peaks of 1 L MoS_2 at ~1.84 eV and ~2.01 eV are known as the A and B excitons, corresponding to direct optical transitions from the highest spin-split valence bands to the lowest conduction bands. The PL spectra in Fig. 2 (a) show that as fluence increase to 5×10^{11} ions/cm^2, the blueshift of A exciton peak is observed. The peak becomes hard to be identified under 1×10^{12} ions/cm^2 fluence and the reason is unclear for now. For clarity, the evolution of the peak position for A exciton emission peak with fluence is shown in Fig. 2 (b). Exciton for as-prepared MoS_2 is X^- (eeh). After losing extra electrons to gas molecule absorbed on defects induced by ^{209}Bi ion irradiation, the exciton will become X^0 (eh), which is of higher energy than X^-[5]. So the A exciton peak shows blueshift after irradiation. PL and Raman spectrum both illustrate that electron density in MoS_2 decrease with the increase of ion fluence.

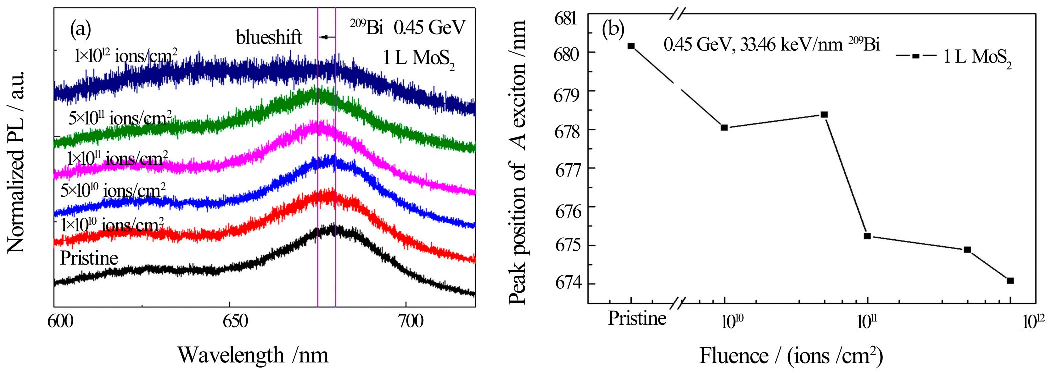

Fig. 2 (color online) (a) Normalized PL spectra of pristine and 0.45 GeV 1 L MoS_2 irradiated by 450 MeV ^{209}Bi ions. The blueshift of A exciton emission peak occurs with increasing fluence. (b) The peak position of A exciton emission peak for 1 L MoS_2 at a serious of fluence, which shows the trend of the blueshift with increasing fluence.

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3 - 23 Research Progress in Group of Energy Materials in 2014

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The progress of research going on in Group of Energy Materials (GEM), Material Research Center, in 2014 is in the following three aspects.

1. Facility development

In order to push forward our study on fusion reactor materials, we upgraded the irradiation terminal (128#) of the sector focused cyclotron (SFC) at HIRFL, by developing a new specimen stage specific for irradiation with low-fluence scattered ions. So far the terminal is capable of irradiation to both very low fluences (10^6 ions/cm^2) and very high fluences (typically 10^{16} ions/cm^2) for various materials. Specimen temperature can be readily controlled using the L-N_2 cooling stage or the the high-T stage (up to 600 °C). Our recent investigation with transmission electron microscopy (TEM) of the defects produced by high-energy Ne ions in steel specimens provides a clear evidence that defects were produced uniformly along the depth in the specimen, indicating that the energy degrader of the terminal works effectively to disperse the ion energy in a wide range. A photo of the terminal together with a SRIM estimate of depth profiles of damage in an 8% Cr reduced activation ferritic/martensitic steel (RAFMS) is shown in Fig. 1.

