

CARBON IMPLANTATION BY POLYATOMIC ION SOURCE OF ORGANIC LIQUIDS

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Abstract

A polyatomic ion source using n-octane (C_8H_{18}) for a shallow implantation of polyatomic carbons was developed. $C_3H_7^+$ or $C_6H_{13}^+$ ions produced by electron-bombardment of n-octane vapor were irradiated onto Si(100) at carbon-equivalent energy of 1 keV for carbon dose of 1×10^{15} , 5×10^{15} and 1×10^{16} cm^{-2} . Depth profile of the carbon was analyzed by X-ray photoelectron spectroscopy. As a result, the $C_6H_{13}^+$ was implanted deeper than the $C_3H_7^+$ at the same incident energy per atom. This is probably due to vertical impact effect corresponding to long-chain form of alkyl ions.

INTRODUCTION

Transient enhanced diffusion (TED) of boron [1] during rapid thermal annealing for recovering implantation damage can be suppressed by incorporation of substitutional carbon in a depth of the dopant region. For ultrashallow junctions of the next generation semiconductors the TED is no avoidable issue due to the need of precise dopant-depth of ~ 10 nm [2].

In order to achieve the precise shallow-implantation of carbon for preventing the TED, implantation of polyatomic carbon ion is a possible solution to the issue. Use of polyatomic carbon ions allows equivalently higher current and thinner damage-depth compared to single-ion implantation in the same energy, which is resulted from mass effect. In this study, we investigated implantation depth of carbon into Si substrate irradiated with mass-separated alkyl ions generated from n-octane (C_8H_{18}) vapor at room temperature. According to Aoki's work about MD simulation of decaborane ($B_{10}H_{14}$), implantation depth of chain-like molecular ions such as the decaborane depends on an impact direction of the molecular; and vertical impact is deeper than horizontal impact [3]. Alkyl ions obtained in present work have long-chain form similarly to the decaborane. Hence long-chain alkyl ions can be considered to produce deeper implantation than short-chain alkyl ions if the vertical impact is major. To examine the size dependence, irradiation with $C_3H_7^+$ and $C_6H_{13}^+$ onto silicon substrate were demonstrated.

EXPERIMENTAL

Alkyl ions were produced by the electron bombardment method [4]. Figure 1 shows Schematic diagram of polyatomic ion source of organic liquid. Liquid n-octane filled in a reservoir was vaporized at 300 K, and was fed into a ionization chamber through a stainless steel tube heated up 473 K to prevent reliquification. The introduced vapor of n-octane was ionized with thermionic electrons of 50 mA having energy of 200-500 eV from a tungsten filament at indicated pressure of $7-8 \times 10^{-5}$ Torr. Alkyl ion beam extracted at 3 kV was focused with a einzel lens and transported to a Wien filter, which has E×B region with static magnetic field of 0.4 T and 1.2 cm spacing electrodes, through a 3mm gap slit. Mass separated ions can be additionally accelerated / decelerated by an applied voltage at a Faraday cup and a target holder, and were irradiated to n-type single crystalline Si(100) wafer.

Figure 2 shows a typical mass spectrum of alkyl ions generated from n-octane at 300 K. The obtained spectrum is basically the same tendency compared with common alkyl molecules whose fragments indicate C_nH_{2n+1} peaks related to m/e of 14 (CH_2) [5]. The highest peak corresponding to $C_3H_7^+$ accounts for 50 % of total amount of obtained ions. The $C_3H_7^+$ and $C_6H_{13}^+$ with the twice molecular mass were selected to irradiation species in order to compare the mass dependence on implantation depths of carbon. The implantation energy was determined at 1 keV per one carbon atom, so that the acceleration voltages for $C_3H_7^+$ and $C_6H_{13}^+$ were fixed to 3 kV and 6 kV, respectively. The irradiation of $C_3H_7^+$ and $C_6H_{13}^+$ were carried out at pressure in the target chamber of 3.0×10^{-5} as indicated value, and up to carbon dose of 1×10^{15} , 5×10^{15} and 1×10^{16} cm^{-2} . The depth profile of implanted carbon was measured by X-ray photoelectron spectroscopy (XPS). Carbon concentration was calculated from peak area ratio between photoelectron signals of C1s, O1s, and Si2p. The XPS measurement and Ar^+ beam etching run cyclically run with a constant time. The etching depth was determined by using a stylus-type surface roughness measurement after the XPS.

