SWTEST
PROBE TODAY, FOR TOMORROW
2024 CONFERENCE

# Optical edge coupling method for fully automated PIC wafer-level testing

FORMFACTOR™

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ihp

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# Overview

- Introduction
- Probing features
- Component of the system
- Requirements and DUT
- Wafer-level results
- Summary

# IHP
## Innovations for High Performance Microelectronics

**Frankfurt (Oder)**

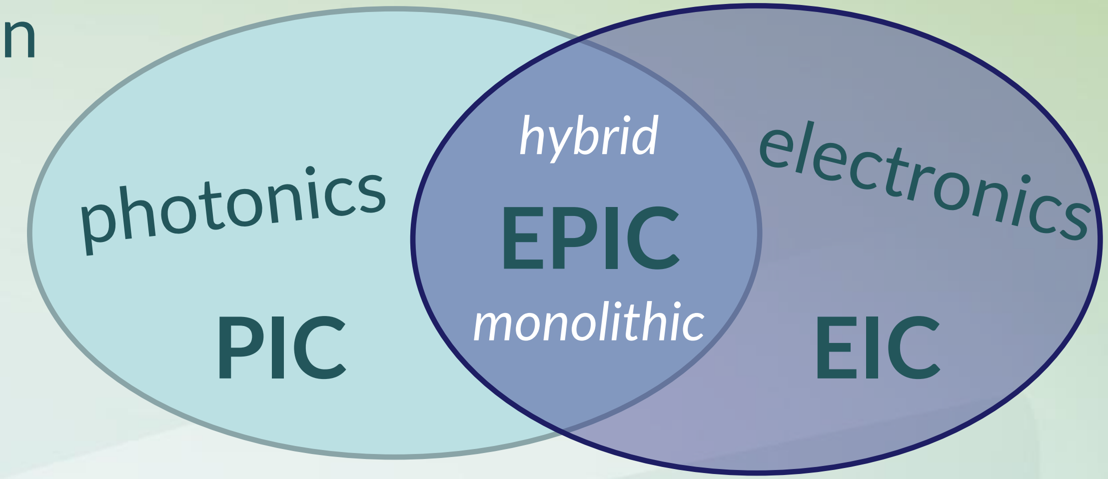
**Institute for R&D & Prototyping**

- RF SiGe BiCMOS Technology
- 0.25 µm and 0.13 µm CMOS
- 200 mm wafers
- 100 WSW
- Silicon Photonic MPW (SiPh and BiCMOS)

# Silicon Photonics

- Photonics building blocks realized in silicon technology:
  - Waveguides
  - Grating/edge couplers
  - Phase shifters
  - Photodiodes

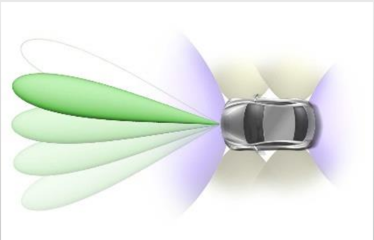
can be combined with electronics.


photonics
PIC
hybrid
EPIC
monolithic
electronics
EIC

- Application space


Optical com


LiDAR


Radar

Source for pictures: https://www.racksolutions.eu, https://phononic.com/resources/automotive-lidar-2020/, https://www.radartutorial.eu

# SILICON PHOTONICS
# fits to microelectronics value chain

Design

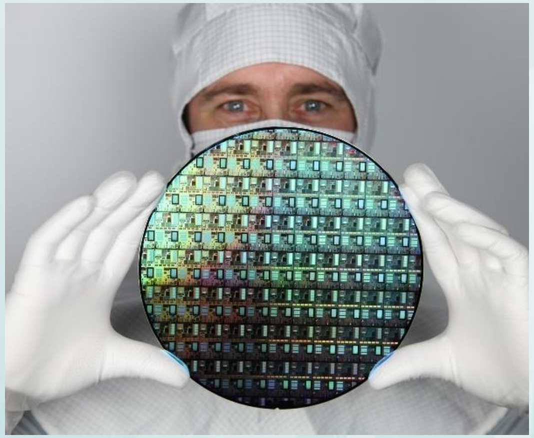
SiPh Fabrication

Testing

Packaging

Electronic design automation EDA

cadence®



?

Is optical probing already established on the same level as electrical probing?

https://www.indiamart.com/

# Electrical probing

State-of-the-art:

- Automated probing on wafer
- Vision probe recognition
- High repeatability
- High throughput

We expect the same from optical probing !

