Controlling reactive processes

How reactive gas control delivers a more stable sputtering process

GENCOA

The flexibility and control provided by a reactive gas controller results in a more consistent deposition rate, and controlled uniformity – even over a large target area.

Improving process control of reactive sputtering

Feedback control of reactive gas enables improved deposition rates, coating properties and process reliability, which is not possible to achieve with constant flow.

It is a well known and troublesome phenomenon that most reactive sputtering processes are highly unstable. A magnetron target can very quickly switch from a metallic state into a fully poisoned condition (Figure 1). This change will make the process unworkable, and results in large variations in the sputtering rate.

One solution would be to use the target in fully poisoned mode (i.e. reaction product all over the target). However, the compounds on the target sputter at a much lower rate than a pure metal (Figure 2, B), hence it is usually not desirable.

A better solution is to use a feedback control system that can very quickly adjust the reactive gas flow in response to the plasma conditions, in order to hold the process in high rate metallic or transition mode (Figure 2, A).

Speedflo's PDF control algorithm automatically adjusts gas input every millisecond in response to sensor values, accurately holding the process at a specified setpoint (Figure 3).

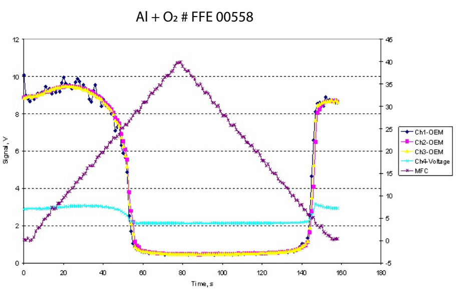

Figure 1 – Transition of process from metallic to poisoned mode. The transition occurs very rapidly requiring the use of feedback control to hold the process in a transition state.

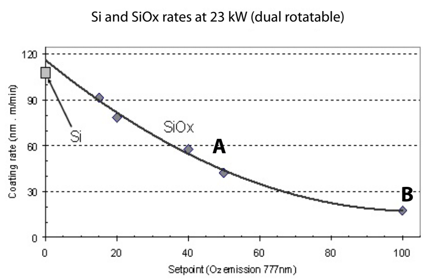

Figure 2 – Coating rates at different sensor setpoints for SiOx

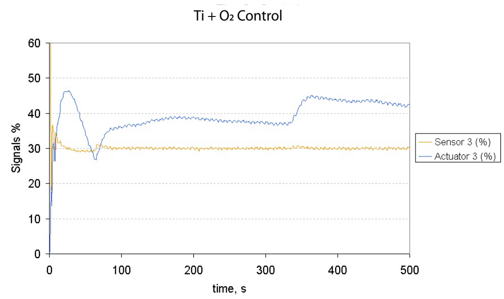

Figure 3 – Feedback control of TiOx process. The actuator level continuously and automatically changes in order to keep the sensor following the setpoint.

Controlling uniformity

Improved deposition rate is only part of the benefits of using a feedback control system for reactive gas regulation. Of great importance for many coatings is the uniformity of deposition over the substrate area. This is particularly challenging for systems with large target areas. In these cases, multiple gas injection zones are required across the target length to shape the deposition profile (Figure 4).

With multiple zones comes increased control complexity and more control options. The complexity arises from the interaction between the zones; a control action on one zone will have an effect on the control dynamics of neighbouring zones. Two main modes of control can be used when controlling multiple zones; individual feedback control of each zone (Figure 5), or a master/slave principal (Figure 6).

The advantage of individually controlling each zone is that the deposition profile can be shaped with a greater degree of flexibility and the profile can be maintained with changing system dynamics (i.e. unstable plasmas).

The main drawback is a greater degree of complexity in the tuning and commissioning of the system. A common problem is that the individual control loops can strongly interact and unstable oscillatory behaviour arises from "fighting" between them, due to the "crosstalk". Should this problem arise, then depending on the skill of the operator, Gencoa may need to provide on-site or remote tuning assistance to optimize stability.

The other option is to have a master feedback control zone with the other gas injection zones being slaved at a set ratio to the master. By adjusting the ratio of the slaving for each zone it is possible to achieve a uniform deposition across the target length (Figure 7).

The flexibility of the Speedflo controller allows for up to eight simultaneous feedback control loops and any combination of master/slave operation to suit every possible system configuration.

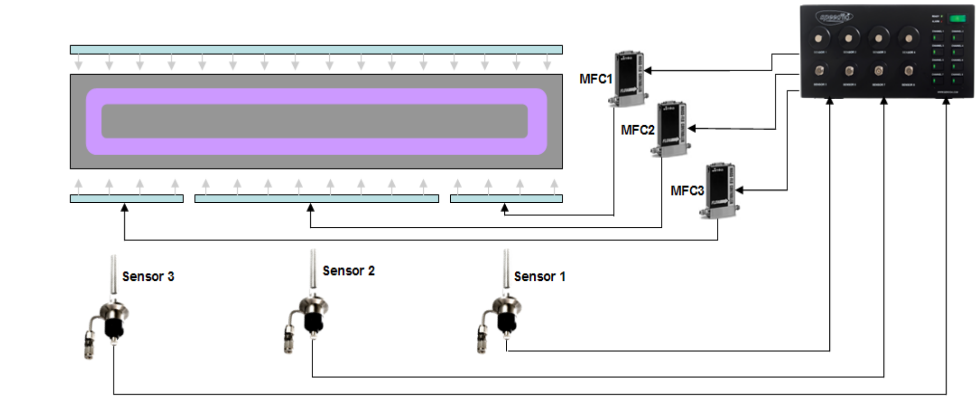

Figure 4 – Typical gas bar configuration for a three zone target (only half of a dual magnetron shown)

