SWTEST
PROBE TODAY, FOR TOMORROW

A FULLY AUTOMATIC ELECTRO-OPTICAL TEST SYSTEM ENABLING THE DEVELOPMENT OF A SILICON PHOTONICS TECHNOLOGY PLATFORM

Jeroen De Coster, Rafal Magdziak,
Peter De Heyn, Erik Jan Marinissen,
Marianna Pantouvaki, Joris Van Campenhout, Philippe Absil

imec
Leuven, Belgium

Dan Rishavy, Joe Frankel,
Kainoa Kekahuna, Kazuki Negishi,
Mike Simmons, Eric Christenson

FormFactor™
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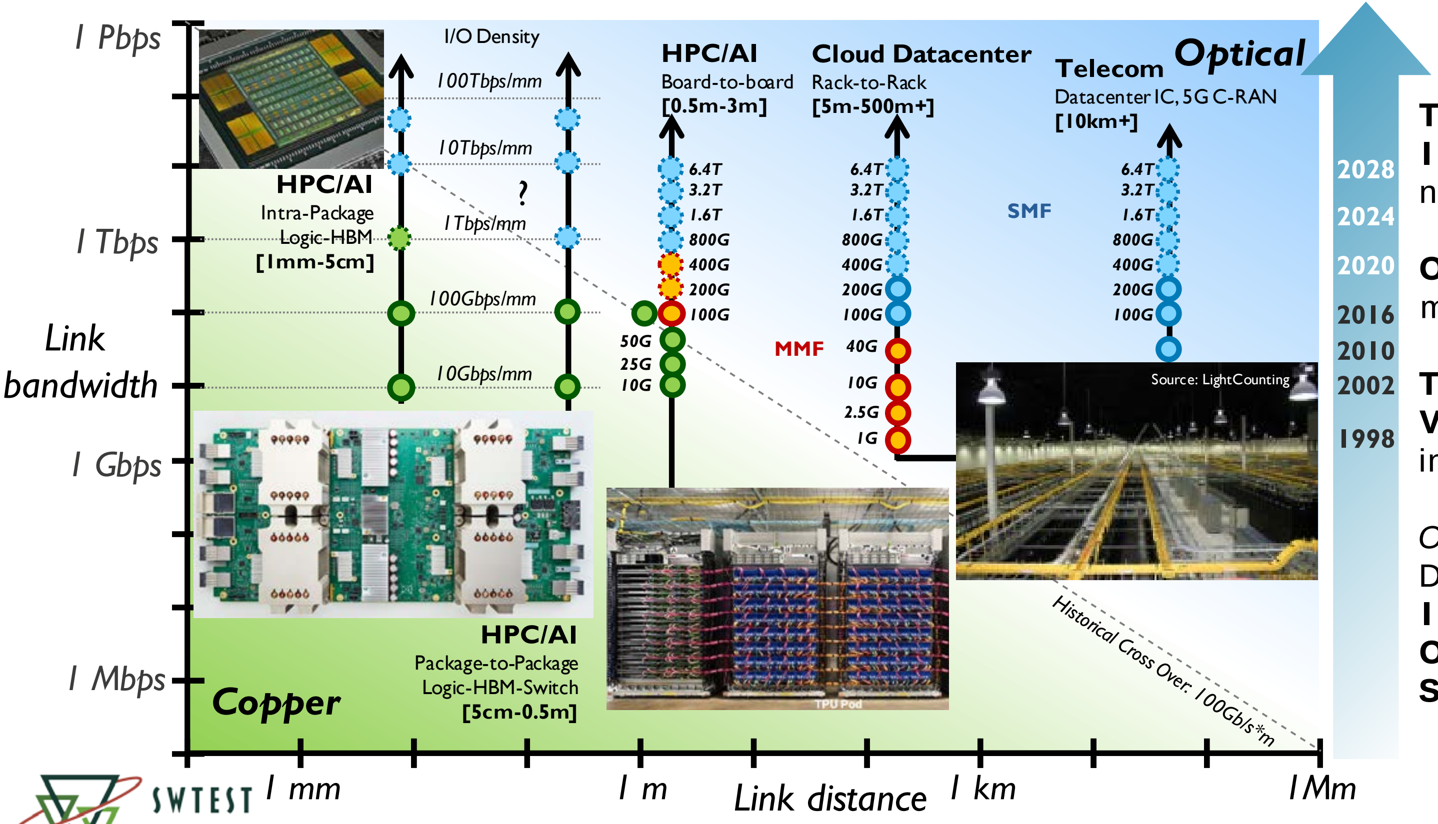
OUTLINE

- What are we developing:
  - Silicon photonics platform
- What do we want to measure?
  - Platform-specific device parameters
- How do we measure
  - Baseline flow, test hardware
  - Python test executive
- Working in the CR environment
- Data analysis and reporting
- Setup monitoring
- Conclusion

OPTICAL INTERCONNECT LANDSCAPE

OPTICAL LINKS REPLACING ELECTRICAL LINKS AT PROGRESSIVELY SHORTER INTERCONNECT DISTANCES



Terabit-Scale Optical Interconnectivity will be needed by **early 2020's**

Optical Interconnects will move **into the rack (<3m)**

Total Optical Transceiver Volume expected to increase >>**10x**

Objective:
Develop a **Silicon Photonic Integration Platform** for **Optical Interconnect Scaling** at all link distances.

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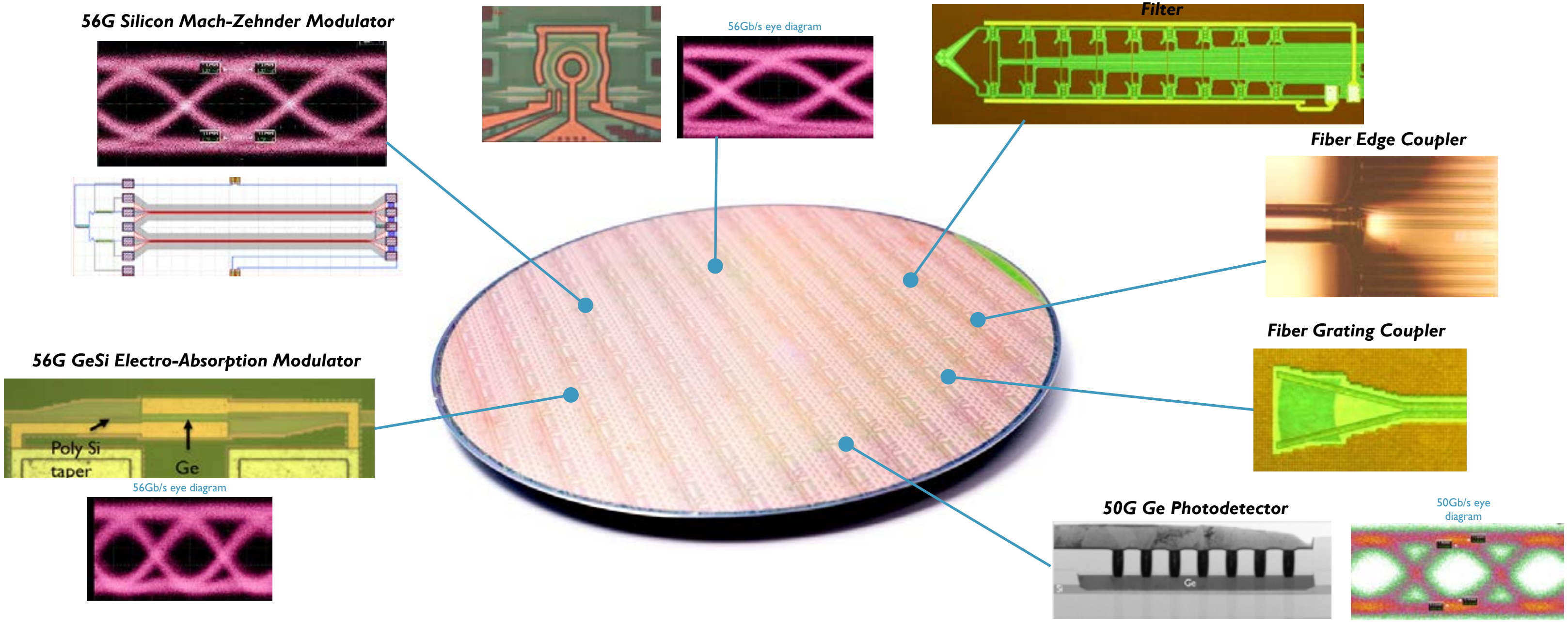
2019 CONFERENCE

What are we developing

IMEC'S 50G SILICON PHOTONICS PLATFORM

FULLY INTEGRATED 50GB/S NRZ, WDM SI PHOTONICS TECHNOLOGY



56G Silicon Mach-Zehnder Modulator

56G Silicon Ring Modulator

56Gb/s eye diagram

8+1-channel DWDM (De-)Multiplexing Filter

Fiber Edge Coupler

Fiber Grating Coupler

56G GeSi Electro-Absorption Modulator

56Gb/s eye diagram

50G Ge Photodetector

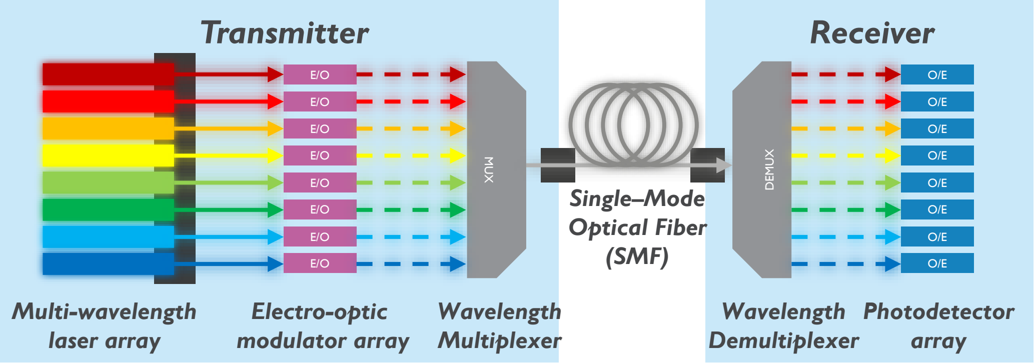
50Gb/s eye diagram

- Co-integration of the 50Gb/s building blocks in a single platform based on CMOS090
- Supports all dominant Si Photonics transceiver concepts pursued in industry & academia
- Available on 200mm [iSiPP200], under development on 300mm [iSiPP300]
- Based on 220nm Silicon / 2000nm BoX SOI wafers

