I-1. PROJECT RESEARCHES

Project 11

PR11

Advanced Applications of Materials Irradiation and Characterization Techniques Using High Energy Particles

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OBJECTIVE:

We have developed and maintained various irradiation facilities (KUR SSS and KURNS-LINAC targets) and characterization facilities (positron annihilation spectroscopy and thermal desorption spectroscopy systems) in Institute for Integrated Radiation and Nuclear Science. This project aims to further advance the development and the improvements of facilities for stimulating joint-use research projects in this area.

RESEARCH SUBJECTS:

R6P11-1 Study to improve transport and measurement performance of a slow positron beamline

The relationship among positron pulse shapes of the KUR slow positron beamline was investigated for quick and easy adjustment of system parameters.

R6P11-2 Micro-vickers hardenss in neutron-irradiated Fe-Cr alloys

The progress of phase separation in Fe-Cr binary alloys was detected using PAS for the correlation between the hardness and phase separation irradiated with neutrons at 473K and 573 K.

R6P11-3 Effect of rhenium doping on vacancy formation in electron-irradiated tungsten studied with positron annihilation spectroscopy

Simple Frenkel pairs were introduced into W-Re dilute alloys through electron irradiation, and the resulting vacancy-type defects were analyzed using positron annihilation spectroscopy.

R6P11-4 Gamma-ray excited photo-emission from nano, micro, and bulk diamonds

Gamma-ray induced luminescence of three types of diamonds, bulk, micrometer-sized, and nano-sized particles was investigated.

R6P11-5 Multiple hydrogen trapping by vacancies in B2-type Fe-Al alloys

Slow positron beam measurements for electron irradiated and hydrogen introduced $Fe_{50}Al_{50}$ alloys were performed as well as computer simulations of positron annihilation in Fe-Al alloys with hydrogen trapping vacancies.

R6P11-6 Change of free volume in highly hydrogenated DLC films due to desorption

Positron annihilation spectroscopy measurements were performed to investigate structural changes in the free volume of H DLC films by soft X ray irradiation and temperature increase.

R6P11-7 Structural analysis of diamond-like carbon coatings using positron annihilation spectroscopy

The microstructural defect behavior of DLC coatings deposited under varying bias voltages was investigated by employing positron annihilation spectroscopy.

R6P11-8 Valuation of the effect of the CHF3 plasma treatment on Si surfaces using the positron annihilation method

CHF_3 plasma treated Si surfaces were investigated using the different plasma conditions to clarify the formation, deposition and sputtering processes of the C related materials.

R6P11-9 Effects of pulse irradiation by charged particles on damage structures in metals

The effects of pulse irradiation on the damage defect evolution were investigated using numerical simulation and electron irradiations.

R6P11-10 Development of slow positron beamline using electron linear accelerator

Preliminary experiments of a slow positron beamline using KURNS-LINAC were performed to confirm the performance of the storage section and beam transport to the sample chamber.

Study to improve transport and measurement performance of a slow positron beamline

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INTRODUCTION: Positron annihilation spectroscopy is an important analytical method to detect vacancy-type defects and vacant spaces of materials. Energy-variable mono-energetic positron beams (slow positron beams) are essential to perform depth-dependent positron annihilation spectroscopy of surface layers such as ion-implanted layers or thin films. As moderation efficiencies to obtain slow positron beams are typically $<10^{-4}$, intense positron sources are required for practical use. A positron source using pair-creation by gamma-rays from a nuclear reactor have been developed by using Kyoto University research Reactor (KUR) to obtain a slow positron beam for materials analysis. In the KUR slow positron beamline, a lifetime measurement system based on a pulsing system using a radiofrequency-driven buncher was developed for the KUR slow positron beamline. In the KUR slow positron beamline, typically it takes about one hour to adjust parameters of the pulsing system. It is desired to reduce the time required for the adjustment for efficient use of the beamline. In this report, the relationship among pulse shapes was investigated for quick and easy adjustment of the pulsing system.

EXPERIMENTS: The pulsing system was adjusted using a standard sample (Kapton) at 2 keV. The lifetime of the Kapton samples was confirmed to be close to the lifetimes found in published papers. The pulsing system consists of three pulse/radiofrequency (RF) circuits (i.e., chopper, prebuncher and buncher) [1]. Each RF circuit was turned on and off to observe the contribution of individual circuits.

RESULTS: Figure 1 shows the pulse shapes measured as lifetime spectra. In Fig. 1(a), broken and solid lines correspond to the spectrum obtained with all the circuits and spectrum obtained without the buncher (with the chopper and prebuncher), respectively. Fire 1(b) shows three spec-tra obtained only with the buncher, where a phase shifter was changed to ±5 % with respect to the best value (0%). Fig. 1 indicates that the pulses, corresponding to the indi-vidual RF circuits, should be at different positions. If this relationship can be recorded or formulated, the adjustment time for the pulse system can be significantly reduced.

