Ion irradiation-induced structure damage to botanic samples using the ion transmission energy spectrum

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Abstract In order to study the mechanism of irradiation-induced damage of botanic samples caused by low energy heavy ions, transmission energy spectrum measurement was performed. Kidney bean slice samples 100 μm in thickness were irradiated by 50 keV N^+ ions. The irradiation beam current density was about 30 $\mu A/cm^2$, and the irradiation ion doses were 1×10^{15}, 1×10^{16}, 3×10^{16} and 1×10^{17} ions·cm^{-2}, respectively. A target set up that could greatly reduce the incident ion current density was designed to achieve the damage-free measurement. The 3.2 MeV H^+ transmitted ion energy spectrum measurement was carried out before and after the irradiation. From the transmission ion energy spectrum, it was found that the kidney bean slice itself was structurally inhomogeneous compared with the PET films ($C_{10}H_8O_4$). Our results indicated that the average mass thickness changed little when the N^+ ion dose was below 3×10^{16} ions·cm^{-2}, but changed obviously when ion dose was beyond 3×10^{16} ions·cm^{-2}.

Keywords Irradiation damage, Energy loss, Low energy ion, Ion transmission energy spectrum, Kidney bean slice

CLC numbers O571.33, TN305.3, Q319$^+$, Q689

1 INTRODUCTION

The new applications of low energy heavy ion beam in irradiated botanical materials were studied in recent years. The beam-induced mutation effect on crop seeds has caused the attention of physicist and biologists.[1,2] For example, low energy ions can induce remarkable mutation to rice seeds.[3] There are many special phenomena when heavy ions bombard botanic sample due to its special structure. Some studies showed that the penetration depths of some ions were far larger than their theoretical projectile ranges.[4,5] For instance, 3 MeV F^+ ions could penetrate 100 μm botanic samples when the irradiation dose was high enough, though its theoretical range was less than 5 μm.[4,5] It has been

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proposed that the ion irradiation damage has significant influence on the ion depth profile in botanic samples.[4]

Some reports[6,7] showed that the mechanism of heavy ions' interaction with organic materials was quite different from the mechanism of heavy ions' interaction with inorganic materials. However, the investigation on the irradiation damage to botanic samples induced by heavy ion bombardment has not been well studied to date.

In our experiments, irradiation damages of botanic samples were studied by the transmission energy spectrum analysis. Possible mechanism was discussed.

2 EXPERIMENTAL METHODS AND RESULTS

2.1 Transmission energy spectrum device and its advantage

3.2 MeV H^+ ions used in the transmission experiment were produced with 2×1.7 MeV tandem accelerator in the Department of Technical Physics, Peking University. The experiment samples were put in the vacuum chamber (about 3×10^{-3} Pa). In order to hold botanic samples, reduce ion current density and complete the multi-target measurement, a target brace was designed, of which the set up is shown in Fig.1. The incident ion beam is scattered by Au film (200 μg·cm^{-2}). After 3.2 MeV H^+ beam transmitting the Au foils, the energy loss was about 7 keV, which could be neglected. And the energy scattering of H^+ ion beam after the Au film could also be neglected. The forward scattering ions within angle of 20° were used in our experiment. The samples were placed vertically to the direction of the ion beam. The ions were detected by Au-Si semiconductor after they transmitted the botanic samples. The signal was amplified, and entered the computer via the multi-channel system, then the transmission energy spectrum was obtained.

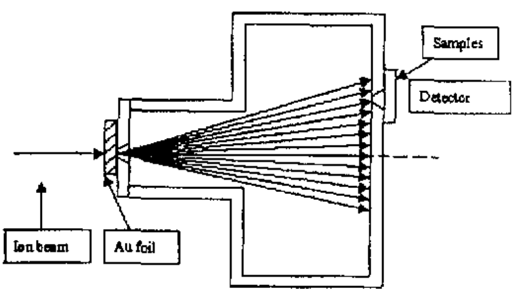

Fig.1 The target brace in the transmission experiment (Au foil about 200 μg·cm^{-2})

According to the Rutherford scattering formula, the scattering crosses at different angles could be calculated. The different scattering cross at 20° angle was calculated as 8.7025×10^{-22} cm^2. Then the yield could be calculated. The incident ion current was 3 nA and the size of beam area was 4×4 mm. The hole on the target brace was a circle with the radius of 3 mm. The horizontal length of the target brace was 60 mm. The ion dose rate could be calculated as 1.08×10^5 ions·cm^{-2}·s^{-1}. Compared with the incident ion dose rate 1.17×10^{11} ions·cm^{-2}·s^{-1}, ion dose rate at 20° angle reduced greatly. According to our previous experimental results,[4,5] the transmission energy spectrum measurement could be considered as a damage-free measurement when H^+ ion dose rate was less than 10^5 ions·cm^{-2}·s^{-1}. The low dose rate and light incident ion could also protect Au-Si detector from ion irradiation damages. In order to confirm whether the measurement was damage-free to samples, a sample was measured twice under the same condition, and the time interval was 20 minutes. It was found that the two transmission energy spectra were nearly the same. So it could be regarded as damage-free measurement.

