Experimental Study on Spray Etching Process in Micro Fabrication of Lead Frame

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The objective of this study is to obtain detailed information for the micro fabrication of lead frames by applying spray technology to wet etching process. Wet etching experiments were performed with different etching parameters such as injection pressure, distance from nozzle tip to etched substrate, nozzle pitch and etchant temperature. The characteristics of single and twin spray were measured to investigate the correlation between the spray characteristics and the etching characteristics. Drop size and velocity were measured by Phase-Doppler Anemometer (PDA). Four liquids of different viscosity were used to reveal the effects of viscosity on the spray characteristics. The results indicated that the shorter the distance from nozzle tip and the nozzle pitch, the larger etching factor became. The average etching factor had good positive correlation with average axial velocity and impact force. It was found that the etching characteristics depended strongly on the spray characteristics.

Key Words: Wet Etching, Lead Frame, Spray Characteristics, Etching Factor, Impact Force

1. Introduction

Micro fabrication techniques have received much attention in recent years because of the trend of the miniaturization and fine pitch in industrial and technological applications such as semiconductor, communication, optics, electronics components and precision engineering. In particular, the electronic industry uses photoetching techniques for micro fabrication of semiconductors, lead frames, shadow masks, ball grid array and so on. Recently, many researches have been conducted to improve the photoetching technologies on electric industries (Abate, 2000; Geissler et al., 2003; Sundaram et al., 2003).

The advantages of photoetching are as follow. There are no burrs on the edges of parts. The substrate has not been subjected to heat or physical deformation. Extremely small features can be obtained and the dimensions can be controlled precisely.

The photoetching processes consist of the preparation and cleaning of metal surfaces, photographic processing of phototooling, coating and development of photoresists, etching through apertures in the resist stencils and stripping of resist after etching. The etching process is the most important in the photoetching processes and spray etching technology has been applied to the production of lead frames. The etching characteristics would depend on the etching system, etchant, characteristics of the metal substrate and etching conditions. An aqueous solution of ferric chloride ($FeCl_3$) is commonly used as the

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etchant. When the echant is sprayed, the quality and productivity of lead frame are determined by the spray system and spray characteristics of etchant. Therefore, it is necessary to study not only the effect of dominant etching parameters on the etching characteristics such as etching rate and etching factor, but also the correlation between the spray characteristics and the etching characteristics.

Allen (1986) investigated the effect of etching time on the depth of etching, line width on lateral etching and etchant formation on etching factor. Visser et al.(2001) investigated theoretical and practical aspects of the miniaturization of lead frames by double sided asymmetrical spray etching. They concluded that a reduction of the material thickness, higher etching factor and asymmetrical etching are necessary for pitch miniaturization. Ueda et al.(1994) investigated the etching kinetics and the absolute limit of fine patterning accomplished by ferric chloride spray etching. A very large etching factor was required to obtain a small pitch.

Although previous studies provided some information on the effect of etching parameters such as etchant, etching conditions and etching method on the etching characteristics, studies on wet etching by application of spray technology are not many (Jung et al., 2004a ; Jung et al., 2004b). Because of the complexity of spray etching process and the lack of detailed information such as a correlation between spray and the etching characteristics, the spray etching mechanisms are not well understood yet.

In this study, we investigated the etching factor and etching rate with different etching parameters. The characteristics of single and twin spray were investigated by measuring droplet size and velocity. Furthermore, we also analyzed the correlation between the etching characteristics and the spray characteristics. The present study will provide important information for the micro fabrication of lead frames.

2. Experimental Set Up

The etching characteristics were obtained by photoetching processes. Ferric chloride solution was applied as the etchant. An alloy 42 sheet with 150 μm thick was used as the metallic substrate for lead frames. The test pattern comprised a group of line/space chart with the pitch width of 160 μm and the slot width in the developed photoresist stencil of 20 μm. The injection pressures (P_l) were 0.3 and 0.4 MPa. The etchant temperature was varied from 45 to 70℃. The distances from nozzle tip to the etched substrate (z) were 150, 200, 250 and 300 mm. After the etching test, the width of the etched slots at the metal surface and the etching depth were measured with three dimensional optical length measuring machine. This method is identical with that conducted by Ueda et al.(1994).

