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Monitoring Accuracy And Robustness In On-Product Diffraction-Based Overlay Metrology

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Introduction

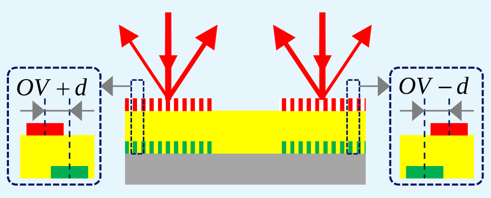
Over the last couple of years Diffraction-Based Overlay metrology (µDBO) has become a Tool-of-Record on many critical layers in logic and memory devices. In µDBO overlay is determined from an intensity difference ΔI between the +1st and -1st diffraction order of light that is diffracted by 2 overlapping gratings.

The optical coupling between these overlapping gratings results in a wavelength-dependent overlay sensitivity K which can be shown with a simplified theory of the µDBO signal formation.

In this poster we will show how µDBO deals with 2 challenges in overlay metrology: Asymmetric grating asymmetry (caused by processing steps like etch and CMP) and grating imbalance (caused by CMP and spin coat).

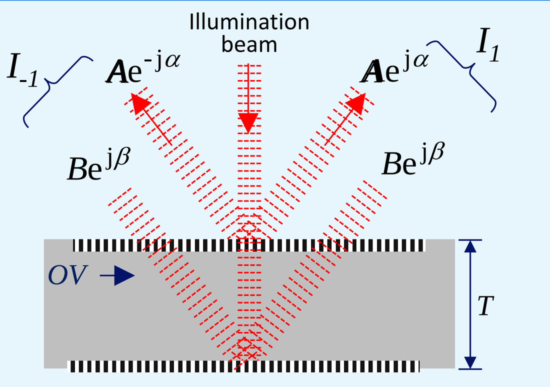
µDBO uses overlapping gratings with a shift +*d* and -*d*

$\Delta I_+ = K(OV+d)$ $\Delta I_- = K(OV-d)$



- K is called *overlay sensitivity*
- OV follows from ΔI_+ and ΔI_-

$$OV = d \times \frac{\Delta I_+ + \Delta I_-}{\Delta I_+ - \Delta I_-}$$



β depends on thickness (T): $\beta \approx 4\pi \frac{T}{\lambda}$

α is proportional to overlay: $\alpha = 2\pi \frac{OV}{P}$

λ : wavelength P : grating pitch

Detected intensities:

$$I_1 = \left|Ae^{j\alpha} + Be^{j\beta}\right|^2 = A^2 + B^2 + 2AB\cos[\beta-\alpha]$$

$$I_{-1} = \left|Ae^{-j\alpha} + Be^{j\beta}\right|^2 = A^2 + B^2 + 2AB\cos[\beta+\alpha]$$

Intensity difference: $\Delta I = 4AB \times \sin(\beta)\sin(\alpha) \approx 8\pi \frac{AB}{P}\sin\left(4\pi\frac{T}{\lambda}\right)OV$

Overlay sensitivity : $K = \frac{\Delta I}{OV} = 8\pi \frac{AB}{P}\sin\left(4\pi\frac{T}{\lambda}\right)$

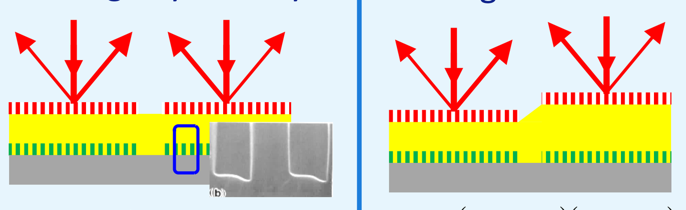
Selecting a Robust Measurement Recipe

Grating asymmetry causes a small offset ΔI_{BG} in the measured µDBO signal. The resulting overlay error can be minimized by picking a wavelength with a large overlay sensitivity K.