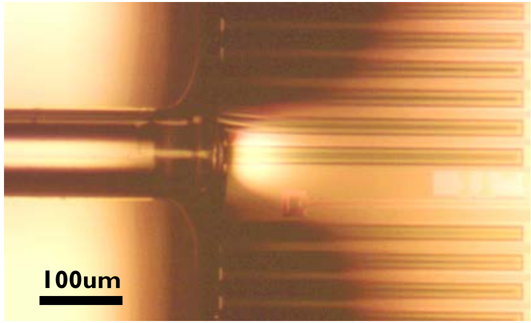
What are we developing

WAFER LEVEL TESTING

FIBER AND LASER COUPLING STRUCTURES

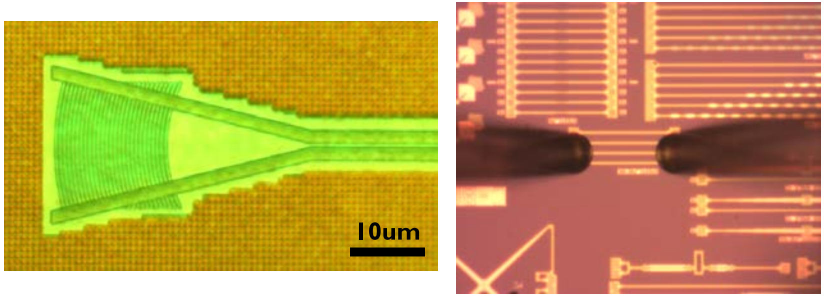


In-Plane Coupler



<2dB loss over 100nm+

Surface-Normal Grating Coupler



<3dB loss over 30nm

INTRODUCTION

WHAT DO WE WANT TO MEASURE

PROCESS CONTROL MONITORING

- Monitor technology-specific parameters
- Observe impact of process splits on these parameters during development of the technology platform

Component		**Test sites**	
Passive		Grating couplers	Insertion loss, bandwidth, peak wavelength
O-band *1310nm*	C-band *1550nm*	Waveguide spirals	Propagation loss, bend loss
		Crossings	Insertion loss, cross-talk
		Transitions	Insertion loss
		Directional coupling	Power coupling, excess loss
		Splitters	Insertion loss, excess loss
Active		Germanium photo diode	Dark current, responsivity
O-band *1310nm*	C-band *1550nm*	Mach-Zehnder interferometer	Insertion loss, Vpi
		Phase shifter loss	Propagation loss

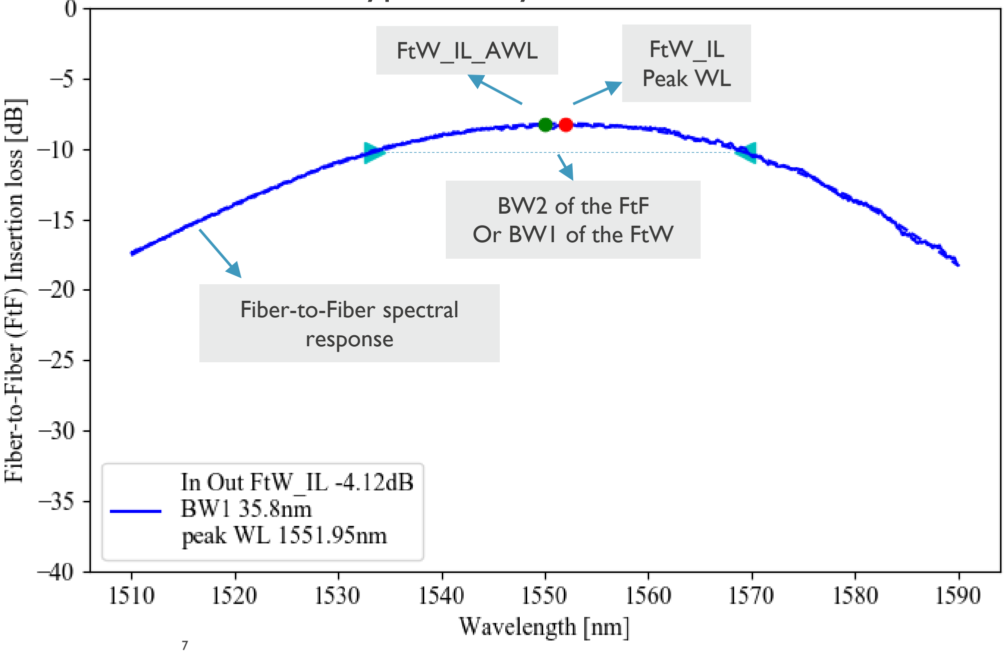
What do we want to measure

PROCESS CONTROL MONITOR STRUCTURES

FIBER GRATING COUPLER (FGC) PERFORMANCE

- A straight waveguide with a grating coupler on both ends
- Measured quantity: wavelength dependent insertion loss, fiber to fiber
- Extracted device parameters
  - Fiber-to-waveguide insertion loss
    FtW_IL_AWL [dB]
  - Peak wavelength
    PWL [nm]
  - Peak wavelength IL
    FtW_IL [dB]
  - 1dB bandwidth
    BW1 [nm]

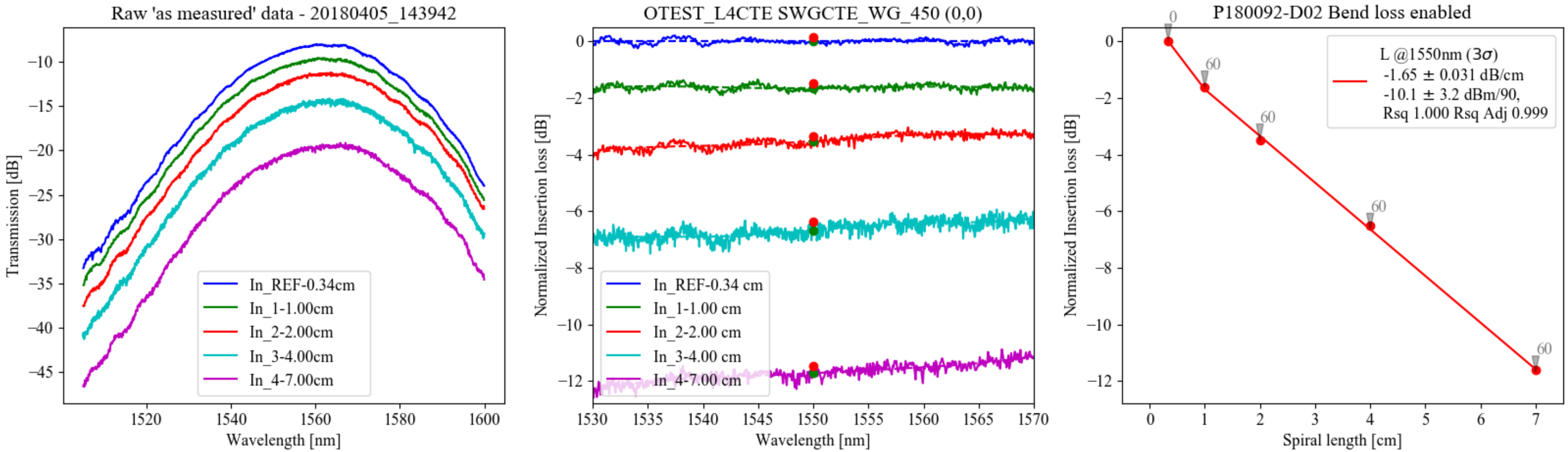
Typical analysis of a FGC



PROCESS CONTROL MONITOR STRUCTURES

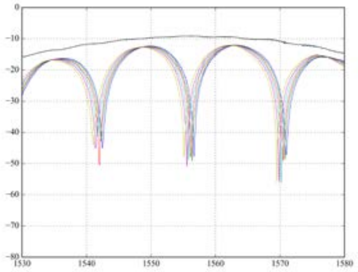
PROPAGATION LOSS TEST

- A set of (spiral) waveguides with increasing lengths *L* , *#bends*
- Measured quantity: wavelength dependent loss vs. length
- Linear regression of IL vs L, #bends to obtain propagation and bend loss

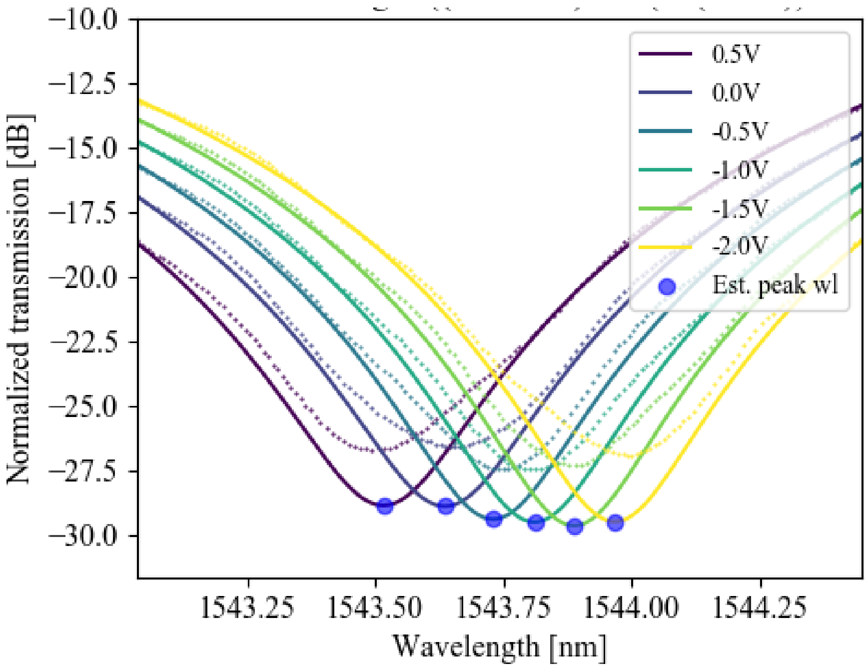


PROCESS CONTROL MONITOR STRUCTURES

MODULATOR TEST



- Measured quantity: IV, wavelength dependent loss vs. DC bias
- Spectral response fitted with raised cosine
  - Data (dotted line)
  - Fit (solid line)
- Parameters extracted:
  - Insertion loss
  - Modulation efficiency Vpi



