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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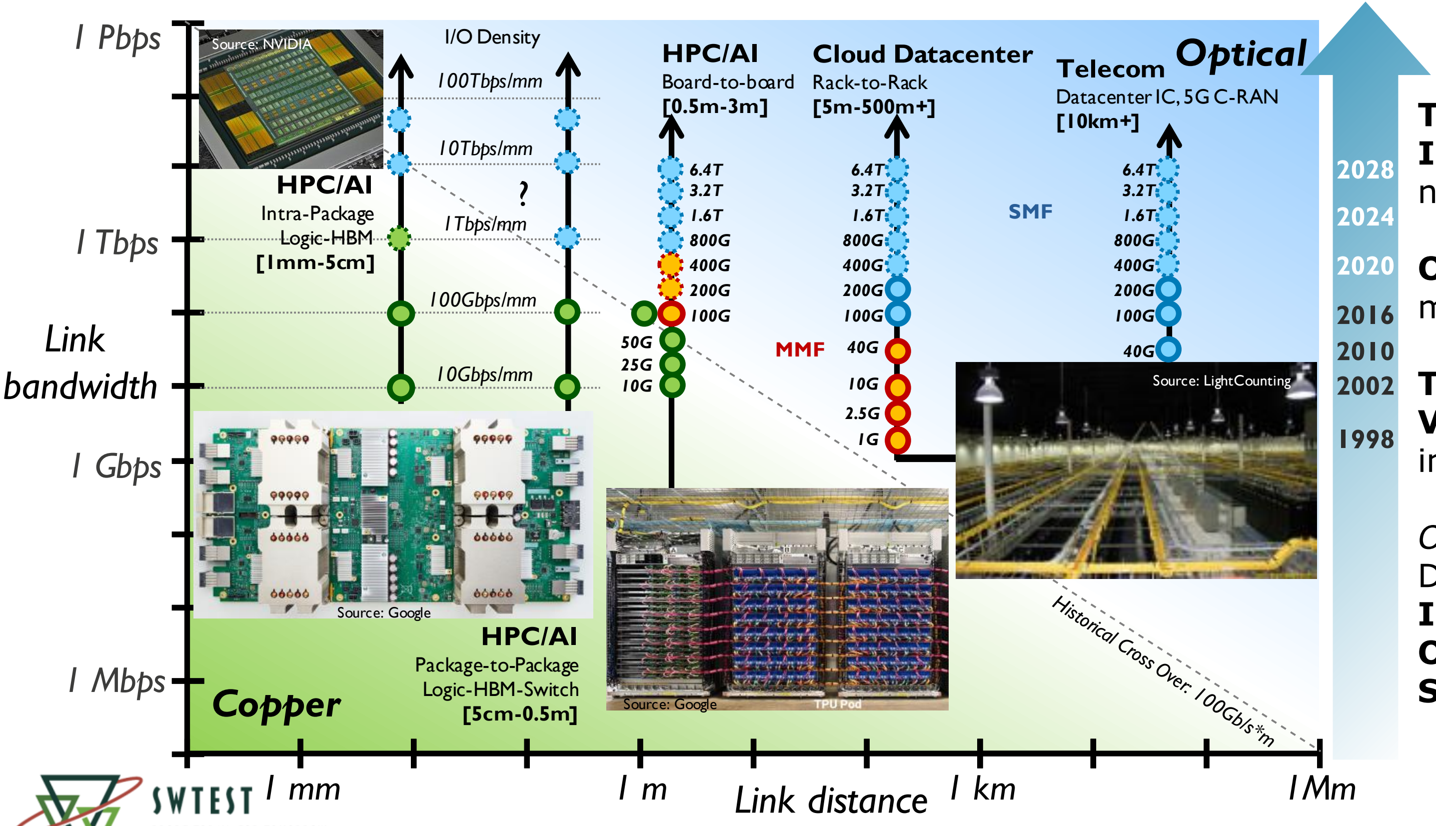
# OUTLINE

- 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)**

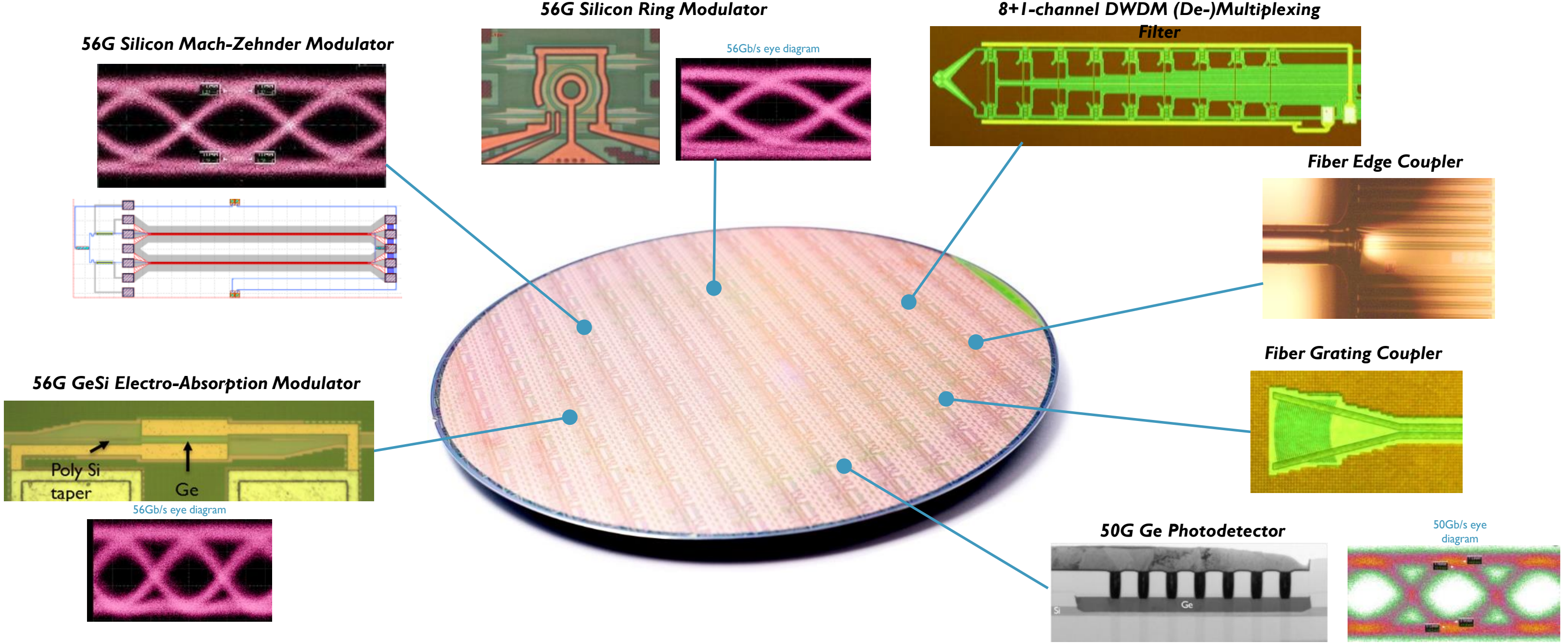
**Total Optical Transceiver Volume** expected to increase >>**10x**

