Review

Semiconductor Device Progress and Latest Mass Flow Controller Trends

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Introduction

The Japanese semiconductor device industry has been losing momentum, and companies in the industry are making efforts to rebuild their profit structures. However, if we look at the industry worldwide, it still has momentum. Production output of semiconductors increased by approximately 60% during the 12 years between 200 and 2012, oligopolies are forming, and 3 major companies make up about 60% of total investment. Technologies for smaller semiconductor devices are emerging, and immersion double patterning exposure, EUV exposure, and DSA technologies are being researched for manufacturing semiconductor devices at the 10-nm level. Also, a 450-mm wafer consortium has been formed, mostly with members from Europe and the US, which is starting to investigate the practical use of large-diameter wafers. As technologies are refined and the industry considers moving toward large-diameter wafers, the requirements for fluids and gases used during film depositing, and etching, etc. are becoming stricter. This paper will discuss the latest mass flow controller (MFC) trends that go along with the industry's move toward smaller semiconductor devices and large-diameter wafers.

Communication Specification Background

Up until the 1990s, MFCs and semiconductor manufacturing equipment were based on analog signals and DC voltage, which provided control signals and managed flow rate output. For chemical vapor deposition (CVD) and etching tools, at least 10 MFCs were installed per tool. There were several problems with this type of setup. It was cumbersome and complicated to deal with connecting cables, noise was generated by things like high-frequency effects, and control had a tendency to become unstable. Based on this background, MFC control was moved to digital, by using serial communication such as RS-485 for the objective of simplifying cables and reducing connection noise. After that, MFC control was standardized by Semiconductor Equipment and Materials International (SEMI) as DeviceNet communication, for the objectives of increasing speed, stabilizing communication, and creating uniform communication specifications, which resulted in an acceleration of digital MFC semiconductor manufacturing equipment. EtherCAT communication is being investigated to increase the speed further for 450-mm devices, and EtherCAT is being investigated for various types of devices, including MFCs.

MFC has diverse Functions and High Performance

Along with the move to digital communication, MFC internal signal processing has also been digitalized. Changing MFC internal signal processing to digital has added the following new functions as well as advanced performance.

Approximating the polynomial curve of the calibration curve

With analog processing, flow rate signals only use the linear portions of flow rate sensor output, and a primary formula is used for approximation. For this reason, sensitivity adjustments based on the gas type were made only using the primary formula trends. With digital processing, polynomial curve approximation is used, and sensitivity adjustments based on the gas type are done using various coefficients, which makes it possible to get higher-accuracy. It is now possible to increase the accuracy of the flow measurement with an adjustment gas from ±1% FS (full scale) of the analog MFC to ±1% SP (set point). Also, the linear portion of flow rate sensor output is used, so it is now possible to increase the flow rate sensor dynamic range to twice of what it was previously. As a result, it is now compatible with multiple ranges and multiple gases, where the flow rate range can be set as desired across the full scale of 25-100% of the base model, and configuration software can be used to change the gas type. With the older analog MFCs, each instrument has been adjusted in a tailor-made mannder by the gas type and full-scale flow rate, so all production was based on the order specifications. As more and more MFCs were used, customers' inventory of spare parts increased, which caused problems. Making digital MFCs compatible with multiple ranges and multiple gases makes it possible for customers to change specifications on their side, and enables device and equipment manufacturers to significantly reduce inventory.

Digital corrections

MFCs make temperature corrections and various other types of corrections to reduce the effects caused by external disturbances. With regard to these corrections, now digital polynomial correction was possible replacing analog linearity corrections, which minimized correction errors.

Digital PID adjustments

Digital MFCs use digital PID adjustments to optimize the PID constant and reduce variances through automation. Also, by continuously changing the PID constant based on the flow rate range and gas type, digital MFCs have achieved high-speed responses in all flow rate ranges.