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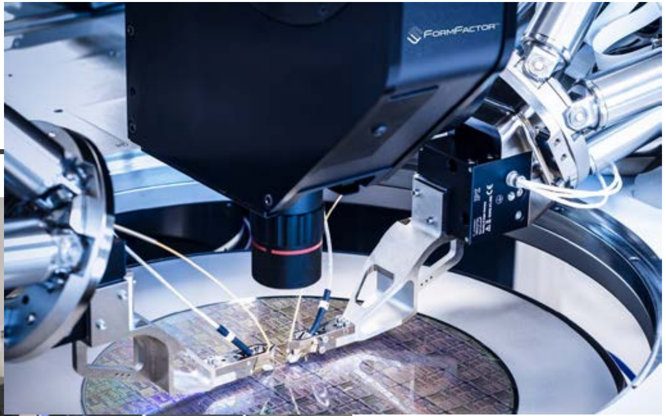
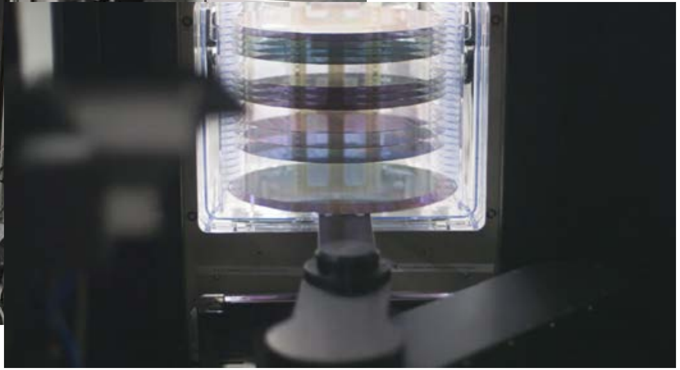
How do we measure

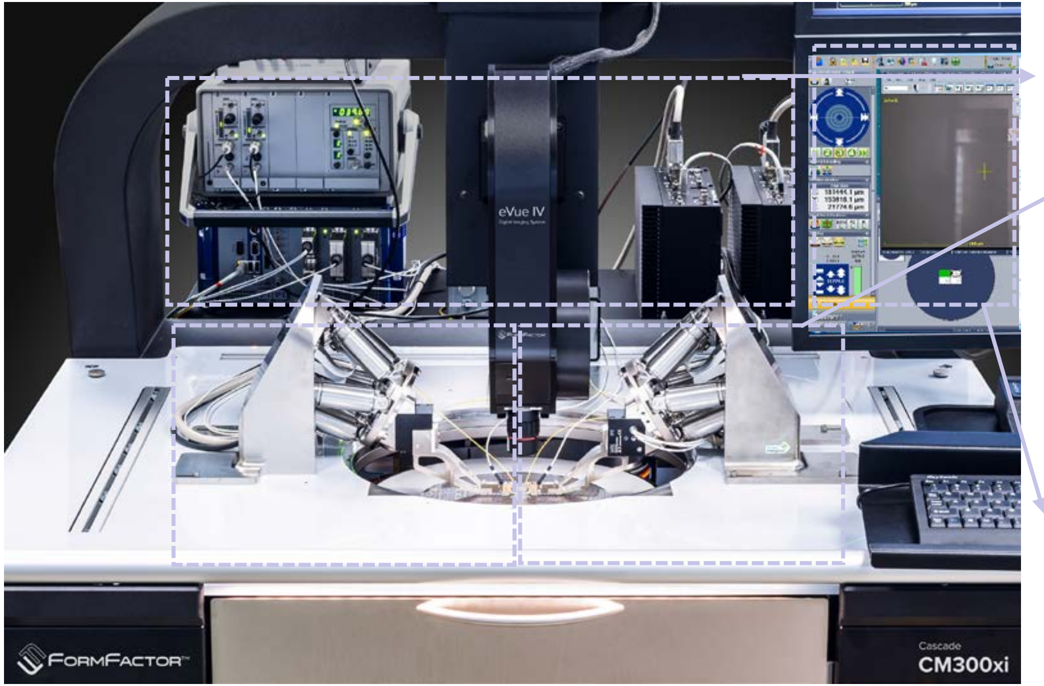
THOR TEST SYSTEM IN IMEC’S 200mm FAB

FORMFACTOR CM300xi-SiPh PROBE STATION WITH SiPh-





AUTONOMOUS SiPh MEASUREMENT ASSISTANT FOR CM300xi

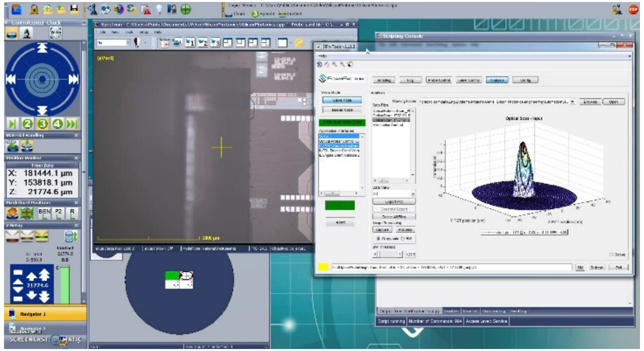


Positioning and Z Displacement Control

Integrated and Validated Single or Dual Sided 6 Axis Automated Positioning

- FFI On-site warranty and spares
- Interchangeable Fiber Arm
- Single Fiber or Array Holders
- Integrated Z Displacement
- Integrated Illumination
- Calibration Kit
- Integration Kit

SiPh-Tools: Automated Calibrations and Alignments



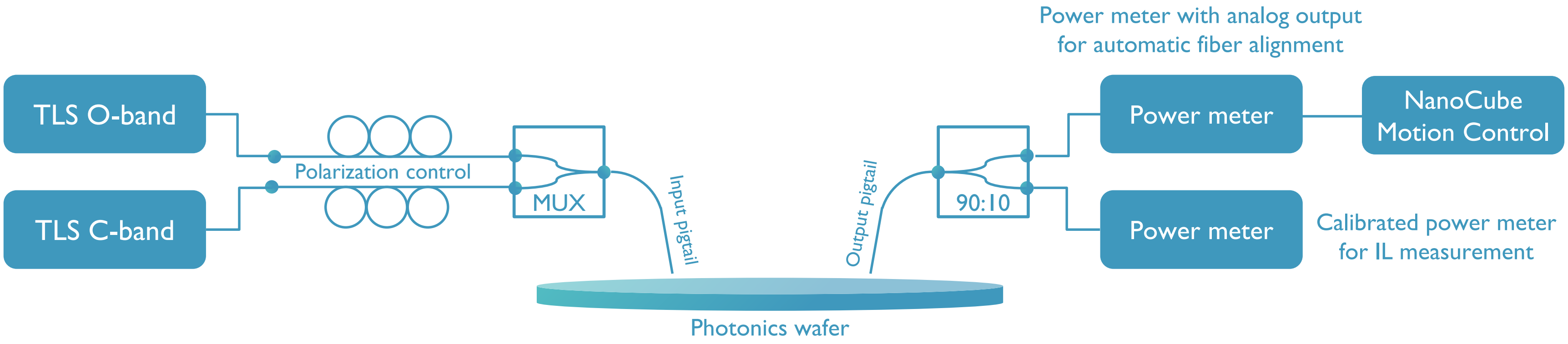
X: 181444.1 µm
Y: 153818.1 µm
Z: 21774.6 µm

FormFactor's Cascade CM300xi Probe Station
Highly Stable and Robust Platform for Optical/Electrical Probing

THOR TEST SYSTEM

SCHEMATIC LAYOUT OF THE OPTICAL PATHS

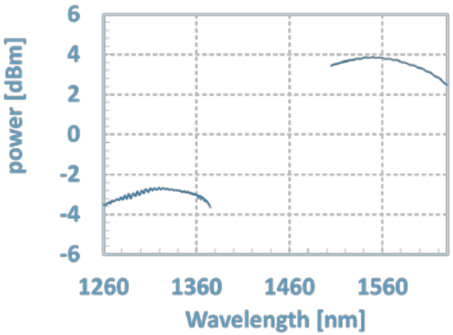
- Dual tunable laser sources O- and C-band
- All single mode fiber (SMF28)
- Measurement pigtails with straight cleaved facets
- Nominal incidence angle 10° from vertical

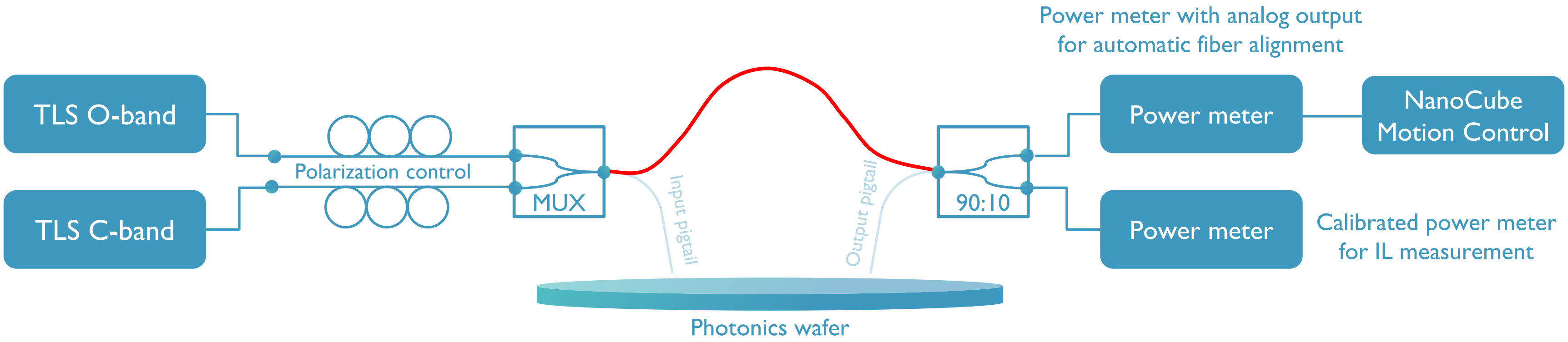


INSERTION LOSS CALIBRATION

NORMALIZATION OF MEASURED LOSS SPECTRA

- Measurement pigtails bypassed with a SMF28 patch cord
- Loss spectrum of components in the optical path measured over full range of TLS
- Measured spectra normalized against this spectrum





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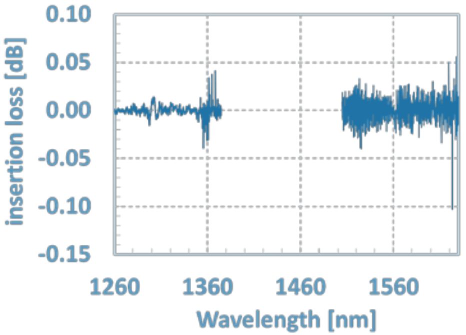
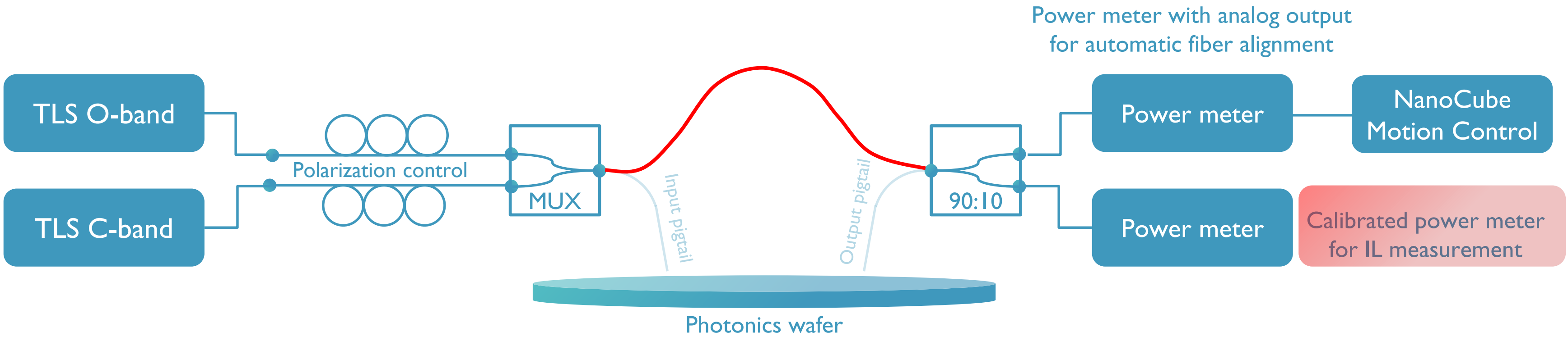



