Controlling the flow – digitally

Emmanuel Bernard, application engineer at Qualiflow, looks at the cost advantages of digital mass flow controllers

As integrated circuits (ICs) increase in complexity and manufacturing equipment becomes more expensive, costs associated with taking equipment off line for any length of time are growing dramatically. Stopping production is a tremendous financial strain.

When a problem appears with a mass flow controller (MFC), a solution must be found in a minimum of time and very often this solution is to change the MFC. Using digital MFCs, as opposed to analog MFCs, can provide a great benefit by allowing semiconductor manufacturers to replace malfunctioning MFCs immediately while keeping a reduced number of spare MFCs in stock.

Most effective means

For many years, MFCs have served as the most effective means of precisely controlling gas flow in processes used in the semiconductor industry.

They are an essential component of many process tools. Since the development of digital MFCs, the most significant advantage to an original equipment manufacturer or end-user is the potential for lowering the cost of maintaining an inventory of spare mass flow controllers..

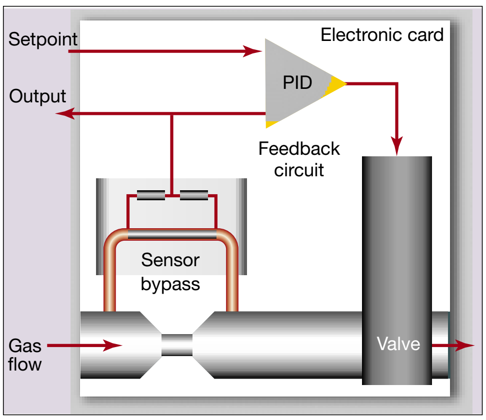

Fig. 1

Because digital MFCs can be programmed to run various gases, the inventory can be significantly reduced. Where wafer manufacturers have traditionally needed to maintain an inventory calibrated for specific gases used in production, they can now maintain a smaller spares inventory pre-calibrated for each of the gases used in the fab facility.

Original equipment manufacturers (OEMs) face the same problem. Often, the configuration of gas type and flow rate are not defined until the machine is almost ready to ship. Changing from customer specification for gas type and flow rate means manufacturing has to take the MFC out, recalibrate and leak check the system again.

An MFC consists of a sensor tube, a bypass, a regulating valve and a feedback circuit (Fig. 1).

Analog MFCs are calibrated to a dedicated gas and full-scale flow by the manufacturer. If the user wishes to select a different gas or full-scale flow, it is necessary to remove the MFC from the system in which it is installed and do a bench recalibration. A purge and leak check of the system is also necessary. This modification is time consuming, expensive and inconvenient.

Analog MFCs must be operated as closely as possible to full-scale flow for optimal accuracy and linearity result. This is a limitation when the user wishes to use an MFC at a high and low flow setpoint. When the setpoint is set at the low end of a specific calibration, the accuracy and linearity are degraded considerably.

Therefore, two analog MFCs with different full–scale flow are required in a gas panel to maintain the accuracy (one for the low flow and another for the high flow). This, naturally, requires larger stocking levels and expense to cover full spares support.

Analog MFCs require an excessively large spares inventory to cover the various needs of a wafer fab and equipment manufacturer. The user must have as many spare MFCs in stock as MFCs in use at any given time.

Fortunately, the development of digital MFCs has overcome many of the limitations of the analog versions.

Digital MFCs open up new era

With digital MFCs, a new era is entered. Among other enhancements, the marriage of digital control to mass flow technology provides greater flexibility, better communication between the MFC and control system, and better optimisation of performance.

Digital MFCs can be calibrated at many points throughout their operating range, resulting in accuracy and linearity specifications that are the function of a setpoint rather than full-scale for most of the operating range.

Users want to run MFCs at widely varying flow rates to accommodate a process while keeping the number of MFCs in a gas panel to a minimum. With digital MFCs, different curves can be stored in a single MFC.

With this capability, a single MFC can be used for a multitude of gases and a wide variety of full-scale flow. It can be used effectively for the entire calibrated flow range, hence the greatly reduced inventory of spares, as it is not necessary to stock MFCS dedicated to specific gases.

Limitations of multicalibration

Some limitations appear when calibrating an MFC with several gases. These limitations are both mechanical (bypass and valve design) and physical (gas properties).

Certain rules can be applied so that a multicalibrated (multicurved) MFC works, despite these limitations:

- Two calibration curves within one MFC cannot have full-scale flows, equivalent N_2, too wide apart. The highest calibration curve (in full-scale flow N_2 equivalent) must be a maximum of three times larger than the smallest calibration curve (in full-scale flow N_2 equivalent) to keep the benefit of accuracy.

$$\frac{Deq_{\max}}{Deq_{\min}} \le 3 \text{ with : } Deq_{N2} = \frac{D_{gaz}}{CF_{gaz/N2}}$$

It is better for multicalibration to have different gases with the same full-scale flow (N_2 equivalent) rather than one gas with different full-scale flow.