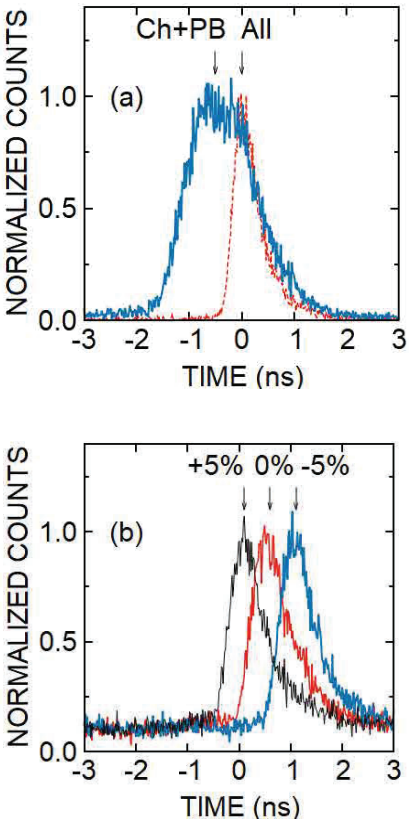

Fig. 1. Lifetime spectra to observe pulse shapes.

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PR11-2

Micro-Vickers Hardenss in Neutron-irradiated Fe-Cr Alloys

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INTRODUCTION: Ferritic stainless and heat resistant steels used as nuclear reactor peripheral materials have high Cr content [1]. In these materials, ductility and toughness remarkably decrease, and hardness and tensile strength increase by aging from 593 to 813 K. This phenomenon is caused by the formation of Fe-rich and Cr-rich phase, and is called 475˚C embrittlement [2]. These changes in mechanical properties are an important issue in terms of evaluation of aged deterioration when it was used as a reactor structural material. Positron annihilation spectroscopy (PAS) is very powerful tool to obtain the information of vacancy-type defects (even single vacancies) and precipitates. In Fe-Cr alloys used in this study, positron affinity of Fe is lower than that of Cr [3]. Therefore, we can detect the formation of Fe-rich phase in phase separation of Fe-Cr alloys using PAS. The purpose of this study is to detect the progress of phase separation using PAS, and to obtain the correlation between the hardness and phase separation in Fe-Cr binary alloys irradiated with neutrons at 473K and 573 K.

EXPERIMENTS: Fe-x wt.%Cr (x = 0, 9, 15, 30, 45, 50, 70, 85, 91, and 100) binary alloys were used in this study. The weight of high purity Fe (99.99%) and Cr (99.99%) were measured, and samples were melted by the arc melting. For neutron irradiation, samples with diameters of 3 mm and thickness of 0.25 mm were cut using the wire electric discharge machine. Fe-xCr (x = 30, 45, 50, 70, 85, 91, and 100) were annealed at 1273K for 1h, and Fe-xCr (x = 0, 9, 15) were annealed at 1073K for 1h in a vacuum ($< 4 \times 10^{-4}$ Pa), and then water-quenching was performed for the suppression of phase separation. The neutron irradiation was carried out at the Material Controlled Irradiation Facility (SSS) of Kyoto University Reactor (KUR) [4]. The irradiation doses were 0.44×10^{-3} , 0.5×10^{-3} and 2.1×10^{-3} dpa. The irradiation temperature was 473K (0.5×10^{-3} dpa) and 573K (0.44×10^{-3} and 2.1×10^{-3} dpa). Vickers hardness tests were conducted using HMV-T2 (SHIMADZU corp.) at room temperature with the test load of 0.9807 mN ($Hv_{0.1}$) and the load holding time of 15 s.

RESULTS: The hardness increased after neutron irradiation in all samples. This is due to the progress of phase separation and the formation of irradiation-induced defects. In Fe-*x*Cr (*x* = 0, 9 and 15), hardness is highest in the 473 K irradiation. Since the vacancy clusters were detected in the PAL measurements in the 473 K irradiation, the greatest cause of the highest hardness was the formation of irradiation-induced defects. In Fe-*x*Cr (*x* = 30, 45, 50, 85 and 91), the hardness of samples irradiated at 473 K for 47 h is almost the same as that of samples irradiated at 573 K for 42 h. The contribution of irradiation-induced defects on the increase in the hardness is difference in each samples. Because the formation of vacancy clusters is detected by the PAL measurements in the 473 K irradiation.

