APPLICATION NOTE: AN 02

PILLARHALL LHAR4 – STANDARD PROCEDURE IN PROCESS MONITORING

This application note describes the standard procedure of PillarHall LHAR4 test chip use in 3D thin film deposition process monitoring.

PillarHall LHAR4 Test Chip enables to quantify thin film conformality by a novel and accurate method. Conformality is determined from **the film penetration depth profile** measured from the PillarHall Lateral High Aspect Ratio (LHAR) test structures.

PillarHall LHAR4 chip handling guide describes how to handle and move test chips safely from the shipment box to the deposition experiments. Notice and use the Chip ID (text on a chip and on a shipment box) in the experiments and data identification.

1. Deposition experiment

Typical thin film deposition experimental run **uses single LHAR4 test chip placed on a center of a carrier wafer** (Fig.1). Optionally the carrier wafer can contain etched pocket holder for the 15 x 15 mm LHAR4 chip and help to avoid unintentional chip movement during the experiment.

Notice that conformality can vary in a wafer area, depending on the reactor system and process conditions. Therefore, the exact position of the chip on the carrier wafer is recommended to be kept in control (such as placing the chip always on the center of the wafer).

In wafer level conformality monitoring, multiple LHAR4 chips are placed on a carrier wafer (Fig.1.). Typical use in that case is 5-9 chips on a carrier wafer per one deposition run.

Figure 1. PillarHall LHAR4 Test Chip can be used as a single chip on the center of the carrier wafer (left), or multiple chips on a carrier wafer to monitor wafer scale conformality.

In wafer level conformality monitoring we recommend using carrier wafers having eched pocket holders for the LHAR4 chips. Presently, Chipmetrics offers 150 mm and 200 mm pocket wafers targeted for wafer level conformality monitoring. Wafers contain pocket holders for 7-9 LHAR4 chips and they can also be customized. We are developing our offering also to 300 mm pocket wafers.

2. Preparation for the measurement: Removal of the top membrane

After deposition experiment and before executing the measurement, the top membrane needs to be removed.

Unload the LHAR4 test chip and carrier wafer from the deposition system, move the LHAR4 Test Chip to the safe location and remove the top membrane by an adhesive tape. **Follow the instructions given in PillarHall analysis guide and in "How to Remove Top Membrane by an Adhesive Tape" video link.**
https://www.youtube.com/watch?v=mos-BfXHgjQ

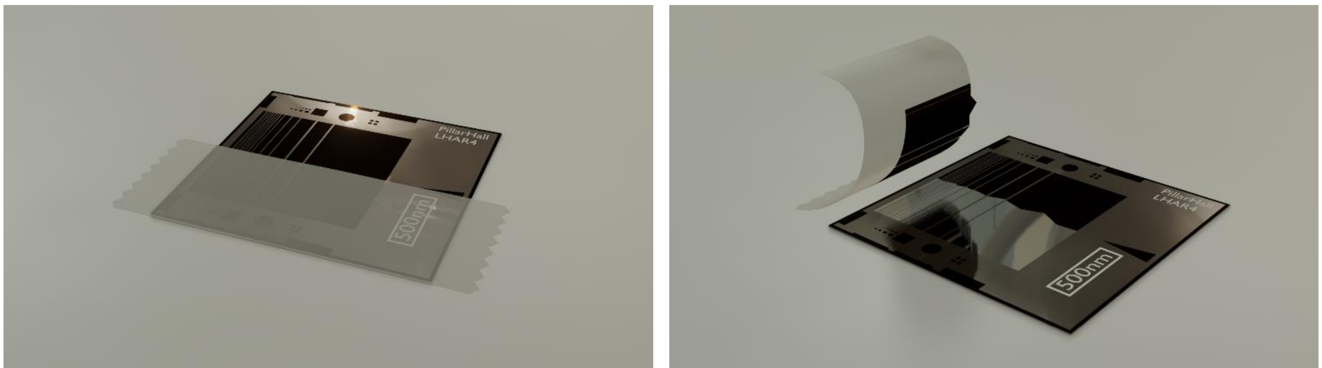


Figure 2. Illustration of the top membrane removal by an adhesive tape

3. Measurement

Guidance for the measurements with more details are given in the **PillarHall Analysis Guide and Chipmetrics Imaging Guide**.