Because of the difference in mass distribution in kidney bean slices, samples must be measured under the same condition to get statistic average value. In this experiment, 12 target places were designed at the symmetric position of the circle. Before the irradiation experiment, transmission energy spectrum method was used to check the samples. If there were small holes or very thin areas in the irradiation area, there would be counts near the position without energy loss. The transmission energy spectrum of 3.2 MeV H^+ through 100 μm kidney slice with some open-paths observed under the optical microscope was done. Fig.2 showed that there was a small peak at 474 channel corresponding to the position without energy loss. It could be concluded that there were some tiny open-paths where the ions could penetrate without energy loss. The total counts were about 1.337×10^6 ions and the total counts near to the small peak were about 1274 ions. We could estimate that the total area of open-paths was 9.5×10^{-4} time of the total transmitted area. The transmitted area of the sample was 9 mm^2, then the area of total open-paths was 8.55×10^{-3}mm^2. So the samples could be checked using the transmission energy spectrum. In the above experiment, the incident H^+ ion current was about 6 nA and the measuring time was 240 seconds. According to the calculation, the ion dose rate that reaches the surface of samples was 2.16×10^5 ions·cm^{-2}·s^{-1}, so the total incident ion was about 4.3×10^6 ions. If there were several ions at 474 channel, then open-paths could be detected. So the detecting efficiency of the device was about 10^{-6} under the condition used.

2.2 Comparison between 105 μm PET film and 120 μm kidney bean slice

In order to study the mass distribution of kidney bean slice, PET film was selected for comparison. 120 μm kidney bean slice (1.20g·cm^{-3}) and 108 μm PET film (1.397 g·cm^{-3}) were used in the transmission experiment. Their transmission energy spectra are shown in Fig.3. The peak positions were nearly the same (116 channel), but the FWHM (Full Width of Half Maximum) of the slice (96 channel) was much larger than that of PET film (30 channel). It showed that the energy straggling of H^+ beam in the kidney bean slice was larger than that in the PET film. It was known that mass thickness of PET film (15.1 mg·cm^{-2}) was larger than that of kidney bean slices (14.4 mg·cm^{-2}). From these results we conclude that the distribution of mass of kidney bean slices is more inhomogeneous than that of PET films. According to the calculation by the software TRIM98, the theoretical range of 3.2 MeV H^+ in PET film ($C_{10}H_8O_4$) and in kidney bean slice (CH_2O) was 128 μm and 144 μm respectively. After 3.2 MeV H^+ ion beam passed 108μm PET film and 120 μm kidney bean slice, the energy loss was about 2.1 MeV and 2.2 MeV, respectively. The peak position of the transmitted ion was calculated as 124 channel and 107 channel, respectively (about 6 keV per channel in our experiment). The theoretical results had the difference of 8-9 channels from the experimental results (116 channel). The difference ratio was about 7%. It indicated that the kidney bean slice could be looked at as a condensed state material when we considered the average mass thickness of kidney bean slice.

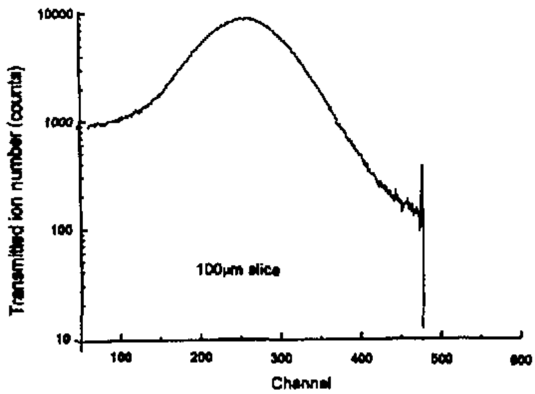

Fig.2 3.2 MeV H^+ transmission energy spectrum of 100μm kidney bean slice sample

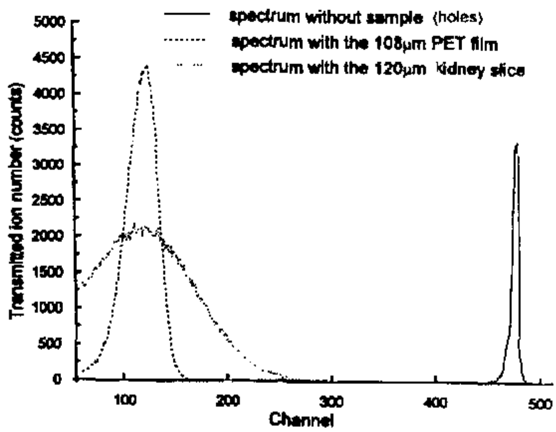

Fig.3 Comparison of the transmission energy spectra with hole, 120 μm kidney bean slice and 108 μm PET film