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

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**

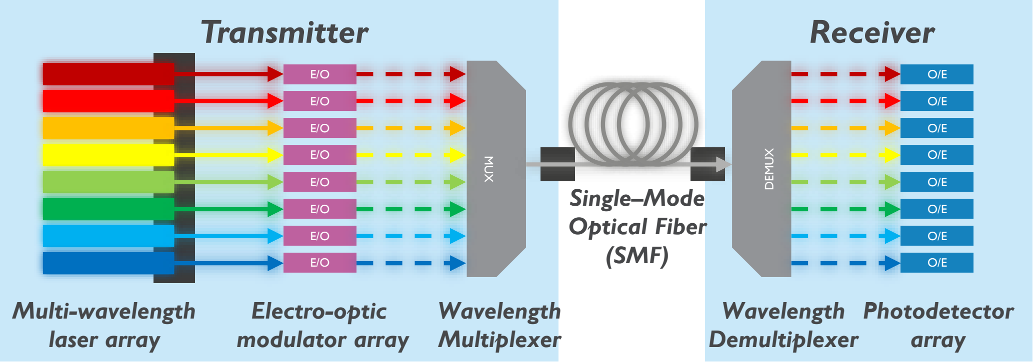
50Gb/s eye diagram

- 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

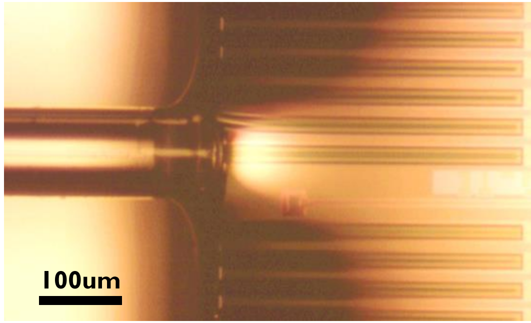
What are we developing

# WAFER LEVEL TESTING

## FIBER AND LASER COUPLING STRUCTURES

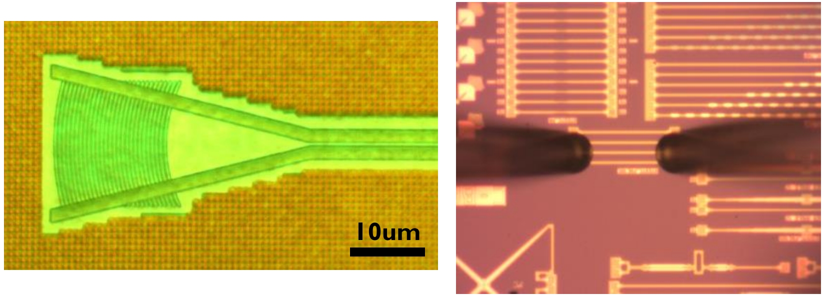


### In-Plane Coupler



<2dB loss over 100nm+

### Surface-Normal Grating Coupler



<3dB loss over 30nm

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# WHAT DO WE WANT TO MEASURE

## PROCESS CONTROL MONITORING

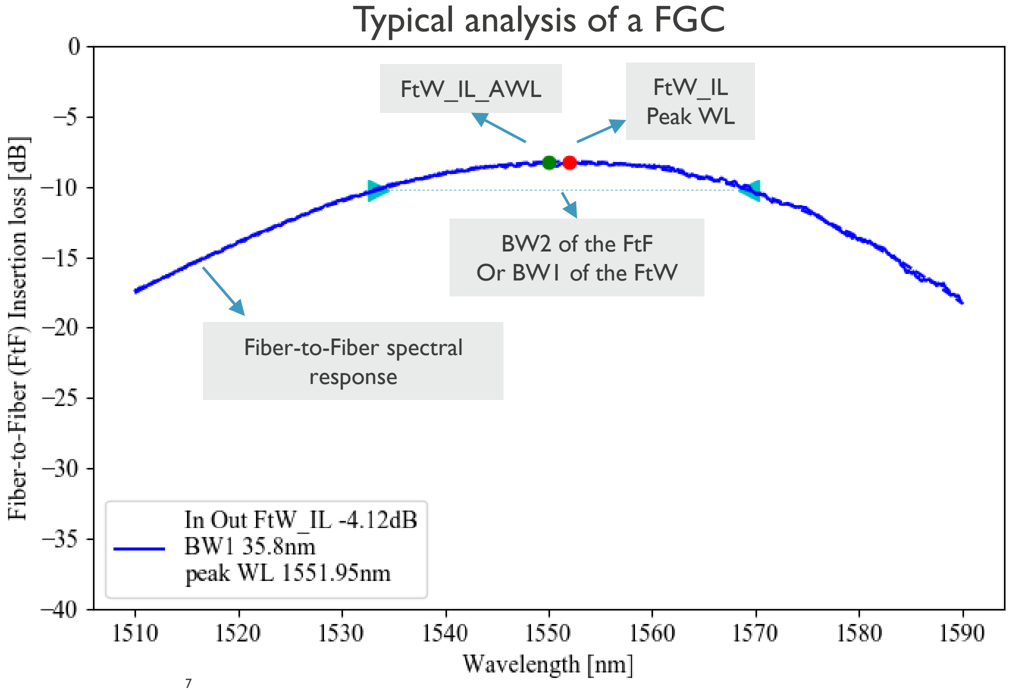
- Monitor technology-specific parameters
- Observe impact of process splits on these parameters during development of the technology platform

| Component | | Test sites | |
|---|---|---|---|
| Passive | | Grating couplers | Insertion loss, bandwidth, peak wavelength |
| O-band<br>*1310nm* | C-band<br>*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<br>*1310nm* | C-band<br>*1550nm* | Mach-Zehnder interferometer | Insertion loss, Vpi |
| | | Phase shifter loss | Propagation loss |

# PROCESS CONTROL MONITOR STRUCTURES

## FIBER GRATING COUPLER (FGC) PERFORMANCE

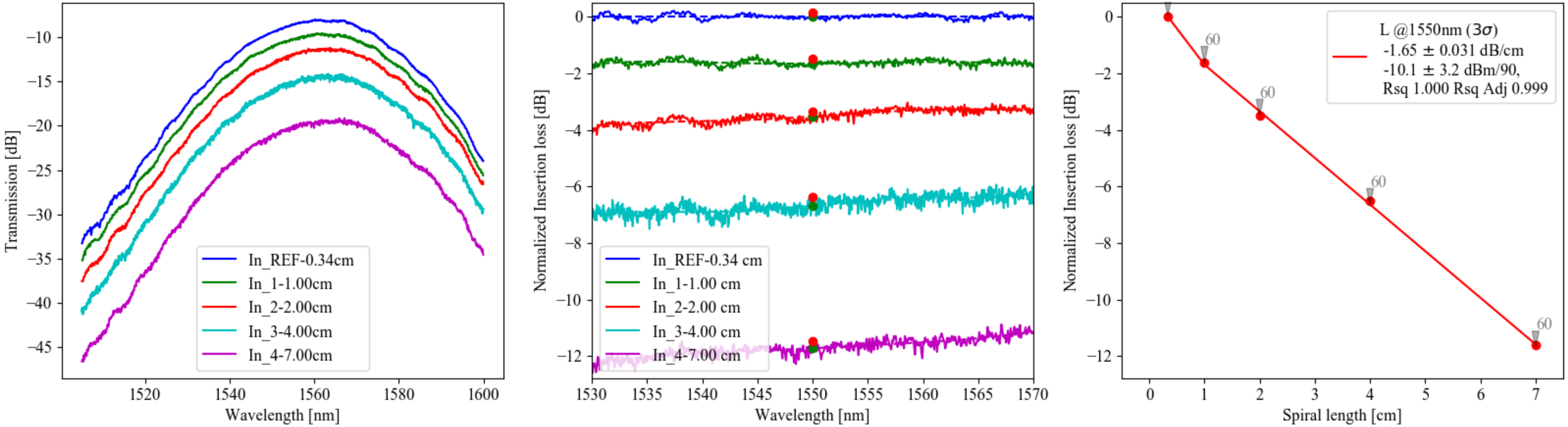
- A straight waveguide with a grating coupler on both ends
- Measured quantity: wavelength dependent insertion loss, fiber to fiber
- Extracted device parameters
  - Fiber-to-waveguide insertion loss
    *FtW_IL_AWL [dB]*
  - Peak wavelength
    *PWL [nm]*
  - Peak wavelength IL
    *FtW_IL [dB]*
  -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



