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# Distribution of injecting flow in a multi-hole nozzle for gas injection by PIV measurements

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## Abstract

The purpose of this study is to investigate the characteristics of injection formed from multi-hole nozzles through PIV measurement and to analyze the flow of distribution. Multi-hole nozzles have applied to various fields including semiconductor equipment. These nozzles need to analyze and control fluid properties because they form the injection flow of each hole according to the operating conditions of a single U-shaped tube. Supplying a 30 lpm flow rate to a linear perforated nozzle with 59 holes with a diameter of 1 mm visualized and analyzed the injection flow for each hole. The injecting flow of each hole formed a jet flow and the velocity field distribution appeared as a Gaussian curve. The function was obtained by curve fitting the measured velocity profiles, and the flow rate in each hole was calculated at any plane. Due to the pressure loss in turn, the flow rate decreased linearly as the length of the tube proceeded and toward the end. Experimental calculation and theoretical flow rates of axially symmetric jet flows were compared with less than 15% error in total flow rate.

## 1 Introduction

Multi-hole nozzles with multiple injection ports are used in various fields. Sprinklers supplying water to crops, disinfection nozzles for sewage treatment, and water sprayers for removing fine dust on roads and air are also multi-hole nozzle type. Controlling the injection flow for each hole relative to simple injection nozzles is important for special precision nozzles such as multi-hole nozzles or showerheads used in semiconductor deposition processes (Sansonnens et al. (2000)). In particular, a nozzle system in which a multi-hole is formed in one main tube surface has an advantage in that the processing cost is reduced and the installation area is narrow.

However, it is difficult to maintain injection uniformity according to operating conditions. Therefore, it is necessary to perform basic analysis and design of nozzle injection flow characteristics for the purpose of maintaining uniformity. For example, nozzles and showerheads used in deposition processes of semiconductor fabrication apply multi-nozzles to process multiple silicon wafers simultaneously. In this case, uniformity of nozzle material injecting is a very important issue in order to keep the process quality of each wafer constant (Elers et al. (2006)).

On the other hand, PIV technology that sprays the particles in the flow field and then obtains the flow velocity through particle tracing has made it possible to analyze the flow with high reliability under various flow conditions (Sheng et al. (2000), Zhang et al. (1997)) due to the development of optical equipment and computing device. This means that it is possible to analyze high-speed or turbulent flow, which is difficult to numerically analyze, through visualization.

Therefore, in this study, we analyze the injection flow in each nozzle when supplying a constant flow rate of air in order to design a multi-hole nozzle composed of several holes in one tube. For this purpose, the injection flow rate of each hole is calculated by the velocity profile measured in the experiment, and the flow characteristics are analyzed according to the position of each hole.

## 2 Experimental method

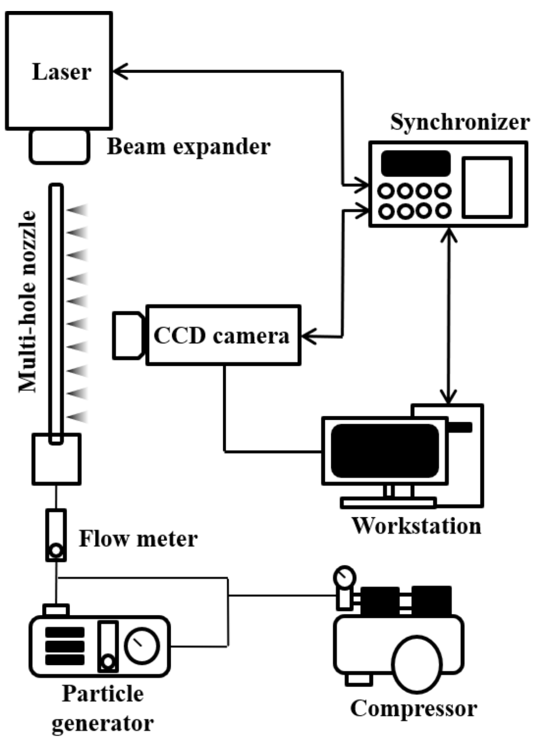



Figure 1: Schematic of the PIV

Table 1 Experimental conditions

| | |
|---|---|
| Dimension | 2D PIV |
| Laser | 532nm/100mJ/6ns |
| Beam sheet thickness | 2 mm |
| Camera definition | 2048 × 2048pixels |
| Pulse separation time | 10 μs |
| Number of capture images | 300 |
| Material of particles | Olive oil |
| Size of particles | 1~10 μm |
| Density of particles | 0.918 g/cm$^3$ |
| Flow rate | 30 lpm |

Figure 1 shows the configuration of the experimental system used in this study. The information about each device and experimental conditions are shown in table 1. The working fluid is a mixed gas of oil particles and air. The compressed air is used to adjust the concentration of oil particles in the mixed gas, and then the flow rate is constantly controlled by the flow meter.