The experimental set-up for the analysis of spray characteristics consists of spray system and PDA (Phase Doppler Anemometer) system. Spray system includes a pumping system, nozzle and pressure gauges. The PDA system consists of an argon-ion laser (Laser Spectra Physics co.), the receiving optics connected to signal processor, three dimensional traverse system and PC running the SIZEware software (DANTEC Co.). The transmitting and receiving optics have the same focal length of 400 mm.

Figure 1 shows the cross-sectional configuration of nozzle used in this study. The single spray characteristics were measured in a quarter region of the whole cross-section by assuming an axisymmetric spray. Measurements of the twin spray characteristics were performed at overlap region

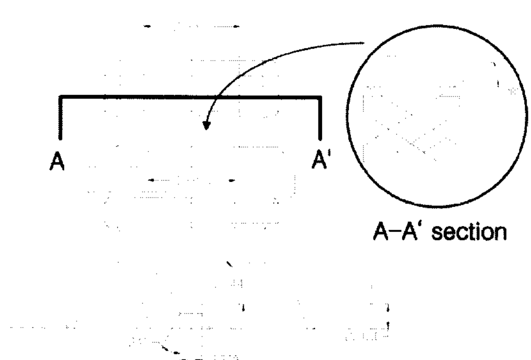


Fig. 1 Cross-sectional configuration of nozzle

of two single sprays. Two nozzles were established in the same position and the nozzle pitches (p) were set to 60, 90 and 120 mm, respectively. The spray characteristics such as the axial velocity, Sauter Mean Diameter (SMD) and impact force were analyzed for 5000 droplets collected in spray cross-section.

3. Results and Discussion

3.1 Etching characteristics under different etching conditions

Figure 2 shows the cross-section of etched substrate. When etching a metal, dissolution of the surface resulted in the formation of sidewall at the photoresist stencil edge. Once this sidewall has been formed, there is nothing to prevent the etchant against dissolving metal from under the stencil to form what is known as undercut. This phenomenon causes serious problems in the micro fabrication of lead frames. As a quantitative description of the shape of the etched recess, the etching factor can be evaluated from the definition (Allen, 1986):

$$\text{Etching Factor} = \text{Etching Depth/Undercut} = 2D/(W_2 - W_1) \quad (1)$$

where W_1 is the width of the slot in the developed photoresist stencil, W_2 is the width of the slot at the metal surface after etching and D is the depth of etch measured when etching is stopped before breakthrough of the metal sheet. Therefore, it is desirable that undercut should be minimized and etching systems giving large etching factors are required for precision of etching in metallic substrates.

Figure 3 shows the variation of the average etching factor of single etching as a function of the distance from nozzle tip for an etchant temperature of 50℃. The measured region of average etching factor is indicated with dot in Fig. 3. The average etching factor with high injection pressure was larger than that with low injection pressure. It was also found that the average etching factor increased with decreasing of the distance from nozzle tip monotonously. This phenomenon is ascribed to the increased axial momentum as closing the distance between the tip and metallic substrates.

Figure 4 shows the average etching factor of twin etching as functions of the distance from nozzle tip, injection pressure and nozzle pitch. The measured region of average etching factor in the twin etching was identical with that in