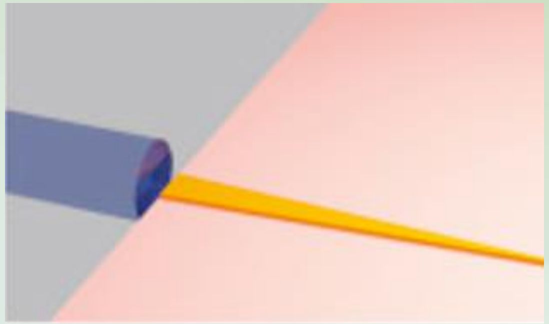
# Optical vs. electrical probing

- In contrast to electrical probing exact optical probe placement matters, also in Z direction
- Prober XY accuracy: 2 µm (1σ)
- Chuck planarity: ±5 µm

Required:

- Position accuracy in sub micron range
  - non contact optical power optimization
- Height control of the fiber
- Reasonable time for the alignment

# On-wafer optical coupling interfaces



| | Grating coupler | Edge coupler |
|---|---|---|
| **Test methodology** | vertical | horizontal / edge |
| **Fabrication effort** | without extra | with extra |
| **Footprint** | small | medium |
| **Equipment (Cost)** | low | high |
| **Coupling loss** | > 3dB | <2 dB |
| **Polarization dependance** | high | low |
| **Bandwidth** | <40 nm | > 100 nm |
| **On- wafer testing** | available | Now available |

drawbacks

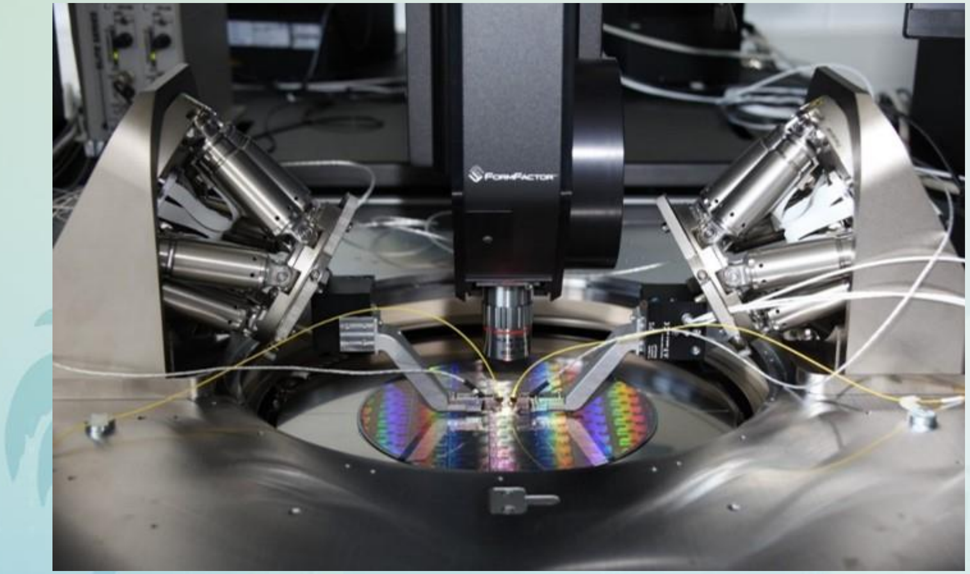
benefits

Source of pictures: https://www.sciencedirect.com/science/article/abs/pii/B9780128133538000087

# Equipment for on-wafer PIC characterisation

- 300 mm Probe Station FormFactor CM300xi with Loader

- 6-axis positioners with Nano Cubes (PI)



- Optical Probe

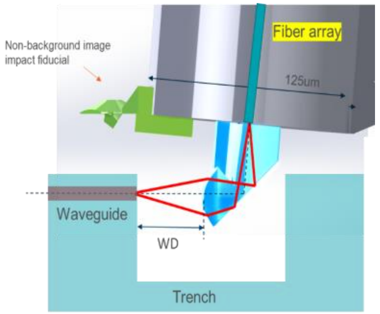
Pharos aLens
*for horizontal/ edge coupling*

