# Run – to –Run Control of ITO Deposition Process

**Kareemullah Khan, Victor Solakhain, Anthony Ricci, Tier Gu and James Moyne**
**University of Michigan and Optical Imaging Systems, Inc., MI**

## Abstract

**This paper describes the design and development of run-to-run control solution for an Indium Tin Oxide (ITO) deposition process. ITO deposition is an inherently complex process making it hard to simultaneously optimize the many characteristics of the ITO film such as optical transmission, resistivity, stresses in the film etc. With the run-to-run control solution, post-process measurements made after every run are used along with empirical process models and drift compensation and noise rejection techniques to suggest new equipment settings for the next run. Theoretical models and simulation results show that this approach gives very stable ITO characteristics. Some of the methods that improve the control algorithm are discussed and future work is explored.**

## Introduction

This research is motivated by the fact that, at the present time, most of the equipment used for manufacturing displays operates in an open-loop mode resulting in non-optimal and in many cases sub-par equipment performance and process results. Research in other industries such as semiconductor manufacturing has proven that 'run-to-run' control can be very effective in controlling long term drift of complex processes [1,2]. Run-to-run control is a form of discrete process and machine control in which the product recipe with respect to a particular machine process is modified ex-situ, i.e., between machine "runs", so as to minimize process drift, shift, and variability. This paper describes a part of an on-going effort to improve the manufacturing characteristics of an in-line sputtering tool at Optical Imaging Systems, Inc. through run-to-run control. We have chosen ITO deposition equipment as our initial research vehicle.

## Objective

ITO (Indium Tin Oxide) is used as the pixel electrode material in most LCDs. Any electrode material used in LCDs should meet the following requirements. : (i) good optical transmission, (ii) low stress in the film in both x & y directions, (iii) good thickness uniformity, and (iv) low sheet resistance. The deposition parameters that affect the above characteristics of the ITO film were identified as (i) temperature of the deposition chamber, (ii) total gas flow, (iii) Power, (iv) scan speed, and (v) oxygen percentage in Argon. A schematic of the process is shown in figure.1.

As with most systems of this type, the ITO deposition process drifts considerably due to equipment and consumable aging. The process is also associated with a fair amount of noise. Both these factors cause the deposited film characteristics to deviate significantly from the target values. This requires the deposition parameters (inputs) to be tuned frequently by the operator. However, due to the inherent complexity of the deposition process, it doesn't always give anticipated results.

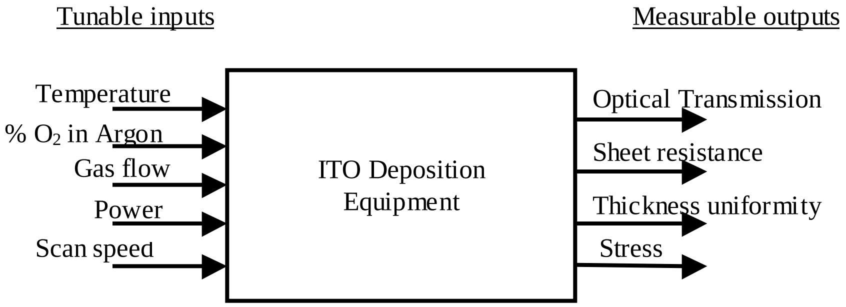

**Figure 1. A black box model of the ITO deposition process**

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It is our contention that the deployment of a run-to-run controller for the process would not only take the responsibility off the operator but also more rapidly and accurately tune the process. Thus, the same strategy that has been effective in controlling processes such as C-M-P (Chemical Mechanical Polishing) and Vapor Phase Epitaxy can also be extended to sputter deposition [1,2].

## Process Models

The first step towards designing a controller is to obtain a process model which would accurately predict the ITO thin film characteristics (outputs) for a given set of input conditions. In this case, the ITO process engineers chose stress & optical transmission as the primary control outputs. Test runs based on a DOE (design of experiments) were conducted to relate process inputs to these outputs. In these runs, ITO films were deposited on a glass substrate under different input conditions. A suitable range around the normal operating point was chosen for the inputs. Table1 shows the data obtained from these experiments.

The data from these runs was used to generate models for the two outputs: optical transmission and stress. A recursive elimination procedure was adopted to minimize the number of terms involved. This resulted in the following process model:

$$\text{CP density} = 0.12125 - 0.00115 * (GF) + 0.001 * (GF*P) \tag{1}$$

$$\text{Stress} = -0.475 + 0.012 * (GF) + 2.987 * (P) + 0.0085 * (T*GF) - 0.0015 (T*GF*P) \tag{2}$$

Where GF - Gas flow,
P - Power,
T - Temperature, and
CP density is a measure of optical transmission property of the film.

The values predicted by these models were compared with the measured values. The $R^2$ values on the models were 95.8% and 96.97% respectively. ($R^2$ gives the square of correlation between the actual and predicted response. An $R^2$ value of 1 occurs when there is a perfect fit.) This indicates that the models are very accurate.

Equations (1) and (2) are now modified to include only the linear terms (see discussion of control algorithm below). The cross-terms are eliminated through Taylor series approximation of the first order around the operating point. The new models generated are used in the controller.