RESULTS AND DISCUSSION

Figure 3 represents depth profiles for $C_3H_7^+$ irradiated Si(100) substrate for the dose of 1×10^{15} , 5×10^{15} , and 1×10^{16} cm^{-2} , respectively. Comparing these results, the

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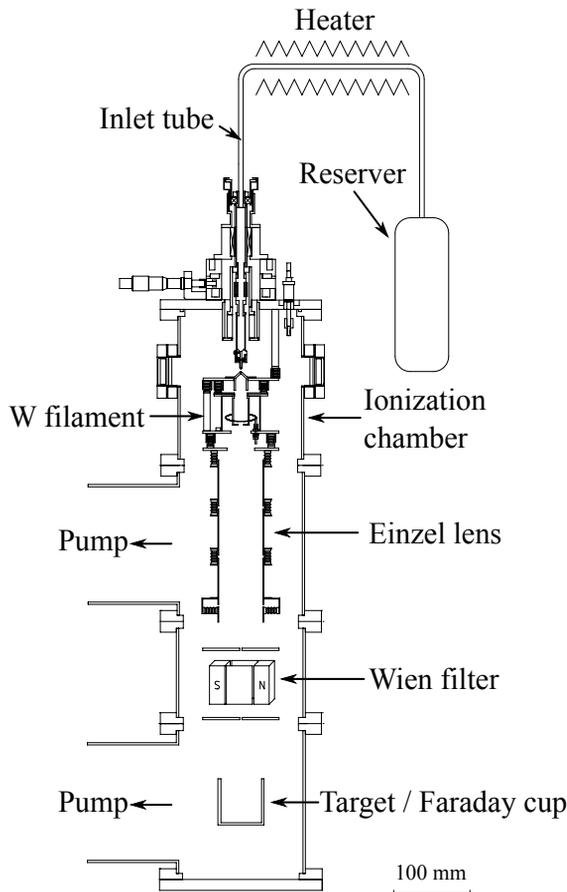


Figure 1: Schematic diagram of polyatomic ion source of organic liquid.

carbon distribution tends to be deeper with increasing the carbon dosage, even though they have the same implantation energy. In addition, slope of the distribution decay can be seen slower according to increase of the dose. Carbon concentrations at the surface are 48 %, 78 %, and 80 % for the dose of 1×10^{15} , 5×10^{15} , and 1×10^{16} cm^{-2} , respectively. To be clear the difference of implantation depth between the C_3H_7^+ and the $\text{C}_6\text{H}_{13}^+$, half-depth is defined that the period of depth it takes for a carbon concentration undergoing decay to decrease by half. The half-depths show 1.5 nm, 7.5 nm, and 10.4 nm for the carbon dose of 1×10^{15} , 5×10^{15} , and 1×10^{16} cm^{-2} , respectively.

Figure 4 shows depth profiles for $\text{C}_6\text{H}_{13}^+$ irradiated Si(100) substrate for the dose of 1×10^{15} , 5×10^{15} , and 1×10^{16} cm^{-2} , respectively. The carbon concentrations are found to be more widely distributed with increasing of carbon dosage, and are similar to the result for C_3H_7^+ irradiation. The slope decay is also same tendency in these irradiation. Surface concentrations of carbon are 46 % and 83 % for 1×10^{15} and 1×10^{15} cm^{-2} , respectively. This is nearly same value as C_3H_7^+ sample. However, for the dose of 1×10^{16} cm^{-2} , the carbon concentration indicates 98 %. This implies that the surface region consists of carbon and

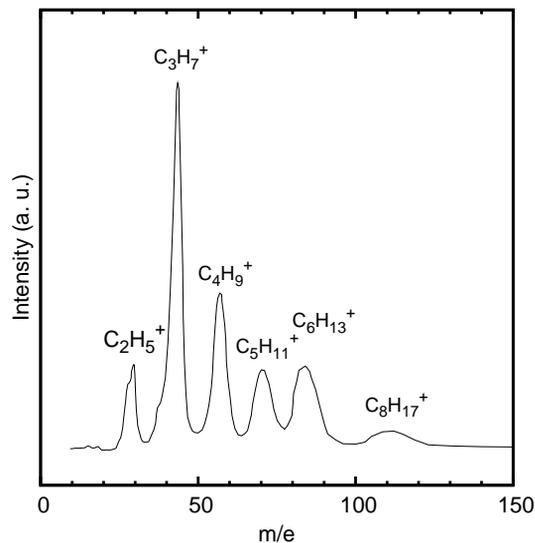


Figure 2: Typical mass spectrum of alkyl ions generated from n-octane.