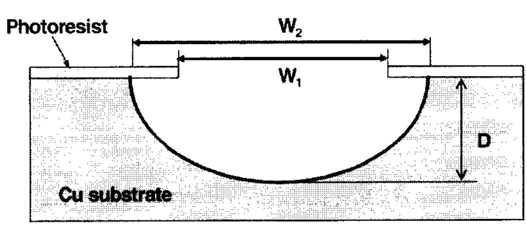


Fig. 2 Cross-section of etched substrate

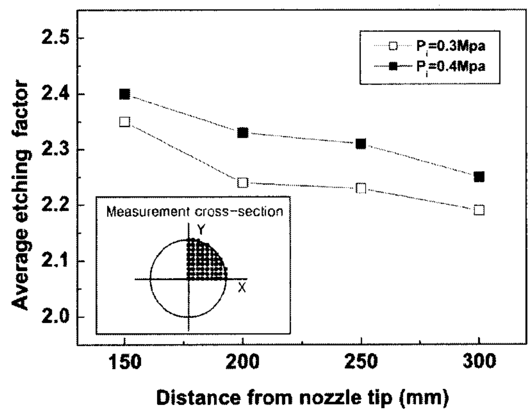


Fig. 3 Average etching factor of single etching at 50℃ as a function of distance from nozzle tip

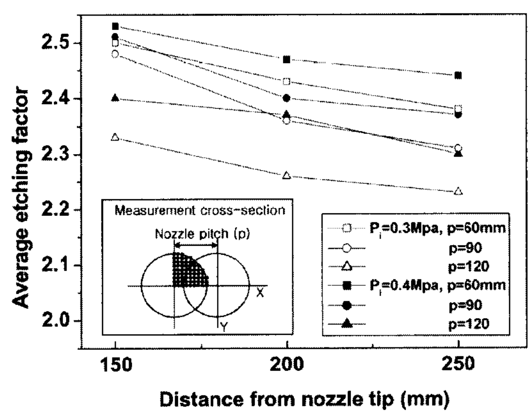


Fig. 4 Average etching factor of twin etching at 50℃ under different etching conditions

single etching as marked in the figure. The average etching factor showed larger values under the high injection pressure conditions. The relation between the average etching factor and the distance from nozzle tip in the twin etching also shows similar tendency with that in the single etching under all nozzle pitch conditions. It was found that the average etching factor increased with decreasing of the nozzle pitch. This is ascribed to the increase of overlap region as the nozzle pitch becomes smaller. Furthermore, it was found that the average etching factor with twin etching was much higher than that with single etching in Fig. 3. This is due to the reduced radial momentum resulted from the droplet collision in the overlap region of twin etching. From the above results, we can see that the etching factor depends strongly on the injection pressure, the distance from nozzle tip and the nozzle pitch. An increase of the injection pressure and a decrease of the distance from the nozzle tip could improve the etching factor. The twin etching and narrower nozzle pitch were also desirable.

Furthermore, because the spray characteristics vary with injection pressure, the distance from nozzle tip and the nozzle pitch, it was necessary to investigate the influence of spray characteristics on etching factor.

3.2 Spray characteristics under different spray conditions

Figure 5 shows the distribution of axial velocity of single spray under different spray conditions. The average axial velocity in the measured region is indicated in each figure. The axial velocity decreased with increase in radial distance from the spray center. This is caused by the fact that the axial momentum at the periphery of the spray decreases due to aerodynamic drag. The average axial velocity showed large values under higher injection pressure and shorter distance from nozzle tip conditions.

Figure 6 shows the distribution of SMD of single spray under different spray conditions. The overall SMD in the measured region is indicated in each figure. The overall SMD represents the arithmetic mean value of the SMD which is measured in a quarter of cross-section. The SMD increased with increase in radial distance from the spray center. The small SMD near spray center is ascribed to the promotion