- Gases containing fluorine (SF_6 Sulphur hexafluoride, WF_6 Tungsten hexafluoride, C_2F_6 Perfluorethane [Freon-116], C_4F_8 Octofluorocyclobutane [Freon-C318] etc) need to be worked out differently because of a much higher diffusivity.

- All calibration curves on one MFC should have similar operating pressures.
- Inert gases can be stored in the same MFC.
- Unless metal seals are used, corrosive gases should not be run with non-corrosive gases in the same MFC.

Digisoft advantages

Qualiflow's digital MFC multicalibration allows up to 10 curves to be stored inside the MFC (typically five curves, but it depends on the gases and their associated flows).

Using the Qualiflow interface Digisoft (Fig. 2), the user is able to shift from one calibration curve to another and select the adequate flow and gas, on site, without recalibration.

Digisoft also allows the user to create new calibration curves from one existing curve. For example, in any process, the user can shift from a 1000 sccm full-scale MFC to a 500 sccm full-scale MFC when changing some parameters on the process.

Instead of using a spare MFC and stopping the equipment, purging the system, changing the MFC etc, Digisoft allows the creation of a new calibration curve in a few seconds, without recalibration (Fig. 3 existing calibration slot 1 slm N_2, Fig. 4 new calibration slot 500 sccm N_2).

Cost reductions

In a wafer fab that is typically processing all the steps of chip manufacturing (epitaxy, chemical and physical vapour deposition, diffusion, etching etc), each service associated with each step will try to minimise its stock of spare MFCs.

The following example illustrates the

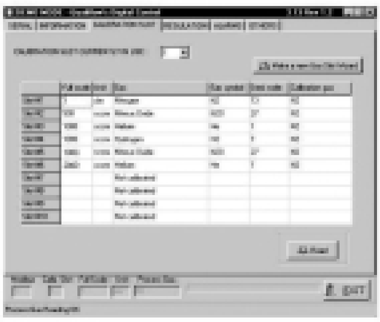

Fig. 2

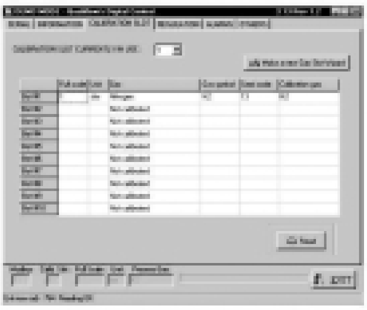

Fig. 3

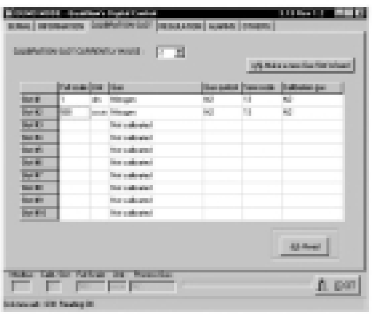

Fig. 4

EQUIPMENT	GAS	FLOW
CVD No.1	Ar (Argon)	100 sccm
	NF_3 (Nitrogen trifluoride)	200 sccm
	N_2 (Nitrogen)	100 sccm
	N_2O (Nitrous oxide)	200 sccm
	O_2 (Oxygen)	50 sccm
	SiH_4 (Silane)	100 sccm
	NH_3 (Ammonia)	200 sccm
	He (Helium)	200 sccm
	H_2 (Hydrogen)	100 sccm
CVD No.2	N_2 (Nitrogen)	1000 sccm
	Ar (Argon)	200 sccm
	He (Helium)	1000 sccm
	H_2 (Hydrogen)	50 sccm
	NH_3 (Ammonia)	200 sccm
	SiH_4 (Silane)	200 sccm
	H_2 (Hydrogen)	1000 sccm
	H_2 (Hydrogen)	200 sccm
	SF6 (Sulphur hexafluoride)	500 sccm
	O_2 (Oxygen)	100 sccm
	N_2O (Nitrous oxide)	500 sccm
	He (Helium)	500 sccm
	N_2 (Nitrogen)	200 sccm
	O_2 (Oxygen)	5000 sccm
	N_2 (Nitrogen)	10000 sccm
CVD No.3	N_2 (Nitrogen)	1000 sccm
	N_2 (Nitrogen)	50 sccm
	Ar (Argon)	200 sccm
	He (Helium)	2000 sccm
	H_2 (Hydrogen)	50 sccm
	NH_3 (Ammonia)	500 sccm
	SiH_4 (Silane)	100 sccm
	H_2 (Hydrogen)	1000 sccm
	N_2 (Nitrogen)	1000 sccm
	SF_6 (Sulphur hexafluoride)	1000 sccm
	O_2 (Oxygen)	200 sccm
	N_{20} (Nitrous oxide)	1000 sccm
	He (Helium)	500 sccm
	N_2 (Nitrogen)	200 sccm
	N_2 (Nitrogen)	10000 sccm