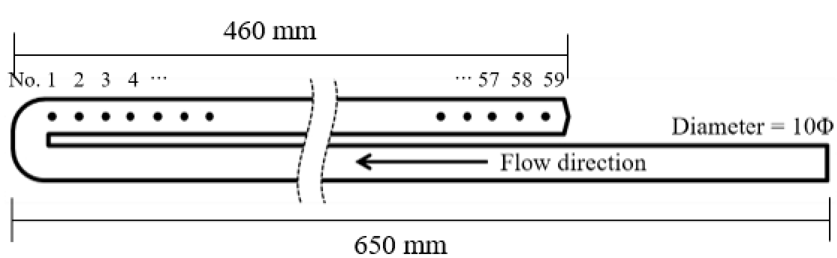
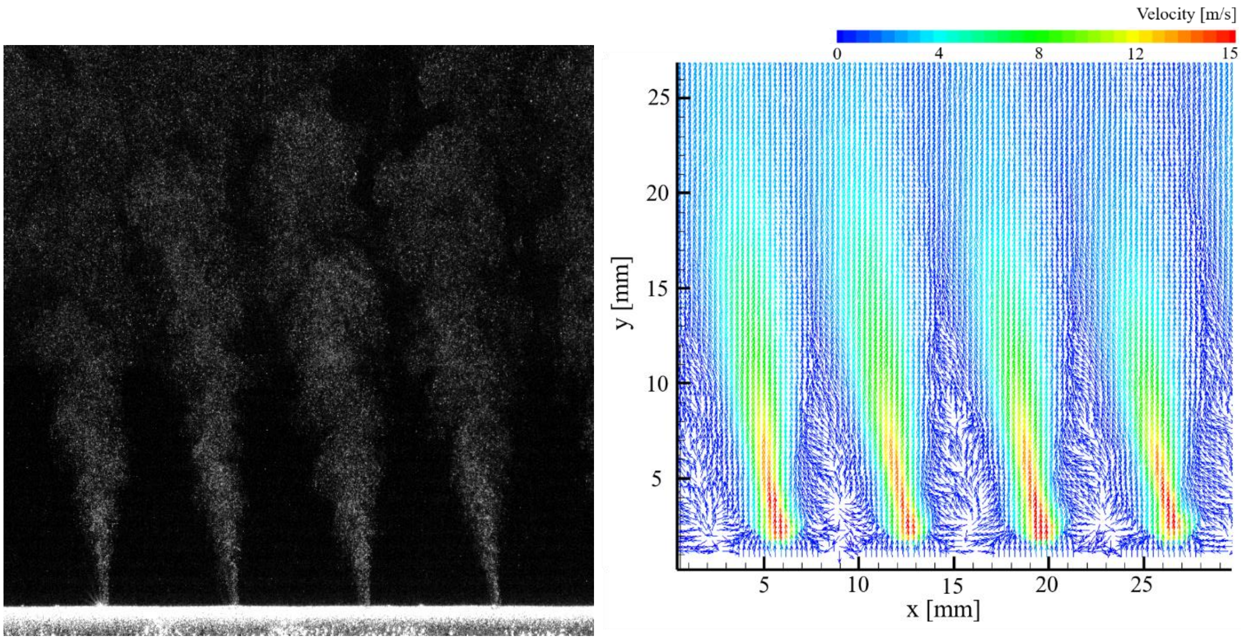



Figure 2: Schematic of the multi hole nozzle

Figure 2 shows the schematic of the multi-hole nozzle used in the experiment. It is a U-shaped single tube (10 mm in diameter) with 59 holes (1 mm in diameter) while maintaining 7 mm spacing in linear parts. There is no special device for individually controlling the flow rate by each hole, and the flow characteristics of each hole is determined by the supplied flow rate.

# 3 Results and Discussion




(a) (b)

Figure 3: PIV instantaneous flow field; (a) injecting flow of multi-hole nozzle, (b) vector field with velocity contour

Figure 3(a) is a photograph of the flow in which a mixed gas of air and oil particles is injecting from a plurality of holes. The injection flow of each hole had the shape of jet flow, diffused as it gets far from the surface of the nozzle. Jet flow was a form of turbulent flow, which was very difficult to calculate or predict due to numerical analysis because the flow changed greatly even with a small difference shape of hole. Therefore, in this study, the injecting flow velocity by the multi-hole nozzle was measured with PIV, and the actual flow and the quantitative flow rate were analyzed. Figure 3(b) is the vector field with velocity contour converted from Figure 3(a). The initial core flow was maintained up about 7 mm from the spray surface and the fluid between each hole flowed into the jet flow by a pressure gradient and a viscous flow.