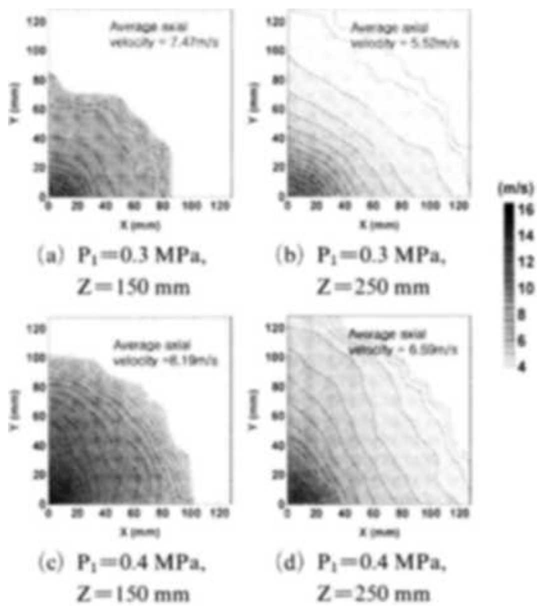


Fig. 5 Axial velocity of single spray under different spray conditions

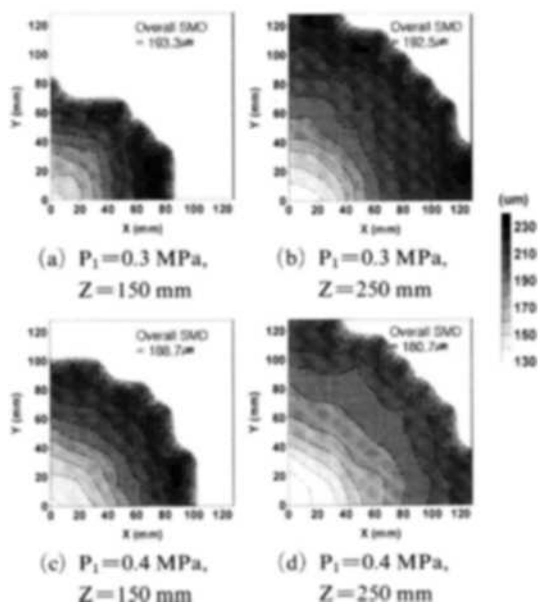


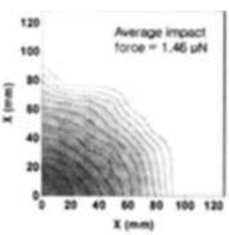
Fig. 6 SMD of single spray under different spray conditions

of atomization by the secondary droplet break-up phenomena, which is resulted from the difference between the droplet and the surrounding gas velocities. Furthermore, the overall SMD showed smaller values under higher injection pressure and longer distance from nozzle tip conditions.

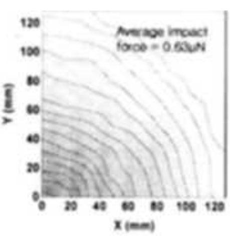
Figure 7 shows the distribution of impact force of single spray under different spray conditions. The equation used to calculate the impact force was written as :

$$Impact\ Force = \frac{\sum_{i=1}^{k} \frac{\pi}{6} d_i^3 \rho U_i}{\Delta t} \qquad (2)$$

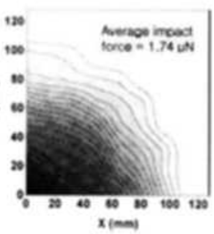
where ρ is the density of droplet, d_i is the droplet size, U_i is the axial velocity and Δt is the sampling time. Eq. (2) is defined as the momentum in flux per unit time. The impact force decreased with increase in radial distance from the spray center. The average impact force showed larger values under higher injection pressure and shorter distance from nozzle tip conditions. This phenomenon was resulted from increased axial velocity and number density with increasing of injection pressure and axial momentum.