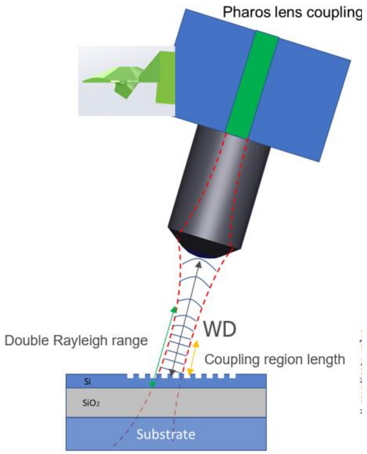
Cleaved Fiber
*for vertical coupling*

CAP sensors

# Pharos Lens for Silicon Photonics Probing

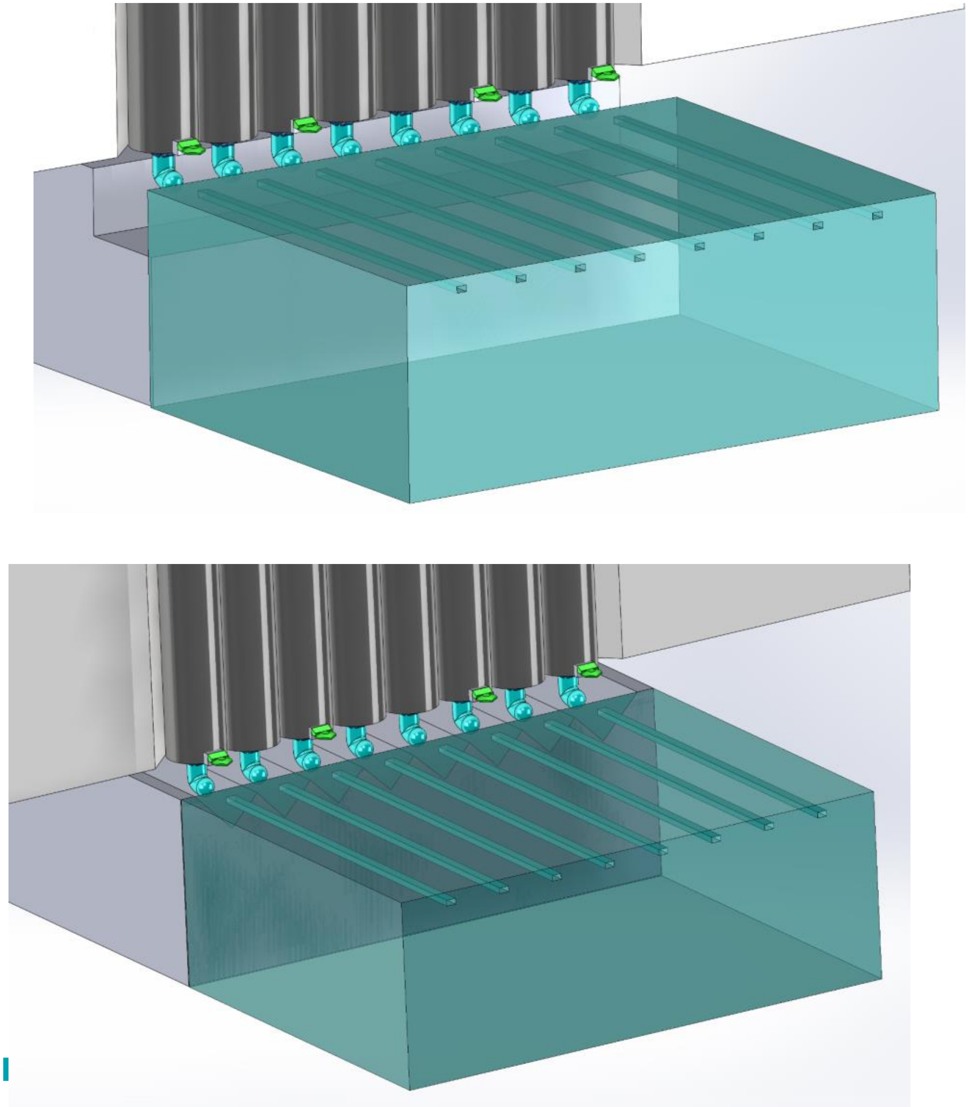
Pharos™
Technology

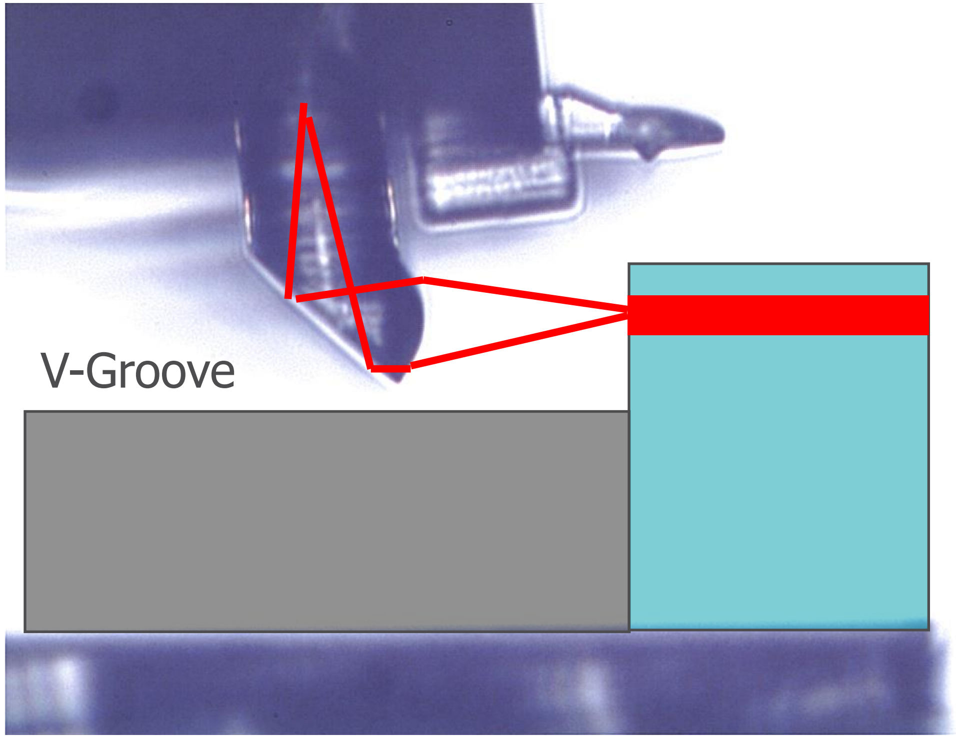




- Wafer level edge and vertical coupling designs
  - Short and long working distance designs
- High coupling efficiency
- High repeatability and stability
- Nearly collimated beam with Plane front wave at grating coupler taper
- Ultra long working distance(WD) possible – ex. up to >800µm
- Tolerant in Z (beam propagation direction) for vertical
  - i.e. large coupling range
- Mode field diameter and working distance

