Technology for Supporting Cutting-Edge Processes
CRITERION D500 Series

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In recent years, along with the trend for scaling-down of semiconductor processes and increasing wafer diameters, there is a demand for higher-performance gas supply systems. In order to meet such a demand, we developed a pressure-based mass flow module, CRITERION D500. The D500 employs a differential pressure flow measurement system for a flow-measuring unit in a linear flow viscous flow range. Therefore, a highly accurate flow measurement and flow control over a wide flow range for process gas can be achieved. The D500 is equipped with G-LIFE function to diagnose process gas flow changes thereby enabling diagnosis during the process. Accordingly, defective semiconductor wafers due to failure of the mass flow control module can be minimized by using the D500, which is a mass flow module with a self-diagnosis function essential for the next-generation process.

Introduction

In cutting-edge semiconductor processes, along with the evolution of scaling-down of processes at a nano-level, it is essential to further increase device productivity. Against such a backdrop, there is a demand for mass flow modules used in semiconductor processes to have functions, such as an improvement of process gas flow accuracy and instrument errors, flow control less susceptible to pressure fluctuations, and early fault detection before failure occurs. In this paper, we introduce the CRITERION D500 series, a mass flow module developed to meet such a demand.

Figure 1 External view of D500

Overview of CRITERION D500

Figure 1 shows the external view of the CRITERION D500. The external dimensions comply with the same international standards, SEMI F82, of semiconductor manufacturing systems as existing Mass Flow Controllers (hereafter "MFCs"). Figure 2 shows the CRITERION D500 structure. The components consist of the pressure sensor for monitoring the supply pressure of in gas line, a gas filter for protecting the body from particles, control valve, two absolute pressure sensors, a laminar flow element (resistive element) (hereafter "Restrictor"), and a temperature sensor. A piezo actuator with fast response and low power consumption is used to actuate the control valve. The flow rate is measured by using upstream and downstream pressures of the Restrictor and gas temperature, which will be converted by the internal arithmetic circuit to an accurate flow rate. The converted flow rate is compared with the given design flow rate to calculate the amount of actuation of the control valve to provide the required flow rate control.

Approach for Guaranteed Accuracy of Process Gas and Reduction of Instrument Errors

The characteristic data for gas used in semiconductor

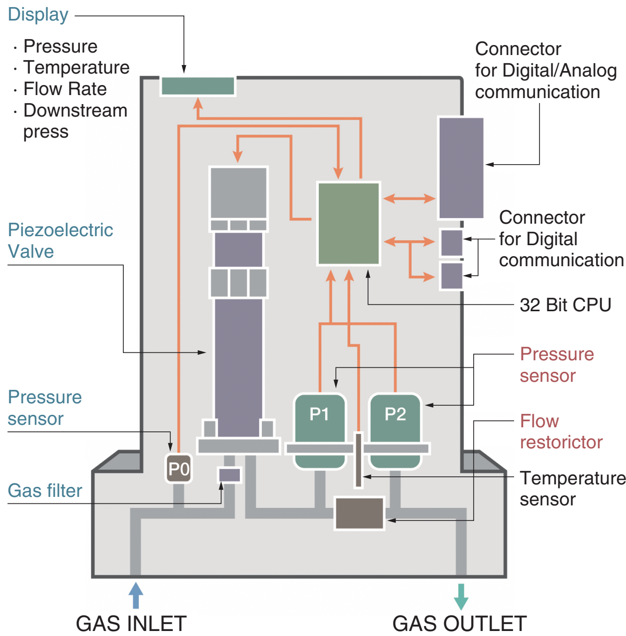

Figure 2 D500 Structure

manufacturing processes is obtained from the ROR System[*1] by using a real process gas. The measurement principle of the ROR System involves the application of the equation of state for an ideal gas in which the flow rate is measured by passing a controlled gas through an evacuated vacuum chamber and converting the rate of rise of the internal pressure of the chamber.

$$Q \propto (\Delta P/\Delta t) \cdot V/T \quad \cdots\cdots (1)$$

Q: Flow rate, P: Rise of pressure, Δt: Time of rise
V: Chamber volume, T: Temperature

