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In situ measurements of optical film parameters and plasma monitoring during reactive sputtering for advanced in-line process control

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Abstract

In this work the spectroscopic ellipsometry and the reflectometry/transmission measurements together with an advanced plasma monitor were used for inline measurements. All systems were installed in an inline sputtering equipment which enables a continuous deposition process—the condition for a direct feedback to the deposition parameters. The metrology tools were connected by a framework software which used an XML over TCP/IP connection. The setup allowed to control the multilayer deposition using a deposition script and to use the metrology tools for measuring the thicknesses and to correct the deposition rates.

Keywords: Inline; Ellipsometry; Reflectometry; Sputtering

1. Introduction

The upcoming requirements for layer deposition require to combine high precision in layer properties over a long time with narrower process windows. Also the demand for low running costs requires more control on the process. During the typical life time of deposition targets, the costs are significantly influenced by the time the process is operational in process parameter window. The time for setting up the process parameters after a target change and the stability against drift are key factors that must be under control to reduce the running cost and to increase the uptime (see Fig. 1).

For increasing the productive time (2) in Fig. 1 the deposition tool has been optimized and additional sensors are used to keep the process within the process window. The sensors were spectroscopic ellipsometry, reflectometry and a monitor for plasma lines.

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2. Process equipment and sensors

2.1. Sputter system

The sputter system was a SV-INLINE reactive (FHR Anlagenbau). SV-INLINE reactive combines innovative equipment design with state of the art PVD process technology. Flexibility and modularity of the innovative concept of the in-line sputter system SV-INLINE reactive are considering especially all equipment design aspects required by MF pulse magnetron sputtering as well as DC and RF sputtering processes. New concepts of substrate transport, chamber design and process control are the basis for high quality coatings, reproducible film properties together with a high level of reliability and low running costs of ownership.

The SV-Inline was equipped with ports to allow layer analysis after each layer of the design. The sample application to be controlled was a $(TiO_2/SiO_2)^n$ on large area glass substrates. The optical sensors were placed as shown in Fig. 2.

The setup allows to sputter any combination of the two materials (others were also available, but are out of scope of this

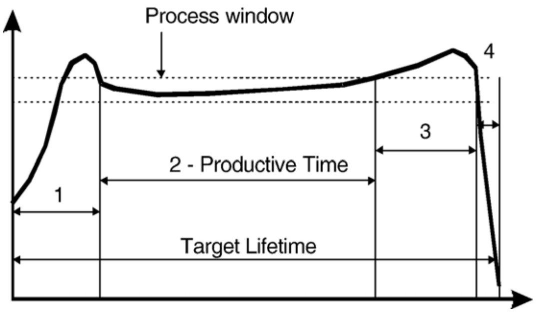

Fig. 1. Productive process time calculation: (1) time to setup process parameters, (2) productive time, (3) process out of process window, (4) target no longer operational.

paper). All sensors were used to study the following process parameters:

- DC, RF or MF pulse substrate bias (material properties)
- substrate pretreatment by heating or plasma processing
- long-term stability of the deposition of controlled reactive process
- uniformity and stability of film properties (thickness distributions)

The flexibility of the SV-INLINE reactive system regarding process combinations ensures highest quality of film and surface properties. The equipment offers a high level of flexibility to potential process changes as required for different products in a rapidly changing high technology market. The utilization of pulse magnetron sputtering processes offers new magnetron coating capabilities in addition to the already established applications.

The number of optical sensors and/or targets can be scaled up very easily (the sequence in Fig. 2 is multiplied).

2.2. Single port spectroscopic ellipsometer

The ellipsometer is based on a SENTECH Instruments SE801 and extended by a vacuum measurement head. Usually an ellipsometer requires 2 ports in order to measure. The ellipsometer has a unique design shown in Fig. 3 which allows the measurement through a single DN160 flange only. It allows fitting the ellipsometer easily to large process chambers, even when there is no room for two flanges.

The ellipsometer has a vacuum autofocus system which allows for compensating different sample thicknesses. The single port design drastically reduces the effort required for thickness alignment and opens the door for automatic control.

The application of in situ measurements on thin glass substrates was challenging in many ways. The backside reflections are always involved and the non-precise sample carrier (compared to ex situ benchtop systems) required to work with some correction parameters, as the angle of incidence offset.

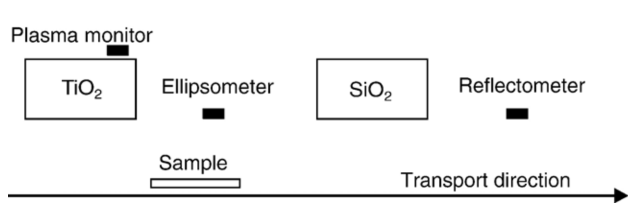

Fig. 2. Positions of optical sensors and targets.

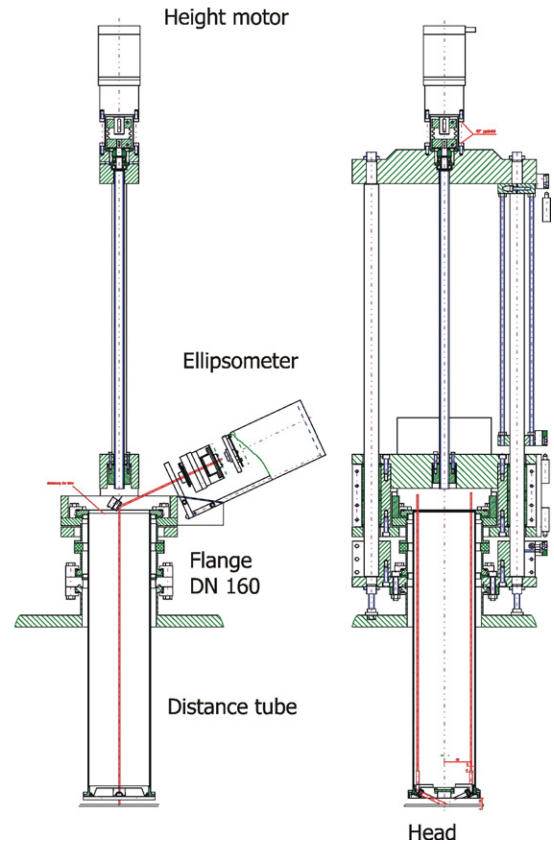

Fig. 3. Ellipsometer setup through a single DN 160 flange.

The ellipsometer has been compared with the reflectometer for several layer systems. The ellipsometer is more powerful in the following cases:

- thin layer(s) less 30 nm (no interference)
- thin layer with refractive index unknown
- many layers need to be determined simultaneouslyThe Table 1 shows a comparison of the measurement errors for the case of Fig. 4.

2.3. Reflectometer

For measuring the reflectivity a production type reflectometer ETA-CSS (Steag ETA-Optik GmbH) shown in Fig. 5 was used. It was equipped with an additional spectrometer for light

Table 1
Accuracy dT of the thickness for the double layer system (see Fig. 4)

	dT[TiO_2]	dT[SiO_2]
Ellipsometer	0.1 nm	0.2 nm
R (no carrier)	1.5 nm	3.2 nm
R (with carrier)	1.5 nm	3.7 nm

The precision of *R* was assumed to be 0.5%. The last row (with carrier) takes an additional fitting of the sample carrier movement into account (sample distance about 1 mm, sample tilt about 0.3°).