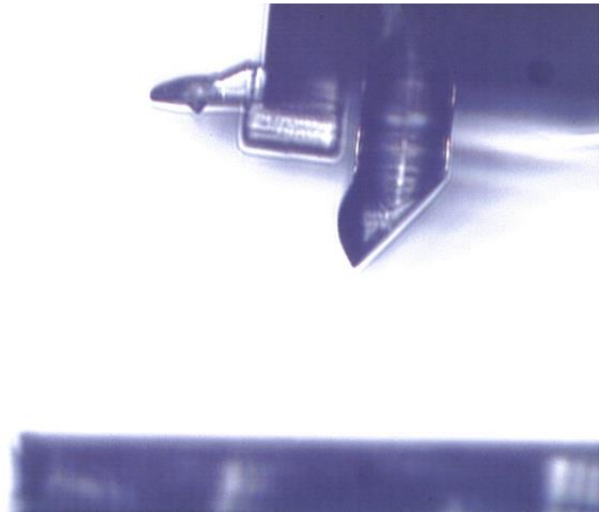
# Applicable for wafer level trench and v-groove



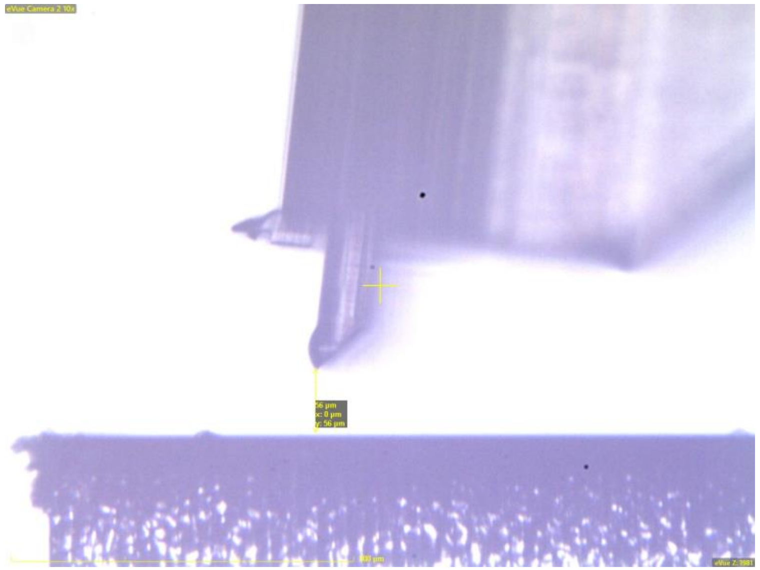


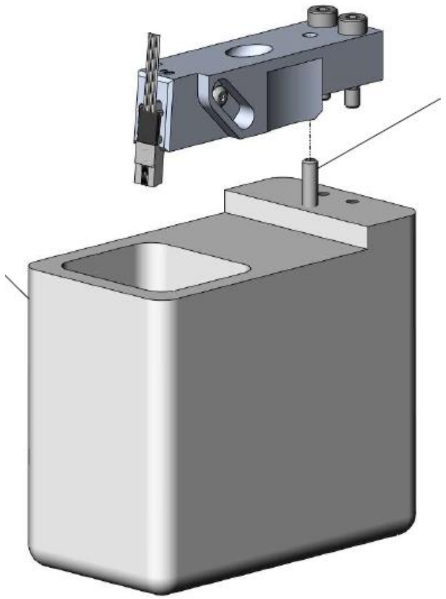
# Pharos Lenses for Grating and Edge Coupling

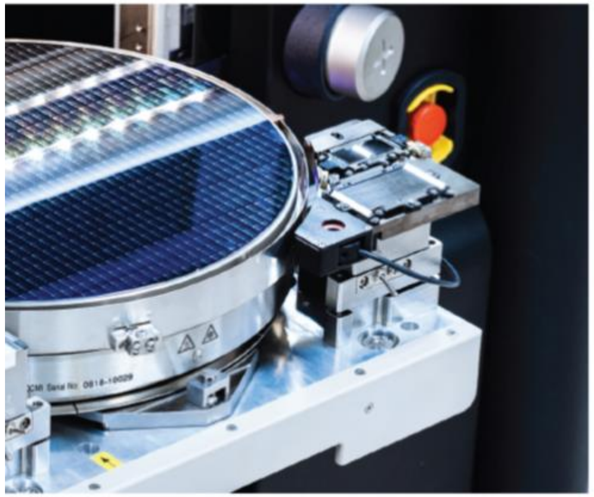
Short Edge Pharos lens (Trench)



