuclear reactors, especially at high temperature[1,2]. Therefore, the selection of the structural material exposed to LBE is an extremely complex problem and compatibility tests are required. Because of their good mechanical properties under irradiation up to 500 ℃, ferritic/martensitic steels are considered to be one of the promising structural materials for advanced nuclear reactors, and so the compatibility tests of SIMP and T91 steel specimens were conducted at 450 ℃ with saturated oxygen.

Test specimens of SIMP and T91 steels were cleaned with glycerine at 150 ℃~180 ℃ after the static LBE corrosion tests in order to remove Pb-Bi from the surfaces[3]. The SEM micrographs for the surface of SIMP and T91 steels after exposing to LBE at 450 ℃ for 500h are showed in Fig. 1, it is clearly observed that the corrosion layer of T91 steel is discontinuous while SIMP steel has continuous corrosion layer.

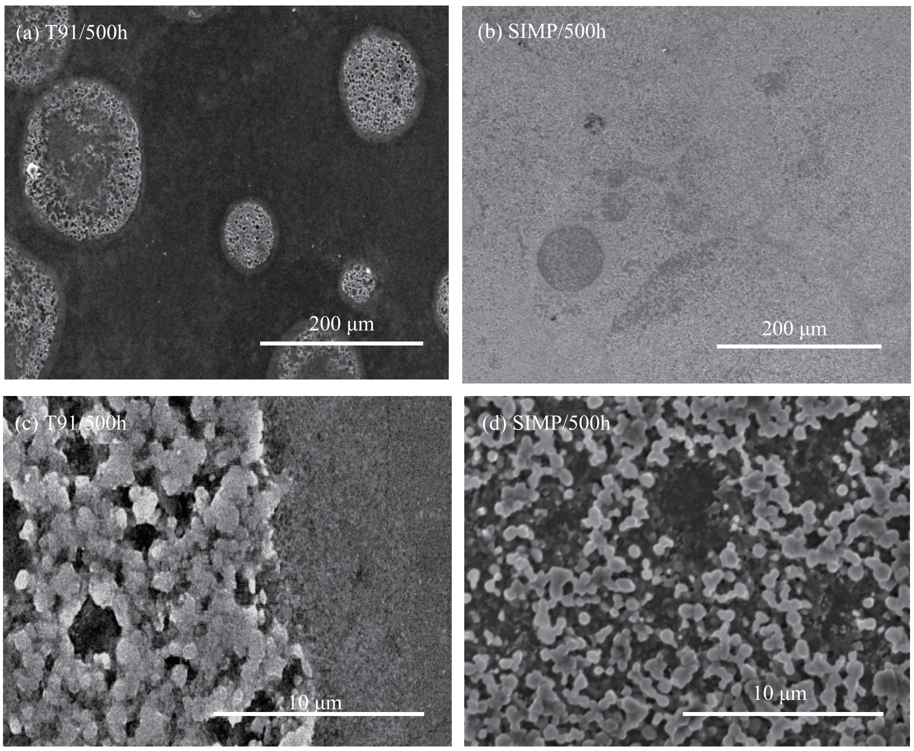

Fig. 1 SEM micrographs of the surface of SIMP and T91 steels after exposing to LBE at 450 ℃ for 500 h. (a) low magnification photograph of T91 steel. (b) low magnification photograph of SIMP steel. (c) high magnification photograph of T91 steel. (d) high magnification photograph of SIMP steel.

In order to reveal the reason of the difference of the surface of SIMP and T91 steels after exposing to LBE at 450 ℃ for 500 h, EBSD analysis was used. The grain orientation distribution for SIMP and T91 steels was showed in