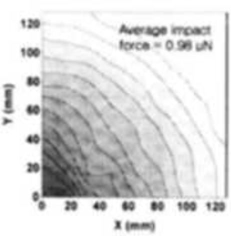
(a) P_1=0.3 MPa, Z=150 mm



(b) P_1=0.3 MPa, Z=250 mm



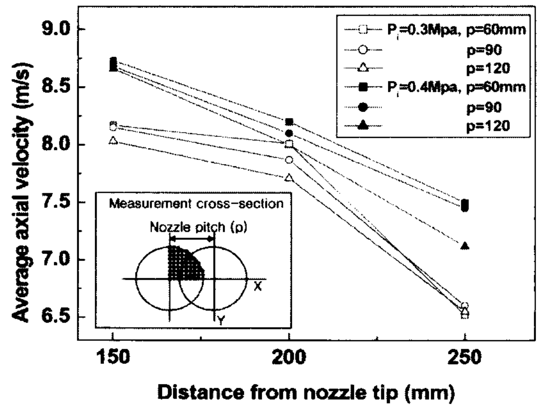
(c) P_1=0.4 MPa, Z=150 mm



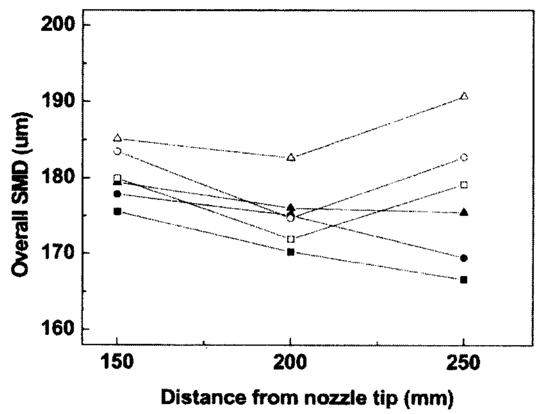
(d) P_1=0.4 MPa, Z=250 mm

Fig. 7 Impact force of single spray under different spray conditions

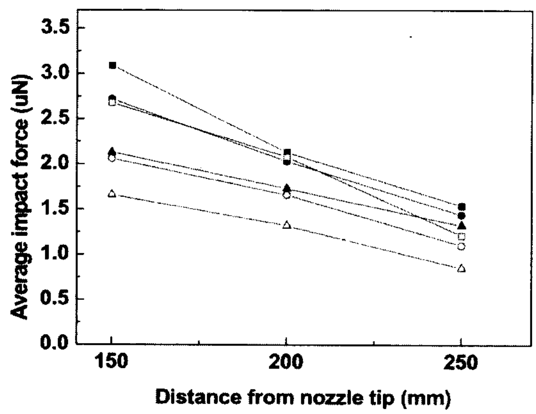
Figure 8 shows the average values of twin spray characteristics with the distance from nozzle tip under different spray conditions.



(a) Average axial velocity



(b) Overall SMD



(c) Average impact force

Fig. 8 Average values of twin spray characteristics under different spray conditions

As shown in Fig. 8(a), the average axial velocity showed larger values for higher injection pressure and shorter distance from nozzle tip. Furthermore, it was found that the average axial velocity increased with decrease in nozzle pitch. The large axial velocity was resulted from increased overlap region as reducing nozzle pitch. This implies that the sprays with larger overlap area have higher momentum in axial direction compared with those with smaller overlap area.

As shown in Fig. 8(b), the overall SMD showed smaller values at higher injection pressure and narrower nozzle pitch conditions. At the pressure of 0.3 MPa, the overall SMD showed minimum values at z=200 mm and it increased with the distance from nozzle tip. This phenomenon was different from the results of single spray. This was ascribed to the coalescence of droplets at this distance where relative axial velocity was decreased drastically.

As shown in Fig. 8(c), the average impact force showed larger values at higher injection pressure, shorter distance from nozzle tip and narrower nozzle pitch conditions.