# PROCESS CONTROL MONITOR STRUCTURES

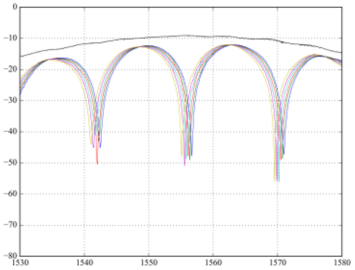
## PROPAGATION LOSS TEST

- 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

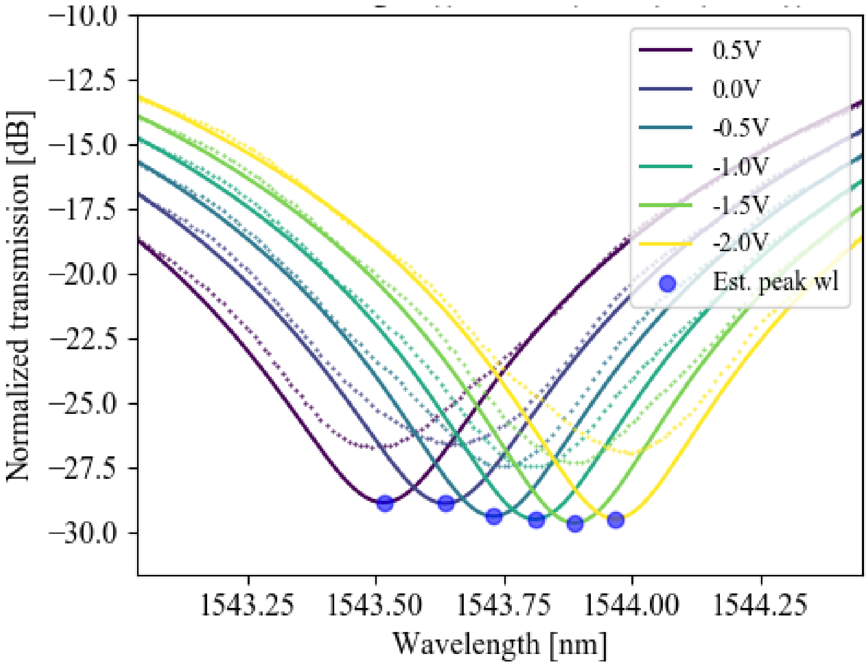


# PROCESS CONTROL MONITOR STRUCTURES

## MODULATOR TEST



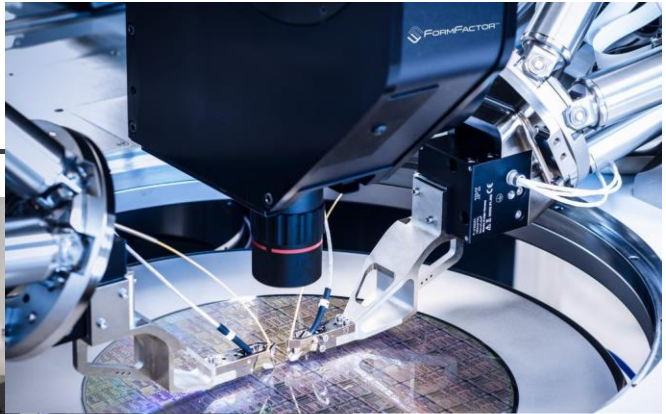
- Measured quantity: IV, wavelength dependent loss vs. DC bias
- Spectral response fitted with raised cosine
  - Data (dotted line)
  - Fit (solid line)
- Parameters extracted:
  - Insertion loss
  - Modulation efficiency Vpi

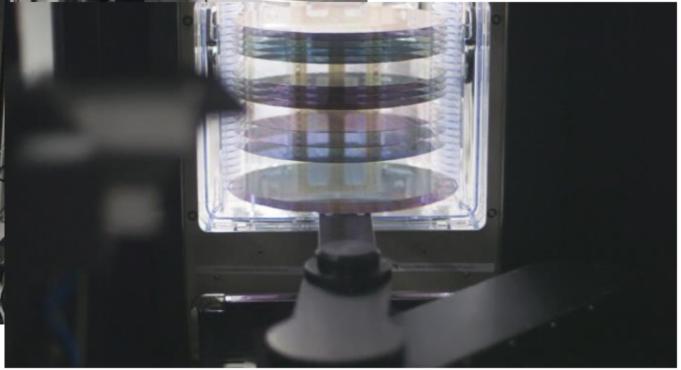


How do we measure

# THOR TEST SYSTEM IN IMEC'S 200mm FAB

## FORMFACTOR CM300xi-SiPh PROBE STATION WITH SiPh-





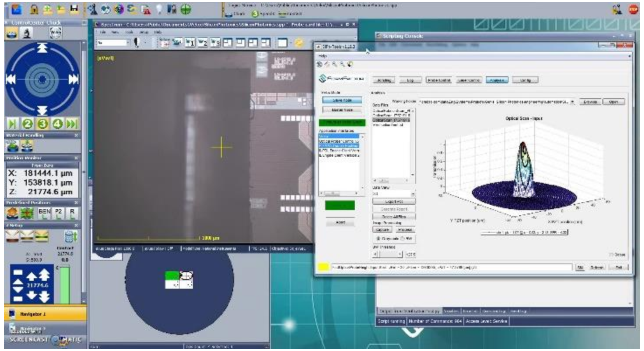
# AUTONOMOUS SiPh MEASUREMENT ASSISTANT FOR CM300xi

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



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

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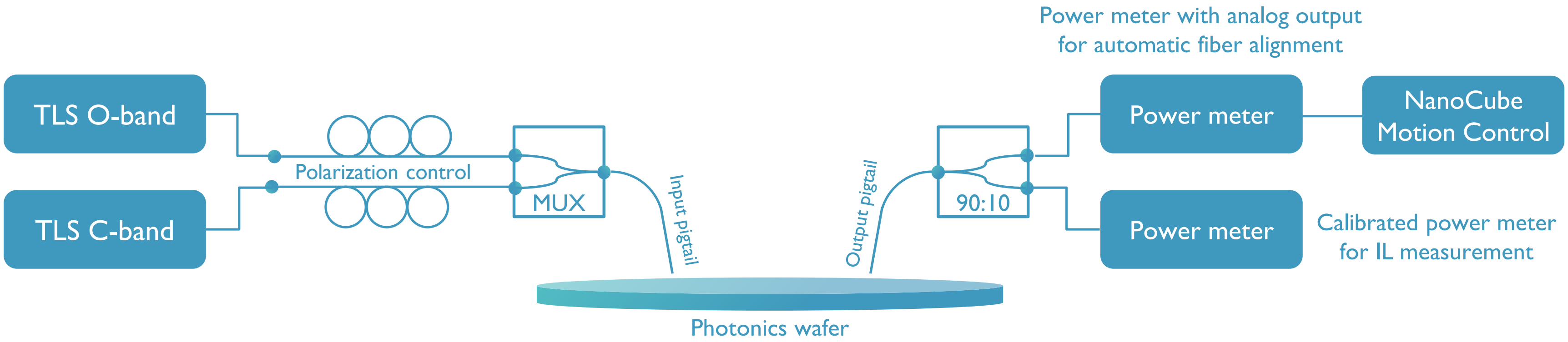
How do we measure