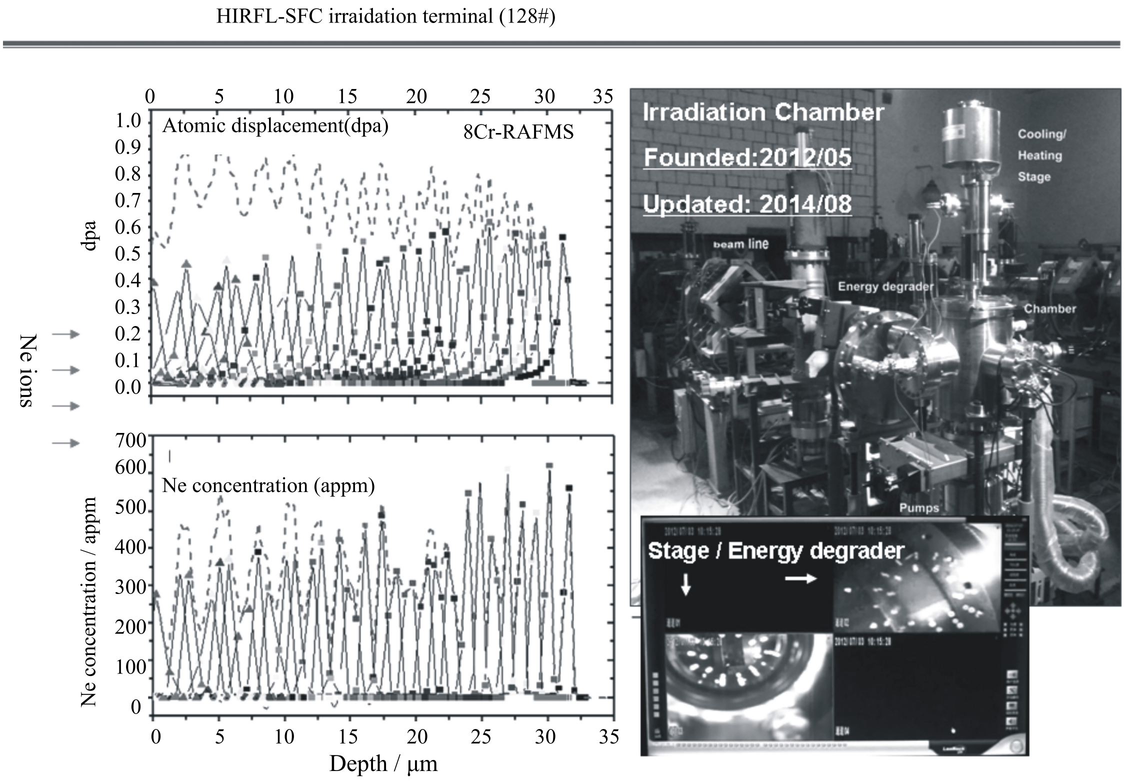
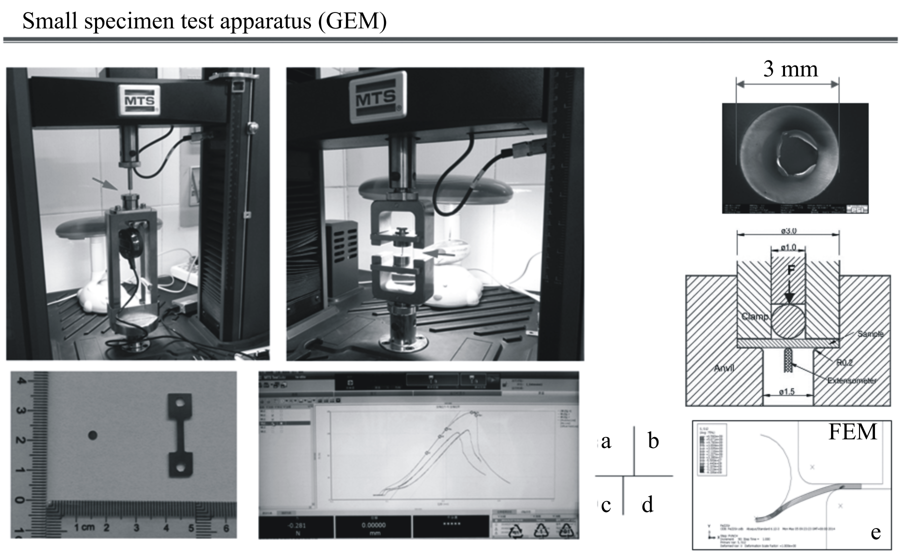


Fig. 1 Irradiation terminal (128#) at SFC, with a SRIM estimate of damage profiles in an 8Cr RAFM steel after irradiation with ^{20}Ne ions (6.17 MeV/u) to 9×10^{16} ions/cm^2.

Meanwhile a small-specimen test apparatus was established in our group to test mechanical properties of miniature specimens before/after irradiation with ions from HIRFL. The apparatus includes a stage for tensile and a stage for small-ball punch test. A finite element model (FEM) was development for data analysis in detail. A primary work was done by comparing the FEM estimates with the experimental results. Good agreement was found between the estimated maximum shear stress and the observed initial circular crack on the tested specimen in the case of the small-ball punch test (Yongqing Xian, Degree thesis, IMP-CAS, 2015). Analysis of data from the small punch test of ODS steels and a RAFM steel irradiated with high-energy ^{16}O and ^{14}N ions are undergoing. A photo of the apparatus and specimens are shown in Fig. 2.



a: small-punch (sp), b: tensile, c: miniature specimens, d: data layout, e : FEM mpdle

Fig. 2 Small specimen test apparatus recently developed in our group.