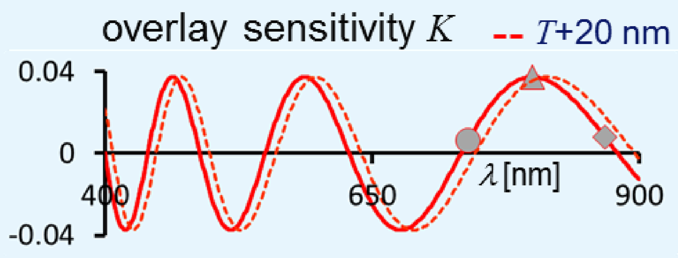
Grating imbalance results in a small difference ΔK of the overlay sensitivity. The resulting overlay error can be eliminated by picking a recipe where K is insensitive to small process changes. A good indicator for this is the σ_k/K variation over the wafer.

According to the simplified swing-curve theory, the best wavelength should be near a peak of the overlay sensitivity K as a function of wavelength. In that region the sensitivity for process changes is low.

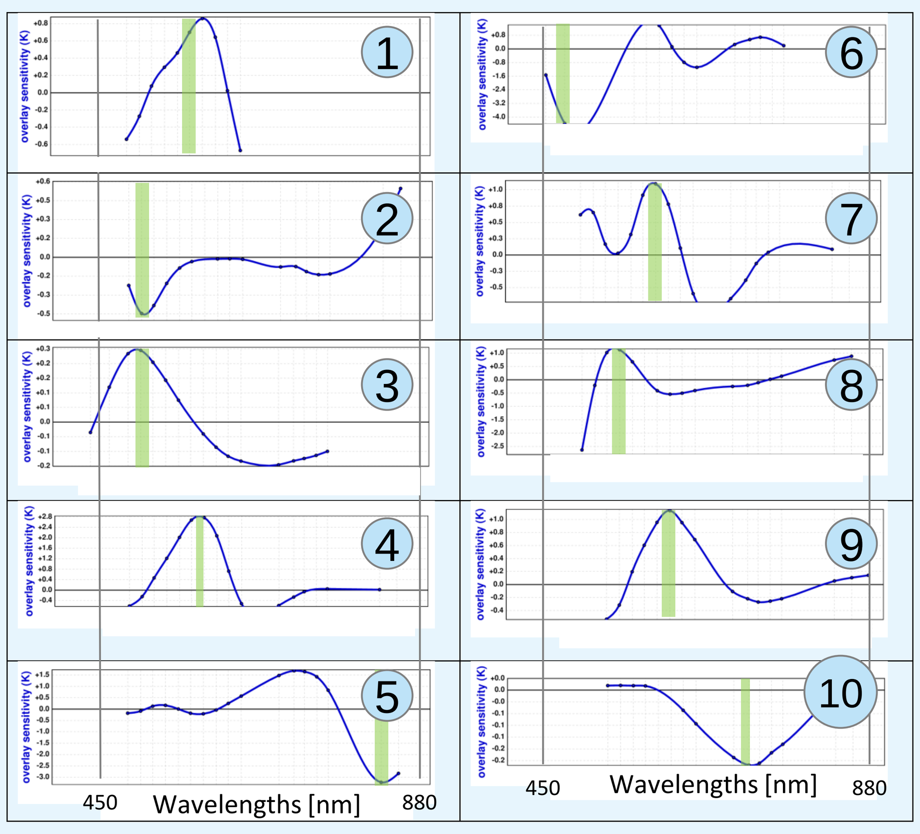
Grating Asymmetry	Grating Imbalance
$\Delta I_+ = K(OV+d) + \Delta I_{BG}$ $\Delta I_- = K(OV-d) + \Delta I_{BG}$	$\Delta I_+ = (K+\Delta K)(OV+d)$ $\Delta I_- = (K-\Delta K)(OV-d)$
error: $\Delta OV = \frac{\Delta I_{BG}}{K}$	error: $\Delta OV = \frac{\Delta K}{K} d$
solution: use a recipe with large K and small $\Delta K/K$	



swing curves for T = 1100 nm



Measured swing curve on different production layers. Shaded areas are the best wavelength regions where K is large and σ_k/K low.