Figure 3 shows the flow characteristics of the Restrictor. This is a 3D mapping of the flow characteristic data for the process gas, which are obtained by the above approach, to pressure and flow rate. These mapped data for the process gas are incorporated in the CRITERION D500 body, thereby achieving a highly accurate flow measurement and guaranteeing the flow accuracy of ±1% of the process gas to the design value. Figure 4 shows the structure of the Restrictor. The Restrictor comprises a laminate structure of sheets with slits formed. The flow range of the CRITERION D500 can be set by increasing or decreasing the number of slits. The Restrictor is structured to allow the gas enter from the center and exit radially. Particularly in the CRITERION D500, the flow path of the Restrictor is curved to obtain the longest flow path compared to existing models. Accordingly, the laminar flow characteristics are improved and instrument errors of the flow characteristics of the process gas are reduced.

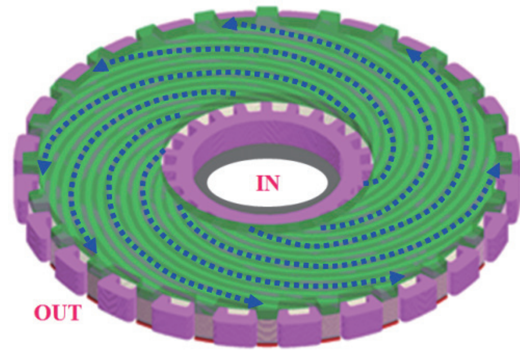

Figure 4 Restrictor

*1: ROR System: ROR stands for Rate of Rise.
An approach to measure mass flow rate by measuring the rate of rise of the pressure in the reference volume

Wide Range Controllability

Figure 5 shows the relationship between the upstream pressure of the Restrictor and the flow rate. The gradient of differential pressure characteristics of the CRITERION D500 in a low flow range is large due to the nonlinear low-pressure characteristics. Thus, flow changes in a low flow range can be detected as a large differential pressure, thereby enabling flow measurement with high resolution even in a low-set flow range. This provides a wide range control to a minimum level of 0.2% to full scale. Since the