3.3 Correlation between etching factor and spray characteristics

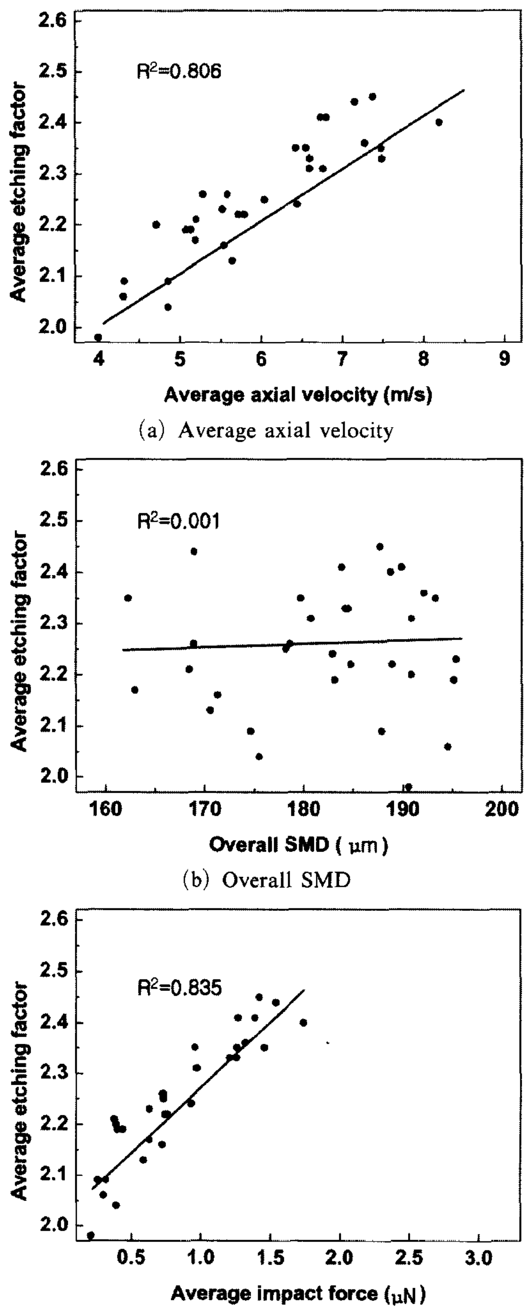
Figure 9 and 10 show the regression lines and the coefficients of determination between the average etching factor and spray characteristics for the single and twin spray, respectively. The equation can be written in a linearized form as follows (Sdiahmed, 1996):

$$Y=\alpha+\beta X \quad (3)$$

where X is independent variable (spray characteristics), Y is dependent variable (average etching factor), α is intercept and β is slope. The value of the parameters α and β were 1.641 and 0.102 in Fig. 9(a), 2.165 and 0.00046 in Fig. 9(b) and 2.032 and 0.258 in Fig. 9(c), respectively.

The coefficients of determination (R^2) were 0.806, 0.001 and 0.835, respectively, in Fig. 9. R^2 has a range of $0 \leq R^2 \leq 1$ and the regression equation is the most significant in the case of $R^2=1$. The significance of regression is statistically evaluated by testing the hypothesis $\beta=0$ using a F-test.

The value of the parameters α and β were



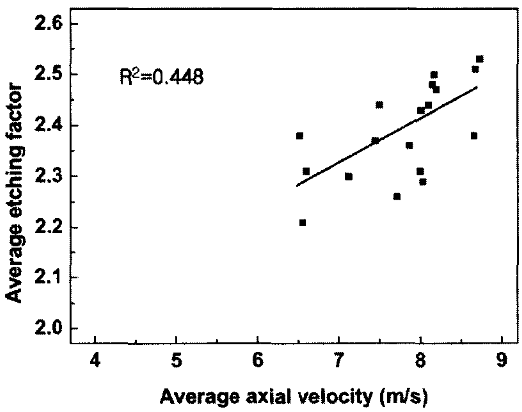
(a) Average axial velocity

(b) Overall SMD

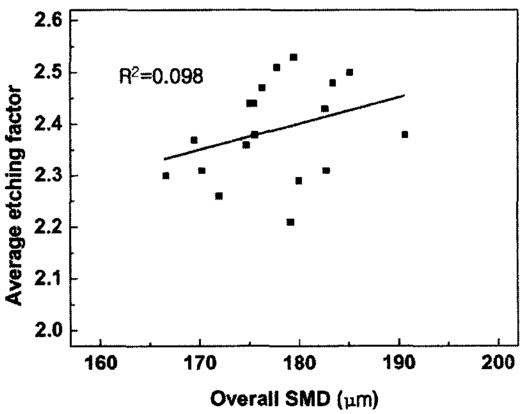
(c) Average impact force

Fig. 9 Correlation between the average etching factor and spray characteristics for the single spray