# THOR TEST SYSTEM

## SCHEMATIC LAYOUT OF THE OPTICAL PATHS

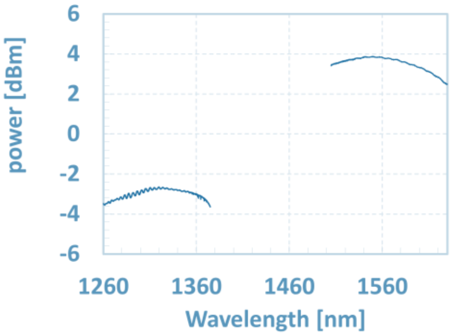
- Dual tunable laser sources O- and C-band
- All single mode fiber (SMF28)
- Measurement pigtails with straight cleaved facets
- Nominal incidence angle 10° from vertical

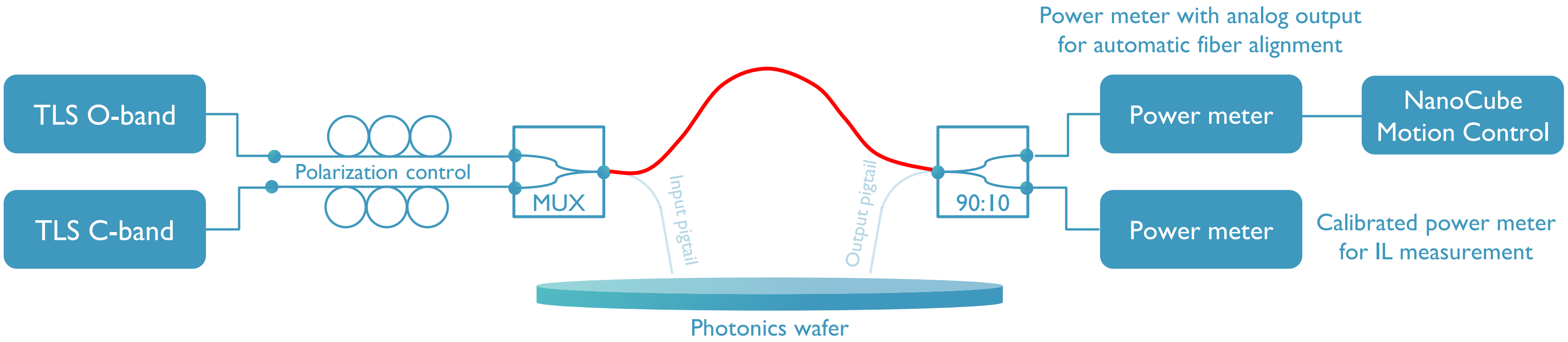


# INSERTION LOSS CALIBRATION

## 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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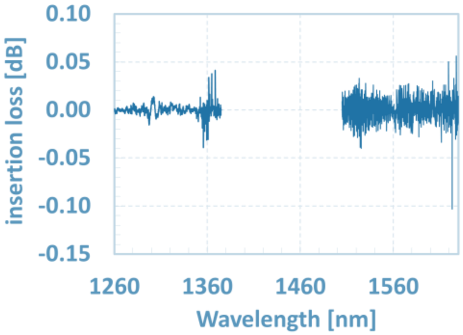
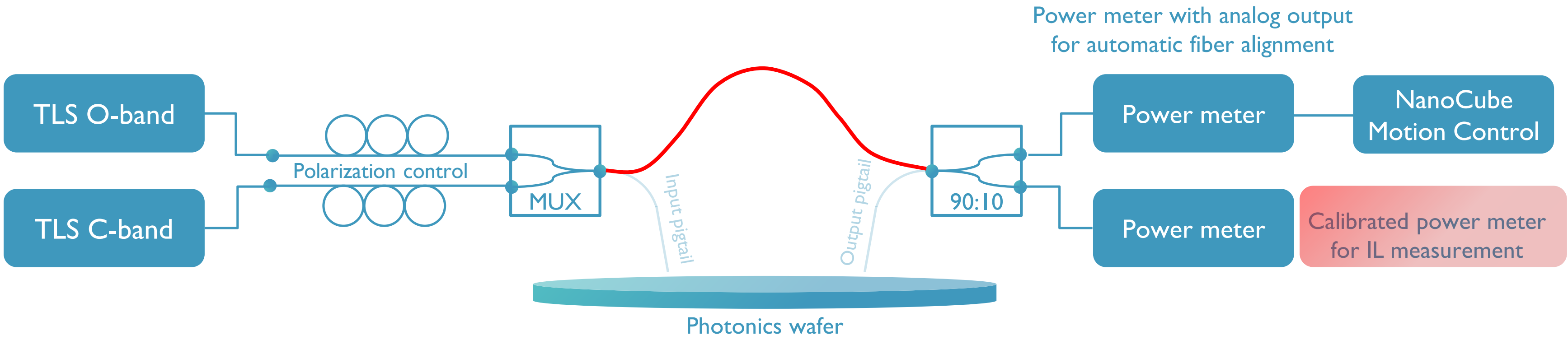