Power meter with analog output
for automatic fiber alignment

TLS O-band

TLS C-band

Polarization control

MUX

Input pigtail

Output pigtail

90:10

Power meter

NanoCube
Motion Control

Power meter

Calibrated power meter
for IL measurement

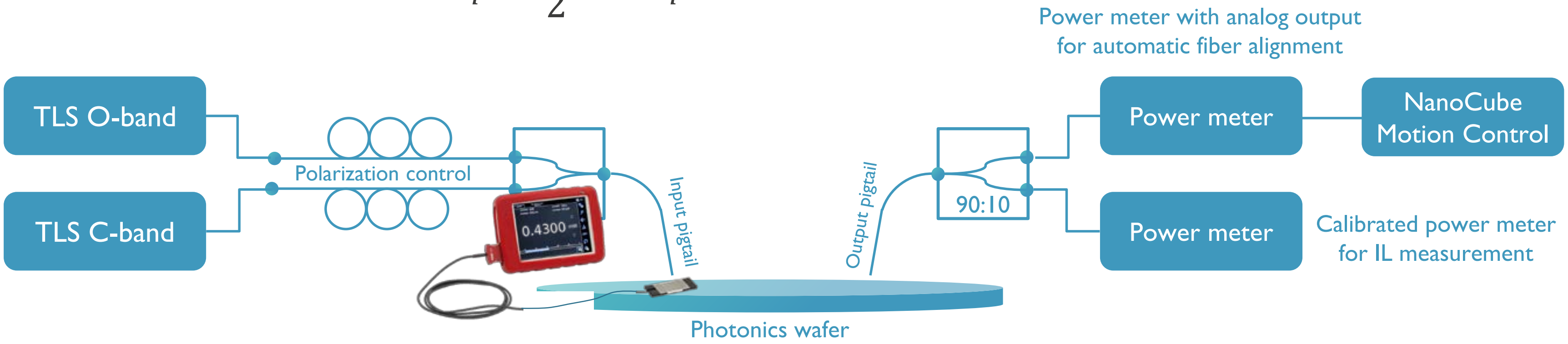
Photonics wafer

ABSOLUTE POWER CALIBRATION

INPUT PIGTAIL POWER MEASUREMENT

- Free-space power meter is used to measure absolute power at tip of input pigtail
- At different Ge photo diode target wavelengths
- Required to estimate power at DUT for responsivity calculation*

$$p_{dut} = p_{tip} - \frac{IL}{2} = p_{tip} - FtW\ IL$$



*assuming equal coupling loss at input and output pigtails

BASELINE MEASUREMENT FLOW

Calibration

- Calibrate wafer-level insertion loss (IL) measurement
- Calibrate absolute input power

Load

- Wafer transport, alignment, profiling
- Set fibers at nominal height
- Polarization tuning

Probe check

- Check probe contact
- Run open/short measurement on a few dies

Measure

```
for die in wafer map:
    for test site in test plan:
        for device in test site:
            chuck movement to device
            chuck Z: 50µm below contact for passives
            for left, right gratings in device:
                fiber movement to input/output gratings
                align left/right fiber at $\lambda=\lambda_0$
                [perform I sweep, detect peak $\lambda=\lambda_I$]
                [re-align at $\lambda=\lambda_I$]
                execute specified test recipe
```

BASELINE MEASUREMENT FLOW

Calibration

- Calibrate wafer-level insertion loss (IL) measurement
- Calibrate absolute input power

1x/month

Load

- Wafer transport, alignment, profiling
- Set fibers at nominal height
- Polarization tuning

Probe check

- Check probe contact
- Run open/short measurement on a few dies

1x/lot

Measure

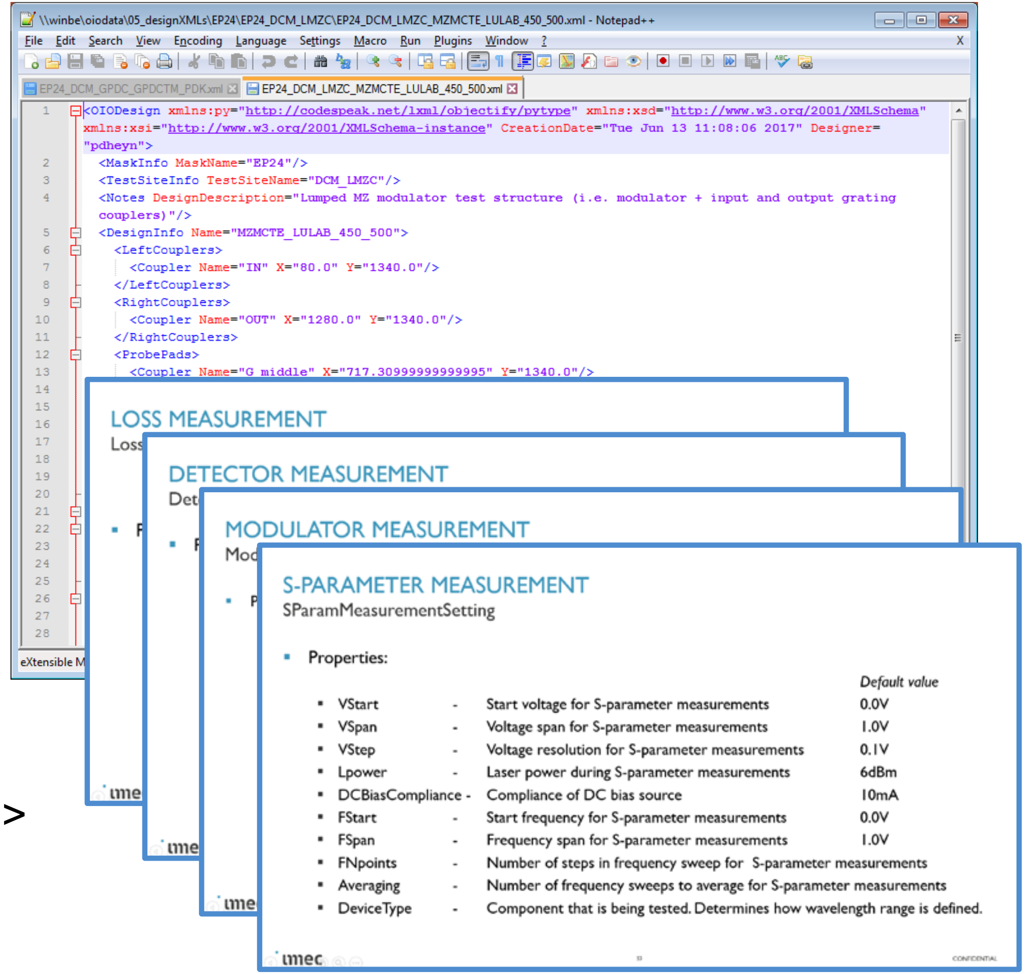
```
for die in wafer map:
    for test site in test plan:
        for device in test site:
            chuck movement to device
            chuck Z: 50µm below contact for passives
            for left, right gratings in device:
                fiber movement to input/output gratings
                align left/right fiber at $\lambda=\lambda_0$
                [perform l sweep, detect peak $\lambda=\lambda_l$]
                [re-align at $\lambda=\lambda_l$]
                execute specified test recipe
```

1x/wafer

How do we measure

TEST EXECUTIVE SOFTWARE

- Python code, hosted on Git
- Code for test execution and data analysis & reporting
- Test plan = Python script
  - Grating coupler and probe pad coordinates pulled from XML design library
  - Settings objects defined for different built-in test recipes
  - Test plan defines a sequence of PortCombo<Input, Output, Probe pad> each linked with test settings object



```
<OIODesign xmlns:py="http://codespeak.net/lxml/objectify/pytype" xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" CreationDate="Tue Jun 13 11:08:06 2017" Designer=
"pdheyn">
  <MaskInfo MaskName="EP24"/>
  <TestSiteInfo TestSiteName="DCM_LMZC"/>
  <Notes DesignDescription="Lumped MZ modulator test structure (i.e. modulator + input and output grating
  couplers)"/>
  <DesignInfo Name="MZMCTE_LULAB_450_500">
    <LeftCouplers>
      <Coupler Name="IN" X="80.0" Y="1340.0"/>
    </LeftCouplers>
    <RightCouplers>
      <Coupler Name="OUT" X="1280.0" Y="1340.0"/>
    </RightCouplers>
    <ProbePads>
      <Coupler Name="G middle" X="717.30999999999995" Y="1340.0"/>
```

LOSS MEASUREMENT

Loss

DETECTOR MEASUREMENT

Det

MODULATOR MEASUREMENT

Mod

S-PARAMETER MEASUREMENT

SParamMeasurementSetting

- Properties:

			Default value
VStart	-	Start voltage for S-parameter measurements	0.0V
VSpan	-	Voltage span for S-parameter measurements	1.0V
VStep	-	Voltage resolution for S-parameter measurements	0.1V
Lpower	-	Laser power during S-parameter measurements	6dBm
DCBiasCompliance	-	Compliance of DC bias source	10mA
FStart	-	Start frequency for S-parameter measurements	0.0V
FSpan	-	Frequency span for S-parameter measurements	1.0V
FNpoints	-	Number of steps in frequency sweep for S-parameter measurements	
Averaging	-	Number of frequency sweeps to average for S-parameter measurements	
DeviceType	-	Component that is being tested. Determines how wavelength range is defined.	