Long Edge Pharos lens (V-groove)

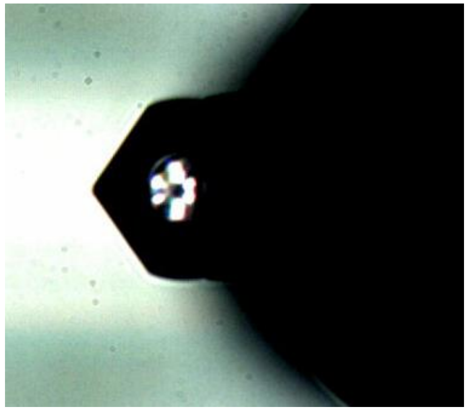






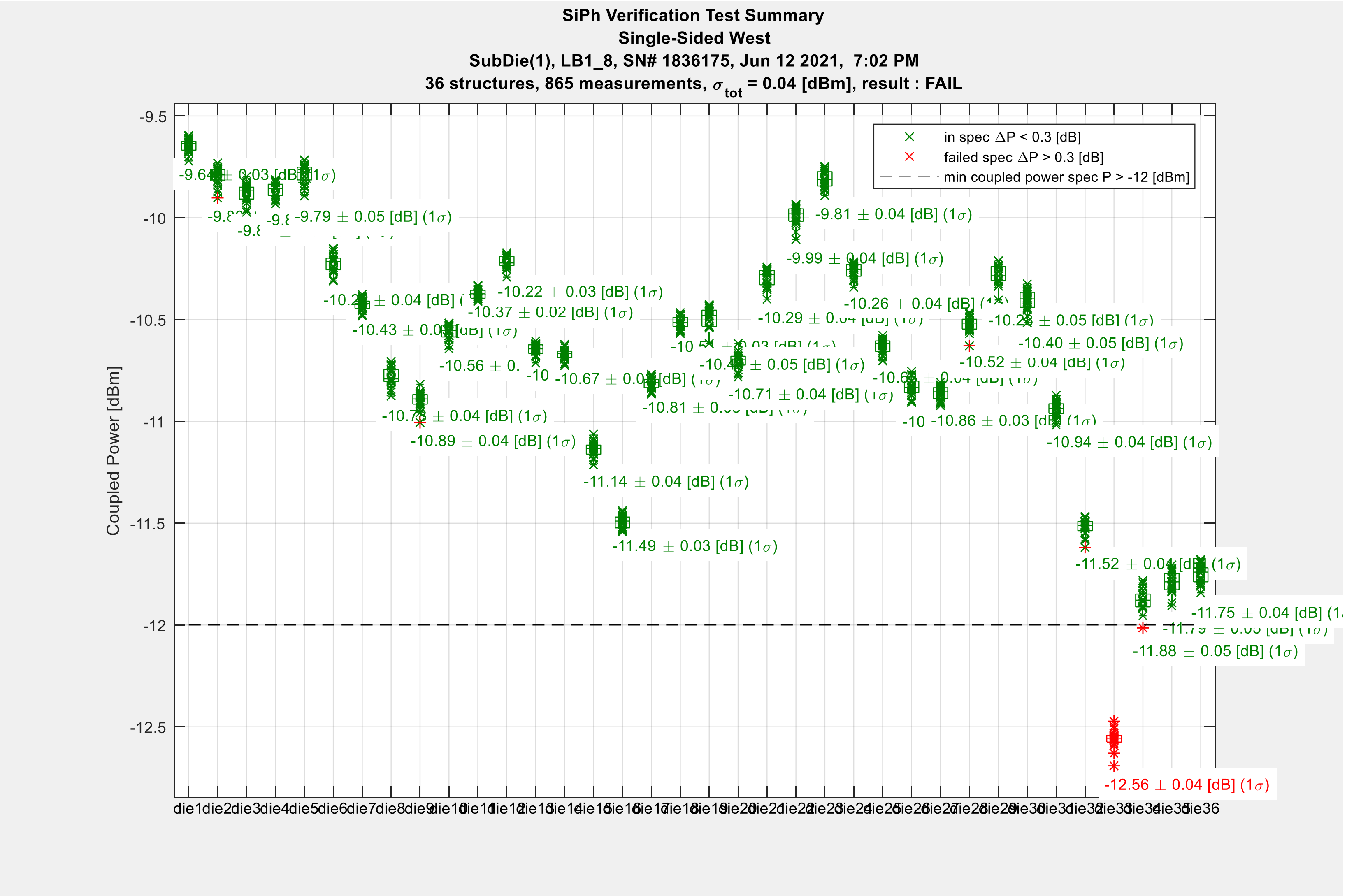
OptoVue Pro

Top View (Fiducial)