New System for Measuring Flow Rate

Thermal MFCs

Figure 1 shows the structure of a thermal MFC. It has a thermal mass flow rate sensor, laminar flow bypass, control valve, and control circuit. Gas is separated into the sensor and bypass, and the flow rate for part of

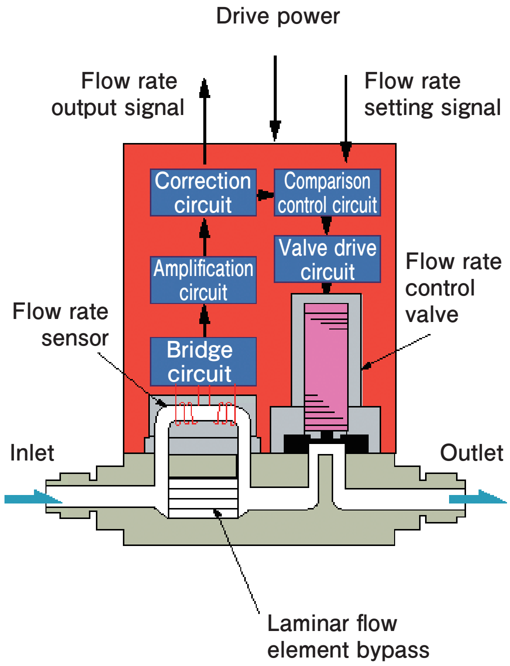


Figure 1 Thermal MFC structure

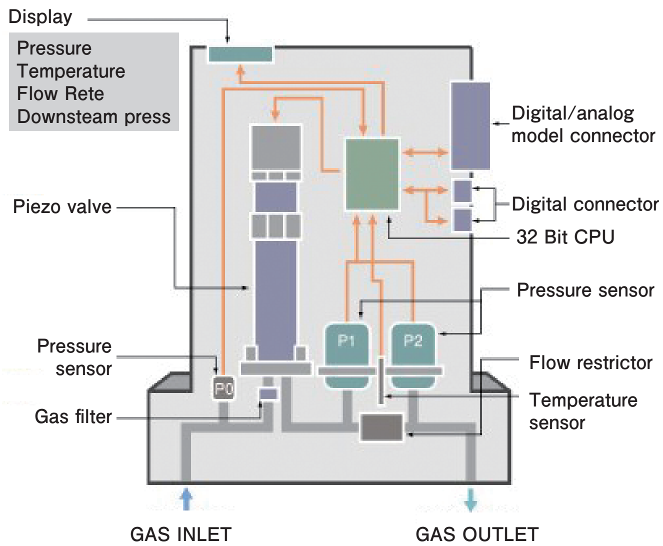


Figure 2 Pressure differential MFC structure

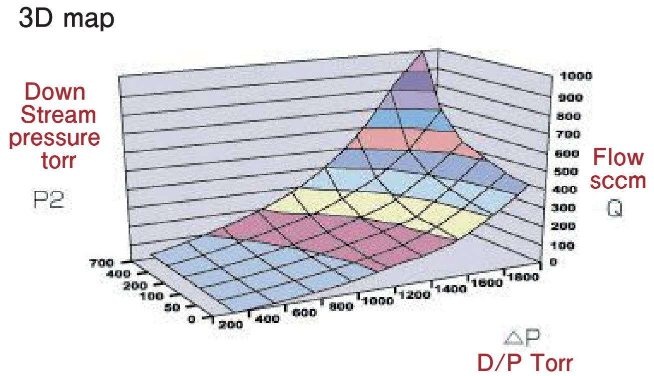


Figure 3 Relationship between mass flow rate and primary pressure and secondary pressure

the separated flow will be measured by the sensor. For this reason, possible causes of flow rate errors include the flow rate sensor and changes to the bypass/sensor flow separation ratio, such as the flow rate range and external factors.

Pressure-type MFCs

Figure 2 shows the structure of a pressure type MFC. It has a restrictor that creates a pressure differential, a pressure sensor for nearby absolute pressure, a control valve, and a control circuit. All the gas flows into the restrictor and contributes to the generation of a pressure differential. The restrictor is a conglomeration of flow paths, which are fine laminar flow elements of the same shape. The flow of each flow path is in a complete laminar flow state, so the full-scale flow rate can be changed by changing the number of flow paths. Also, the characteristics of each flow path are designed so that they match, so using the process gas characteristics to evaluate the characteristics of the minimum flow path makes it possible to get the same characteristics by changing the number of paths. For that reason, it is possible to assure a flow rate accuracy of ±1% SP (set point) for process gas as well.