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PR11-3

Effect of rhenium doping on vacancy formation in electron-irradiated tungsten studied with positron annihilation spectroscopy

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INTRODUCTION: In tungsten (W), which is considered a promising material for fusion reactors, the retention and accumulation of hydrogen isotopes due to neutron irradiation pose a significant problem. Recently, it has been reported that the addition of rhenium (Re) significantly reduces hydrogen isotope accumulation [1], which is believed to be due to the suppression of irradiation defect formation, the primary trapping sites for hydrogen. In fact, it has been found that the formation of vacancy-type defects is significantly suppressed in W-5Re compared to pure W [2].
The aim of this study is to further investigate the effect of Re addition on vacancy formation. To this end, simple Frenkel pairs were introduced into W-Re dilute alloys through electron irradiation, and the resulting vacancy-type defects were analyzed using positron annihilation spectroscopy.

EXPERIMENTS: The specimens used were pure W and W-xRe alloys (x = 0.1, 0.3, 1.0, and 5.0 at.%). After annealing at 1800°C for 1 hour (1600°C for 1 hour for x = 5.0), electron irradiation was performed at the Kyoto University Institute for Integrated Radiation and Nuclear Science (KURNS) Linac facility (8 MeV, <100°C, approximately 3.5×10^{23} e^-/m^2). After irradiation, vacancy-type defects were investigated via positron annihilation measurements (lifetime measurements and coincidence Doppler broadening measurements).

RESULTS: Figure 1(a) shows the dependence of the average positron lifetime (τ_{ave}) on Re composition. Before irradiation, τ_{ave} ranged from 110 to 117 ps. Since these values are close to the positron lifetime in bulk W, it is assumed that almost no vacancy-type defects existed before irradiation. After irradiation, τ_{ave} increased in all samples, indicating positron trapping at vacancy-type defects introduced by irradiation. In all samples, long-lifetime components were barely observed in the positron lifetime spectra, suggesting little positron trapping by vacancy clusters. Figure 1(b) shows the increase in τ_{ave} ($\Delta\tau_{ave}$) due to irradiation. Compared to pure W, $\Delta\tau_{ave}$ increased with Re composition up to about 1%, indicating an increase in positron trapping at vacancy-type defects. On the other hand, at 5% Re composition, $\Delta\tau_{ave}$ was smaller than that of pure W, consistent with previous findings on W-5Re [2]. Theoretical calculations have proposed that Re strongly binds with W interstitial atoms, lowering their mobility and increasing the frequency of interstitial-vacancy recombination, thereby suppressing the formation (retention) of vacancy-type defects [3]. However, based on the present results, it is suggested that other mechanisms may also need to be considered. For example, since Re has a positive (attractive) binding energy of 0.22 eV with vacancies in W [3], it is possible that Re stabilizes vacancies.

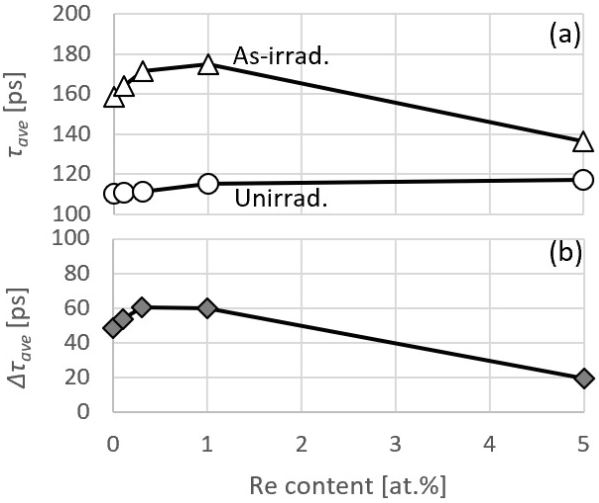

Fig. 1. Re content dependency of (a) average positron lifetime, (b) increase of average positron lifetime.

PR11-4

Gamma-ray excited photo-emission from nano, micro, and bulk diamonds

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INTRODUCTION: Diamonds are known to emit defects- and impurity-related green, yellow, and red fluorescence when exposed to ultraviolet light [1] as well as blue to green visible lights [2]. Recently, the authors have observed gamma-ray irradiation-induced luminescence in the bulk wide gap semiconductors, such as GaN [3], although it has a smaller band gap than that of diamond. As an application of gamma-ray irradiation, we have already reported the gamma-ray-enhanced quenching phenomenon of photoconductance in GaAs [4]. Recently, research on gamma-ray detectors using single-crystal bulk diamond has been progressing [5]. Therefore, studying gamma-ray induced emission from diamond powders with a wide diameter range from nano- to micro-meters and bulk diamond substrate will lead to fundamental research as a material for future gamma-ray detectors. In this work, we investigate gamma-ray induced luminescence of three types of diamonds, bulk, micrometer-sized, and nano-sized particles.

