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Modification of bamboo surface by irradiation of ion beams

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Abstract

When beams of hydrogen ions, He^+ and Ar^+ were irradiated onto bamboo surface, gas release of hydrogen, water, carbon monoxide and carbon dioxide were enhanced. Time evolution of the gas emission showed two peaks corresponding to release of adsorbed gas from the surface by sputtering, and thermal desorption caused by the beam heating. The difference in etched depths between parenchyma lignin and vascular bundles was measured by bombarding bamboo surface with the ion beams in the direction parallel to the vascular bundles. For He^+ and Ar^+, parenchyma lignin was etched more rapidly than vascular bundles, but the difference in etched depth decreased at a larger dose. In the case of hydrogen ion bombardment, vascular bundles were etched faster than parenchyma lignin and the difference in etched depth increased almost in proportion to the dose. The wettability of outer surface of bamboo was improved most effectively by irradiation of a hydrogen ion beam.

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Keywords: Bamboo; Chemical sputtering; Wettability

1. Introduction

Natural materials gather more attention as environmental protections are considered to be important. Bamboo plants grow almost everywhere in pan pacific area, and have been used as the resource to build traditional Asian houses. Bamboo can be a raw material to fabricate a composite material and its applicability is being investigated [1]. To modify the surface property of bamboo suitable for specific use, plasma based surface modification method can be used. The understanding on interaction between bamboo surface and energetic charged particles is necessary so as to optimize the efficiency of the surface process. This paper reports the investigation on the interactions of hydrogen ion (H_n^+), argon ion (Ar^+), and helium ion (He^+) beams at energies of several keV with bamboo surface.

2. Experimental methods

The apparatus consisted of two vacuum chambers as schematically illustrated in Fig. 1. The first chamber contained a sample target holder at the center to minimize the contamination from the wall onto the target. Part of the gas released from the surface of the target was detected by the quadrupole mass analyzer (QMA) installed in the

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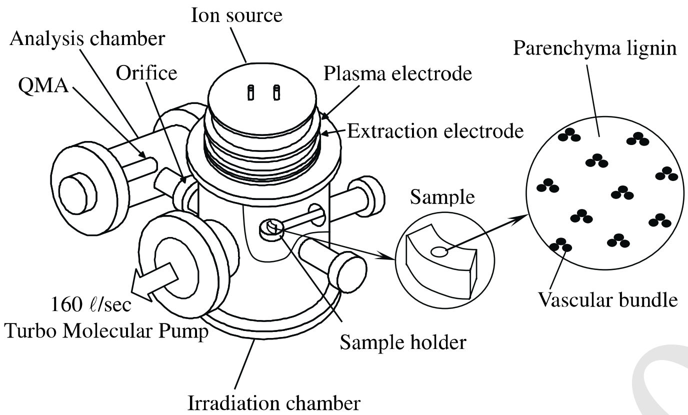

Fig. 1. Schematic illustration of the experimental setup and the orientation of the bamboo sample.

second chamber which was connected to the first chamber with a 4 mm diameter 20 mm long conduit. The first and the second chambers were evacuated with 160 and 50 l/s turbo molecular pumps, respectively.

Plasmas of H_2, He and Ar were produced in an 8 cm diameter, 5 cm deep cylindrical plasma source. Ions were extracted from a plasma source through a 3-electrode beam-extraction system with the acceleration–deceleration potential arrangement. There were 19 holes of 3 mm diameter opened with 6 mm spacing on these extraction electrodes to achieve a homogeneous ion beam irradiation across the entire area of the target. The beam traveled 12 cm in vacuum from the ground electrode of the extractor to hit the surface of the bamboo sample.

After placing the bamboo sample on the holder as shown in Fig. 1, the chambers were evacuated until the pressure became lower than 10^{-3} Pa. The gas to be ionized was introduced into the plasma source by keeping the pressure of the chamber containing the target below 4×10^{-2} Pa. With this residual gas, a dilute plasma was formed near the sample due ionization by the incident ion beam, and the charge up of the bamboo surface was suppressed by this surrounding plasma. The beam current density striking the sample surface could not be measured during the experiment with the presence of surrounding plasma, and the ion beam current during the experiment was kept at 2 mA by adjusting the extraction current. This current corresponded to about 10 μA/cm^2 ion beam current density at the target.