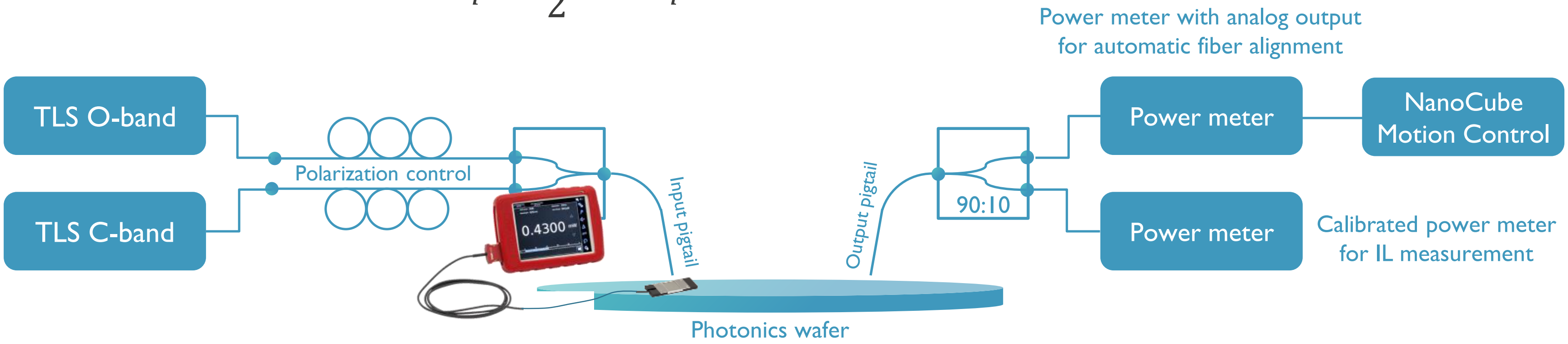


# ABSOLUTE POWER CALIBRATION

## 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

How do we measure

# 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**

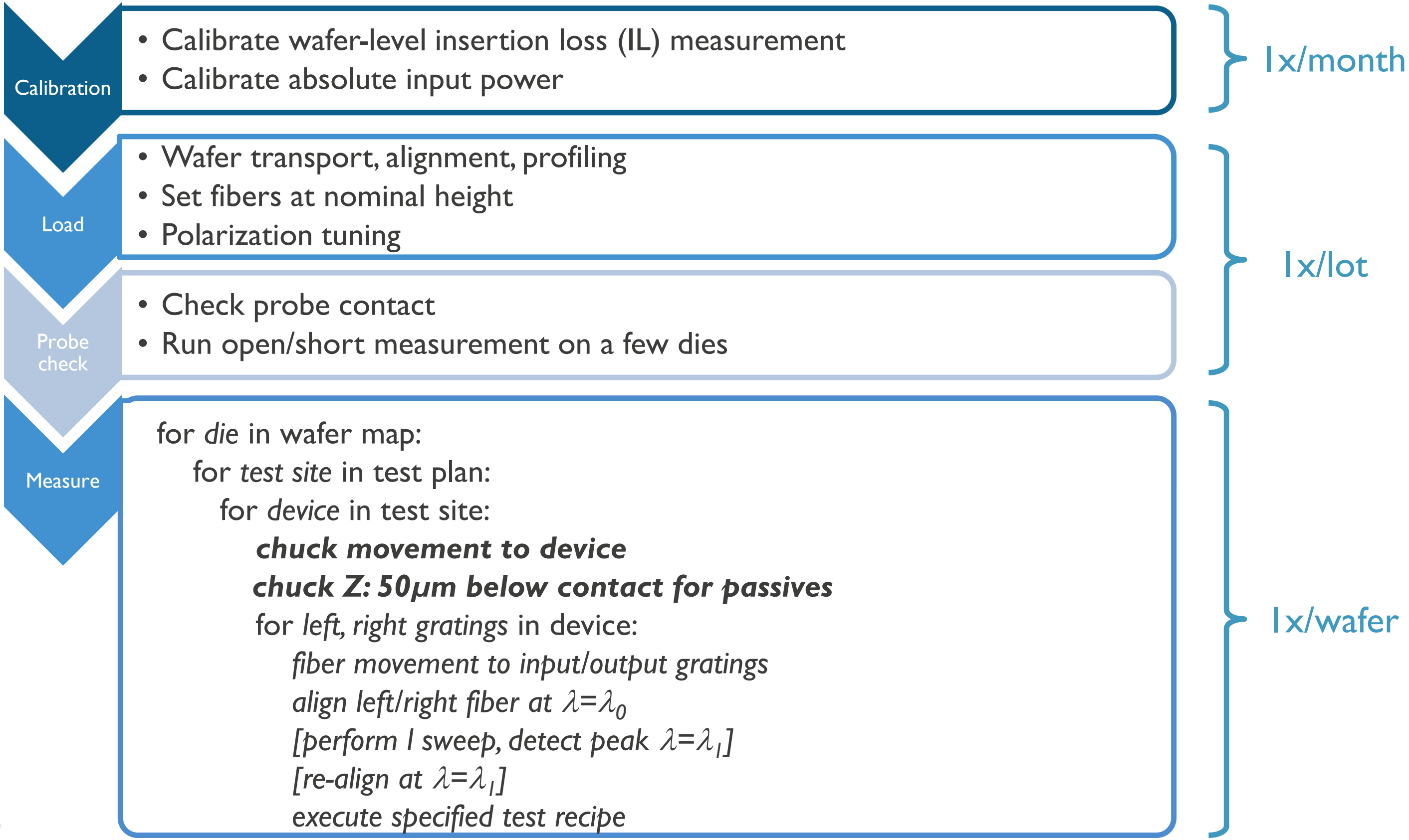
- Check probe contact
- Run open/short measurement on a few dies

**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 l sweep, detect peak $\lambda=\lambda_l$]
                [re-align at $\lambda=\lambda_l$]
                execute specified test recipe
```

How do we measure

# 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**

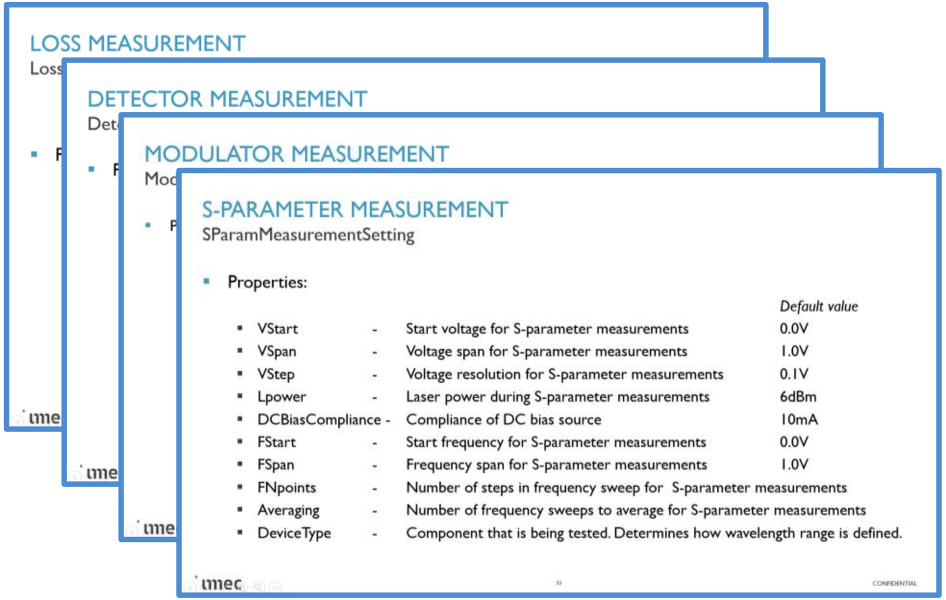
```
for die in wafer map:
    for test site in test plan:
        for device in test site:
            chuck movement to device
            chuck Z: 50µm below contact for passives
            for left, right gratings in device:
                fiber movement to input/output gratings
                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



LOSS MEASUREMENT

Loss

DETECTOR MEASUREMENT

Det

MODULATOR MEASUREMENT

Mod

S-PARAMETER MEASUREMENT

SParamMeasurementSetting

- Properties:

| Property | | Description | *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

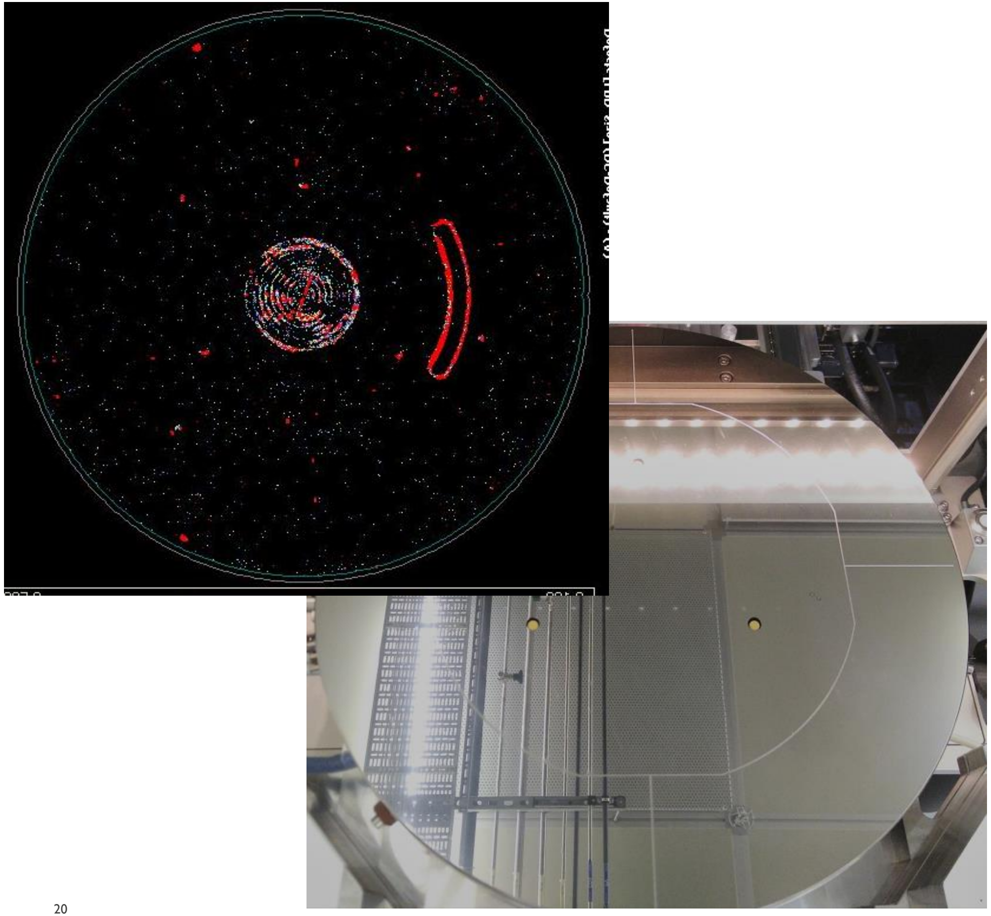
- Motivation
  - Operating the tool in a clean room allows to pull out wafers, measure, give feedback to process integration
  - Resulting in faster feedback
  - Wafers are not lost for processing, i.e. more inspections are possible
- Hence we need to verify metal/particle contamination in the tool
  - 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