EXPERIMENTS: Samples used for the present study are bulk single crystal substrates, transparent diamond particles with a size of 90 to 165 μm (micron-sized), and white to gray nano-diamond particles with a size of about 10 nm. Bulk and micro-sized diamond samples were purchased from Sumitomo Electric Industries Ltd. Nano-diamond samples were purchased from Tokyo Chemical Industry Co., Ltd. The diamond crystals were irradiated at room temperature with gamma-rays of 1.17 and 1.33 MeV from a cobalt-60 source of Institute for Integrated Radiation and Nuclear Science, Kyoto University. The gamma-ray irradiation induced photo luminescence measurements were performed by using a charge coupled device (CCD) equipped spectrometer (QE Pro, Ocean Insight Co. Ltd.).

RESULTS: Figure 1(a) shows gamma-ray-induced luminescence spectra of nano, micro, and bulk diamonds measured at room temperature with an absorbed dose of 1.0 kGy/h. The gamma-ray induced luminescence for the bulk-diamond sample is more intense than those for nano- and micro-diamond ones. It should be noted that the luminescence intensity of the bulk-diamond is one-third as weak as that of GaN wafer [6]. The gamma-ray induced luminescence from micro and bulk diamonds was observed from 375 nm to 850 nm with a peak at around 525 nm, whereas the luminescence from nano- diamond was observed from 375 nm to 800 nm si 200 with a peak at 450 nm.

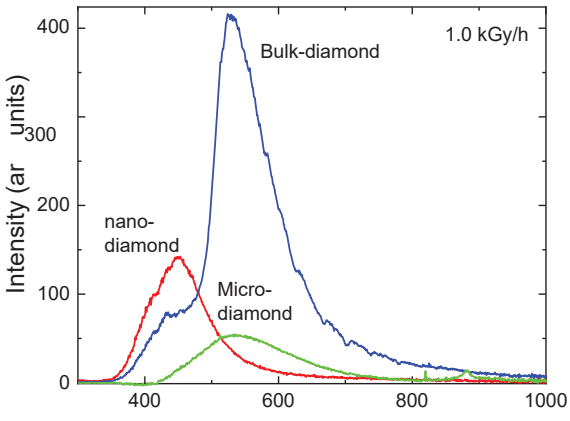

Fig. 1. Gamma-ray-induced luminescence spectra of nano, micro, and bulk diamonds measured at room temperature with an absorbed dose of 1.0 kGy/h.

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[5] K. Ueno *et al.,* Jpn. J. Appl. Phys., **58** (2019) 106509.

PR11-5

Multiple hydrogen trapping by vacancies in B2-type Fe-Al alloys

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INTRODUCTION: B2 ordered Fe-Al alloy is used as high strength at high temperature material because of its good properties such as specific strength to weight ratio, oxidation resistance. However, it is known that Fe-Al alloy with B2 ordered structure is easy to form vacancy and anti-site atom defects. On the other hand, the vacancy type defects in this alloy first principles calculation result indicate that not only one hydrogen atom but also several hydrogen atoms can be trapped in a single vacancy in B2 ordered Fe-Al alloy. However, the interaction between vacancies and hydrogen atoms in this type of Fe-Al alloy is not cleared yet. So far, we have investigated the nature of defect structures in B2 type Fe-Al alloy [1]. In this study, we have performed slow positron beam measurements for electron irradiated and hydrogen introduced $Fe_{50}Al_{50}$ alloys, and also performed computer simula-tions of positron annihilation in Fe-Al alloys with hydrogen trapping vacancies, and discussed the experimental results from these results.

EXPERIMENTS: B2 ordered $Fe_{50}Al_{50}$ alloy was prepared by arc melting method. Sliced samples with the thickness of 0.5 mm were irradiated with an 8 MeV electron beam at room temperature to a dose of 4×10^{18} /cm^2 at KURRI, Kyoto University. Hydrogenated samples by electro-chemical method after electron irradiation were examined by positron lifetime measurement by using slow positron beam with the energy of 4 keV at KURRI facility. Positron lifetime calculation of super imposed atom method have performed for B2 ordered 80x80x80 cell including an atomic vacancy and a hydrogen atom.

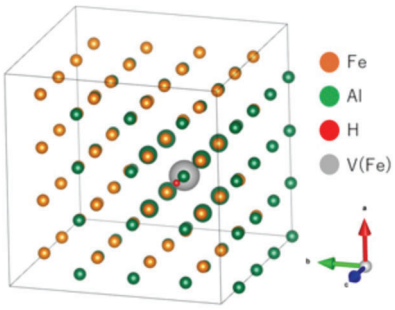

Fig. 1. Calculated atomic position of hydrogen trapped by Fe vacancy in Fe-Al alloy.