2.3 Energy loss comparison at different ion doses

In the experiments, after being carefully selected using the transmission method, 100 μm kidney bean slices were irradiated with 50 keV N^+ at different ion doses of 1×10^{15}, 1×10^{16}, 3×10^{16} and 1×10^{17} ions·cm^{-2}. The beam current was 30 μA and the beam size was 25 cm^2. Before and after the irradiation experiment, the transmission experiment was done. A transmission energy spectrum at ion dose of 1×10^{16} ions·cm^{-2} was given in Fig.4. The peak position of the transmission energy spectrum had shifted a few (3 channels) to the high-energy direction and FWHM had little change after irradiation. Because the experimental error was about 2 channels, it could be concluded that the average mass thickness changed little when the ion dose was 1×10^{16} ions·cm^{-2}. It could also be seen that there was no count at higher energy region than 474 channel, which suggested that there was no direct holes or open-paths after 1×10^{16} ions·cm^{-2} N^+ ion irradiation. In our experiment nine samples were measured to make statistical operation for different ion doses. The average value of energy loss change was shown in Fig.5. For ion doses 1×10^{15}, 1×10^{16} and 3×10^{16} ions·cm^{-2}, all the average channel changes were around 1.5 channels, less than 2 channels (the error). It was thought that the change of average mass thickness was not obvious. However for ion dose 1×10^{17} ions/cm^2, the average channel change was about 6 channels, which was greater than the error. As shown in Fig.5, the change in average mass thickness was not obvious below the ion dose point, 3×10^{16} ions·cm^{-2}, but was obvious above it. This experimental phenomenon was also observed in mass measurement experiments.[8]

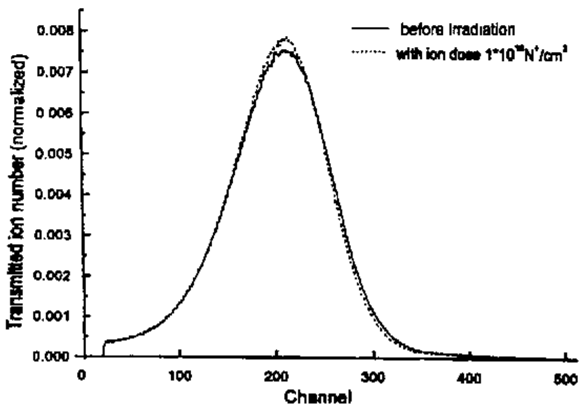

Fig.4 The comparison of 3.2 MeV H^+ transmission spectrum of 100 μm kidney bean slice before and after $1\times10^{16}N^+\cdot cm^{-2}$ irradiation

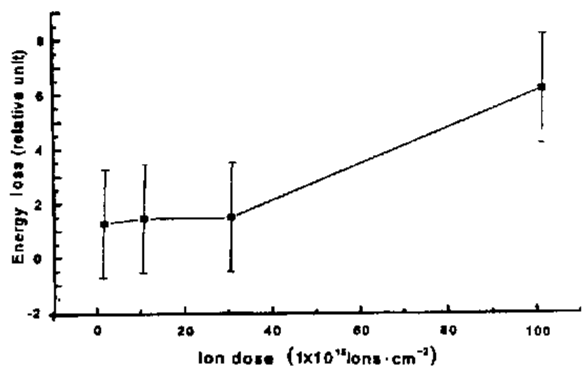

Fig.5 The average value of energy loss change at different ion doses

3 CONCLUSIONS

In our experiments, a target brace that can reduce the incident ion current density greatly was designed, the damage-free measurement could be made. From the transmission energy spectrum experiment, the following conclusions can be obtained:

1) As an efficient method, H^+ transmission spectrum method can be used to select the perfect samples.

2) The homogeneity degree of samples can be obtained by analyzing FWHM. The mass distribution of kidney bean slice is more inhomogeneous than PET film.

3) From the peak position comparison of transmission energy spectra, the energy loss changed after N^+ ion irradiation. However, when the N^+ ion dose was below 3×10^{16} ions·cm^{-2}, the change in average mass thickness was not obvious. When ion dose was above 3×10^{16} ions·cm^{-2}, the change in average mass thickness (i.e., the damage) was

obvious.

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