Table 1

GAS	FLOW
O_2 (Oxygen)	50 sccm
H_2 (Hydrogen)	50 sccm
N_2 (Nitrogen)	50 sccm
Ar (Argon)	100 sccm
N_2 (Nitrogen)	100 sccm
SiH_4 (Silane)	100 sccm
H_2 (Hydrogen)	100 sccm
O_2 (Oxygen)	100 sccm
NF_3 (Nitrogen trifluoride)	200 sccm
N_2O (Nitrous oxide)	200 sccm

Table 2

GAS	FLOW
NH_3 (Ammonia)	200 sccm
He (Helium)	200 sccm
Ar (Argon)	200 sccm
SiH_4 (Silane)	200 sccm
H_2 (Hydrogen)	200 sccm
O_2 (Oxygen)	200 sccm
N_2 (Nitrogen)	200 sccm
NH_3 (Ammonia)	500 sccm
SF_6 (Sulphur hexafluoride)	500 sccm
N_2O (Nitrous oxide)	500 sccm

Table 3

GAS	FLOW
He (Helium)	500 sccm
N_2 (Nitrogen)	1000 sccm
He (Helium)	1000 sccm
H_2 (Hydrogen)	1000 sccm
SF_6 (Sulphur hexafluoride)	1000 sccm
N_2O (Nitrous oxide)	1000 sccm
He (Helium)	2000 sccm
O_2 (Oxygen)	5000 sccm
N_2 (Nitrogen)	10000 sccm

Table 4

MFC NUMBER	FLOW/GAS
1	500 sccm SF_6
	1000 sccm SF_6
2	100 sccm SiH_4
	200 sccm O_2
	200 sccm N_2
	200 sccm He
	200 sccm Ar
3	50 sccm O_2
	50 sccm N_2
	100 sccm Ar
	100 sccm O_2
	100 sccm N_2
4	5000 sccm O_2
	10000 sccm N_2

Table 5

MFC NUMBER	FLOW/GAS
5	200 sccm NF_3
	200 sccm N_2O
	200 sccm SiH_4
	500 sccm He
6	500 sccm N_2O
	1000 sccm N_2
	1000 sccm He
	1000 sccm H_2
	1000 sccm N_2O
	2000 sccm He
7	200 sccm NH_3
	500 sccm NH_3
8	50 sccm H_2
	100 sccm H_2
	200 sccm H_2

Table 6

impact of multicalibrated digital MFCs in reducing the cost-base for the fab facility.

Example of savings

In processes such as chemical vapour deposition, for example (deposition of Si_3N_4, SiO_2), if we consider a small cluster of equipment (three CVD machines), the service may need the gases and their associated flow as listed in Table 1.

In order to change a malfunctioning MFC immediately, and therefore to avoid keeping one of the tools down too long, the user must maintain a stock of MFCs large enough to allow replacement of any of the MFCs present in the three tools. Using analog or single curve digital spare MFCs, the user has to stock 29 MFCs (see Tables 2-4).

With multicalibrated MFCs, in respect to the rules mentioned previously, the user can reduce this number from 29 to only eight spare MFCs (Tables 5–6 and Fig. 5).

Digisoft is a convenient solution for dealing with these MFCs (Fig. 2: example of MFC Number 6).

The user can change the gas calibration of the spare digital MFC to any other gas on site, without recalibration.

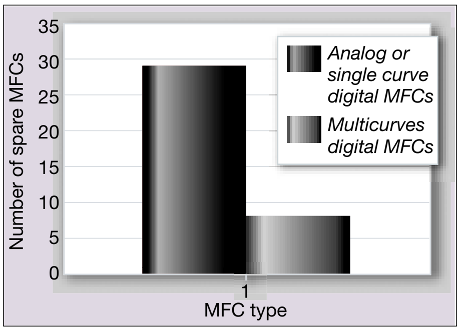

Fig. 5

Summary

The advent of digital MFCs and multicalibration is resulting in significant cost savings to the semiconductor industry.

These savings mean that prospective users of this evolution in technology are giving serious consideration to this form of calibration. ■

References

1. G. Chizinsky, 'Multi-Gas Selection Capability of a Digital Mass Flow Controller', *Semiconductor Fabtech*, 8th Edition, p.161, 1998.

2. T. Huynh & P. Navratil, 'Hot controllers: Compensation technique for in situ environmental temperature effects in thermal mass flow controllers', *Cleanroom Technology*, p.26, July/August 2002.

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