RESULTS: Fig. 1 shows the atom site of B2 ordered Fe-Al alloy with iron vacancy (V_{Fe}) and hydrogen calculated by the first principles calculation. Hydrogen atom trapped in a vacancy not the center of vacancy but near the octahedral site. Fig. 2 show the positron annihilation lifetime of electron irradiated (vacancy introduced) Fe-Al at around 400 nm depth as a function of hydrogen charging time. Positron lifetime decreases with increasing hydrogen charging time showing that hydrogen trapping by vacancies. The calculated positron lifetime considering the arrangement of one hydrogen atom in an iron vacancy is shown by the arrow in Figure 2. The positron lifetime after 80 hours of hydrogen charging is almost the same as the calculated value. Furthermore, after 160 hours of charging, the positron lifetime comes down to about 160 ps, which is the same as the value calculated when two hydrogen atoms are arranged at the o-sites facing each other in the vacancy.

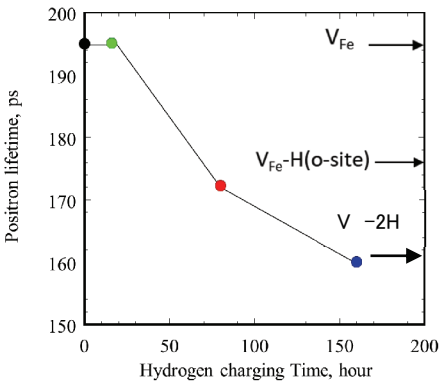

Fig. 2. Positron annihilation lifetime in hydrogen charged Fe-Al measured with 4 keV positrons and calculated values of H-V complexes.

References

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PR11-6

Change of Free Volume in Highly Hydrogenated DLC Films due to Desorption

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INTRODUCTION: Highly hydrogenated diamond-like carbon films (H-DLC films) have been found to release hydrogen and other elements upon soft X-ray irradiation or temperature increase, resulting in a decrease in volume, an increase in density, and an increase in the $sp^2/(sp^2+sp^3)$ ratio of carbon atoms [1]. In this study, positron annihilation spectroscopy (PAS) measurements were performed to investigate the differences in the structural changes in the free volume of H-DLC films between the desorption processes induced by soft X-ray irradiation and temperature increase.

EXPERIMENTS: H-DLC films, whose hydrogen content was 50%, were deposited on Si wafers using Plasma Enhanced CVD method with film thickness of 400 nm. The H-DLC films were heated from room temperature to 1100°C using an electric furnace and were irradiated with white light up to 1000 eV at BL06 of NewSUBARU. PAS measurements were performed using a slow positron beam system installed at the B-1 hole of KUR. Positrons generated in the reactor were thermalized, and accelerated up to 30 keV just before the irradiation chamber, and irradiated onto the sample. The γ rays generated by annihilation were observed using a Ge detector.

RESULTS: The dependences of S parameter, which indicates the momentum shift of the γ-rays produced by positron annihilation, and the positron annihilation lifetime (PAL), on soft X-ray irradiation dose and rising temperature are shown in Figs. 1 and 2, respectively. In both desorption processes, the PAL increased, which indicated that the free volume in the H-DLC film increased. The S parameter increased with temperature for desorption by temperature rise, but decreased with increasing soft X-ray dose for soft X-ray irradiation. This is thought to be due to the increase in annihilation with the inner shell electrons of carbon due to desorption of hydrogen without inner shell electrons around the free volume in the H-DLC film. In conclusion, the difference in the desorption processes, in which both carbon and hydrogen are desorbed at rising temperatures, whereas only hydrogen is desorbed by soft X-ray irradiation, is considered to make a difference in dependence of the PAL and S parameter.

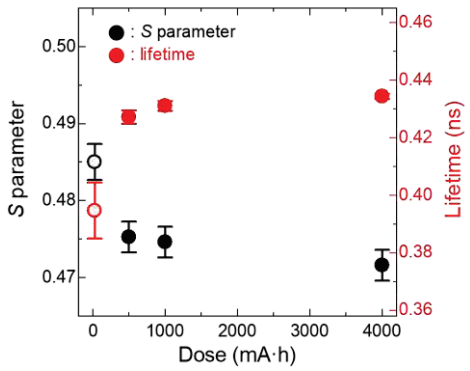

Fig. 1. Dependence of S-parameter and Positron annihilation lifetime on soft X-ray dose.

