AccuFlux™ Process Monitor Optical Flux monitoring during multi-component thin film deposition using Atomic Absorption Spectroscopy

Abstract

SVT Associates AccuFlux™ optical deposition flux monitor based on Atomic Absorption Spectroscopy is perfect for monitoring codepostion of materials from multiple sources in thin film vacuum deposition processes. It provides independent monitoring of the different elements being deposited. As an optical technique, it provides this monitoring without physically shadowing the substrate, and with a minimum of in-vacuum components. An innovative high sensitivity optical design provides flux measurements equivalent to growth rates as low as 0.001 nm/s. Examples of monitoring deposition during MBE and during deposition of a CIGS PV thin film are shown.

September 2008, Note No. 1602

Introduction

The AccuFlux™ is a deposition flux monitor based on Atomic Absorption Spectroscopy (AAS) used in thin film deposition. Monitoring the deposition is key to controlling the composition of the deposited film. The AccuFlux™ is able to simultaneously measure the elemental flux from multiple evaporant sources during film growth. It uses the optical technique Atomic Absorption Spectroscopy to measure the material passing through a light beam located between the sources and the substrate. AAS uses a wavelength of light corresponding to the absorption line of the atomic species of interest. That wavelength is resonantly absorbed by the corresponding element, giving the technique its selectivity in the presence of other elements in the optical path. In the AccuFlux™, multiple wavelengths are used – one for each element being monitored. The AccuFlux is available in models with up to 4 channels for monitoring 4 elements simultaneously.

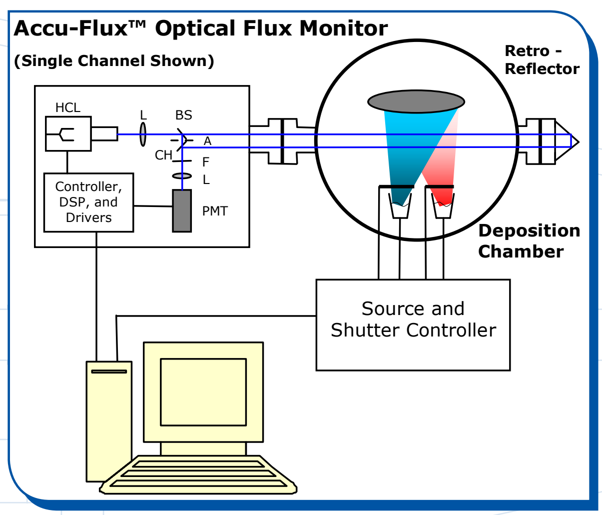


Figure 1 - Schematic of the AccuFlux showing one channel of the optics used for deposition flux monitoring, in one possible optics configuration. Up to 4 channels are available for monitoring and controlling up to 4 sources. HCL = Hollow Cathode Lamp, L = Lens, BS = Beam Splitter, A = Aperture, CH = Chopper, F = Filter, PMT = Photomultiplier tube.

Elements and Sensitivity

The sensitivity and signal strength of this technique is high, resulting in typical accuracies of better than 1%. Deposition rates can be measured from as low as 0.001 nm/s to 5 nm/s depending on the element. The Absorbance, which determines the relative sensitivity, is shown below for several elements. Monitoring of additional elements is available.

Al	2.50	Mg	760.00
Ba	0.42	Mn	140.00
Co	63.00	Ni	44.40
Cr	36.00	Pb	37.00
Cu	60.00	Si	1.14
Fe	27.27	Sr	16.67
Ga	1.50	Ti	0.44
Ge	2.14	Zn	305.00
In	13.33		

Table 1: Sensitivity of Common elements in Deposition Processes; Absorbance per unit concentration.

Configurations

The AAS technique used in the AccuFlux is unobtrusive because only the light beam which passes between the sources and the substrate intercepts the flux of material being deposited. Several optional geometric configurations of the optics are possible and the configuration can be optimized for a given deposition system depending on the space available and sensitivity required. The beam enters and exits the vacuum chamber through two or one windows. The light sources and detectors are located outside of the vacuum which reduces maintenance of invacuum parts when compared to other techniques. The AccuFlux allows precise calibration without breaking vacuum.