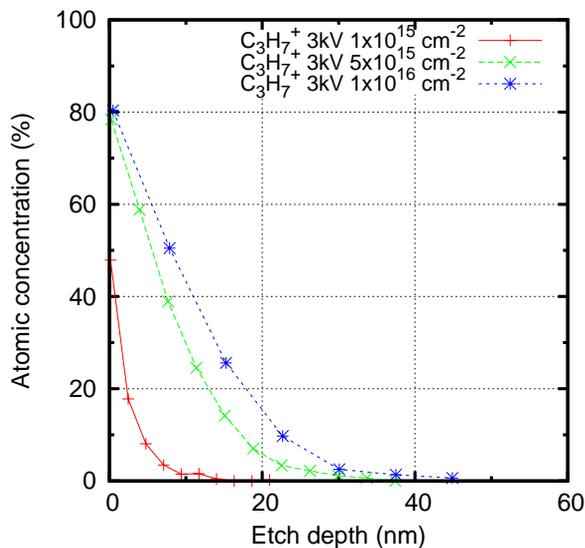


Figure 3: Depth profiles for C_3H_7^+ irradiated Si(100) substrate. Carbon doses were 1×10^{15} , 5×10^{15} , and 1×10^{16} cm^{-2} .

compounds layer. According to preliminary surface roughness measurement, which was carried out to evaluate surface level differences between masked and exposed surface from $\text{C}_6\text{H}_{13}^+$ irradiation with 1×10^{16} cm^{-2} at 1 keV, the exposed surface area was raised for 20 nm from masked level. These result implies that carbon compounds deposition, mixing and amorphization of silicon are consequently occurred at the irradiated area. The half-depths show 3.0 nm, 10.1 nm, and 19.7 nm for the carbon dose of 1×10^{15} ,

5×10^{15} , and 1×10^{16} , respectively. The half-depths of the $C_6H_{13}^+$ is deeper than that of the $C_3H_7^+$, and is well agreed with vertical impact for the decaborane. Since the alkyl ions obtained at present work was generated by using electron bombardment, it is considered that main ionized site in the molecular is terminal CH_2 . Due to the localized charge, incident alkyl ions impact vertically the Si substrate with grounded or negative potential, and caused the deeper implantation.

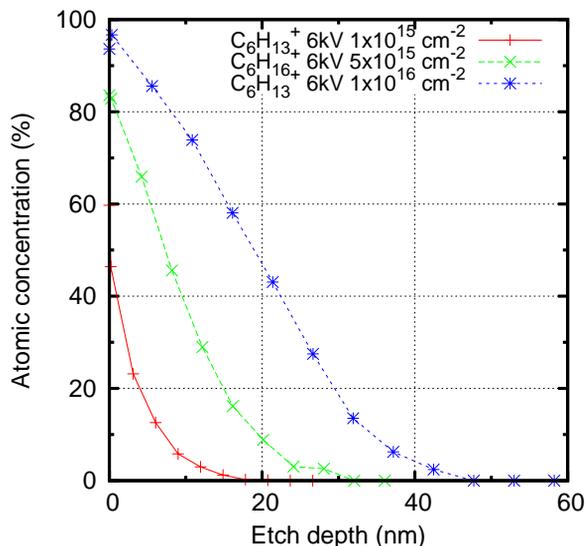


Figure 4: Depth profiles for $C_6H_{13}^+$ irradiated Si(100) substrate. Carbon doses were 1×10^{15} , 5×10^{15} , and 1×10^{16} cm^{-2} .

SUMMARY

We investigated irradiation effect of $C_3H_7^+$ and $C_6H_{13}^+$ obtained from n-octane liquid at room temperature onto silicon substrate by using the polyatomic ion source we developed. From depth profile of XPS measurements, deeper implantation depth for the $C_6H_{13}^+$ than that for the $C_3H_7^+$ was observed. This result is probably caused vertical impact effect due to the molecular form of alkyl chain and the terminal charge.

ACKNOWLEDGEMENT

A part of this work was conducted in Kyoto-Advanced Nanotechnology Network, supported by "Nanotechnology Network" of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

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