A typical use is optical metrology measurements. Most common tools are optical microscope, reflectometer line-scanner and ellipsometer line-scanner.

INSTRUMENT	SPECIFICATION
Optical digital microscope	20-50x magnification, efficient illumination and optics, filters useful.
Reflectometer line-scanner	Spot size preferably <10 microns.
Ellipsometer line-scanner	Spot size <50 microns.

In addition, other metrology tools can be compatible as well. Typical requirements for the metrology measurement instrument are as follows:

- Versatile lateral scanning area 50-1000 microns (x, or xy)
- Height resolution < 1 nm (z)
- Lateral resolution < 5 microns (xy)

In the optical microscope measurement user captures the digital images for image analysis (instructed in the Chipmetrics image analysis guide). User can also send the image files to Chipmetrics Image Analysis Service.

In the spectrometer line scanners, when applicable to the thin film sample material, the instrument outcome is directly the film thickness. User should carefully position the scanner stage starting point such that membrane edge position can be identified. Chipmetrics can also offer measurement instrument services for customer's sample chips.

Generally, microscope and reflectometer sensitivities are limited by the film thickness (requires preferably >20 nm thickness) while ellipsometer is compatible to lower thickness (<10 nm). However, ellipsometer has typically lower lateral resolution than optical microscope or reflectometer.

Figure 3. Optical microscope measurement (left) and image (right) of a selected LHAR test structure.

4. Data for process monitoring

The aim of the measurement is to get numerical values for the film penetration depth profile. Profile is the film thickness as a function of the film penetration distance. Figure 4 illustrates a typical penetration depth profile.

The film penetration depth profile allows to determine characteristic values for conformality. The recent scientific literature [1] has proposed to use the penetration depth 50% (PD50%, ie. penetration distance point where film thickness has 50% of its initial value). Additionally, the slope at the PD50% position can be useful when modelling the reaction kinetics in ALD (Fig 4).

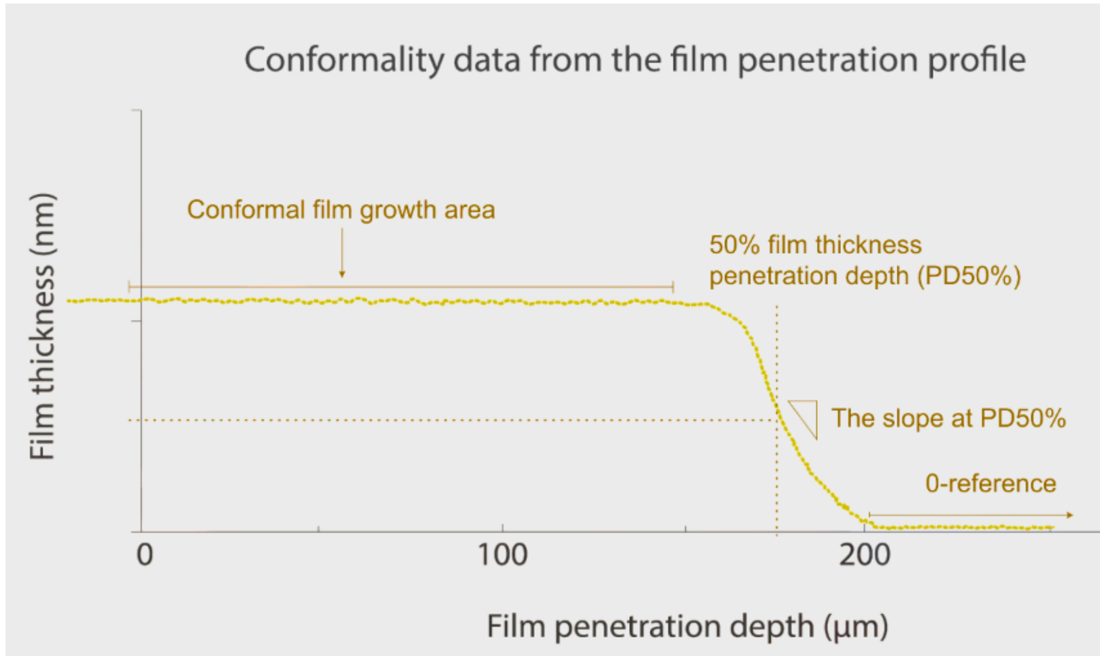
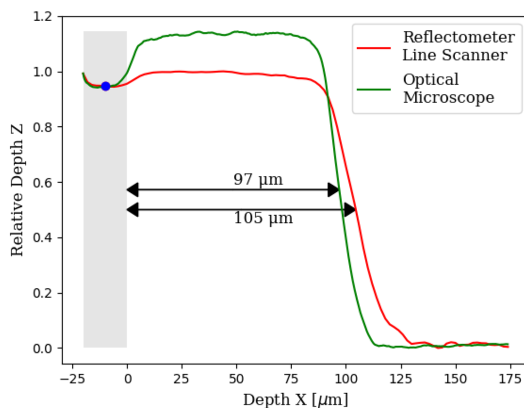