An interface to a control computer is provided. This allows closed loop control of flux or film thickness. The monitor is temperature stabilized to eliminate drift over long deposition sequences. The AccuFlux can be used for MBE or other thin film deposition techniques. The AccuFlux™ can monitor the flux from multiple sources during simultaneous codeposition of a multicomponent film.

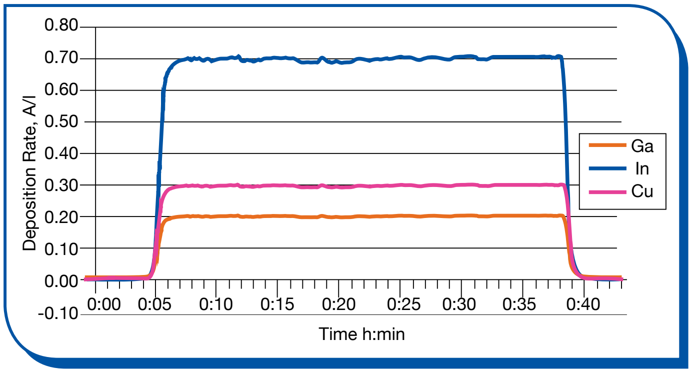
Alternative Methods

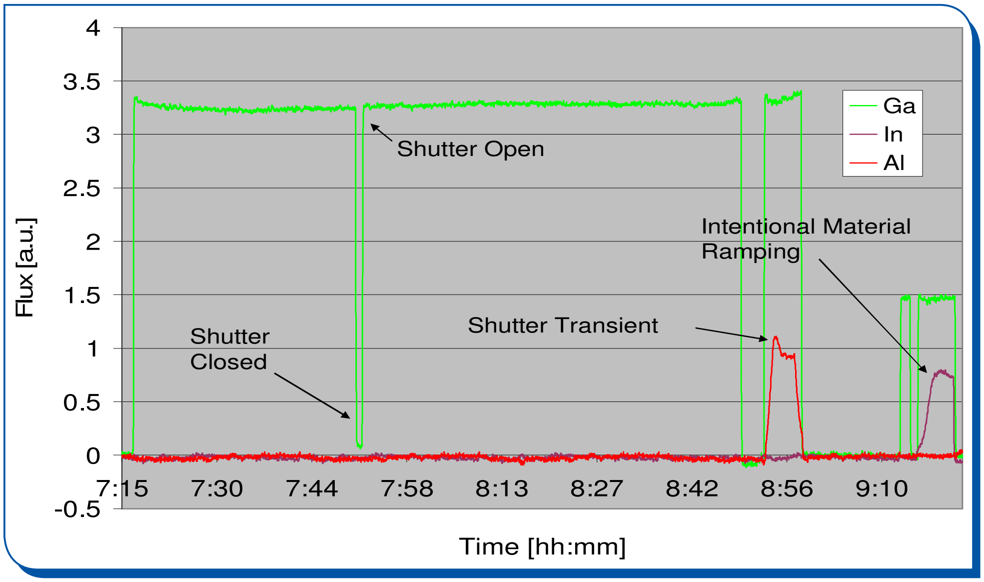
Other methods of monitoring the flux from deposition sources mostly involve characterizing each individual source prior to film growth and then setting the same parameters to achieve a desired deposition rate. One method used in MBE uses an ionization gauge moved in front of the source. Other methods include using a quartz crystal monitor (QCM), or Electron Impact Emission Spectroscopy (EIES), as summarized in the table below.