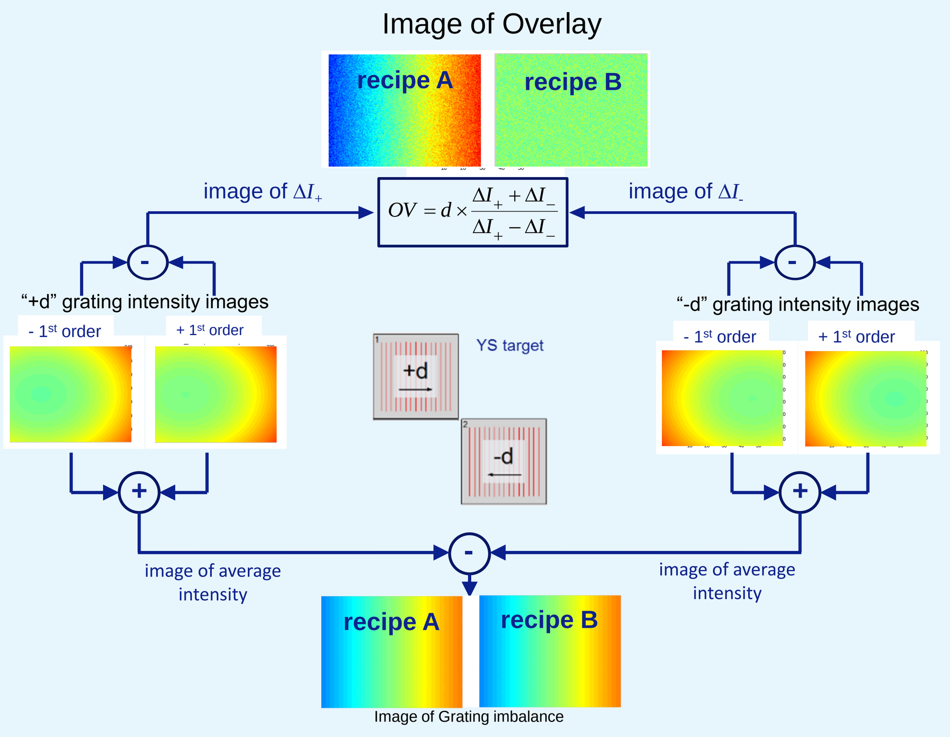


Monitoring Grating Imbalance (GI)

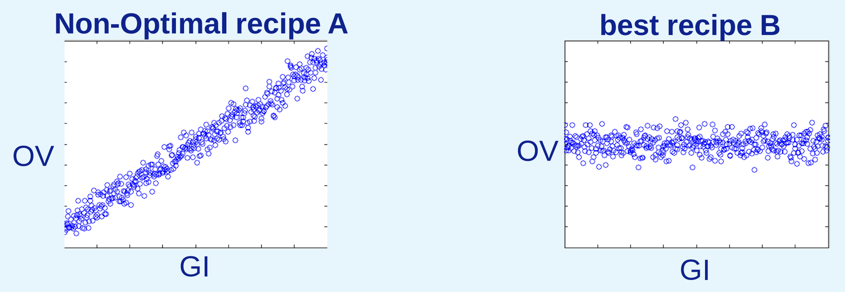
Image plane detection of µDBO has a unique capability for run-time detection of (changes in) Grating Imbalance (GI).

GI shows up as a stack variation within a grating. It's impact on overlay can be quantified in a nm-number by measuring GI and Overlay on a per-pixel basis in a grating image as shown in the drawing.