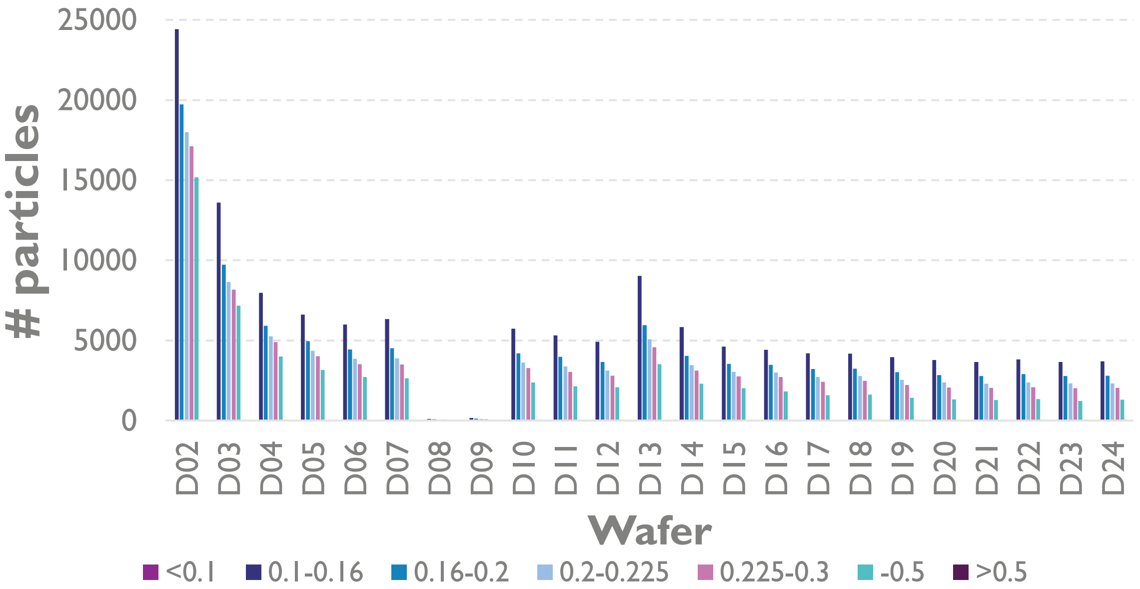
- Visible marks of robot arm, pre-aligner, chuck lift pins



# BACKSIDE PARTICLE MEASUREMENT

## VERIFICATION OF CLEANING PROCEDURE

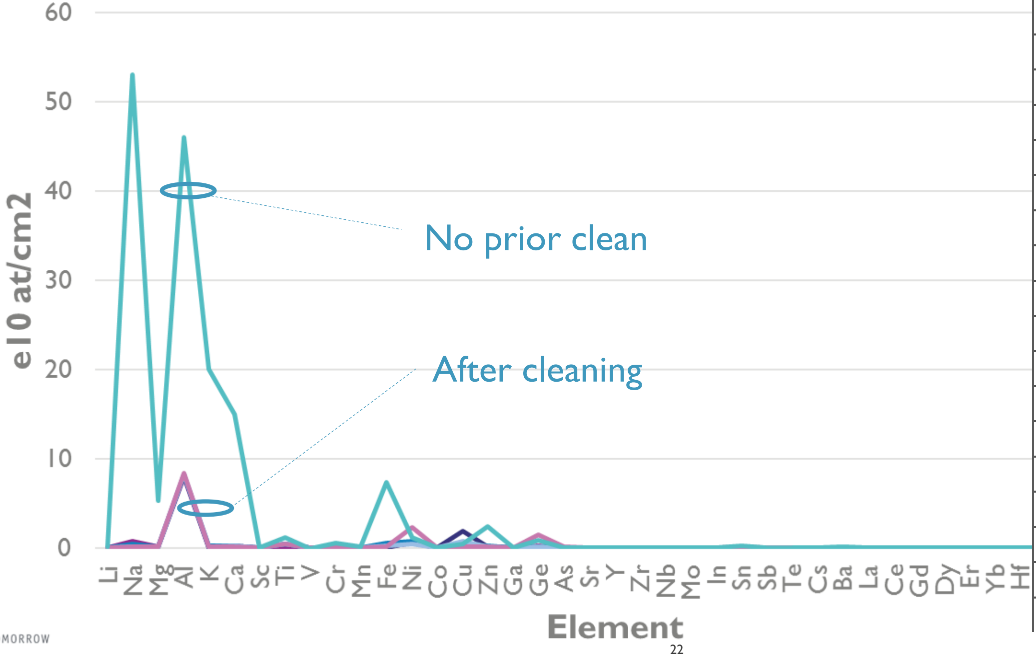
- Initial tool status: measured ~100 level 5 wafers
- No cleaning done before loading witness wafers
- After 10 wafers, particle count drop below spec limit for target contamination level 3
- Chuck cleaned with IPA after wafer 12
- Then loaded wafers 13-24
- Particle count stabilized after another 3-4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