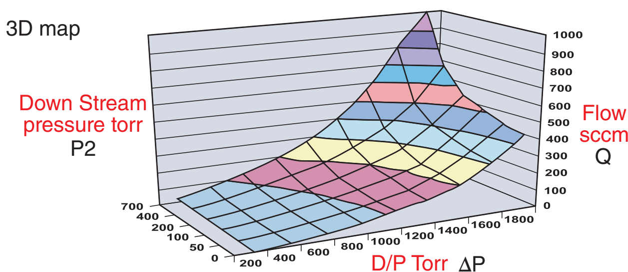

Figure 3 Flow characteristics of the restrictor

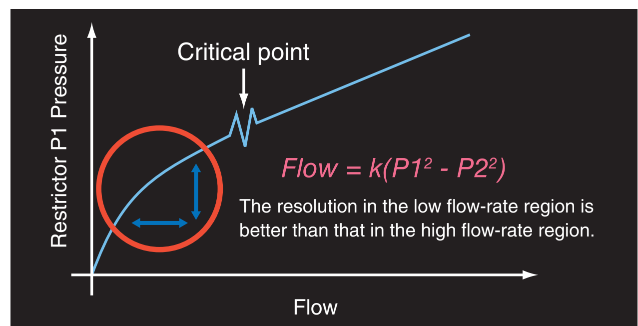

Figure 5 Nonlinear characteristics diagram

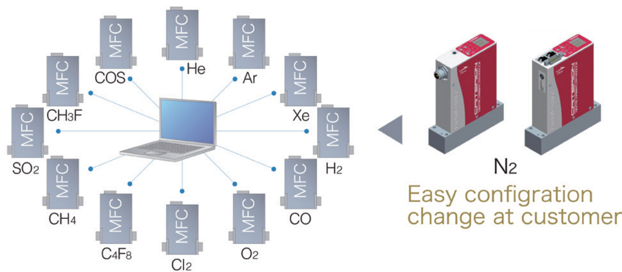

Figure 6 Multi-gas, Multi-range function

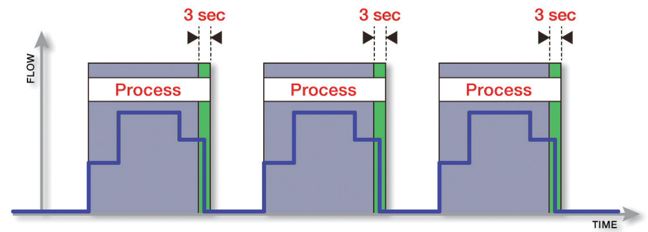

Figure 8 G-LIFE example

flow range previously covered by multiple units can be dealt with by one unit of the CRITERION D500, it is possible to reduce the number of the line components associated with a MFC installed in the system.

Multi-gas/Multi-range Compatibility

A change to the gas specifications by the customer (hereafter "Multi-gas/Multi-range Function") cannot be achieved with existing models, because the calibration gas varies depending on the gas specifications, but since the laminar flow characteristics of the Restrictor are improved with the CRITERION D500 as described above, a single calibration gas can be used uniformly and the multi-gas/multi-range compatibility is provided. Figure 6 illustrates the Multi-gas/Multi-range Function. The gas type and flow range for the CRITERION D500 can be changed by the customer, as required, using a personal computer and the dedicated software. Therefore, the CRITERION D500 enables to reduce a significant amount of inventory compared to existing MFCs, which need to maintain their inventory by specifications.

Inclusion of Self-diagnosis Function (G-LIFE[*2])

Figure 7 provides the diagnosis method for G-LIFE. G-LIFE calculates the internal volume, using the equation

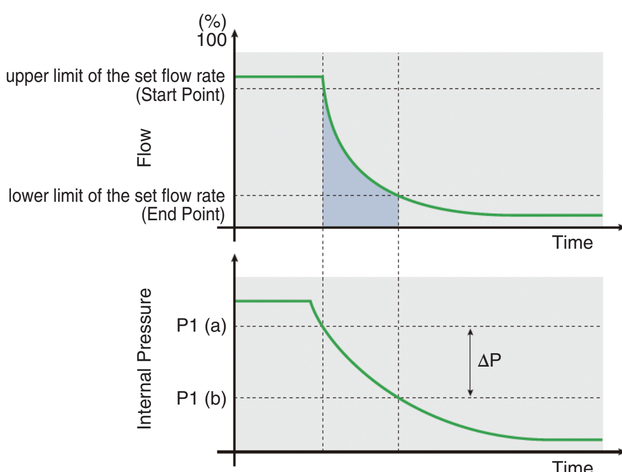

Figure 7 Diagnosis method for G-LIFE

of state for a gas, from the integral value at the fall time of the flow output from the flow control condition to the flow rate set to 0%. By comparing the internal volume calculated and the initial internal volume previously obtained, a highly reliable and repeatable diagnostic test can be performed within a few seconds. Figure 8 shows an example of G-LIFE. The CRITERION D500 needs no additional external reference instrument and can perform a diagnostic test during the inline process. A diagnosis of changes from the initial state can be performed by implementing G-LIFE using the fall time of the flow rate during the process, thereby enabling validation of the process and prediction of troubles, leading to reduction in defective wafers and system downtime.

*2: G-LIFE: Gas Law check of Integrated Flow-restrictor Equation

Pressure Fluctuation Characteristics

Existing general thermal MFCs are susceptible to upstream pressure fluctuations. Therefore, in an existing gas supply system, the effect of the pressure fluctuations caused by other gas lines is reduced by using a pressure regulator. However, there is a demand for a more compact, small, and light design of gas supply systems for cost reduction. The CRITERION D500 has the flow-measuring unit installed on the downstream side of the control valve so that it is less affected by the effect of supply pressure fluctuations and can achieve stable flow control by introducing a newly developed control algorithm for reducing the fluctuations. Figure 9 shows

