APPLICATION OF HEAVY IONS IN IMP

Shen Wenqing (沈文庆) and Hou Mingdong (侯明东)

(*Institute of Modern Physics, Academia Sinica, Lanzhou 730000, China*)

(Received Nov. 1989)

ABSTRACT

In this paper a general description about the application of nuclear techniques in IMP during the past few years is given. The possibility and proposal for heavy ion application by using HIRFL (the Heavy Ion Research Facility of Lanzhou) are reviewed.

Keywords: Nuclear techniques Application of heavy ions Review

I . MAIN FACILITIES IN IMP

There are four accelerators in Institute of Modern Physics (IMP). The 200 kV ion implantation machine is mainly used for the study of material modification. The 600 kV Cockcroft- Walton set is used for the application with neutron. The 2× 2 MV electrostatic tandem, which was the first tandem made in China and started its operation in 1986, is used for ion beam analysis and a supersensitive mass spectrometer as well. The HIRFL consists of a 1.7m sector- focus cyclotron ($K=69$) as the injector and a sector- separated cyclotron ($K=450$) as its main accelerator. HIRFL can accelerate C- ions to 88 MeV/u, N, O and Ne- ions to 100 MeV/u, Ar- ions to 46 MeV/u and Xe- ions to 4.8 MeV/u, respectively, and started to deliver the beam of C- ions of the energy 50 MeV/u in late 1988. After 1990 a ECR source will be mounted on the injector, then the energy and the sort of the accelerated particles will be improved greatly. At HIRFL eight experimental equipments are prepared for various fields of research. Among them atomic physics equipment and irradiation equipment will mainly serve for application research with heavy ion. These two equipments include following installations: a gas- jet target chamber, a beam- foil spectroscopy target chamber, a VUV monochromator McPherson- 247, a particle- X ray coincidence system, a cryostat system from 4K to 800K, a beam uniformity system with magnetic sweeping and a device for sample exchange etc. This facility will be the important research center of heavy ion science in China.

II . PREVIOUS ACTIVITIES OF INSTITUTE IN THE FIELD OF NUCLEAR TECHNIQUES

A variety of studies on the application of nuclear techniques has been extensively performed in IMP during the past few years. The main projects which have been achieved are in brief presented as follows.

1. Material modification

The surface modifications of GCr15 ball- bearing steel implanted with N- ions at various doses at the implantation temperature from 50°C to 350°C were investigated by means of CEMS, wear test and X- ray diffraction. Above the dose of 5×10^{17} N- ion/cm^2, the surface hardness goes up fast and the wear resistance is improved obviously because ε - Fe_{2+x} (C,N) and/or ε - Fe_2 (C,N) and ζ - Fe_2N phases are formed. The similar study for 9Cr18 SS was also carried out. The N- ions implanted polymer exhibits disorder structure and their conductivity increases greatly. The GaP photodetectors were implanted with Zn- ions to enhance their sensibility.

2. Ion beam mixing

We have studied the atomic mixing of Ti layer on Al induced by irradiation with 100 keV Ar- ions at LN temperature by using Rutherford backscattering analysis. The results show that the amount of intermixing σ^2 is approximately linearly dependent on the dose and the interfacial oxide layer may have a great influence on the intermixing. The results may be explained by a model of the collision cascades and the interstitial or vacancy diffusion. The mixing effect and compound formation induced by 600 keV Kr- ions bombardment in Al/Cr system were also investigated.

3. Nuclear analysis techniques

We have established a series of nuclear analysis techniques such as NRA, XRF, PIXE and FNAA etc. The nitrogen concentration and depth profile in α - Fe and GCr15 steel, which were produced by implantation at different temperature, were obtained by using $^{14}N(d,\alpha_1)^{12}C$ nuclear reaction analysis. The element analyses for human hair, blood, tissue, Hippophae rhamnoides and the catalyst etc. have been performed by using PIXE technique. For example, the content percent of rhodium and phosphorus in the supported liquid phase catalyst $RhH(CO)(PP\varphi_3)_3$ were obtained (Rh- 0.113%, P- 1.95%). The fast neutron activation was used to determine the content of the elements in archaeological samples because its nondestructive character is a particularly valuable feature.

4. Mossbauer spectroscopy

We are continuously engaged in Mossbauer spectroscopy study and lay stress on its application in industrial field. A systematical study on the 2:17 type permanent- magnet alloy $Sm_2(Co\ Fe\ Cu\ Zr)_{17}$ was made to find out the effects of the additional elements and the different heat treatment on the magnetic properties and the microstructure. The studies on the performances of three new ethylbenzen dehydrogenation iron catalysts, on the action of Cr_2O_3 in solid solution of the iron series catalysts, on the roasted temperature of iron ores in reduction atmospher and on the anomaly of specific magnetization coefficient of siderite and hematite ores were in detail investigated. These results provide valuable data for the improvement of preparation process of catalyst and roasted process of iron ores, respectively.

5. Radiation damage in metals

The radiation damage induced by the bombardment with 72 MeV C– ions in nickel and stainless steel was examined by means of positron annihilation technique and transmission electron microscope. The results showed that the vacancies and some vacancy– cluster were formed in nickel during the irradiation, while the radiation damage in SS is distinct. The theoretical calculation on the damage cross section and damage depth distribution in pure metals irradiated by 10 MeV/u heavy ion was achieved. In the calculation the nuclear forces were considered.