TEST EXECUTION

OPERATING MEASUREMENT TOOL IN CLASS 1000 CLEAN ROOM

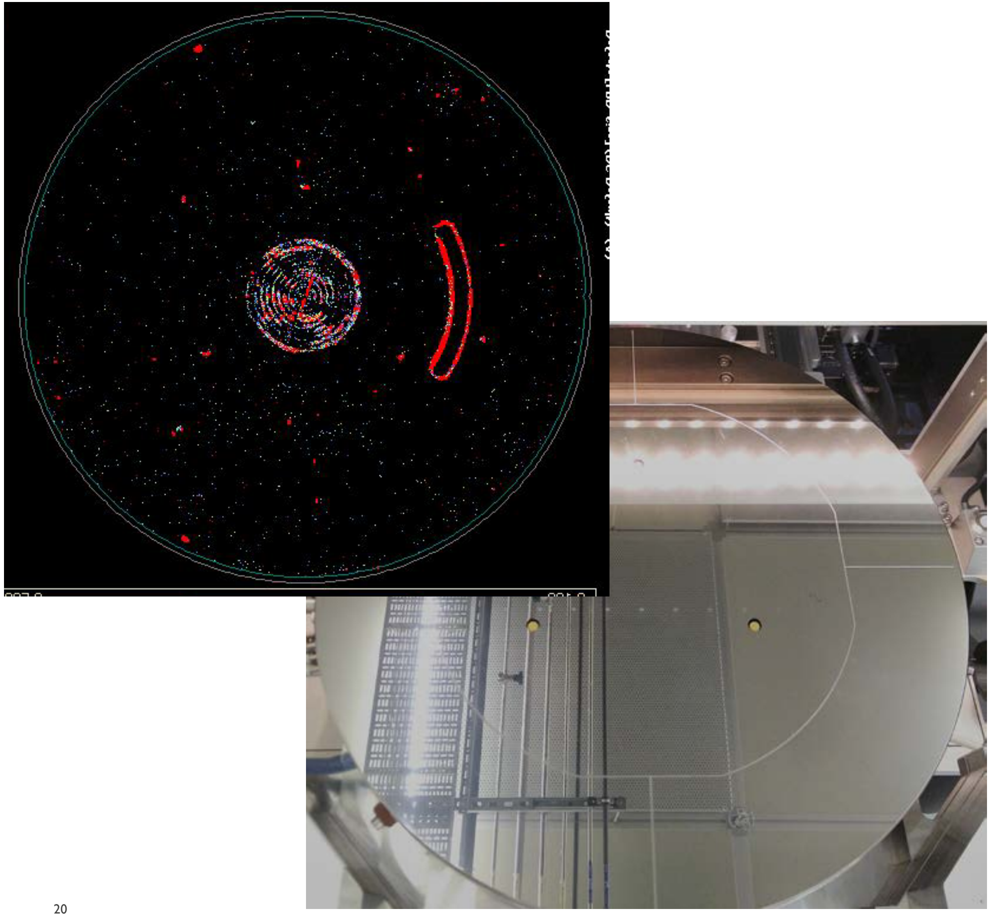
- Motivation
  - Operating the tool in a clean room allows to pull out wafers, measure, give feedback to process integration
  - Resulting in faster feedback
  - Wafers are not lost for processing, i.e. more inspections are possible
- Hence we need to verify metal/particle contamination in the tool
  - Front side particles: from clean room ambient, electrical probing
  - Front side metal contam: probing
  - Back side particles: robot arm, wafer chuck
  - Back side metal: robot arm, wafer chuck

TOOL CONTAMINATION STATUS

BACKSIDE PARTICLE MEASUREMENT

- Typical witness wafer work flow
  - Front-side particle measurement
  - Wafer flip
  - Go through normal load/unload cycle on tool
  - Wafer flip
  - Front-side particle measurement

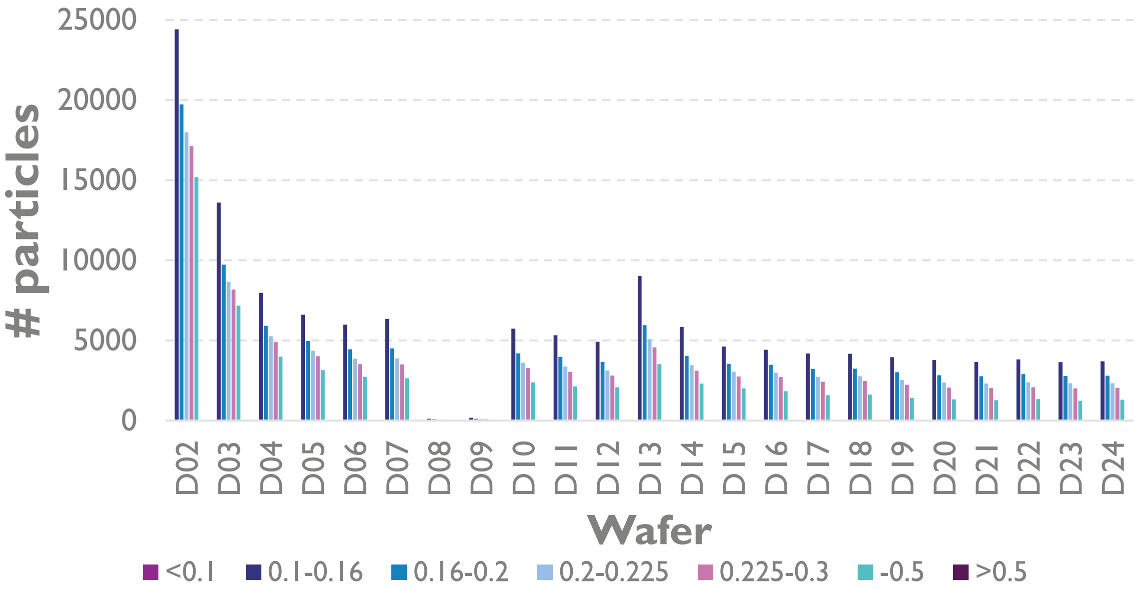
- Visible marks of robot arm, pre-aligner, chuck lift pins



BACKSIDE PARTICLE MEASUREMENT

VERIFICATION OF CLEANING PROCEDURE

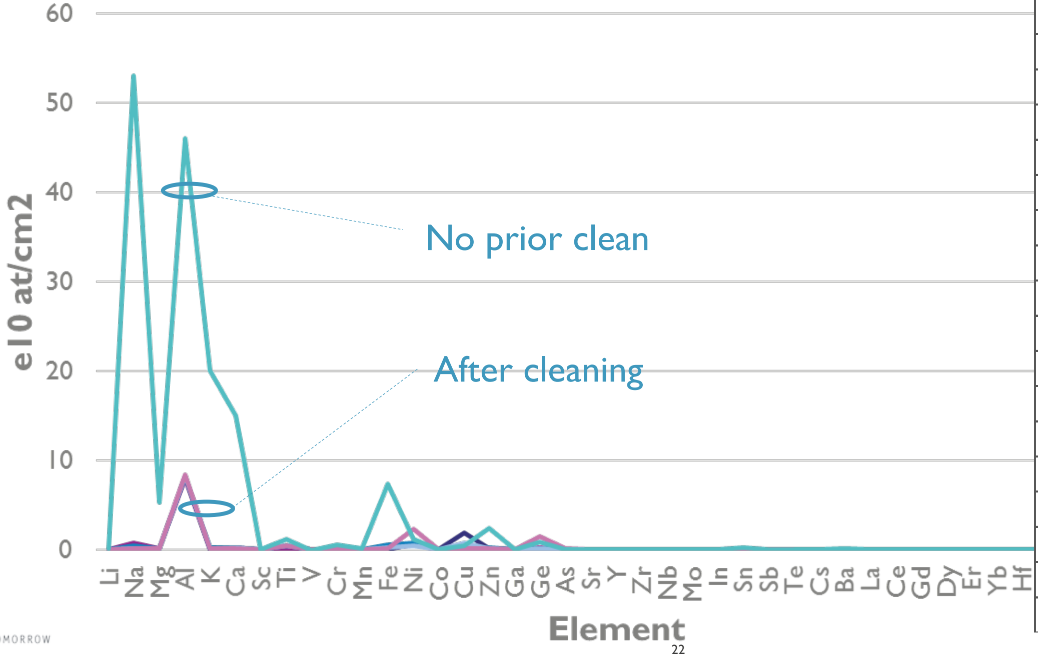
- Initial tool status: measured ~100 level 5 wafers
- No cleaning done before loading witness wafers
- After 10 wafers, particle count drop below spec limit for target contamination level 3
- Chuck cleaned with IPA after wafer 12
- Then loaded wafers 13-24
- Particle count stabilized after another 3-4 wafers



BACKSIDE METAL CONTAMINATION – TXRF MEASUREMENT

VERIFICATION OF CLEANING PROCEDURE

- Measurement without and with cleaning step prior to cycling witness wafer
  - Initial tool status: level 3
  - Cleaning step - wipe with IPA and blow dry N_2



No prior clean

After cleaning

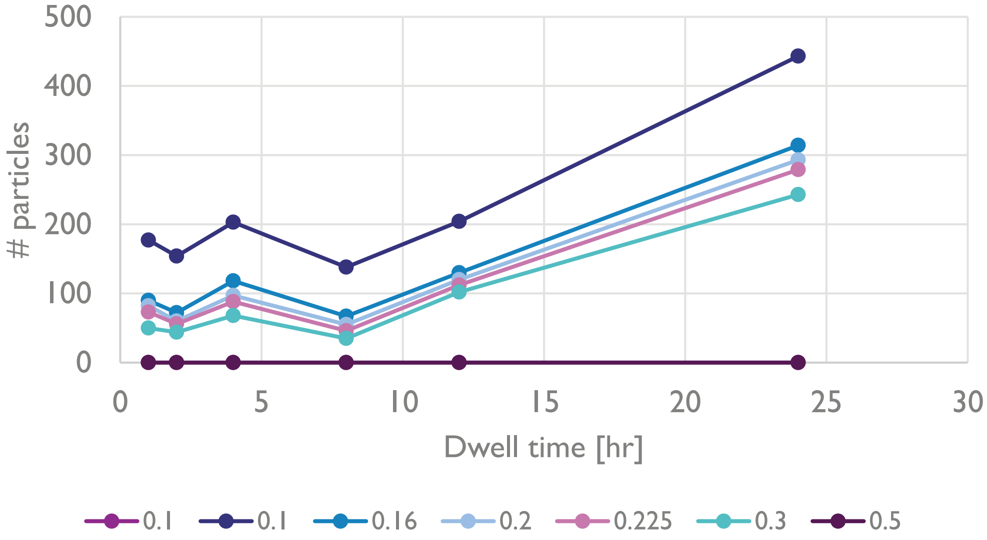
DuploWaferId	Element	Conc	WL	SL
D03	Li	0.04	10	100
D03	Na	0.8	100	999918
D03	Mg	0.15	100	999916
D03	Al	8	100	999907
D03	K	0.068	9999999	9999994
D03	Ca	0.24	9999999	9999992
D03	Sc	0.0037	10	100
D03	Ti	0.078	100	999924
D03	V	-4.00E-06	100	999925
D03	Cr	0.035	10	100
D03	Mn	0.0014	10	100
D03	Fe	0.08	10	50
D03	Ni	0.59	10	100
D03	Co	0.0016	10	100
D03	Cu	0.2	10	100
D03	Zn	0.11	10	100
D03	Ga	0.00044	100	999910
D03	Ge	0.19	100	9999998
D03	As	0.042	100	999908