## Control Algorithm

The next step is to embed these mathematical models into the Generic Cell Controller (GCC), which is the enabling technology and software solution for our data collection and control system [2]. The GCC collects metrology data (measured values of outputs) and controls the process by suggesting the recipe for the next run based on the advice of a control algorithm. The algorithm used in this implementation is the ‘MIT gradual mode algorithm’ [3]. The algorithm uses a first order linear approximation of the process at the operating points and dynamically models the adjustment of zeroth order constant terms “run-to-run”. An exponentially weighted moving average filter is used to distinguish between the noise and real disturbances such as process drift. This filtering thus helps eliminate some of the harmful effects that random noise can have on a control system by time averaging this noise with data from previous runs. The weighting factor $\alpha$ can be set to adjust the extent of this averaging. As $\alpha$ is increased the relative weighting of the previous runs is decreased.

| Temperature (°C) | Gas flow (sccm) | Power (W) | Scan speed (in./min) | CP density | Stress (GPa) |
|---|---|---|---|---|---|
| 25 | 60 | 0.485 | 0.065 | 0.10 | 2.296 |
| 50 | 60 | 0.485 | 0.065 | 0.08 | 1.856 |
| 25 | 60 | 0.725 | 0.097 | 0.09 | 1.639 |
| 50 | 60 | 0.725 | 0.097 | 0.08 | 1.200 |
| 25 | 120 | 0.485 | 0.065 | 0.04 | 3.318 |
| 50 | 120 | 0.485 | 0.065 | 0.04 | 2.879 |
| 25 | 120 | 0.725 | 0.097 | 0.06 | 2.662 |
| 50 | 120 | 0.725 | 0.097 | 0.06 | 2.229 |
| 25 | 90 | 0.605 | 0.081 | 0.06 | 2.479 |