3. Experimental results

3.1. Gas emission characteristics during beam irradiation

The mass spectrum taken with the beam turned off was subtracted from that with the beam turned on to obtain the beam induced gas release as there was the substantial background gas emission from the bamboo surface. Various kinds of gas emissions were found by irradiating the bamboo surface. These include H_2, H_2O, CO and CO_2. The emissions of some molecules, for example mass = 31, became smaller during the ion beam irradiation. The increase in the gas emission was also observed for mass = 29, 31 and 45 after turning off the ion beam irradiation.

There are two direct mechanisms leading to the enhanced gas emission by the irradiation of charged particle beams. One is the physical sputtering causing emission of gaseous atoms and molecules cutting the chemical bonds at the surface. The other is the thermal desorption due to the elevation of surface temperature [2]. In Fig. 2, a typical gas release characteristic for CO is shown as a function of time. As shown in the figure, there were two peaks in gas emission due to ion beam irradiation onto bamboo surface. A relatively

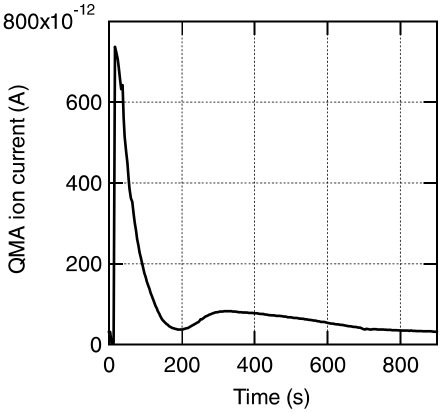

Fig. 2. Time history of CO gas emission due to ion bombardment of He^+ onto bamboo surface.

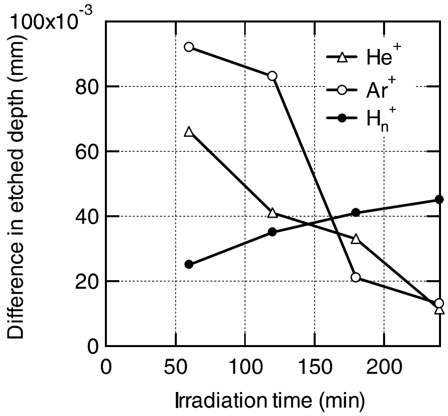

Fig. 3. The difference in the etched depth between the vascular bundles and parenchyma lignin caused by the ion beam irradiation. For Ar^+ and He^+, parenchyma lignin was etched more than vascular bundles, while vascular bundles were etched more than lignin for Hn^+. The dose rate corresponds to 4×10^{15} atoms/cm^2 min.

sharp peak appeared soon after the start of the irradiation. The second peak took the maximum at later time and usually showed a larger decaying time constant than that of the first peak. When the duration of the ion beam was limited to several seconds, and the target was cooled down for several minutes, the second peak did not become obvious for repeated irradiation. Since the temperature of the bamboo surface should not become high under this operation, while the surface temperature during the steady state beam irradiation was estimated to be from 200 to 300 °C by the infrared radiation. Namely, the second peak appears by the increase of the surface temperature, and corresponds to the thermal desorption. The height of the first peak was always larger when the sample was freshly loaded, while it was smaller for samples after several times of irradiation. The amount of gas adsorbed on the bamboo surface is larger for the freshly loaded sample, and the physical sputtering of adsorbed gas can cause the appearance of the first peak.