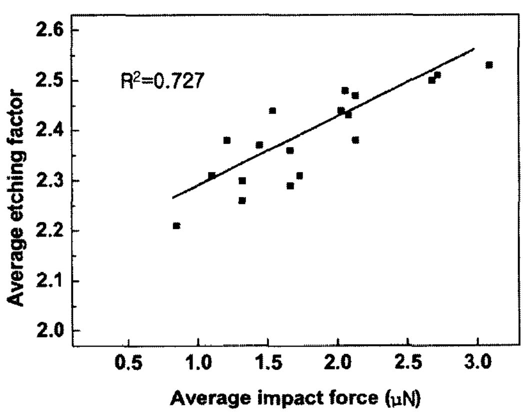
1.72 and 0.085 in Fig. 10(a), 1.53 and 0.0049 in Fig. 10(b) and 2.15 and 0.133 in Fig. 10(c), respectively. R^2 were 0.448, 0.098 and 0.727, respectively, as shown in Fig. 10.



(a) Average axial velocity



(b) Overall SMD



(c) Average impact force

Fig. 10 Correlation between the average etching factor and spray characteristics for the twin spray

The average etching factor had good positive correlation with average axial velocity and impact force, while there was little correlation between the overall SMD and the average etching factor. From the above results, it was found that the etching characteristics depended strongly on the spray characteristics.

3.4 Etching and spray characteristics with properties

Figure 11 shows the variation of the average etching factor and etching rate with the etchant temperature. The etching rate is defined as follows:

$$\text{Etching Rate} = \text{Etching Depth/Etching Time} \tag{4}$$

The etching rate means the depth of etched substrate in axial direction per unit etching time. Therefore, by increasing the etching rate, the productivity could be improved. The average etching factor and etching rate increased with increase of etchant temperature and injection pressure. By increasing etchant temperature, used etchant is rapidly replaced by fresh etchant due to the decrease of viscosity. Therefore, we intend to investigate the effect of the viscosity on the spray characteristics. The properties of four different viscosity liquids used in this study are listed in

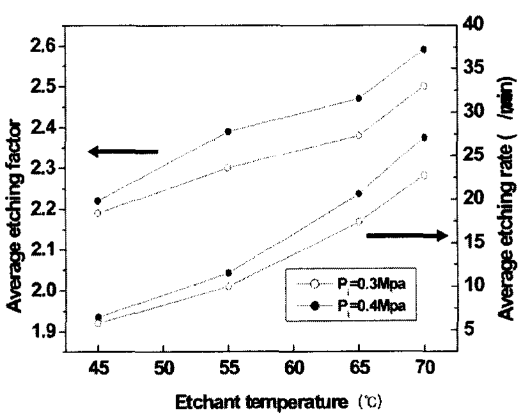


Fig. 11 Average etching factor and etching rate with etchant temperature at z=200 mm

Table 1 Properties of the four different testing liquids

Test liquids	W1	W2	W3	W4
Kinematic viscosity ($m^2/s \times 10^{-6}$)	0.85	2.51	5.1	7.52
Surface tension ($N/m \times 10^{-3}$)	70.9	72.5	73.1	73.5
Composition (wt%) water/sugar starch/salt	100/0 0/0	73/18 9/0	59/30 3/8	50/30 5/15