**Table 1. Data obtained from the DOE**

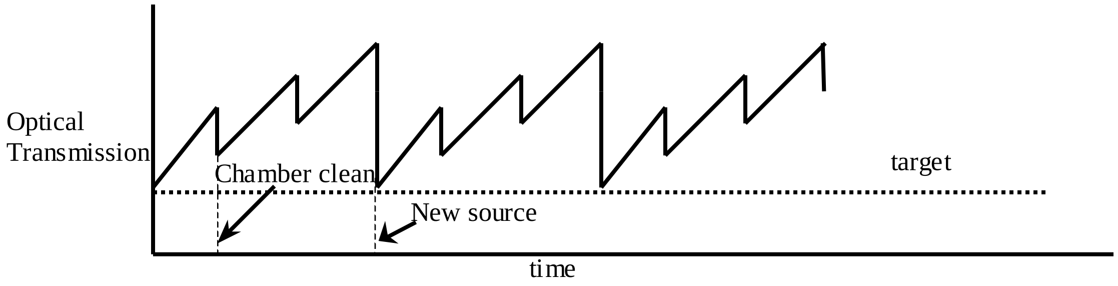


**Figure 2. Variation of Optical transmission with time for an uncontrolled process**

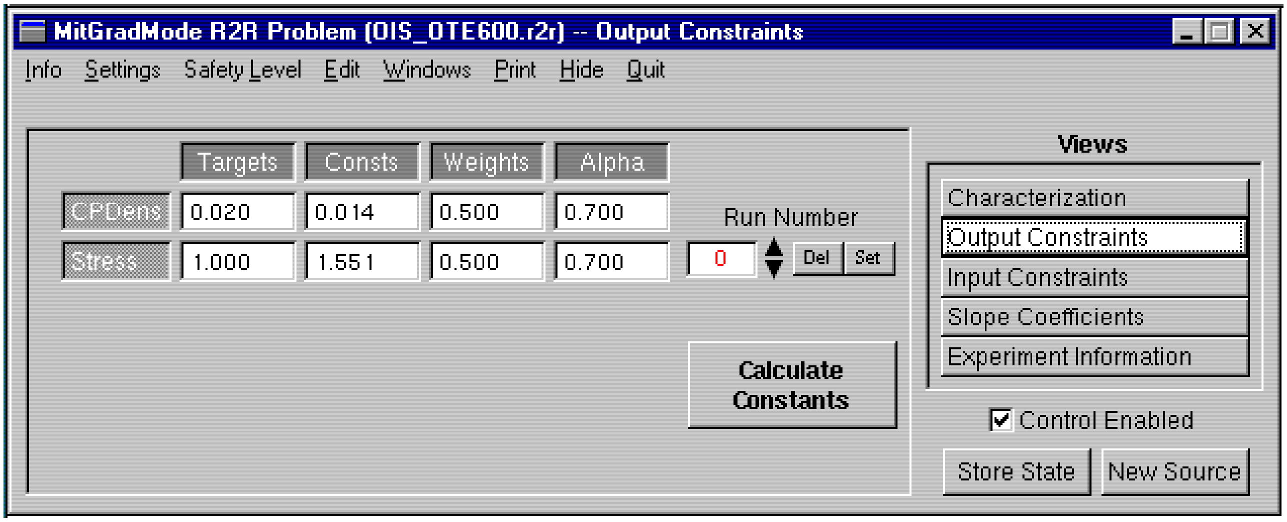
### Change of source

Like many other deposition processes, the ITO process uses a source, which sputters material onto the substrate and gets depleted with use. The characteristics of the ITO films depend on the number of life hours left on the source. Usually, a new source deposits better films than a used target. So, the ITO characteristics degrade with time (drift) as the source gets constantly depleted, and revert back to their original values whenever the source is replaced. The same trend is observed with 'chamber cleaning' (the magnitude of the change in this case is much lower than the one observed when the source is replenished). Figure 2 illustrates the variation in optical transmission with chamber cleans and source replenishments for an open loop (uncontrolled) process.

The change of source has been accounted for in the GCC control system by employing 'store state' and 'new source' buttons (see figure3). The 'store state' button is used to store a controller state configured to control from a 'new source' condition (as shown in fig.2). Whenever the source is replaced, the 'new source' button is pressed. The EWMA weighting factor is set to 1 (discards the history from previous runs) and the model parameters are set to the 'store state' value. In this way the controller adapts quickly to the new source conditions.

### Process Control

The behavior of the process controlled by the GCC has been compared against the behavior of an uncontrolled process. Realistic values of drift and noise were incorporated into the simulation. Figure 4 shows the comparison. It can be seen that, the uncontrolled process drifts away from the target whereas the controlled process remains close to the target.


MitGradMode R2R Problem (OIS_OTE600.r2r) -- Output Constraints

| | Targets | Consts | Weights | Alpha |
|---|---|---|---|---|
| CPDens | 0.020 | 0.014 | 0.500 | 0.700 |
| Stress | 1.000 | 1.551 | 0.500 | 0.700 |

Run Number: 0

☑ Control Enabled

**Figure 3. Picture of one of the windows showing the new source button**

## Conclusion

The characteristics of ITO studied in this paper are very important and play a large role in determining the performance of the LC displays. If the display is to meet the specifications, these properties have to be very close to the target values. In an uncontrolled process, the process tends to drift over time away from the target. In the presence of a controller, this can be avoided, thus significantly reducing scrap and increasing process capability. It also contributes towards process automation and lessens the burden on the operator.

In this paper we have demonstrated the design, implementation and benefits of run-to-run control for an ITO deposition process. As part of the next phase of this project the controller will be applied to the actual process to verify these benefits. Further, studies indicate that a number of display manufacturing processes are ideal candidates for process improvement using this run-to-run control approach. Thus, implementation of run-to-run control could have significant impact on yield and throughput of the display industry.

## Future Work

Presently, the controller can be utilized to control one process. When the equipment is used for multiple processes (i.e., multiple targets), the controller has to be reset before every process switch. The future work involves equipping the controller with a more powerful algorithm, which solves for a different target each time while still being able to capture the weighted drift values [4]. In this way the controller could track and model equipment and consumable aging while suggesting recipes for changing targets. Issues of model stability and dynamic EWMA factor adjustment will have to be investigated before the controller can be used in this fashion.

## References

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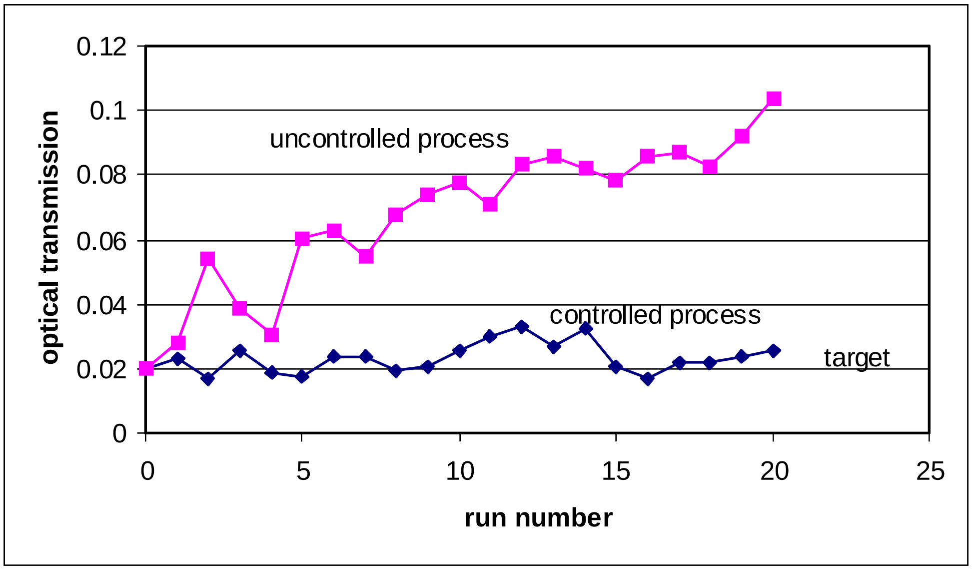

**Figure 4. Simulation of the ITO deposition process with and without the controller**

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