Figure 3 shows the relationship between the mass flow rate and the primary pressure and secondary pressure. When the gas is a compressed fluid, the mass flow rate is related to the pressure differential and the secondary pressure, so a complicated calculation (including temperature corrections) would be required in order to calculate the mass flow rate based on the pressure. The pressure sensor also makes various corrections. Processing these types of complicated calculations at high speeds makes it possible to control feedback to the control valve. Pressure type MFCs were made possible only with high-performance CPUs for high-speed calculation processing, as well as high-accuracy small pressure sensors and high-accuracy restrictors.

Mass Flow Rate Traceability System

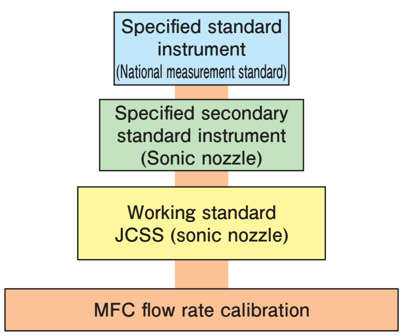


Figure 4 Mass flow rate traceability system in Japan for low gas flow rates at or below 5 m^3/h

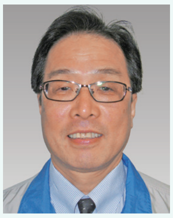
Figure 4 shows the current mass flow rate traceability system in Japan for low gas flow rates of 5 m^3/h and below. A weighing method that uses a high-resolution scale is used as the primary national measurement standard. Gas is put into a measurement container and the mass is directly measured using a high-resolution scale. An ISO toroidal throat Venturi nozzle (sonic nozzle) is used as the secondary standard and certificated using the primary standard instrument. The sonic nozzle is also used as a working standard and certified by JCSS (Japan Calibration System Service) accredited laboratories using the secondary standard instrument. MFC manufacturers use this type of working standard to certify each of their MFCs. It is possible to meet international standards with JCSS by mutual recognition arrangements (MRA) of international laboratory accreditation cooperation (ILAC). However, the above system is only assured for inert gases such as nitrogen and argon, and MFC manufacturers use flow rate standards for inert gases to come up with their own systems for other process gases.

Standardizing Process Gas

As mentioned above, flow rate management systems have been built for inert gases, and it is possible to assure traceability to the national measurement standard. However, a system has not been prepared for active gases that possess qualities such as corrosion, toxicity, and reactivity, and the current status is that flow rates for these vary by the MFC manufacturer. For that reason, in terms of equipment, to change MFC manufacturers, small adjustments are made for each case using other standard flow rate instruments and device chambers. Also, in some cases, the adjustment range exceeds the tolerance range, MFC manufacturers make special adjustments on their side. In this situation, equipment and device manufacturers now have stronger requirements for the standardization of process gases for MFC manufacturers. Activities to standardize these requirements have begun, led by the 2013 SEMI Standards Committee.

Conclusion

As defined in “More Moore”, recent semiconductor devices not only have high integration by making semiconductor devices smaller, but also have high integration by using 3D implementation and new materials. Also, as defined in “More Than Moore”, things beyond the digital circuits, such as passive elements, sensors, and actuators are being integrated, and high integration activities are continuing, including the function aspect. In addition to these, semiconductor devices are being made smaller and there is a move toward larger-diameter wafers. Activities for further high integration and higher functionality of semiconductor devices are underway to promote the further evolution of smart phones and tablet computers and the spread of high-functionality products such as 4K TVs in the future, and requirements for MFCs will probably get stricter in the future. HORIBA would like to meet these requirements in the future by making MFCs with higher performance, higher functionality, and higher reliability.



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