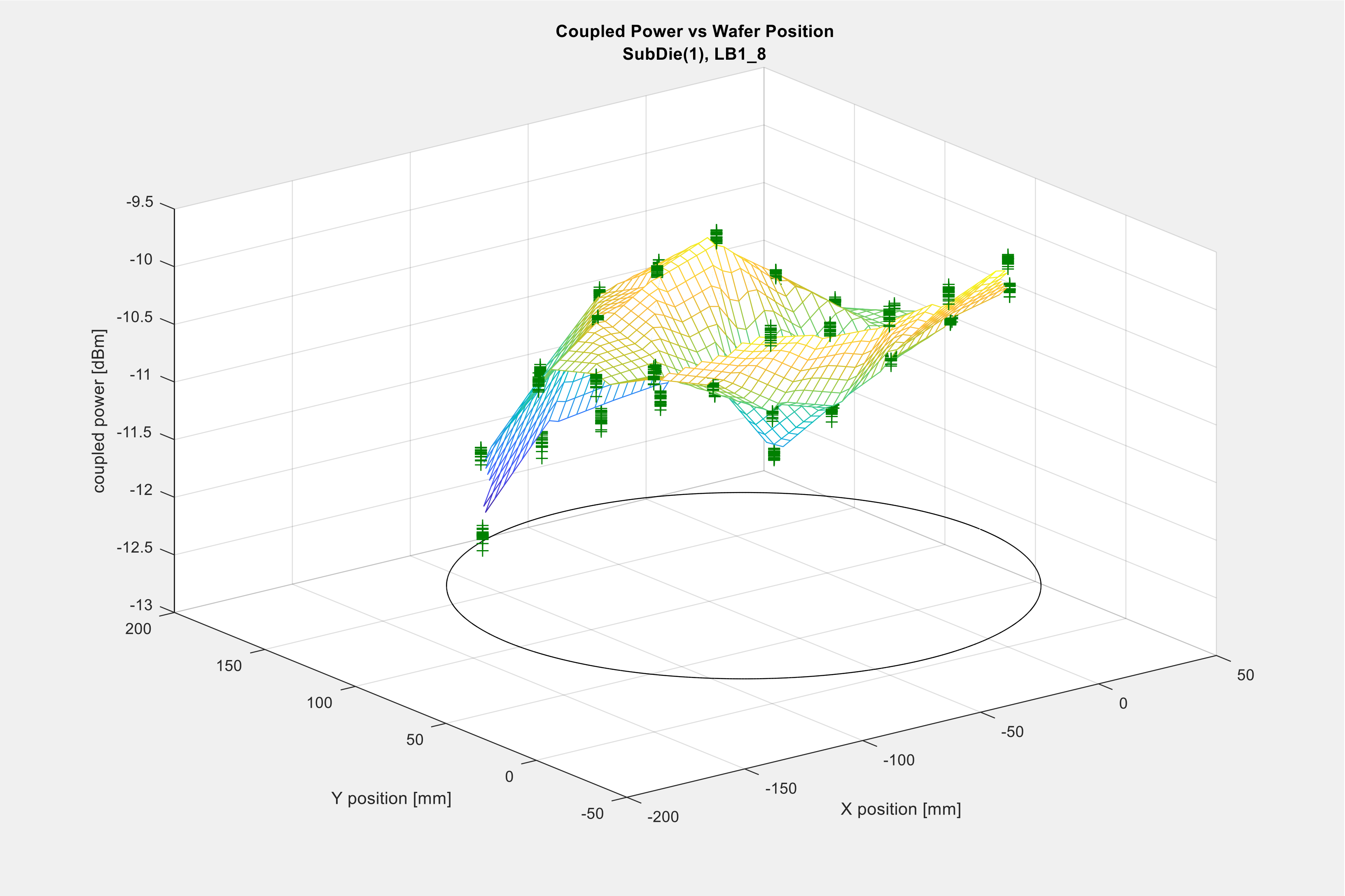
# Coupled Power by Structure – LB1_8

**36 die**
**1 subdie**
**4 channels**
**24 passes**



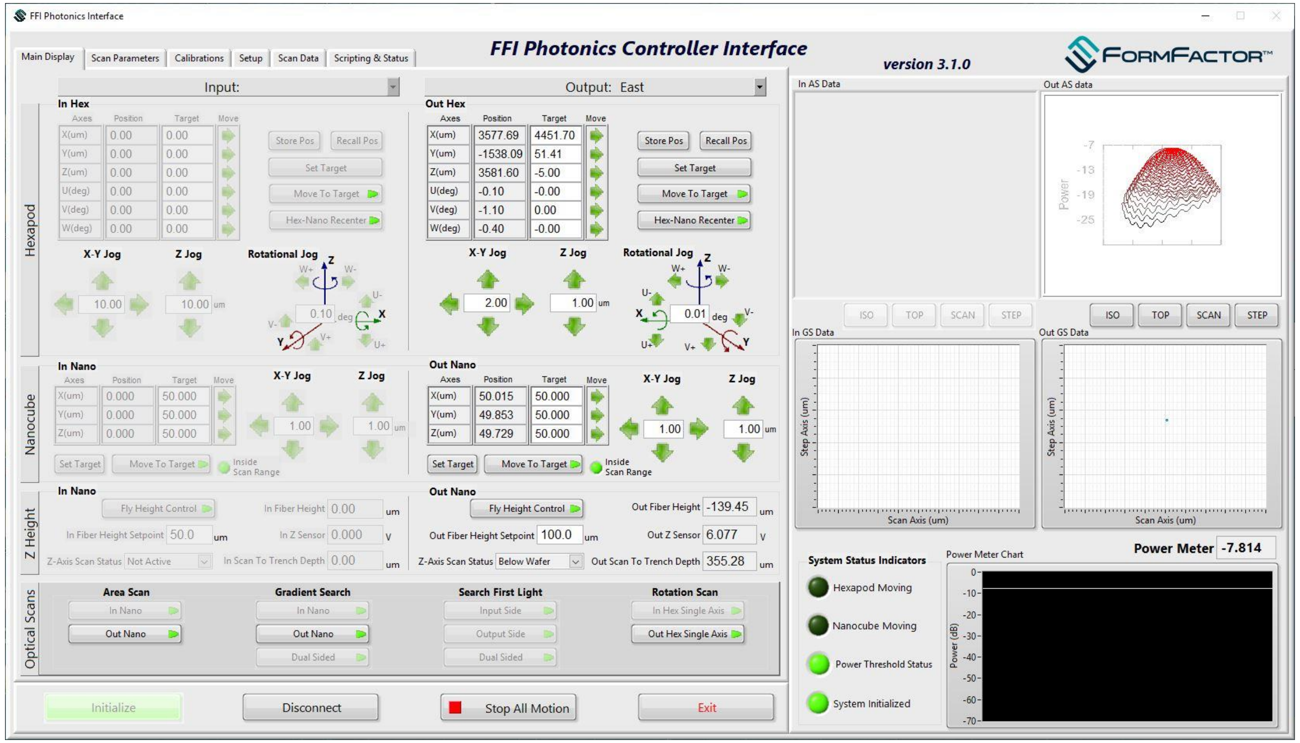
# Coupled Power vs Wafer Position – LB1_8

**36 die**
**1 subdie**
**4 channels**
**24 passes**



# Scanning and 3D coupling result-Long Lens (MFD=6µm)

One scanning example



Input:

Output: East

**In Hex**

| Axes | Position | Target |
|---|---|---|
| X(um) | 0.00 | 0.00 |
| Y(um) | 0.00 | 0.00 |
| Z(um) | 0.00 | 0.00 |
| U(deg) | 0.00 | 0.00 |
| V(deg) | 0.00 | 0.00 |
| W(deg) | 0.00 | 0.00 |

X-Y Jog 10.00; Z Jog 10.00 um; Rotational Jog 0.10 deg

**Out Hex**

| Axes | Position | Target |
|---|---|---|
| X(um) | 3577.69 | 4451.70 |
| Y(um) | -1538.09 | 51.41 |
| Z(um) | 3581.60 | -5.00 |
| U(deg) | -0.10 | -0.00 |
| V(deg) | -1.10 | 0.00 |
| W(deg) | -0.40 | -0.00 |

X-Y Jog 2.00; Z Jog 1.00 um; Rotational Jog 0.01 deg

**In Nano**

| Axes | Position | Target |
|---|---|---|
| X(um) | 0.000 | 50.000 |
| Y(um) | 0.000 | 50.000 |
| Z(um) | 0.000 | 50.000 |

X-Y Jog 1.00; Z Jog 1.00 um

**Out Nano**

| Axes | Position | Target |
|---|---|---|
| X(um) | 50.015 | 50.000 |
| Y(um) | 49.853 | 50.000 |
| Z(um) | 49.729 | 50.000 |

X-Y Jog 1.00; Z Jog 1.00 um

**In Nano**

In Fiber Height 0.00 um
In Fiber Height Setpoint 50.0 um
In Z Sensor 0.000 V
Z-Axis Scan Status Not Active
In Scan To Trench Depth 0.00 um