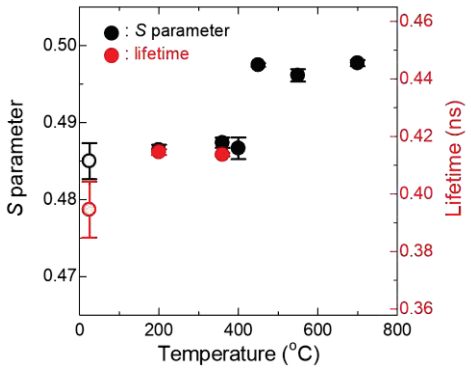

Fig. 2. Dependence of S-parameter and Positron annihilation lifetime on rising temperature.

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PR11-7

Structural Analysis of Diamond-Like Carbon Coatings Using Positron Annihilation Spectroscopy

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INTRODUCTION: Enhancing the efficiency of mechanical systems has led to a growing interest in coatings that reduce friction. Among these, diamond-like carbon (DLC) coatings have gained considerable attention due to their outstanding tribological and mechanical properties [1]. The microstructure of DLCs can be tailored to suit various industrial applications, with potential structures ranging from graphite-like carbon (GLC) to polymer-like carbon (PLC), depending on fabrication techniques and deposition conditions [2]. These structural variations are primarily influenced by factors such as hydrogen content and the ratio of carbonaceous bonds (sp^2 and sp^3). In addition, research suggests that defects also contribute to the overall properties of these coatings [3]. To analyze defect behavior in materials, positron annihilation spectroscopy (PAS) serves as an effective investigative tool. This study aims to explore the microstructural defect behavior of DLC coatings deposited under varying bias voltages by employing PAS.

EXPERIMENTS: The hydrogenated coatings were synthesized using the plasma-based ion implantation (PBII) technique. Deposition was carried out on standard Si (100) wafers. To control the microstructural characteristics, varying negative bias voltages between -1 and -10 kV were directly applied to the target as a deposition parameter. The deposition time was adjusted to achieve a coating thickness of approximately 1 μm. The defect behavior within the coating's microstructure was analyzed based on the S-parameter and positron lifetime, both measured at a positron energy of 5 keV.

RESULTS: Figure 1 shows the S-parameter profiles (a) and the corresponding normalized S-parameter and positron lifetime values (b) for F-DLC films deposited at different bias voltages using PBII. In Figure 1(a), the S-parameter increases with positron energy, reflecting typical positron diffusion behavior. A higher negative bias leads to an increase in the S-parameter, suggesting larger open-volume defects. Figure 1(b) summarizes the bias dependence of S/S_{Si} and positron lifetime, both of which rise from –5 to –10 kV. This trend indicates that void size increased with implantation energy, while π-electron density remained largely unchanged.

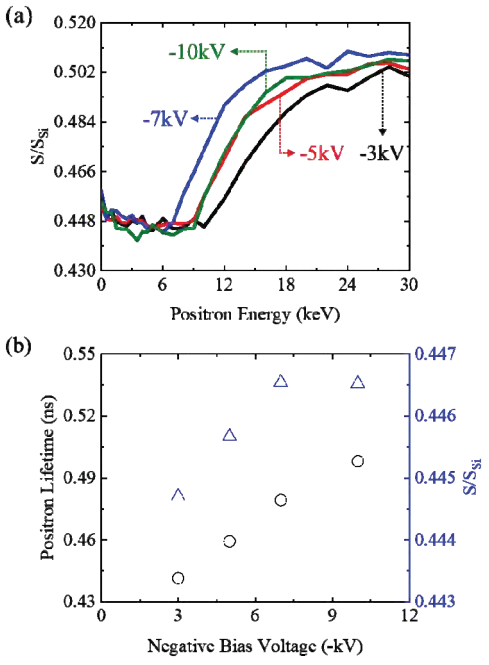

Fig. 1 (a) S- arameter depth profiles o F-DLC films. (b) bias voltage dependence of normalized S- arameter and positron lifetime at different bias voltages.

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PR11-8

Valuation of the Effect of the CHF3-Plasma Treatment on Si Surfaces using the Positron Annihilation Method

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INTRODUCTION: In our previous study [1], we have found that the S-parameter of the CHF_3-plasma-treated Si surface was smaller than that of untreated Si, especially in the surface region, indicating the formation and the deposition of C-related materials during the process. In the present study, to clarify the formation, deposition and sputtering processes of the C-related materials, the CHF_3-plasma-treated Si surfaces were investigated using the different plasma conditions.

EXPERIMENTS: The CHF_3-plasma with the gas pressure of 10 Pa and the RF power of 40 W was irradiated for 30 or 120 min. on Si substrates with the size of 18 mm x 18 mm cleaved from a Si (100) wafer in the experiment. The Si substrates were mounted on the sample stage of the plasma chamber, which was connected to the blocking condenser and negatively charged during the plasma treatment, or on the cover of the chamber, which was directly connected to ground. The S-parameters were obtained from the Doppler broadening for the energy of the γ-ray by the positron-electron annihilation and the elemental analyses were obtained from the energy dispersive X-ray analysis (EDX) and the X-ray photoelectron spectroscopy (XPS).