2. Radiation damage in ODS ferritic steels and vanadium alloys

ODS ferritic steels and vanadium alloys have higher creep strength and higher resistance to irradiation swelling than conventional RAFM steels, and have high prominence for application in Gen IV and fusion reactors. Irradiation embrittlement (loss of ductility and toughness) under intensive neutron irradiation in the advanced reactors is a serious concern for these alloys. However, irradiation experiment using current fission reactors is very time-consuming and expensive. Heavy ion beams in the HIRFL energy range provide a fast and economical approach for the test of irradiation embrittlement of the candidate alloys. The projective range of HIRFL heavy ions in can reach several tens of micro-meters, and meets the criteria for the use of the miniature specimen technique to test ductility/toughness of the alloys. One of our recent progress is the test of effect of microstructure control on the irradiation embrittlement in the ODS ferritic steels. In the new type ODS steel, the oxide particles were refined with a significant increase of number density and decrease in average size (Fig. 3). The small-punch test of the new

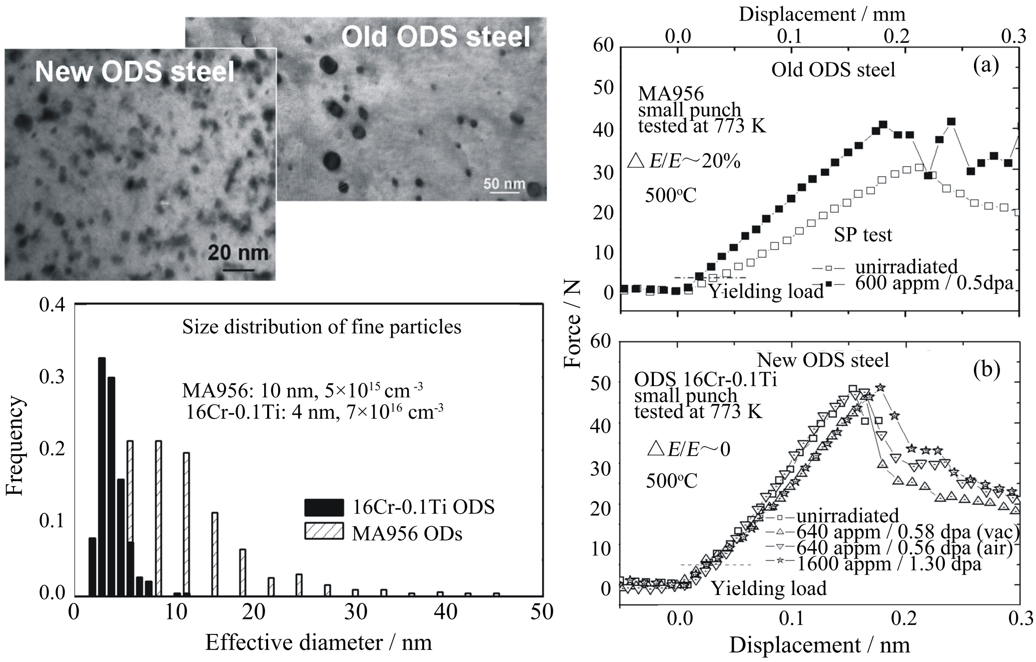


Fig. 3 Microstructures of two ODS ferritic steels, and data of irradiation embrittlement of the ODS steels from 6.17 MeV Ne-ion irradiation experiment in HIRFL.

ODS steel and a old ODS steel specimens irradiated with Ne-ions in SFC shows that the new ODS steel has no observable decrease of ductility after irradiation to 1.3 dpa / 1 600 appm-Ne, while the old ODS steel exhibits some loss of ductility (about 20%). It is the first time to provide data of irradiation embrittlement of this new ODS steel. The results was published in Journal of Nuclear Materials[1].

Besides, irradiation hardening of different ODS steels and vanadium alloys was studied by using ion beams in IMP. Some of the results were recently published[2−3]. The vanadium alloy research is described by Yang et al in a report in this volume.

3. Radiation response of nitride-base LED

The nitride-base LED is regarded the next generation LED with high light emission efficiency and good merit of energy conservation. The performance of nitride-base LED in radioactive conditions is an importance concern for its application in nuclear power plants or space ship/satellites. In 2014 we carried out irradiation test experiment of nitride-base LED using HIRFL ion beams and studied the degradation of light emission power with irradiation dose. An investigation of the change of the InGaN/GaN hetero-junction behavior was carried out in an effort to know the mechanisms of the degradation of light emission power. The research is described in more detail in another report by Gou et al in this volume.

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