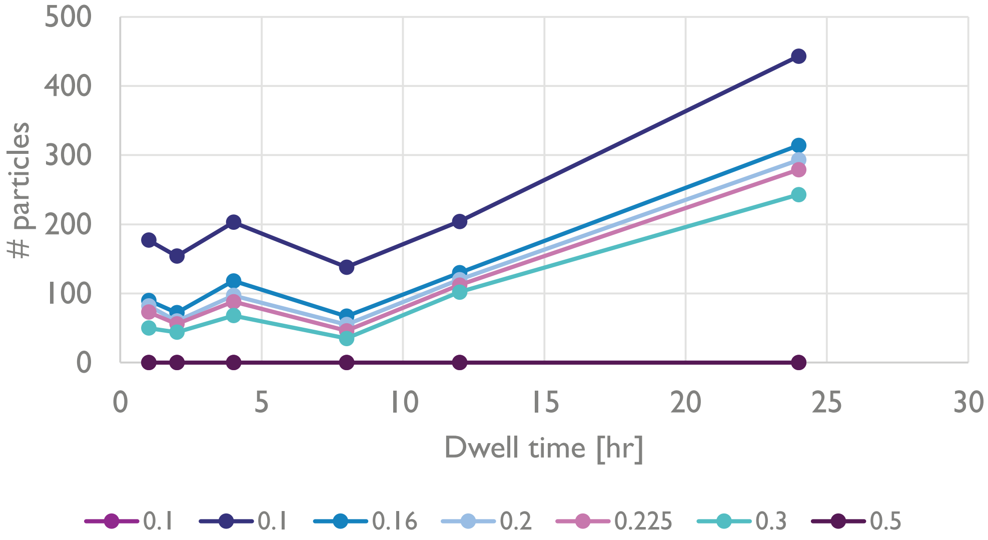
After cleaning

| 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 |

# 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

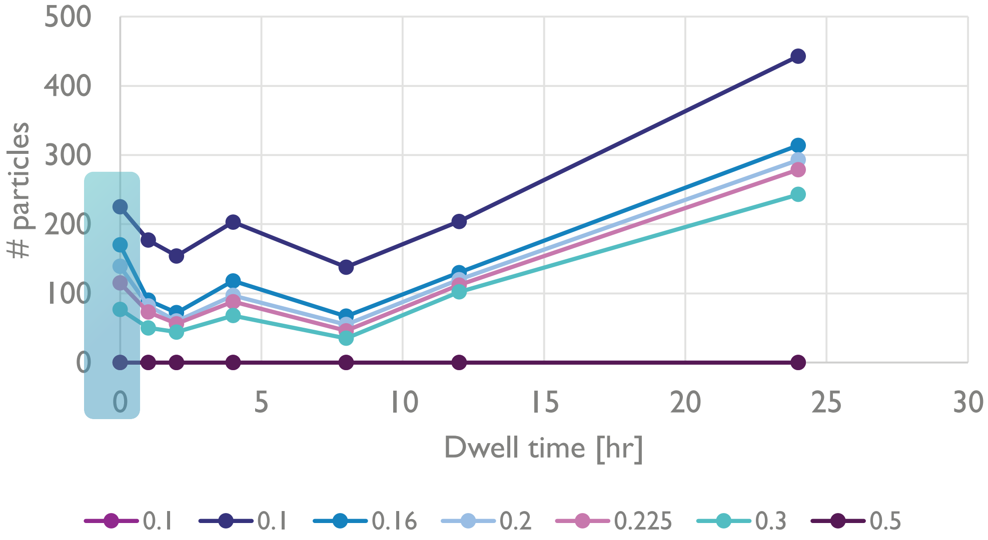


Operation in clean room

# 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

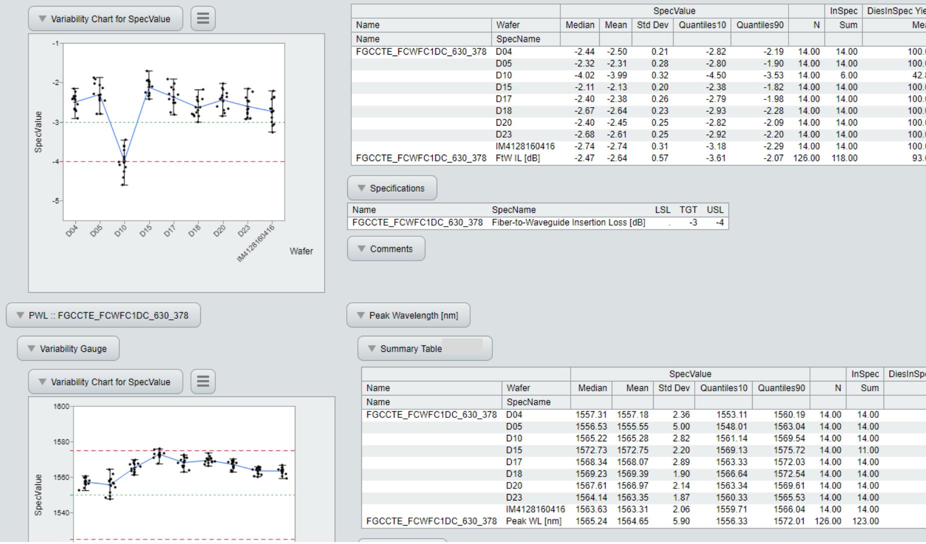
## ANALYSIS WORK FLOW

- 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

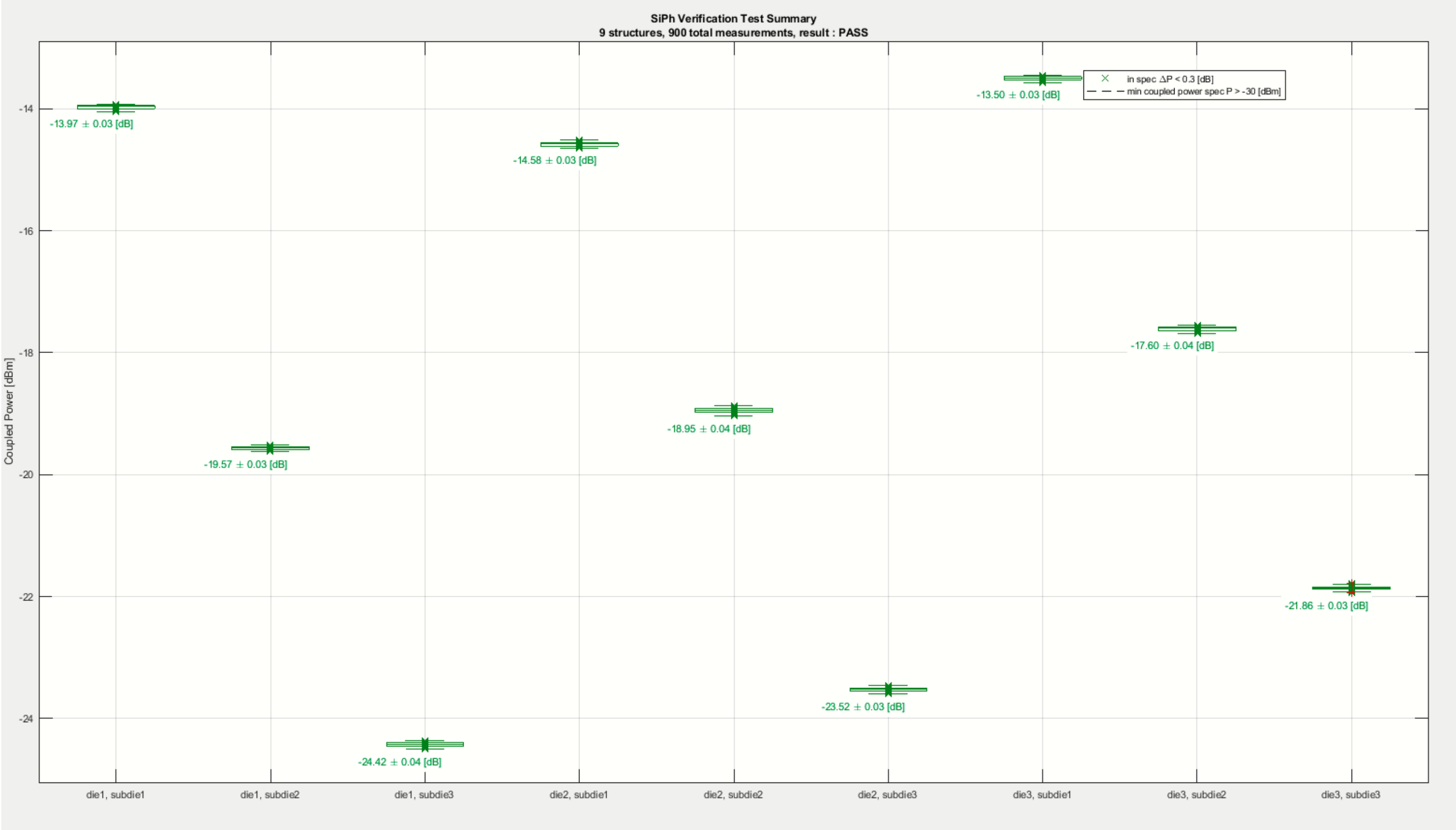


| | | SpecValue | | | | | | InSpec | DiesInSpec Yie |
|---|---|---|---|---|---|---|---|---|---|
| Name | Wafer | Median | Mean | Std Dev | Quantiles10 | Quantiles90 | N | Sum | Mea |
| Name | SpecName | | | | | | | | |
| FGCCTE_FCWFC1DC_630_378 | D04 | -2.44 | -2.50 | 0.21 | -2.82 | -2.19 | 14.00 | 14.00 | 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 | |

