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Micro structure processing on plastics by accelerated hydrogen molecular ions

H. Hayashi [a,*], S. Hayakawa [b], H. Nishikawa [a,b]

[a] Research Organization of Advanced Engineering, Shibaura Institute of Technology, 307 Fukasaku, Minuma-ku, Saitama City 113-8656, Japan
[b] Graduate School of Science and Engineering, Shibaura Institute of Technology, Japan

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ABSTRACT

A proton has 1836 times the mass of an electron and is the lightest nucleus to be used for accelerator in material modification. We can setup accelerator with the lowest acceleration voltage. It is preferable characteristics of Proton Beam Writer (PBW) for industrial applications. On the contrary "proton" has the lowest charge among all nuclei and the potential impact to material is lowest. The object of this research is to improve productivity of the PBW for industry application focusing on hydrogen molecular ions. These ions are generated in the same ion source by ionizing hydrogen molecule. There is no specific ion source requested and it is suitable for industrial use. We demonstrated three dimensional (3D) multilevel micro structures on polyester base FPC (Flexible Printed Circuits) using proton, H_2^+ and H_3^+. The reactivity of hydrogen molecular ions is much higher than that of proton and coincident with the level of expectation. We can apply this result to make micro devices of 3D multilevel structures on FPC.

1. Introduction

We have proposed GTH (Groove and Thru-Hole) structures [1] to utilize capabilities of Proton Beam Writer (PBW) [2] as a processing tool to make microelectronic devices on the surface of flexible printed circuit (FPC). The basic idea of GTH structure is utilizing shallow and wide surface structure (Groove) that is used for the container of functional material and deep, small structure (Thru-Hole) that is used for interconnecting grooves each other to form electronic circuits [Fig. 1]. The 1MV acceleration voltage is enough for making 20 μm-depth thru-hole structure on polyimide and polyester [3] and 1 μm beam size is enough for making micrometer-size structure by direct patterning. On the contrary the processing time expected by required dose for plastics is not feasible for industrial applications. The processing time for material modification should be the major issue for industrial applications of PBW.

2. Proton and hydrogen molecules

PBW is an equipment to accelerate and focus protons to irradiate target material for modification. The capability of material modification is usually evaluated by beam intensity that is measured by current density on the target material. The simplest method to reduce modification time is obtained by increasing beam current taking care of charge up effect as the current density is the measure of both net charge transfer and number of charged particles. Hydrogen molecular ions have 2 for H_2^+ and 3 for H_3^+ protons in the structure and are expected somewhat different effect from a bare proton. As for hydrogen molecular ions (H_2^+, H_3^+) the number of protons is double for H_2^+ and triple for H_3^+. As the total charge of ion is compensated by the electron charge, the charge in nucleus of molecule is not observed directly but only q/m (q: net charge and m: mass of ion) is counted on acceleration parameter. That is q/m value of them is reduced to 1/2 and 1/3 respectively. Reduction of q/m value is equivalent to reduction of acceleration voltage for a single proton. 1MV acceleration is equivalent to 500KV acceleration for H_2^+ and equivalent to 333KV for H_3^+. As the mass portion of electron in ion is much less than proton, only the nucleus that is proton of projected ion will penetrate into target material. Electrons in the cloud of ion will be scattered at the surface of target. As the result the projected ion will act as multiple single protons. But the above mechanism is not the same for the ions of atoms such as He^+ or Li^+ ion because these ions act as single particle made of multiple number of protons (and also neutrons) and they cannot play as single proton in the target material. We summarized above situation in Tables 1–3.

* Corresponding author.
E-mail address: hhayashi@cba.att.ne.jp (H. Hayashi).

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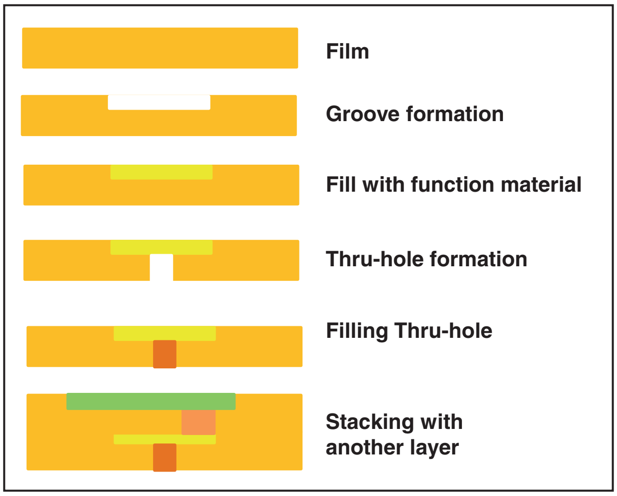

Fig. 1. Basic GTH Structure.