Operation in clean room

FRONT SIDE PARTICLE MEASUREMENT

VERIFICATION OF PROBING AND AMBIENT

- Experiment #1: variable wafer dwell time on chuck: 1-2-4-8-12-24 hours
  - Only for dwell times > 10h, clear relationship between dwell time and #particles

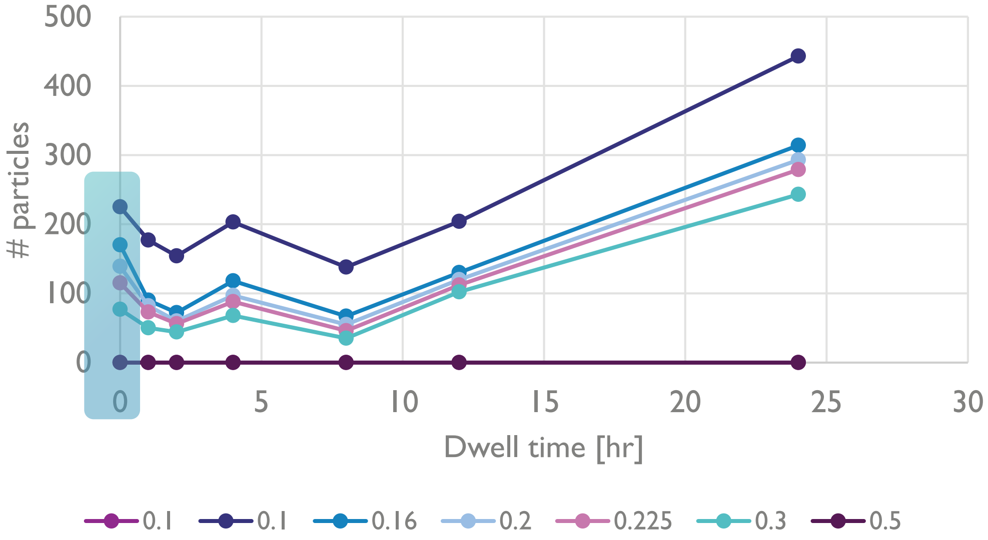


Operation in clean room

FRONT SIDE PARTICLE MEASUREMENT

VERIFICATION OF PROBING AND AMBIENT

- Experiment #1: variable wafer dwell time on chuck: 1-2-4-8-12-24 hours
  - Only for dwell times > 10h, clear relationship between dwell time and #particles
- Experiment #2: probe touchdowns



AUTOMATED DATA ANALYSIS

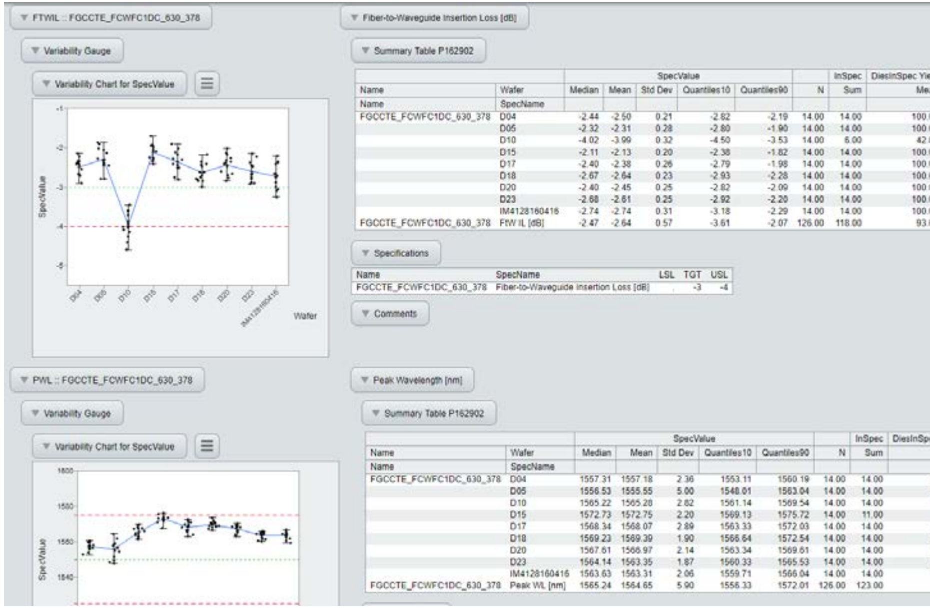
ANALYSIS WORK FLOW

- Python code in Git repository for data analysis
- Automation:
  - oio_pyro_service: Pyro 4 (Python remote objects) daemon encapsulated in a windows service (defined using win32serviceutil module) which exposes a number of analysis methods
  - oio_email_service: a windows service that encapsulates an email client; e-mail used to trigger analysis/report generation for a specified lot/wafer/...
  - Windows task scheduler to scan network folders for new data and automatically generate reports overnight
  - XML file meta data is used to select analysis method

AUTOMATED DATA ANALYSIS

REPORTING

- Output:
  - 1 csv file per lot and per component class
    - loss, photodiode, modulator, mmi, dc, …
  - Aggregated data table with all components
  - Aggregated data table including wafer statistics and spec check
    - Target, USL and LSL defined per component/parameter and project
  - HTML report
  - Results are also consolidated per component type across different lots



		SpecValue						InSpec	DiesInSpec Yie
Name	Wafer	Median	Mean	Std Dev	Quantiles10	Quantiles90	N	Sum	Me
Name	SpecName								
FGCCTE_FCWFC1DC_630_378	D04	-2.44	-2.50	0.21	-2.82	-2.19	14.00	14.00	100.
	D05	-2.32	-2.31	0.28	-2.80	-1.90	14.00	14.00	100
	D10	-4.02	-3.99	0.32	-4.50	-3.53	14.00	6.00	42.
	D15	-2.11	-2.13	0.20	-2.38	-1.82	14.00	14.00	100.
	D17	-2.40	-2.38	0.26	-2.79	-1.98	14.00	14.00	100.
	D18	-2.67	-2.64	0.23	-2.93	-2.28	14.00	14.00	100.
	D20	-2.40	-2.45	0.25	-2.82	-2.09	14.00	14.00	100.
	D23	-2.68	-2.61	0.25	-2.92	-2.20	14.00	14.00	100.
	IM4128160416	-2.74	-2.74	0.31	-3.18	-2.29	14.00	14.00	100.
FGCCTE_FCWFC1DC_630_378	FtW IL [dB]	-2.47	-2.64	0.57	-3.61	-2.07	126.00	118.00	93.

Name	SpecName	LSL	TGT	USL
FGCCTE_FCWFC1DC_630_378	Fiber-to-Waveguide Insertion Loss [dB]		-3	-4

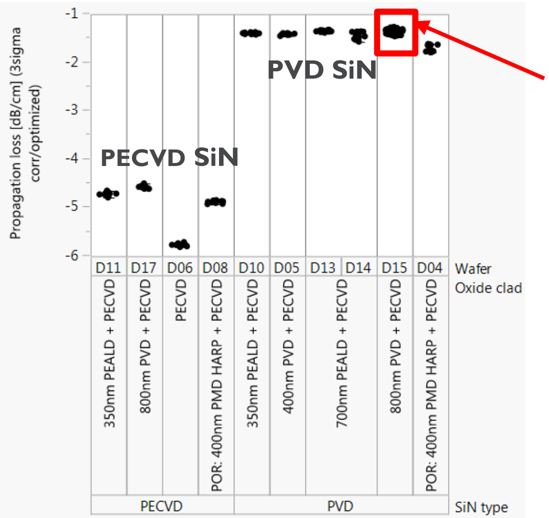
		SpecValue						InSpec	DiesInSp
Name	Wafer	Median	Mean	Std Dev	Quantiles10	Quantiles90	N	Sum	
Name	SpecName								
FGCCTE_FCWFC1DC_630_378	D04	1557.31	1557.18	2.36	1553.11	1560.19	14.00	14.00	
	D05	1556.53	1555.55	5.00	1548.01	1563.04	14.00	14.00	
	D10	1565.22	1565.28	2.82	1561.14	1569.54	14.00	14.00	
	D15	1572.73	1572.75	2.20	1569.13	1575.72	14.00	11.00	
	D17	1568.34	1568.07	2.89	1563.33	1572.03	14.00	14.00	
	D18	1569.23	1569.39	1.90	1566.64	1572.54	14.00	14.00	
	D20	1567.61	1566.97	2.14	1563.34	1569.61	14.00	14.00	
	D23	1564.14	1563.35	1.87	1560.33	1565.53	14.00	14.00	
	IM4128160416	1563.63	1563.31	2.06	1559.71	1566.04	14.00	14.00	
FGCCTE_FCWFC1DC_630_378	Peak WL [nm]	1565.24	1564.65	5.90	1556.33	1572.01	126.00	123.00	

N. Golshani et al, imec PTW April 2018

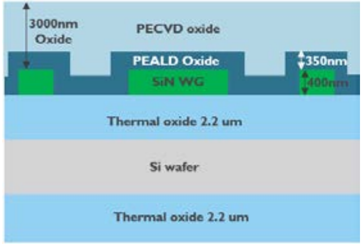
SiN WG PROPAGATION LOSS

MEASURED PROPAGATION LOSS AT **1520NM** WAVELENGTH

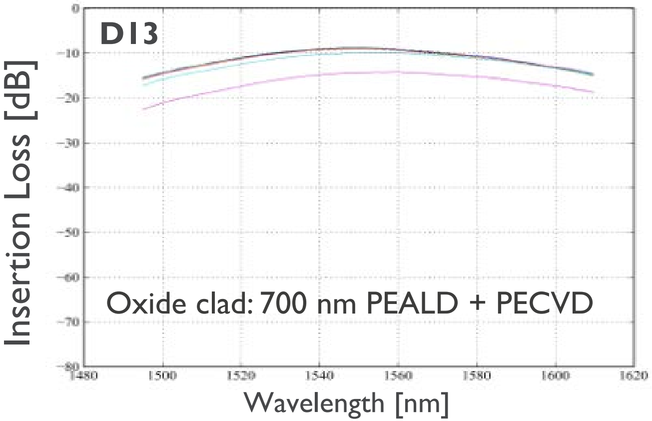
Waveguide propagation loss at 1520nm
W= 840nm, TE Polarization