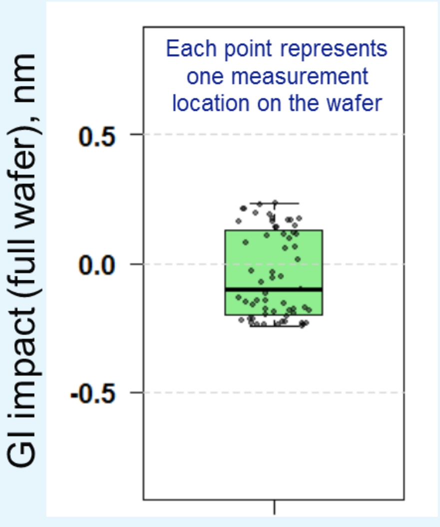
A plot of overlay as function of GI is a straight line. For a good recipe this slope should be 0 which indicates that GI has no impact on OV.



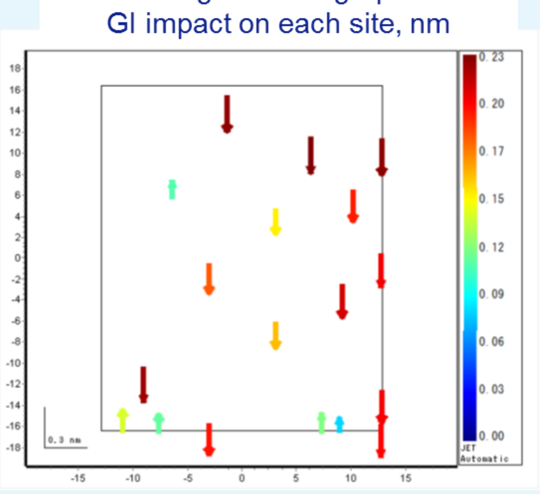
Site level grating imbalance KPI ("nm-like") can be derived



measured GI data



Average field-fingerprint
GI impact on each site, nm

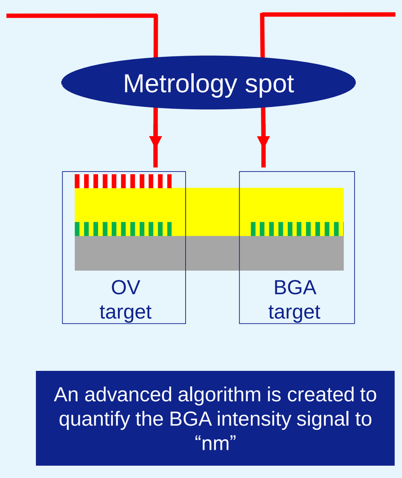


Monitoring Bottom Grating Asymmetry (BGA)

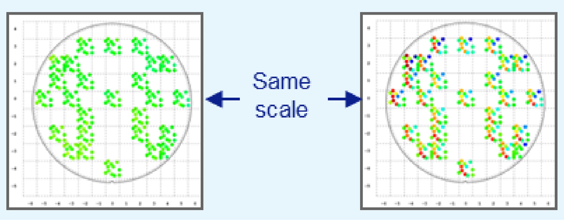
A large measurement spot can simultaneously measure overlay from a µDBO target and a Bottom Grating Asymmetry (BGA) intensity signal from a dedicated bottom grating (BGA target).

We can use the simplified µDBO signal formation theory to calculate an estimated asymmetry-induced overlay error that from the measured BGA intensity signal.

This run-time overlay error estimation can flag sudden process changes in a high-volume manufacturing environment.



BGA map in "nm"



KPI	Description	Wafer 1	Wafer 2
On product overlay		X nm	~ 2X nm
Stack Sensitivity (mean)	OVL signal contrast	-0.349	-0.350
Overlay sensitivity (K) (mean)	process dependency of OV	31.294	30.947
σ(K)/mean(K)	Overlay Signal to Noise	0.047	0.044
Grating Imbalance (m3s)	stack variation within the target real-estate	0.141	0.160
BGA intensity (99.7%)	Bottom grating asymmetry	7.581	31.111
BGA error in "nm" (99.7%)		1.566	5.916

Same recipe is used

An excursion wafer (#2) is successfully detected by BGA KPI where bottom grating asymmetry (BGA) impacting overlay measurement: here BGA increased significantly and other KPIs (such as contrast etc.) are not impacted