Table 1
Acceleration Parameter of Hydrogen Based Ions.

Hydrogen Based Ions	Characterization Parameter of Ion Acceleration Phase		
	Charge[*1]	Mass[*2]	Velocity
H^+(Proton)	1	1	1
H_2^+	1	2	$1/\sqrt{2}$
H_3^+	1	3	$1/\sqrt{3}$

[*1] Normalized by charge of proton.
[*2] Normalized by mass of proton.

Table 2
Impact Phase Parameter of Hydrogen Based Ions.

Hydrogen Based Ions	Characterization Parameter of Ion Impact Phase		
	Charge[*1]	Mass[*2]	Kinetic Energy
H^+(Proton)	1	1	1
H_2^+	2	2	1
H_3^+	3	3	1

[*1] Normalized by charge of proton.
[*2] Normalized by mass of proton.

Table 3
Energy Dissipation in Irradiated Volume.

Hydrogen Based Ions	Dissipated Kinetic Energy in Irradiated Volume	
	Range(μm)	Relative Energy Density
H^+(Proton)	20.0	1.0
H_2^+	8.0	2.5
H_3^+	3.9	5.1

3. Experimental

We proved the reactivity of hydrogen molecular ions by experiment. Procedures are ion generation, ion separation, focusing, irradiation on target material, development the irradiated material and qualification by laser microscope, SEM and FT-IR spectra.

3.1. Ion generation

All ions (Proton (H^+), H_2^+, H_3^+) are generated at the same time in PIG type ionizer introducing hydrogen molecules into the ionizer. At the first step hydrogen molecules are collided with electrons and ionized or dissociated to atoms or excited to radicals. [4,5]

$$H_2 + e \rightarrow H_2^+ + e + e$$

$$H_2 + e \rightarrow H_2^* + e$$

$$H_2 + e \rightarrow H + H^* + e$$

$$H^* + e \rightarrow H^{**} + e$$

$$H_2^* + e \rightarrow H_2^{**} + e$$

Then radicals are collided again by electrons and ionized. [6–10].

$$H_2^{**} + e \rightarrow H_2^+ + e + e$$

$$H^{**} + e \rightarrow H^+ + e + e$$

H_3^+ is generated by the collision between H_2^+ and H_2.

$$H_2^+ + H_2 \rightarrow H_3^+ + H$$

All those collisions occur as random process. Therefore all ions are mixed in an ionizer.

3.2. Extraction and acceleration of ions

Generated ions in an ionizer are extracted by extracting electrode that is biased by negative voltage and guided to a linear accelerator. To avoid mixing negative ions and electrons, a suppressor electrode, biased to negative voltage, is set before guiding all ions to the accelerator. All positive ions are mixed, therefore accelerated at the same acceleration voltage.

3.3. Ion separation

Then extracted ions are separated by means of cross electric and magnetic field. Putting x for the direction of beam line and using V_x for velocity of ion in this direction, E_y for deflection electric field in y direction and also B_z for the deflection magnetic flux, the balancing condition is calculated as follows

$$E_y = V_x B_z$$

$$V_x = \sqrt{\frac{qV}{2m}}$$

where q is total charge of ion and m is mass of ion.

Therefore we can adjust electric field using the following condition for ion separation.

$$E(H^+) : E(H_2^+) : E(H_3^+) = 1 : \frac{1}{\sqrt{2}} : \frac{1}{\sqrt{3}}$$

E (H^+): Electric field applied for Proton(H^+) at the same B_z
E (H_2^+): Electric field applied for H_2^+ at the same B_z
E (H_3^+): Electric field applied for H_3^+ at the same B_z

3.4. Focusing

Slitting and focusing mechanism must be applied to get micrometer-size ion-beam. Slitting is simply limit-beam area within the capability of demagnification of magnetic quadrupole lens. We can get 1 μm beam for both proton and molecular ions. The current of magnet lens is increased for heavy ions.

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