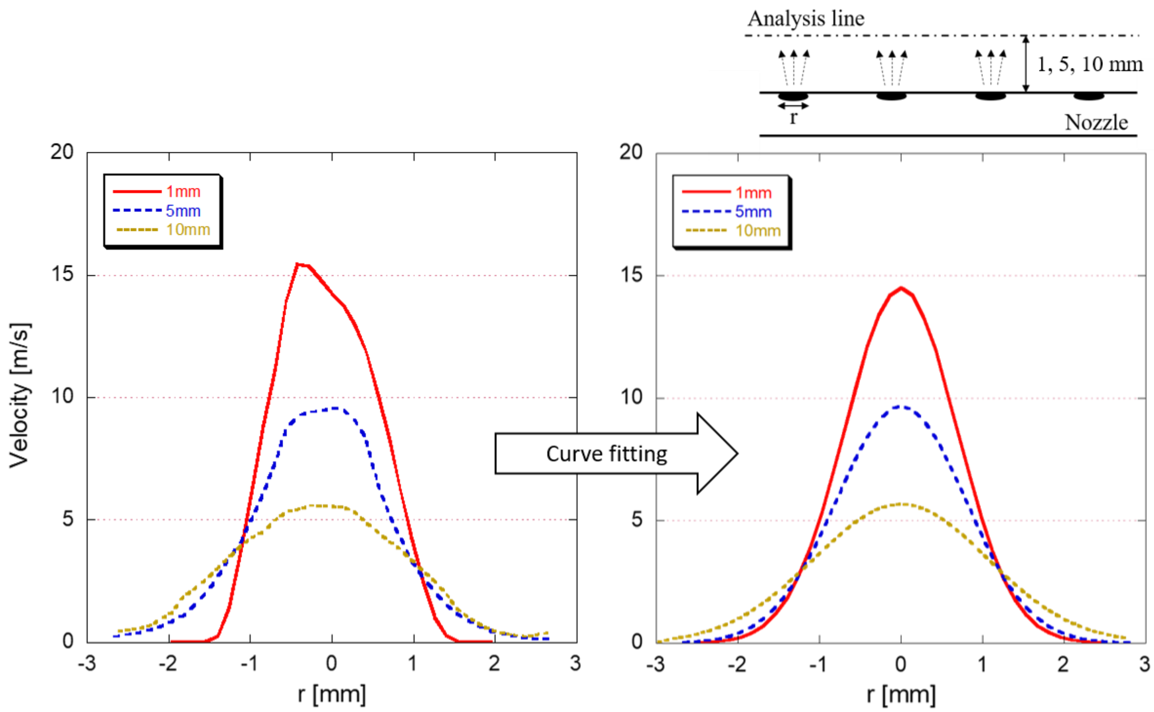



Figure 4: Velocity profiles according to distance from hole(left), and fitted curve of velocity

The left side of figure 4 showed the velocity profiles obtained by setting the analysis line at 1mm, 5mm, and 10mm from the exit of hole. The velocity profile was a Gaussian curve in which the symmetry velocity decreased from the center axis of the hole to the maximum velocity and decreased from the center axis to the left and right. Therefore, the flow velocity according to the radius can be expressed by the Gaussian function as shown in Eq. (1)

$$\mathrm{v(r)} = \mathrm{a} \cdot e^{-(\frac{r-b}{c})^2} \tag{1}$$

The coefficients a, b, and c for determining the curvature are obtained using the least-squares curve fit method, and the graph of the function can be drawn as shown on the right side of figure 4. The flow velocity function in each hole is obtained. The flow velocity can be calculated by integrating $v(r)$ as in Eq. (2)