	SVT AccuFlux™ Atomic Absorption	Quartz Crystal Monitor	Inficon® Guardian EIES
Sensitivity	High–Dual Pass, Long Flux Path, Lens Optics	Low Small sample area Thermal Effects	Filament and detector sensitivity changes over time/coating effects
Reliability	Routine Maintenance outside of the Vacuum, long lamp life with duty cycle control	Vacuum Dependent Thermal Drifts (Shutters) RF Interference	Unpredictable due to filament
Material Flux Accuracy	< 1%	Very poor for low fluxes Typ. > 5%	N/A – Reference Only
Vacuum Maintenance	Not Required	Frequent	Required
Material Flexibility	Multi-Material	One material at a time Limited lifetime	Multi-Material, but background effects
Drift (24 hrs)	< 0.5%	Unpredictable	> 5% (Se)
Flux Measurement Methodology	Direct Atomic Absorption of Full Flux Path (Profile)	Indirect via non-selective Freq. measurement	Indirect via small/partial sample flux collection
Detector Technology	PMT w/reference and lock in	Mode-Lock without reference	PMT with lock-in, poor light collection efficiency, no ref.
Data Acquisition	1000 Hz	10 Hz	10 Hz

EXAMPLE 1: CIGS

Copper – Indium – Gallium – Selenide (CIGS) thin film photovoltaic (PV) structure. Composition monitoring of the absorber layer during deposition offers control for high yield and efficiency.





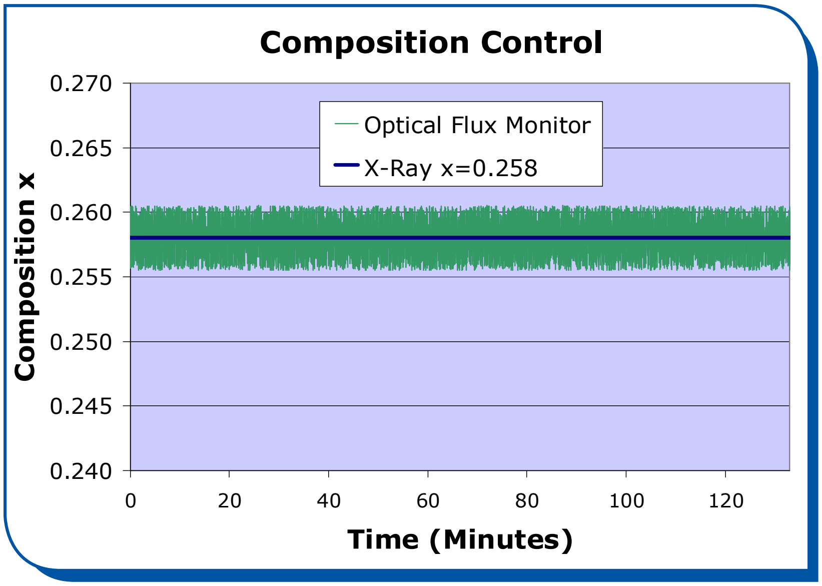
Production HBT Device Deposition (7" x 6" Wafers)

EXAMPLE 2: MBE – MONITORING GA, IN, AL

The following data was collected using the AccuFlux, during MBE growth of a structure used in a commercial heterojunction bipolar transistor. The abrupt changes in deposition flux are due to source shutter operation. Other changes in In and Al flux due to intentional changes in source power are observed. The excellent signal strength and stability, signal selectivity and response time of the AccuFlux provide monitoring of the flux transients during MBE.

EXAMPLE 3: MBE – $IN_XGA_{1-X}AS$

Comparison of $In_xGa_{1-x}As$ composition x as measured with the AccuFlux Optical Flux Monitor to *ex-situ* x-ray data displaying composition control better than 0.3%. The AccuFlux data shows excellent stability and signal to noise ratio.



Summary

The AccuFlux provides sensitive, stable, nonintrusive optical in-situ flux monitoring of deposition sources. The technique is material specific and selective for simultaneously monitoring multiple flux components. A wide range of species can be monitored.

An innovative high sensitivity optical design provides flux measurements equivalent to growth rates as low as 0.001 nm/s. Typical Accuracies are better than 1%. It allows accurate calibration of graded layers and of ternary structures.

The AccuFlux gives precise and reproducible data for flux and composition control for reproducible thin film deposition. The AccuFlux can be used in closed loop control of the deposition sources, or shutters.

Please refer to SVT Associates AccuFlux Product information for Specifications and software description.

Figure 2: AccuFlux™ Hardware

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