Figure 4. The film penetration depth profile and characteristic values of conformality.

The measurement provides PD50% unit in meters. Since the penetration depth depends strongly on the aspect ratio, the PD50% value is typically given as dimensionless distance (practically same as aspect ratio). This is obtained as follows:

PD50% (AR) = PD50% (L) / Gap Height (h)

Where PD50%(L) is the measured penetration depth and Gap Height (h) is 500 nm, as is in PillarHall LHAR4 test chips where all LHAR test structures have same gap height, h = 500 nm.



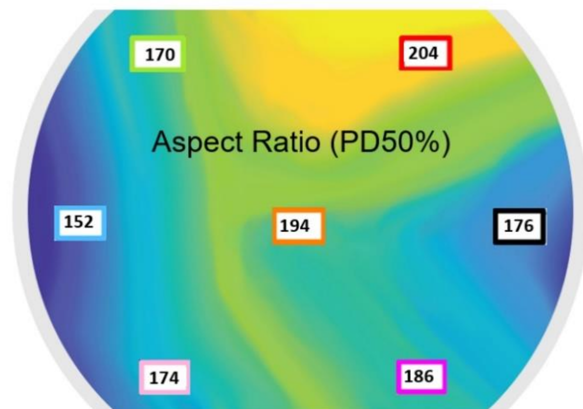


Figure 5. Examples of conformality measurement data.
Left: Film penetration depth profiles measured by optical microscope and reflectometer and extracted PD50% (L) values.
Right: PD50% (AR) values measured in the different positions on the wafer with the color illustration.

References

Scientific articles

1. Saturation Profile Based Conformality Analysis for Atomic Layer Deposition: Aluminum Oxide in Lateral High-Aspect-Ratio Channels, J. Yim, O.M.E. Ylivaara, M. Ylilammi, V. Korpelainen, E. Haimi, E. Verkama, M. Utriainen and R. L. Puurunen, *Phys. Chem. Chem. Phys*. **22** (2020), 23107, https://doi.org/10.1039/D0CP03358H
2. Sticking probabilities of H2O and Al(CH3)3 during atomic layer deposition of Al2O3 extracted from their impact on film conformality, K. Arts, V. Vandalon, R.L. Puurunen, M. Utriainen, F. Gao, W.M.M. Kessels, H.C. Knoops, *J. Vac. Sci. Technol. A* **37** (2019) art. 030908; https://doi.org/10.1116/1.5093620
3. Conformality in atomic layer deposition: current status overview of analysis and modelling, V. Cremers, R.L. Puurunen, J. Dendooven, *Appl. Phys. Rev*. **6** (2019) art. 021302; https://doi.org/10.1063/1.5060967

Product and service documents

- PillarHall Chip Handling Guide
- PillarHall Analysis Guide
- PillarHall LHAR4 Product Data Sheet
- Chipmetrics Film Penetration Depth Profile Measurument Services
- Imaging Guide for PillarHall LHAR4

Video links

- How to Remove Top Membrane by an Adhesive Tape: https://www.youtube.com/watch?v=mos-BfXHgjQ
- Animation introducing PillarHall Test Chip: https://www.youtube.com/watch?v=hOuprlmLy2E

Further information

- www.chipmetrics.com (company web site)
- www.pillarhall.com (product and science behind PillarHall technology)