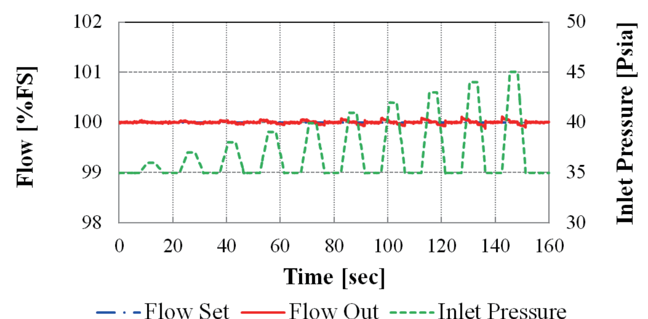

Figure 9 The output of D500 to pressure fluctuation

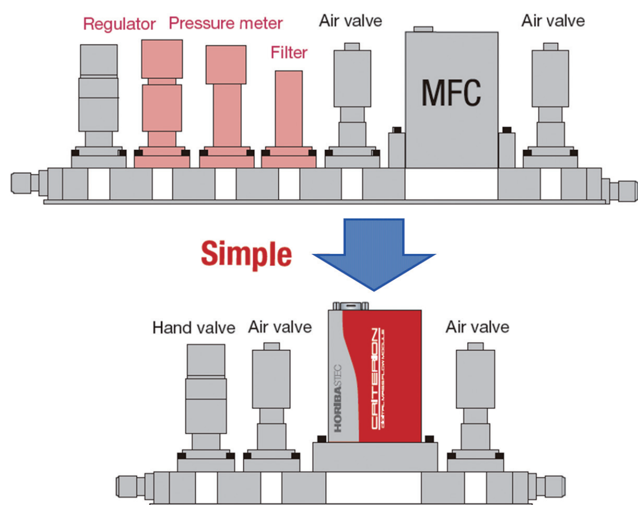

Figure 10 Piping structure

the behavior of the flow output due to pressure fluctuations applied to the CRITERION D500. Even with pressure fluctuations of 10 Psi, the effect of the fluctuations is ±1% or less to the design flow value. Thus, the CRITERION D500 is applicable to a gas supply system without a pressure regulator. In addition to the above improvements to reduce pressure fluctuations, the CRITERION D500 is equipped with a pressure sensor that continually monitors the gas supply pressure so that it can be used without a gas line pressure regulator and pressure meter as shown in Figure 10 and contribute to a simple structure of a gas supply system and cost reduction.

LCD Multi-display

Figure 11 shows a LCD multi-display. A large LCD multi-display is mounted on the upper part of the CRITERION D500 to display information. Figure 12 shows the information that can be provided by the display. The displayed information will be switched each time the Display button is pressed. This function makes it fast and easy to check of the operating condition and operating environment of the body.

Figure 11 LCD Multi-display

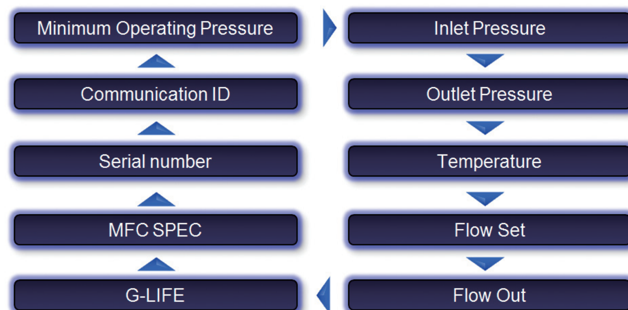

Figure 12 Display information

Conclusion

The CRITERION D500 is a model that accommodates miniaturizing wafers and increasing wafer diameters and contributes to improving the productivity of gas supply systems. The D500 is also designed environment friendly to achieve reduction in greenhouse gas emissions in the manufacturing process, thereby reducing the environmental load. The CRITERION D500 is optimum for the flow control of process gas in the next-generation semiconductor production, which we believe can offer greater value in flow control than ever, and will continue to contribute to the development of the semiconductor industry.

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