- **D15:**
  - **SiN: PVD**
  - **Oxide: PVD + PECVD**



PVD/PECVD SiN WG on Si wafer



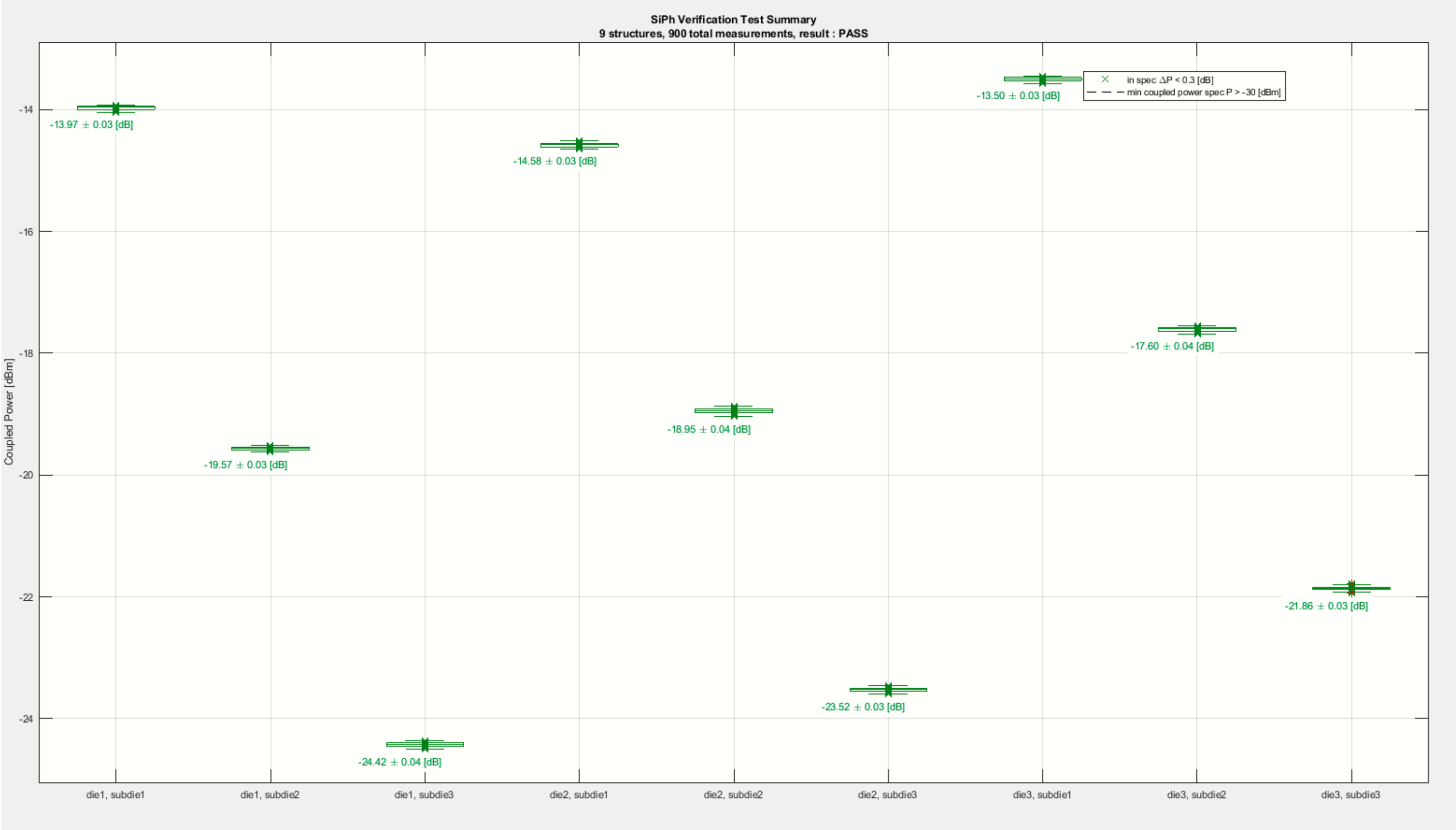
Oxide clad: 700 nm PEALD + PECVD

			Propagation loss [dB/cm] (3sigma corr/optimized)						
SiN type	**Oxide clad**	**Wafer**	**Mean**	**Std Dev**	**Min**	**Max**	**Quantiles90**	**Quantiles10**	**N**
PECVD	350nm PEALD + PECVD	D11	-4.72	0.03	-4.79	-4.65	-4.67	-4.77	15.00
	800nm PVD + PECVD	D17	-4.57	0.03	-4.61	-4.50	-4.51	-4.60	15.00
	PECVD	D06	-5.77	0.02	-5.81	-5.71	-5.72	-5.80	15.00
	POR: 400nm PMD HARP + PECVD	D08	-4.88	0.02	-4.92	-4.84	-4.85	-4.92	15.00
PVD	350nm PEALD + PECVD	D10	-1.40	0.02	-1.42	-1.37	-1.37	-1.42	14.00
	400nm PVD + PECVD	D05	-1.41	0.02	-1.45	-1.39	-1.39	-1.44	14.00
	700nm PEALD + PECVD	D13	-1.35	0.02	-1.38	-1.32	-1.32	-1.38	14.00
		D14	-1.43	0.07	-1.57	-1.35	-1.36	-1.53	15.00
	800nm PVD + PECVD	D15	-1.34	0.04	-1.46	-1.26	-1.30	-1.41	100.00
	POR: 400nm PMD HARP + PECVD	D04	-1.70	0.07	-1.79	-1.62	-1.62	-1.79	13.00

Propagation loss at 1520 nm:

- Last PTW : 4.9dB/cm
- Now : 1.34 dB/cm

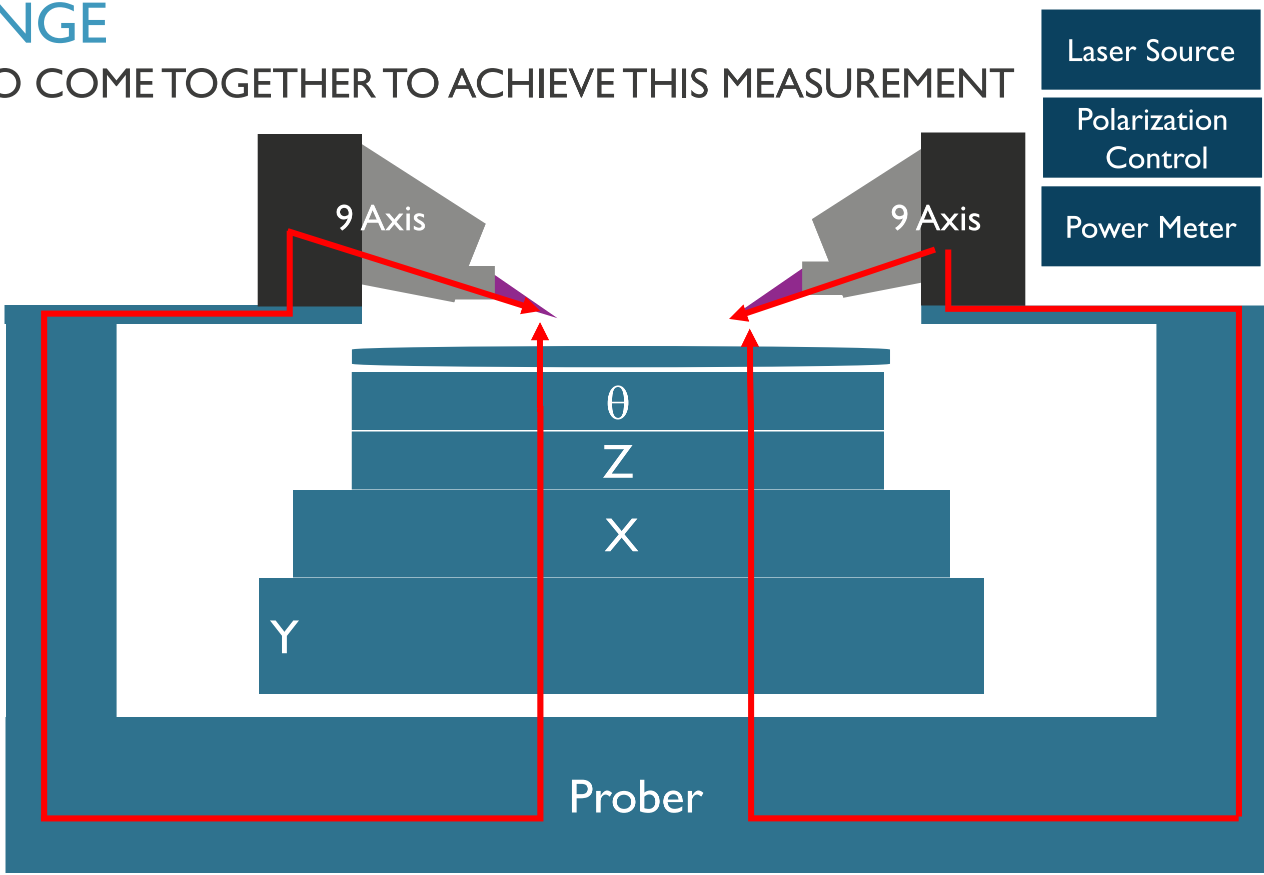
<.3 dB COUPLED POWER REPEATABILITY



SYSTEM LEVEL CHALLENGE

THE SUBSYSTEMS THAT NEED TO COME TOGETHER TO ACHIEVE THIS MEASUREMENT PERFORMANCE:

- ~1m Kinematic Loop
  - Fiber Tip / Z Displacement Sensor
  - 9 DOF of two positioners (18 Axis)
  - Prober platen and Base
  - XYZ and Theta chuck stack
  - Wafer
- Components
  - Laser Source
  - Polarization control
  - Power Meter
- Characteristics needed to achieve:
  - Stable kinematic loop
  - Positioning calibrated to Probe Station
  - Well tuned servo control
  - Optimized scanning motion
  - Stable input power and polarization
  - Stable environment



MEASUREMENT REPEATABILIITY

LOSS MEASUREMENT ON 2 WAFERS

- Measurement sequence:
  - Transport first wafer from cassette to pre-aligner
  - Rotate wafer at 87 deg
  - Transport wafer to ID reader
  - Read ID
  - Transport wafer to pre-aligner
  - Align wafer to 88.53 deg
  - Transport wafer to prober
  - Auto-align the wafer
  - Perform a Z profiling of the wafer (using autofocus on 7 dies)
  - Set chuck and fiber home position
  - Perform a loss measurement on 13 dies (5 spirals, LR fiber alignment on each spiral)
  - When measurement finishes, return fibers to home position
  - Transport wafer from prober to cassette
  - Repeat above steps for all remaining wafers in the cassette (only two wafers in this experiment)