3.2. Ion beam damage to vascular bundles and parenchyma lignin

In the structure of bamboo, vascular bundle fibers are contained in parenchyma lignin. The independent etch rates for the two materials were difficult to measure, because the shape of the bamboo sample changed after the beam irradiation. Thus, the difference in the etched depth between parenchyma lignin and vascular bundles was measured. Beams of hydrogen ions, He^+ and Ar^+ were injected onto the bamboo surface cut in the direction perpendicular to the orientation of the vascular bundles as shown in Fig. 1. The result is shown in Fig. 3. It was found that beams of Ar^+ and He^+ caused more etching on parenchyma lignin part than on vascular bundles, while the irradiation of hydrogen ions caused more etching on vascular bundles than parenchyma lignin. As shown in the figure, the difference in etched depth appeared to become smaller as the doses were increased for He^+ and Ar^+. On the contrary, the difference in etched depth increased in accordance with the dose of hydrogen ions.

The density of vascular bundles ranges from 1.3 to 1.6 g/cm^3 and is higher compared to that of parenchyma lignin from 0.3 to 0.4 g/cm^3. Because both materials are mainly composed of C with some O and H, their volumetric etching rates due to physical sputtering are considered to be proportional to the inverse of volumetric density. Meanwhile, for carbon atoms in solids, Ar^+ is more effective than He^+ for the physical sputtering. The result in Fig. 3 at lower dose shows more effective etching of parenchyma lignin by Ar^+ than that by He^+, which indicates the etching of bamboo by these ions are mainly due to physical sputtering process. The reduction in etched depth difference between the vascular bundles and parenchyma lignin at a larger dose suggests some mechanism causing more etching of vascular bundles and/or less etching of parenchyma lignin with the increased irradiation time exist.

The surface temperature of the bamboo sample became high under the ion beam irradiation as explained previously. The sample surface was heated with infrared radiation from hot tungsten filament in vacuum to investigate the effect of temperature. The heating caused the gas emission of the sample, and the etching of the vascular bundles was observed. Thus, the reduction in etched depth difference at a larger dose can be attributable to the sublimation of vascular bundles due to surface heating by the ion beam irradiation. The enhanced etching of the vascular bundles by the hydrogen ions is probably caused by chemical sputtering, judging from the larger release rates of hydrocarbon and hydrocarbon oxides during the beam irradiation [3].

3.3. Enhancement of wettability by beam irradiation

The change in wettability of the outer surface of bamboo was investigated by measuring the contact angle with pure water. The result for 6.5 keV ion beam is shown in Fig. 4. Among He^+, Ar^+ and Hn^+ ion beams, the efficiency of wettability enhancement by hydrogen ion beam was the largest. The presence of chemically active species in the surrounding plasma is known to enhance the change in wettability by ion beam irradiation [4]. Thus the enhanced change in wettability for Hn^+ beam can be understood as more efficient modification of cellulose surface by chemical sputtering. Meanwhile, the surface of the bamboo heated by incandescent tungsten filament in vacuum did not show substantial enhancement in wettability as was observed for the ion beam irradiated bamboo surface.

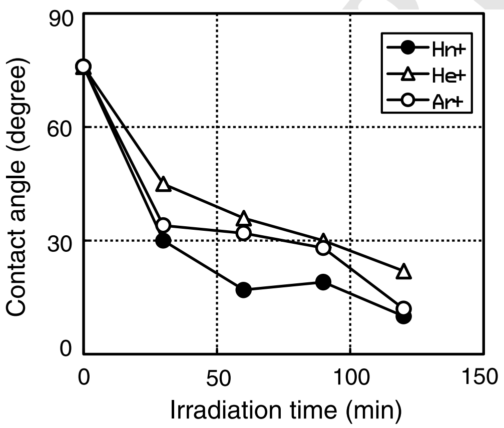

Fig. 4. Plots showing the reduction of contact angle of pure water on outer surface bamboo by ion beam irradiation. The dose rate corresponds to 4×10^{15} atoms/cm^2 min.

4. Conclusion

Through the ion beam irradiation experiment, hydrogen ions are found effective to enhance wettability. Heating of the bamboo materials causes depletion of vascular bundles by sublimation and outgas due to thermal desorption. For these reasons, the intermittent hydrogen plasma process is suitable for the wettability enhancement process of bamboo materials surface with less damage and outgas due to heating.

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