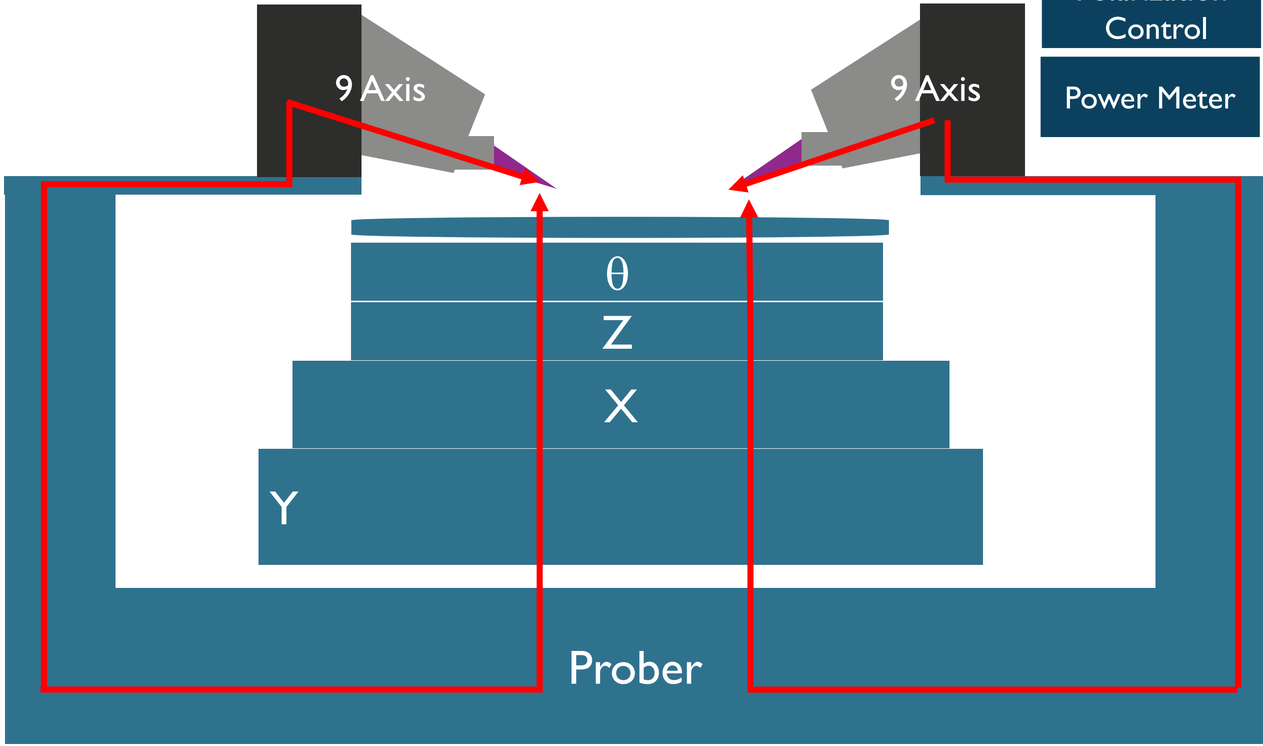
# <.3 dB COUPLED POWER REPEATABILITY



# 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



Laser Source

Polarization Control

Power Meter

# 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 | | |

Test setup monitoring

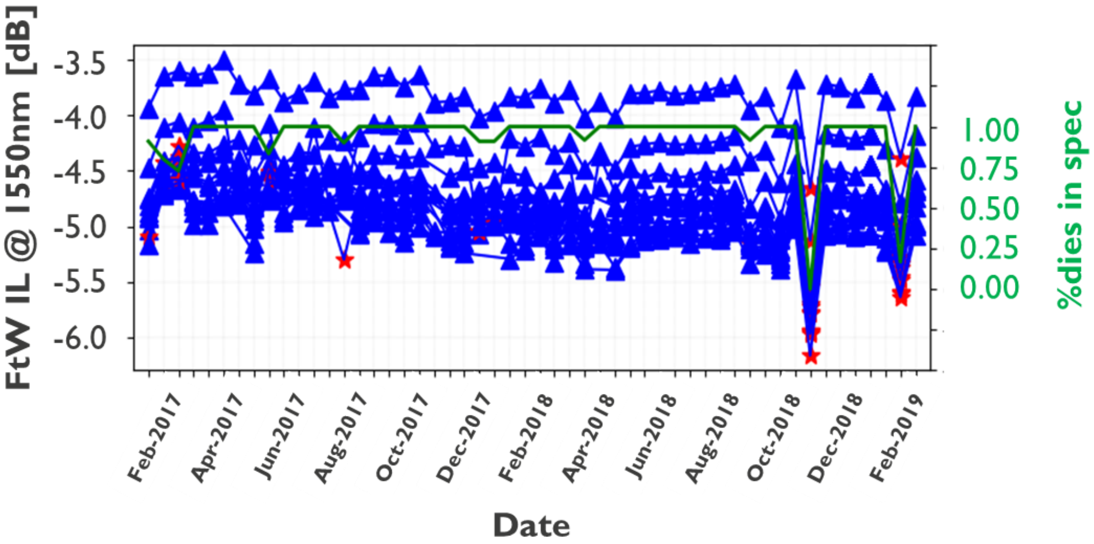
# MEASUREMENT REPRODUCIBILITY

## 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



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# 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 |

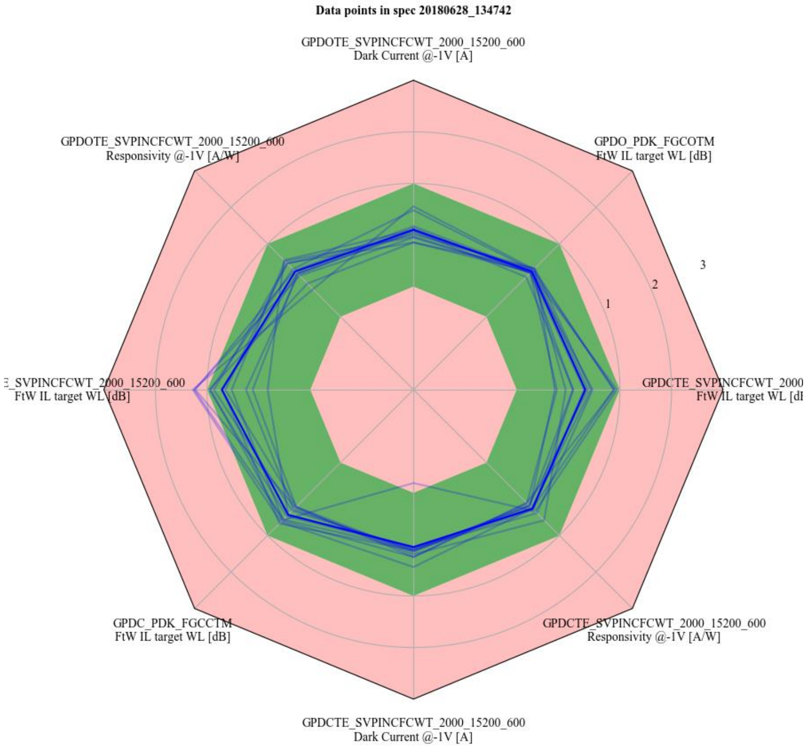
# MEASUREMENT REPRODUCIBILITY

## 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

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# THANKS FOR YOUR ATTENTION

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June 2-5, 2019