20x

Test setup monitoring

MEASUREMENT REPEATABILIITY

LOSS MEASUREMENT ON 2 WAFERS

Wafer			(0,0)	(0,2)	(-1,-2)	(2,1)	(-2,2)	(2,-3)	(-3,0)	(3,-1)	(4,-2)	(-4,2)	(-4,-3)	(5,0)	(-5,-1)		**StdDev/Mean**
D05	Propagation loss [dB/cm]	Mean	-1.83	-1.8	-1.74	-1.79	-1.8	-4.81	-1.79	-1.78	-2.03	-1.86	-7.16	-1.76	-3.27	-2.570769231	
		Std Dev	0.0042	0.0048	0.0044	0.0059	0.01	0.0428	0.0041	0.0051	0.006	0.0064	0.0532	0.0063	0.0109	0.012623077	**-0.004910233**
		N	20	20	20	20	19	20	20	20	20	20	20	20	20		
	FtW IL [dB]	Mean	-5.25	-5.25	-5.21	-5.25	-5.25	-5.8	-5.28	-5.18	-5.29	-5.28	-11.3	-5.23	-5.7	-5.79	
		Std Dev	0.0159	0.0159	0.0149	0.0161	0.0291	0.0238	0.0113	0.0151	0.0143	0.0129	0.02	0.0241	0.0112	0.017276923	**-0.002983925**
		N	20	20	20	20	19	20	20	20	20	20	20	20	20		
	Peak WL [nm]	Mean	1553	1552	1551	1553	1551	1554	1551	1553	1553	1549	1564	1552	1551	1552.846154	
		Std Dev	0.0839	0.0717	0.0785	0.0822	0.0858	0.097	0.0818	0.0717	0.0785	0.0632	0.0754	0.0959	0.0822	0.0806	**5.19047E-05**
		N	20	20	20	20	19	20	20	20	20	20	20	20	20		
	FtW 1dB BW [nm]	Mean	33.16	34.13	33.97	33.39	34.3	33.75	34.07	33.54	33.35	34.77	36.54	33.31	34.23	34.03923077	
		Std Dev	0.0941	0.1027	0.0717	0.1053	0.0996	0.0822	0.0822	0.0839	0.052	0.0886	0.0717	0.0882	0.0822	0.084953846	**0.002495763**
		N	20	20	20	20	19	20	20	20	20	20	20	20	20		
D14	Propagation loss [dB/cm]	Mean	-2.16	-2.12	-2.12	-2.16	-2.24	-4.07	-2.11	-2.09	-2.09	-2.21	-6.67	-1.97	-2.36	-2.643846154	
		Std Dev	0.0089	0.0092	0.006	0.0059	0.0061	0.0088	0.0083	0.0072	0.009	0.0131	0.0152	0.0183	0.0035	0.009192308	**-0.003476869**
		N	19	19	19	19	19	19	19	19	19	19	19	19	19		
	FtW IL [dB]	Mean	-5.62	-5.66	-5.63	-5.66	-5.68	-5.86	-5.72	-5.58	-5.63	-5.7	-12.7	-5.59	-5.72	-6.211538462	
		Std Dev	0.0264	0.0117	0.0116	0.0137	0.0116	0.0177	0.0233	0.0142	0.024	0.0146	0.0213	0.02	0.0147	0.017292308	**-0.002783901**
		N	19	19	19	19	19	19	19	19	19	19	19	19	19		
	Peak WL [nm]	Mean	1542	1539	1539	1542	1539	1541	1539	1541	1540	1537	1555	1540	1538	1540.923077	
		Std Dev	0.0804	0.0795	0.0505	0.0795	0.0981	0.1047	0.0901	0.1182	0.0901	0.0813	0.0795	0.0996	0.0766	0.086776923	**5.63149E-05**
		N	19	19	19	19	19	19	19	19	19	19	19	19	19		
	FtW 1dB BW [nm]	Mean	36.06	37.39	37.21	36.81	37.58	37.2	37.07	36.81	36.6	38.29	40.29	36.55	37.85	37.36230769	
		Std Dev	0.0996	0.1011	0.1055	0.0958	0.111	0.0841	0.1011	0.1097	0.1047	0.0804	0.0766	0.1069	0.0736	0.096161538	**0.002573758**
		N	19	19	19	19	19	19	19	19	19	19	19	19	19		

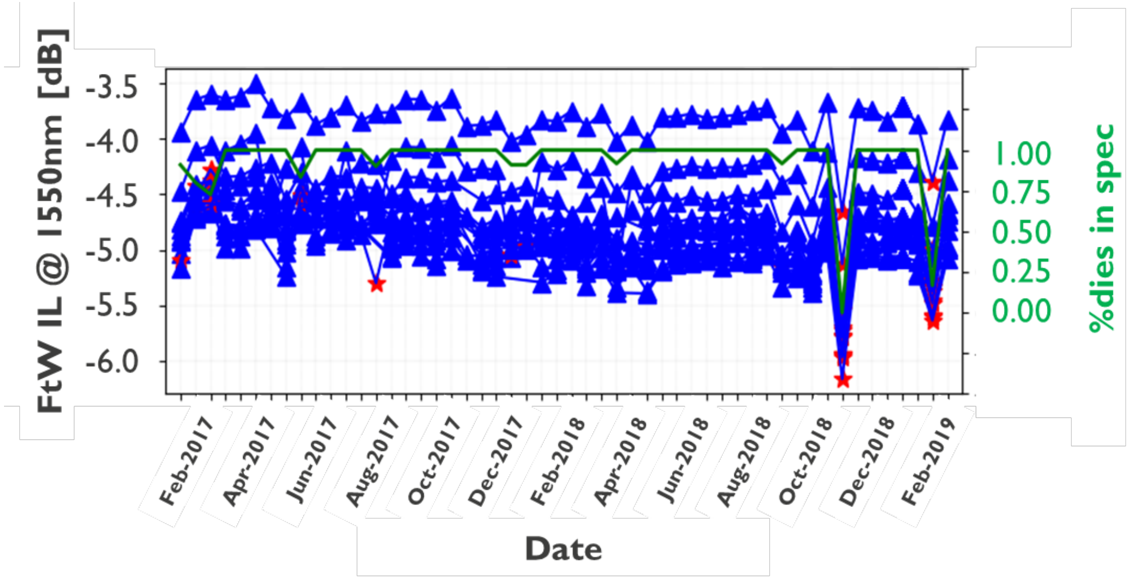
MEASUREMENT REPRODUCIBILITY

REFERENCE WAFER MEASUREMENTS

- Repeated measurement of same wafer/dies/structures, ~bi-weekly interval

- Evolution of 8 device parameters tracked
  - FtW IL, TE/TM, C/O band
  - Photo diode responsivity
  - Photo diode dark current

- Also implemented Western Electric rules



Test setup monitoring

MEASUREMENT REPRODUCIBILITY

REFERENCE WAFER MEASUREMENTS

- Corrective actions taken when required

Symptom	Possible cause	Corrective action
Id too low	Bad probe contact	Adjust probe overtravel
		Clean probe tips
FtW IL out of spec	Incorrect fiber height	Adjust fiber heigt
	Fiber facet not clean	Clean fiber facet
	Polarization not well calibrated	Calibrate input SOP
	Fiber facet damaged	Replace measurement pigtail
	Setup loss not well calibrated	Calibrate setup loss
Responsivity out of spec and FtW IL is also out of spec	First solve issue with FtW IL	See steps above
Responsivity out of spec but FtW IL is in spec	Poor calibration of pigtail output power	Calibrate power at tip of input pigtail
	Imbalance between input and output pigtail FtW IL	Check if input and output pigtails are at same height

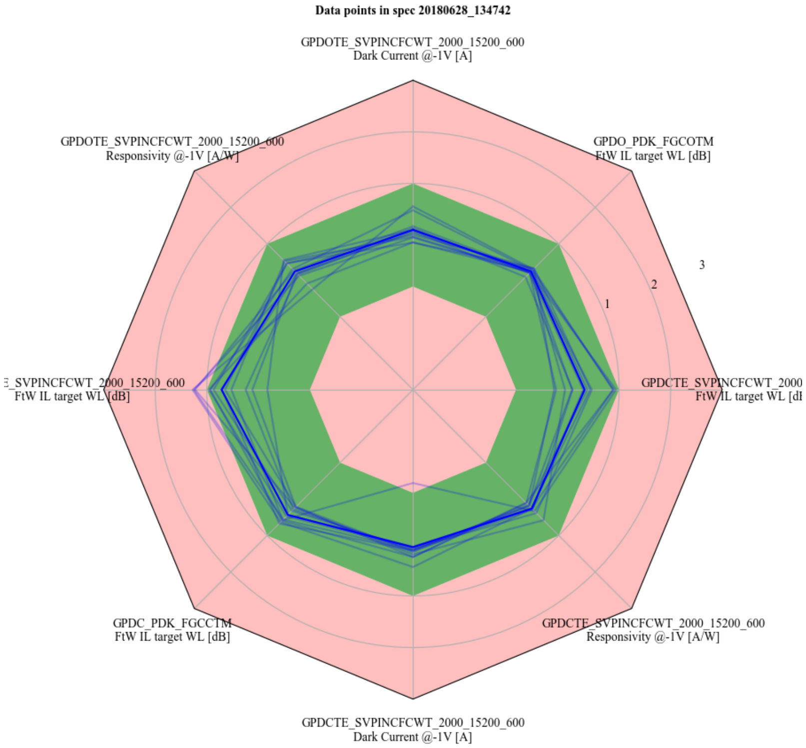
MEASUREMENT REPRODUCIBILITY

REFERENCE WAFER MEASUREMENTS

- Data analysis
  - Target value for each die/device/parameter defined as average of past measurements
  - Each data point is normalized as (i-th observation of quantity x_j)

$$p_{ji} = \frac{x_{ji} - \mu_i}{\sigma_i}$$

  - For each die, parameters p_j (j=1...8) are plotted on a radar plot
  - Green zone is ±1σ
  - Bold blue line = wafer average



CONCLUSION

- Running PCM measurements in clean room enables faster feedback to process integration engineers
  - Enables checking process changes in-line to tune parameters
- Inline measurements require a fully automated tool - FormFactor CM300xi-SiPh
- Calibration procedures are in place to ensure accuracy of measured parameters
- Dual use case of measurement data
  - Ensure technology-specific device parameters are meeting PDK specifications
  - Validating the effect of process/design changes on those structures
- Contamination analysis verifies that the tool operates within cleanroom specification
  - Tool is not a source of contamination
- Test Setup Monitoring is used to demonstrate the tool is providing repeatable and reproducible measurements

SWTEST

PROBE TODAY, FOR TOMORROW

THANKS FOR YOUR ATTENTION

FormFactor™

imec

June 2-5,2019