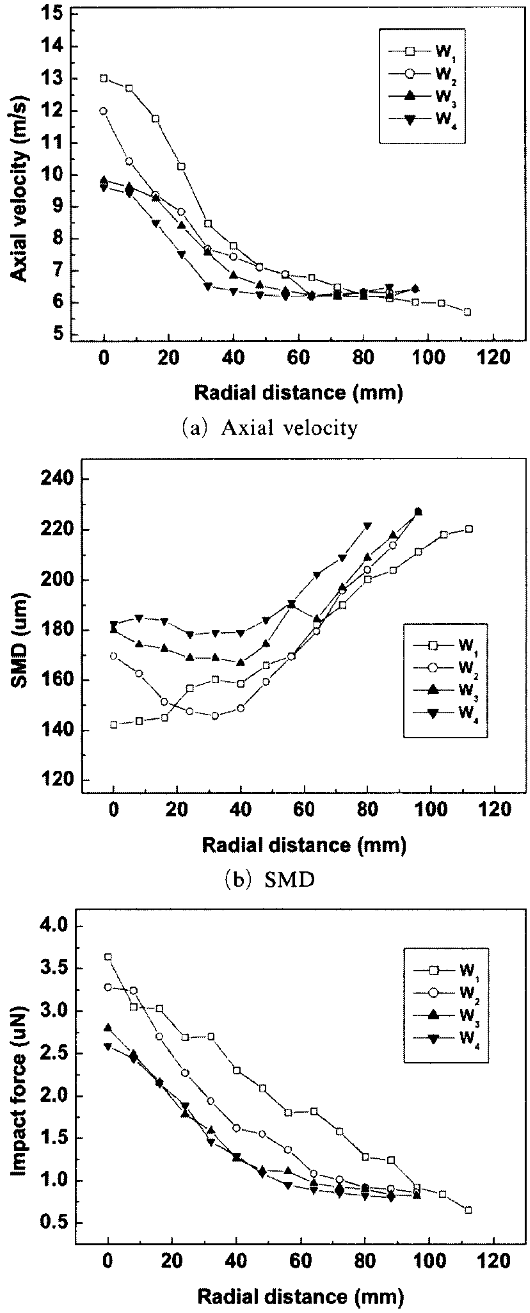
Table 1. The test liquids are pure water and water solutions blended with different quantities of additives (sugar, starch and salt).

Figure 12 shows the variation of the spray characteristics with radial distance and liquid viscosity at z=200 mm and P_l=0.4 MPa. As shown in Fig. 12(a), the axial velocity tended to decrease monotonously with increase of radial distance and kinematic viscosity.

In Fig. 12(b), the higher kinematic viscosity, the larger droplet size was. This result agreed with that of the previous studies (Chang et al., 1997; Choi et al., 2002).

In Fig. 12(c), the impact force tended to decrease with increase of radial distance and kinematic viscosity. It was also observed that the trends of spray characteristics from other viscosities under the same spray conditions showed similar results with radial distance. These results demonstrated that water was enough to investigate the influence of spray characteristics on etching characteristics as test fluids.

As shown in Figs. 11 and 12, the liquid spray with lower viscosity has larger average etching factor and etching rate, higher axial velocity and impact force and smaller SMD than the higher viscosity liquid spray.



(a) Axial velocity

(b) SMD

(c) Impact force

Fig. 12 Spray characteristics with radial distance and liquid viscosity at z=200 mm and P_l=0.4 MPa

4. Conclusions

Etching characteristics and spray characteristics were investigated for various parameters of etching and spray such as injection pressure, distance from nozzle tip, nozzle pitch and the property of liquid. The correlations between etching characteristics and spray characteristics were analyzed. The results are summarized as follows:

(1) The shorter the distance from nozzle tip and nozzle pitch, the larger average etching factor became. The average etching factor showed larger values at the higher injection pressure.

(2) The average axial velocity and impact force increased with decreasing of the distance from nozzle tip and nozzle pitch.

(3) The average etching factor had good positive correlation with average axial velocity and impact force. The coefficients of determination (R^2) between the average etching factor and impact force for the single and twin spray were 0.835 and 0.727, respectively.

(4) The average etching factor and etching rate increased with increasing of etchant temperature. The higher axial velocity and impact force are observed for lower viscosity liquid spray.

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