RESULTS: As shown in Fig. 1, the S-parameters of all CHF_3-plasma-treated samples were smaller than that of Si. The S-parameters of the samples mounted on the cover were smaller than those of Si and the samples on the stage, and affected on deeper region by increasing process time, indicating the growing of deposited new materials on the surfaces. From the EDX analysis, the element composition of the material was C:Si = 64.3:35.7, indicating the deposited material was C-related one which was formed from involatile materials by the gaseous decomposition of the CHF_3 gas during the plasma process. Figure 2 shows the more precise component of the deposited materials obtained by the XPS measurement. F was also detected. For the samples mounted on the stage, however, the smaller S-parameters relative to Si were observed only near the surface region, indicating the sputtering of the deposited materials by energetic ions from the plasma. The effect of the CHF_3-plasma treatment directly on Si surfaces, which show the almost the same tendency with that of the BF^{2+}-implanted Si, is still an issue in the future.

REFERENCE:

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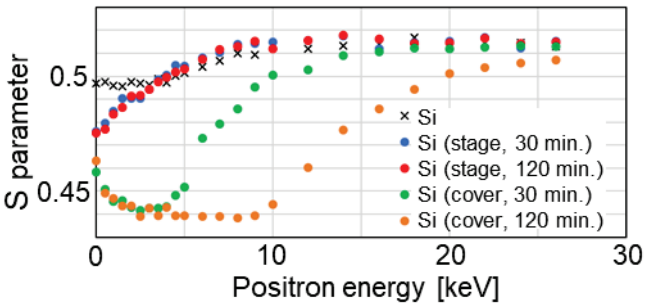

Fig. 1. S-parameters of Si and CHF_3-plasma- treated Si positioned on the sample stage or the cover of the plasma chamber, exposed for 30 or 120 min.

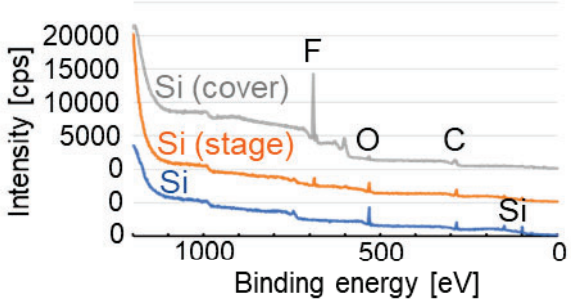

Fig. 2. XPS spectra for Si and CHF_3-plasma-treated Si positioned on the sample stage or the cover of the plasma chamber.

PR11-9

Effects of Pulse Irradiation by Charged Particles on Damage Structures in Metals

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INTRODUCTION: Irradiation experiments are crucial for the development of nuclear materials. High-energy charged particles like ions and electrons, which are created in accelerators, are commonly employed in these experiments. The time structures of ion and electron beams from accelerators that use radio frequency or beam scanners are characterized by periodic/discontinuous intensities. The purpose of this study is to clarify the effects of pulse irradiation on the damage defect evolution.

EXPERIMENTS: Self-ion irradiation of Fe with the accelerating energy of 2 MeV was performed by tandem accelerator in Research Center of Ion Beam Technology, Hosei University. The irradiation temperature and total dose were 573 K and 1 dpa, respectively. The other irradiation conditions are in Table 1, where τ and T are the pulse dulation and fluquency, respectively. The effect of irradiation damage was investigated with positron annihilation spectroscopy in the slow positron beamline at the Kyoto University Research Reactor.

Table 1. The irradiation conditions of Fe by tandem accelerator with 2 MV at 573 .K.

Specimen	Fe	Fe	Fe
Beam train	Pulse τ/T: 10^{-4}s/10^{-3}s, 1kHz	Pulse τ/T: 1^{-1}s/1s, 1Hz	Continuous
Average damage rate	6.1x10^{-6} dpa/s	8.1x10^{-6} dpa/s	6.5x10^{-6} pa/s

RESULTS: By changing the accelerating voltage, the penetration length of positron changes. S parameter depends on the total amount of spaces in Fe, such as vacancies and their clusters formed by irradiation. Near the surface, the effect of the surface is significant, and we chose the area from 300 to 800 nm for S parameter as shown in Figure 1. The clear difference between unirradiated specimens and irradiated specimens, and the effect of beam structures is detected.