$$\mathrm{Q} = \int_0^{\infty} v(r) 2\pi r dr \tag{2}$$

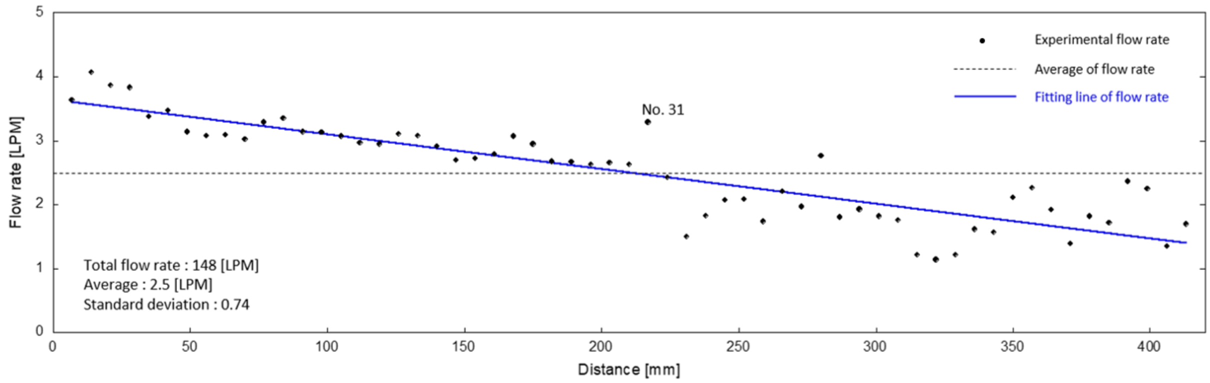



Figure 5: Flow rate calculated at 10mm distance from the exit of each hole

Figure 5 is a graph showing the flow rate of each hole calculated at the 10mm (analysis line). The flow rate depending on the position tended to gradually decrease toward the last nozzle. This flow distribution is analyzed as a result of the pressure loss accompanied by sequential injection flow from the main tube to each hole. Also, after the 31st hole, the change in flow rate was a serious consequence that the pressure at the end of the tube accumulates and becomes unstable. When the flow rate of 30 lpm was supplied to the multi-hole nozzle, the sum of each hole flow rate at a distance of 10mm was calculated as 148 lpm. The increase in the total flow rate along the measured distance is due to the influx of ambient fluid. On the other hand, it is necessary to validate the quantitative value of the increased flow rate through theory.

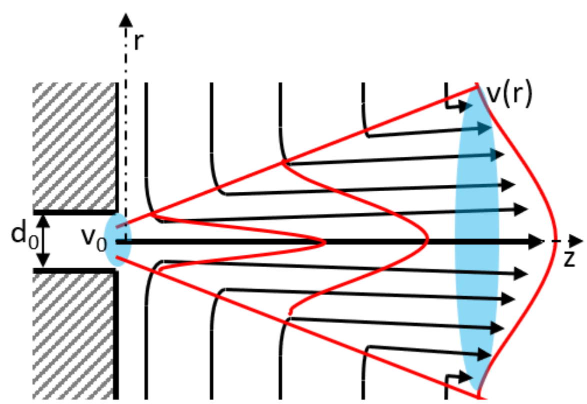



Figure 6 Streamline pattern and velocity profiles for a circular jet

Figure 6 shows the characteristics of the axially symmetric circular jet (Schlichting (1979)). The characteristics of this jet flow are consistent with the injecting flow of each hole in this study. The theoretical flow rate according to the distance $z$ from the injecting hole of the axially symmetric circular jet can be calculated by Eq. (3)

$$\mathrm{Q} = \int_0^\infty v(r) 2\pi r dr = 8\pi\varepsilon z \tag{3}$$

where ε is turbulent eddy viscosity, obtained from the following equation.

$$\varepsilon = 0.013 v_0 d_0 \tag{4}$$

When the diameter of hole is $d_0$ and the initial velocity of injecting flow is $v_0$, the flow rate $Q_0$ is approximated to Eq. (5)

$$Q_0 = (\pi \frac{d_0^2}{4}) v_0 \tag{5}$$

Thus, the supplied flow rate and the increased flow rate can be compared by Eq. (6)

$$\frac{Q}{Q_0} = \frac{8\pi\varepsilon z}{\pi\frac{d_0^2}{4} v_0} = \frac{0.42z}{d_0} \tag{6}$$

Assuming that the injecting flow rate of each hole is uniform, the total flow rate at a distance of 10mm from the hole is calculated as 126 lpm. This is less than the flow rate of 148 lpm which is calculated by velocity profiles curve fitting. This difference was analyzed due to the equation calculates the flow rate increase for a single jet. Therefore, it was considered that the flow rate is further increased by the neighboring holes in the multi-hole nozzle.

# 4 Conclusions

In this study, the injecting flow characteristics and flow rate of a multi-hole nozzle were measured using PIV. Since the injection flow of each hole had the characteristic of jet flow, the flow rate can be calculated by curve fitting with Gaussian function. The injecting flow rate tended to decrease as the pressure loss increases toward the nozzle end, and severe change due to pressure accumulated at the end of the main tube. The total flow rate calculated at a distance of 10mm from the hole was more than the initial supplied flow rate. It was compared with the theoretical flow rate of the axially symmetric jet. Effect of the injecting flow of the neighboring holes, the total injection flow rate was more than the flow rate calculated using the axially symmetric jet flow theory.

# Acknowledgements

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