It should be mentioned that a significant progress has been made in the study on $^{13}CO_2$– breath test with ^{13}C– methacetin which is achieved through collaboration with the First Hospital of Lanzhou Medical College and the Institute of Lanzhou Geology. The test based on the marking stable isotope and mass spectral analysis is a advanced technique for measuring liver function and diagnosing liver cirrhosis. In addition, the crude petroleum water content monitor has been developed and made available to the user.

Ⅲ. THE PROPOSAL FOR HEAVY ION APPLICATION RESEARCH AT HIRFL

The HIRFL provides the possibility for a wide range of application research with heavy ion. Therefore, our main interest has been shifted to this field in recent years. A few projects have been proposed and some of them have gained the financial support from Academia Sinica and National Natural Science Foundation.

1. Simulation of radiation damage in structural materials

The radiation damage of materials in future reactors of all types is a major problem which must be addressed during the next few decades. For example, the swelling of structural materials in a neutron environment has appeared in practically all metals. Heavy ion simulation is an effective technique for the study of fundamental mechanisms of the processes involving radiation damage produced by fast neutron and for a fast examination of the radiation properties of all sorts of materials. A radiation effect that takes several years to obtain in largest of the high– flux reactors can be attained in only a few hours with a heavy ion beam with an intensity of the order of a few microamperes. In heavy ion simulation, ions of various kinds can be used to study radiation defects in the "pure" form, without introducing any foreign atoms into the material. The radiation dose can be determined more accurately and the temperature and other irradiation conditions can be better controlled. The high energy ions from HIRFL have much larger range than that from small accelerators, and they can provide much more accurate information about the character of radiation damage. Our research project includes two parts. The first one is to determine the cross section of defect production by means of measuring resistivity under LHe temperature and to compare the experimental results with the theoretical results. The second one is to study the dependence of the swelling on the radiation dose, irradiation conditions, the composition of the material, its previous heat treatment and mechanical working. At the beginning of this year, a stack of HT- 9 ferrite and pure nickel samples were irradiated with 50 MeV/u C- ion from HIRFL and the samples of 316L stainless steel were subsequently irradiated with 4.5 MeV/u C- ion from the injector SFC at three different temperatures. The irradiated samples will be analysed by PAT, ME and TEM.

2. Preparation of nuclear track filters

Nuclear track filters offer distinct advantages over other microporous filter. Therefore they are extensively applied to many areas of scientific investigation and industrial production. Heavy ion accelerators are very suitable for generating nuclear track filters because they can provide monoenergetic, monoisotopic, highly parallel ion beams. Many laboratories in the world have produced microporous membranes with heavy ion accelerators. As the first step, we attempt to prepare the track holes which can filter mycoplasmas. We will make great effort to seek new applications of nuclear track filters and nuclear track techniques.

3. Atomic physics with heavy ions

The atomic physics based on the accelerators has been extensively studied in the past two decades. Like the GANIL (France) and RRC (RIKEN, Japan), the HIRFL provides the new possibility to conduct the research programm of the atomic physics, particularly in some new fields which need highly stripped heavy ions. On our HIRFL, the project for studying atomic physics consists of two parts. One part is the fast ion beam- foil spectroscopy measurements, mainly on the mean lifetime measurements for some atomic energy levels of highly charged ions, which are of great importance and useful for the verification of some theoretical model calculations and for the developments of new techniques, plasma physics and astrophysics. The second part is the investigation of ion- atom dynamic collision processes, especially the inner- shell vacancy production mechanisms for the collision system ($Z_P \geqslant Z_T$) in the energy region where the experimental measurements have been less made yet. As the first experiment, we shall measure the Li- like spectra of Ar and the oscillator strength of $2p^2P^o$- $3d^2D$ transition. A proposal for the establishment of high resolution zero- degree- Auger- spectroscopy technique and the related research theme is under way to apply for grant.

4. The biological effect of heavy ions on plant seeds

Scientists pay great attention to the studies on the biological effects of heavy ions due to the distinct difference of dosimetric character between heavy ions and X- and γ - rays. In order to study the mechanism in the effects of heavy ions on living things and to reveal the possibility to breed new varieties, we, with the collaboration of Lanzhou university, attempt first to investigate the genetic effects of high- Z

energetic ions on plant seeds and then to find application of heavy ions to bioengineering. After the plant seeds, such as wheat, bean and rape, are irradiated with heavy ions, the seeds and their seedings will be examined cytologically, morphologically and ultramicroscopically. We shall observe the genetic variation of second generation and offspring. And we shall try to discover the mechanism of the variation according to various parameters measured, such as survival rate or inactivation, chromosome aberration, single and double strand break of DNA, and according to different environmental condition, such as temperature humidity, oxygen atmosphere etc.

ACKNOWLEDGEMETS

This is a short review of the activities and the future projects of Institute. Most of the topics in this paper is taken from unpublished summaries, Annual Report of IMP and some published papers. All authors of them are sincerely thanked. Special thanks are due to Drs. Chen Keqin, Liu Bing, Wei Zengquan et al.