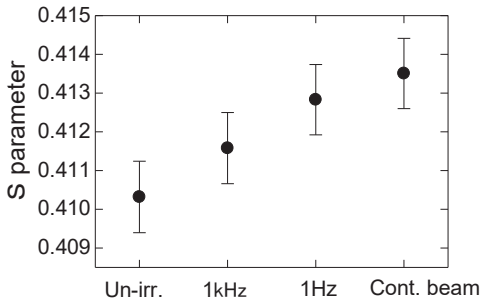

Fig.1

Reaction kinetic analysis was performed based on the rate theory. It describes the reaction rates among point defects and their defect clusters. Figure 2 shows the accumulation of point defects after 0.1 dpa irradiation at 300°C with three irradiation conditions, 1kHz (τ/T=, 10^{-4}s/10^{-3}s), 1Hz (0.1s/1s), and continuous beams (Cont.). The accumulation of interstitials (I in Fig. 2) in clusters are almost the same. However, clear differences in vacancy accumulation (V in Fig. 2) can be seen. The order of vacancy accumulation is the same as that of slow positron measurements.

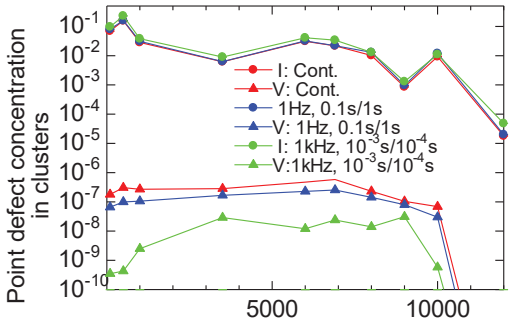

Fig.2

PR11-10

Development of slow positron beamline using electron linear accelerator

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INTRODUCTION: Slow positron beams (energy-variable monoenergetic positron beams) have been widely used to investigate vacancy-type defects in thin films or near-surface layers in ion irradiated materials. Intense slow positron beams can be generated through pair-creation reactions by large-scale experimental facilities such as nuclear reactors and accelerators. In terms of accelerator-based positron sources, so far, radiofrequency-driven electron linear accelerators (LINAC) have been mainly used. In principle, LINAC-generated positron beams are not continuous (i.e., pulsed beams), while reactor-based positron beams are continuous. The pulsed beams can be potentially applied for unique applications such as pump-probe type measurements [1]. This study aims at such unique applications using KURNS-LINAC.

EXPERIMENTS: A 30 MeV electron beam with a pulse width of 5 μs was generated using the KURNS-LINAC. A water-cooled tungsten converter and a Pt-mesh moderator were used at the source part. Generated positrons are extracted with a bias voltage of 10 V and magnetically guided to the beamline. A linear storage section was installed to control time structures of the slow positron beam. The original pulse with a width of 5 μs can be stretched or delayed by controlling the waveforms applied the entrance and exit electrodes in the linear storage. The beamline was extended to the sample chamber with a pulsing system for positron lifetime measurements in the measurement room next to the target room. The pulse system consists of transmission-type chopper electrodes and radiofrequency (RF) driven prebuncher and buncher electrodes.

RESULTS: Preliminary experiments showed that the slow positron beam was successfully transported to the sample chamber. Annihilation gamma-rays were detected by a scintillation detected behind the sample chamber. Fig. 1 shows the annihilation gamma-ray signals recoded by an oscilloscope at the end of the linear storage section. When the delay of the storage were changed from 50 μs to 250 μs, gamma-rays signals (negative pulses) were shifted accordingly. It indicates that the linear storage successfully worked. The pulse stretching performance can be indicated in Fig. 1 as well. The original pulse width of 5 us was stretched to ~100 μs. The pulse system for positron lifetime measurements was examined by feeding appropriate pulse/RF signals. The pulse formation and bunching were confirmed for individual electrodes.

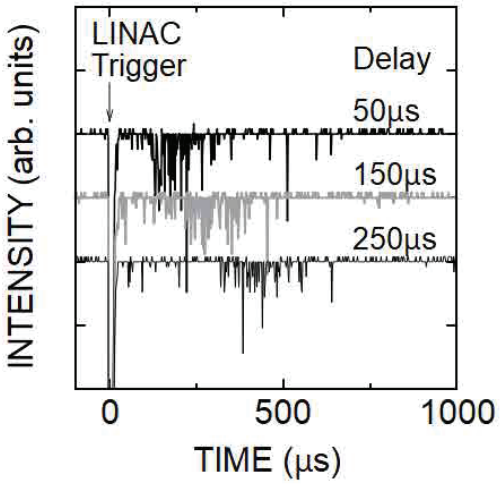

Fig. 1 Positron signals recorded for different delay times of the linear storage.

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[1] A. Kinomura *et al.,* Rev. Sci. Instrum., 85 (2014) 123110.