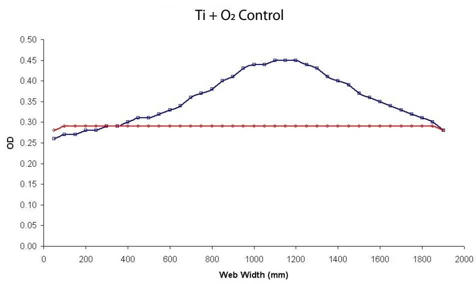

Figure 7 – Control of uniformity across a large target length using five zone trimming gas bars. The blue line corresponds to the uniformity distribution when the gas is injected in a small portion of the central area. The red plot is an optimized trimmed gas distribution producing uniform coating over the entire substrate length.

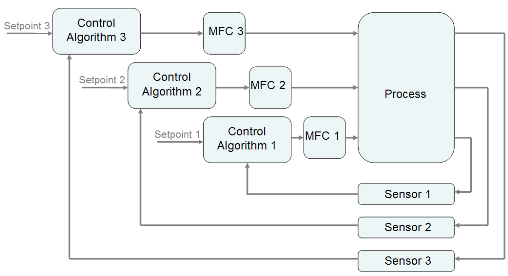

Figure 5 – Schematic illustrating multi-zone feedback control principal

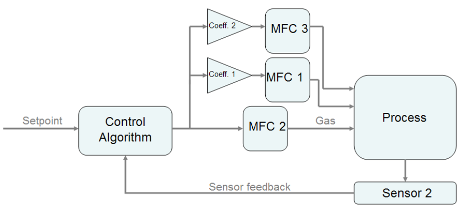

Figure 6 – Schematic illustrating master/slave control principal.

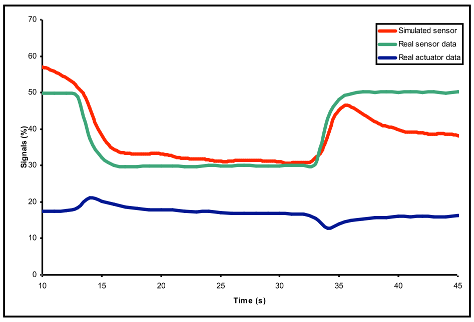

Figure 8 – Comparison of simulation and real data. Real actuator data was fed into the simulation and compared with the corresponding real sensor data

Controller tuning with Speedflo Simulator

Finding the right gains for a reactive gas control system can be difficult as they are a factor of many variables such as type of target and reactive gas, pumping speed, sensor position and type, gas delivery pipe length, magnetron configuration, setpoint and vacuum chamber size amongst others. In general, low order mathematical models, which describe the dynamic relationship between the actuator (mass flow controller) and the sensor as a function of all the system parameters, are required to be able to pre-determine controller gains at the design stage.

Unfortunately, these models have not been developed for sputtering processes and even if they were, the variability and uncertainty of system parameters would make the results questionable. Therefore, controller tuning for reactive sputtering processes is something of a "trial and error" procedure during the commissioning of the system. Understanding of the cause and effect relationships between the controller gains and the controlled system dynamics is absolutely critical in order to tune the controller efficiently. The best way to develop this understanding (without resorting to studying complex control theory) is simply by gaining experience of tuning the control system in practice.

Whilst a model of the system that can be used for designing controller gains is currently out of reach, it is possible to create a generic model of a reactive sputtering process by analysing actuator and sensor data (Figure 8). Using this proprietory model, Gencoa has developed a simulation of the Speedflo controlled sputtering system to provide the user with "virtual" experience of control system tuning. The model used in the Speedflo Simulator captures the cause and effect relationships between controller gains, setpoint levels, gas delivery pipe length and disturbance (such as arcs) on the stability and dynamic response of the controlled system.

The Speedflo Simulator package contains two interfaces: the *basic version* (Figure 9) which strips the interface down to the absolute essentials, and an *advanced version* (Figure 10) which provides a complete real-time simulation of the actual Speedflo interface and includes almost all the features found in the real system.

The complete Speedflo Simulator package is only 5MB in size and will run directly from an .exe on any Windows operating system, without the need for any reactive sputtering process hardware.

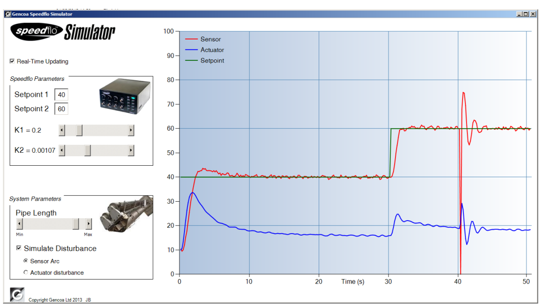

Figure 9 – Speedflo Simulator basic interface .

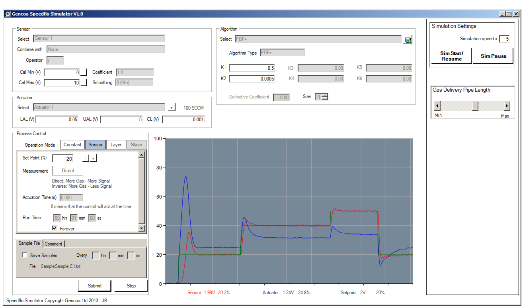
Figure 10 – Speedflo Simulator advanced interface.