**Out Nano**

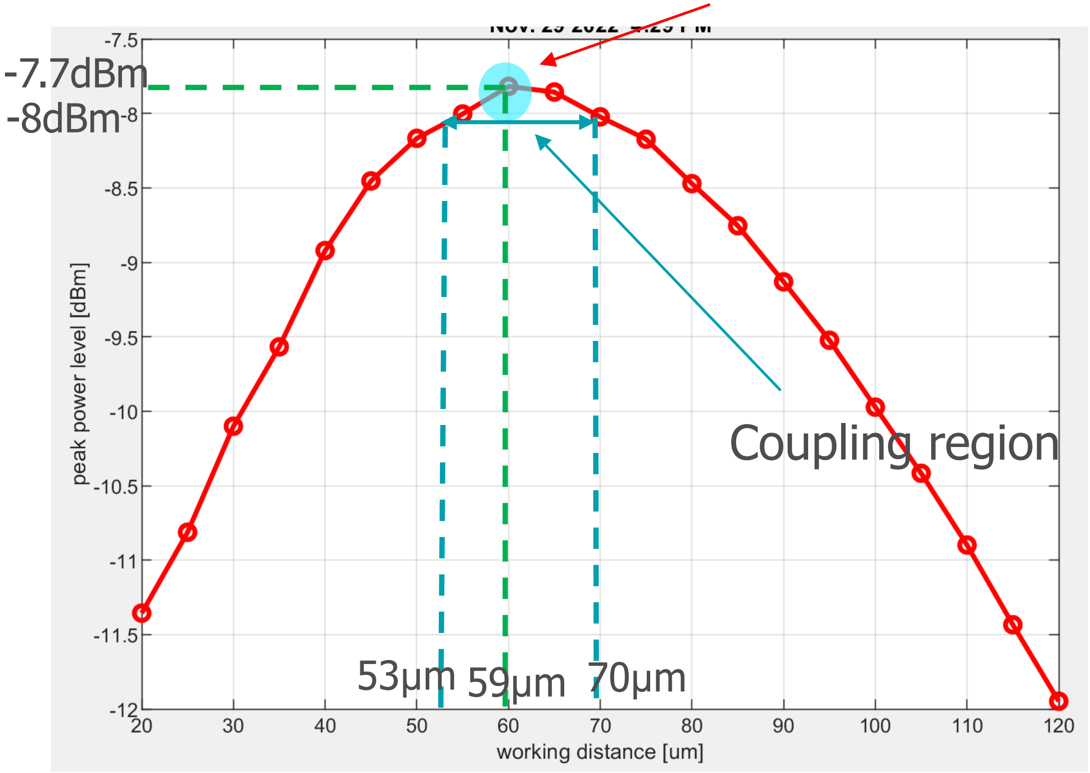
Out Fiber Height -139.45 um
Out Fiber Height Setpoint 100.0 um
Out Z Sensor 6.077 V
Z-Axis Scan Status Below Wafer
Out Scan To Trench Depth 355.28 um

**System Status Indicators**

- ● Hexapod Moving
- ● Nanocube Moving
- ● Power Threshold Status
- ● System Initialized

**Power Meter** -7.814

Max coupling at 59um which agrees with simulation



-7.7dBm

-8dBm

Coupling region

53µm 59µm 70µm

Input power -2.2 dBm

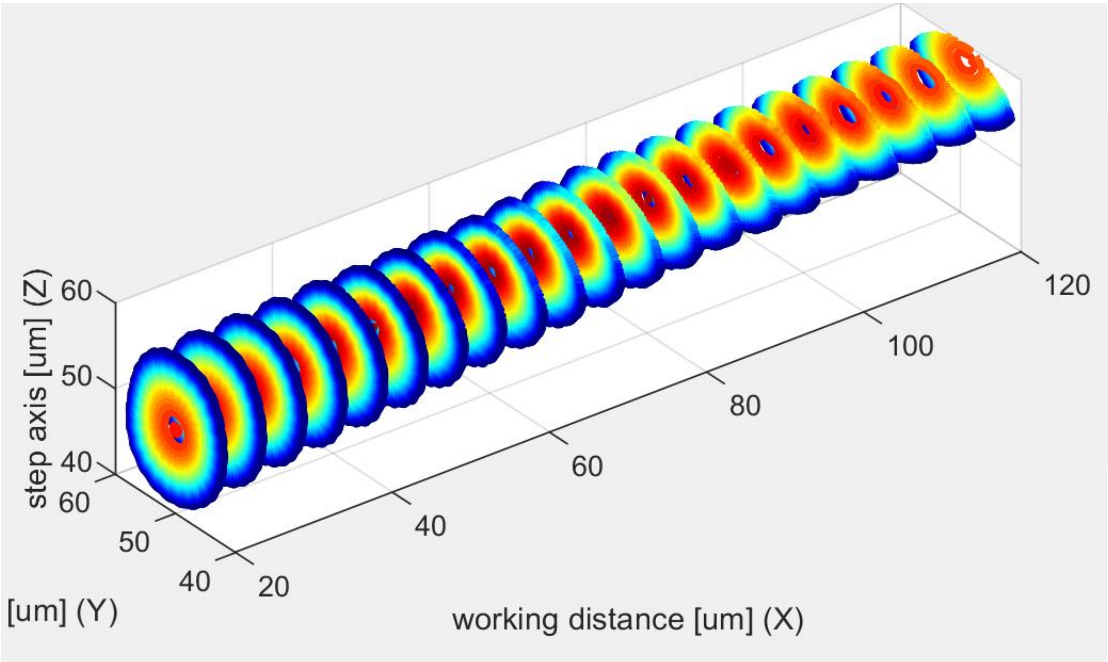
Power coupler loss (7.7-2.2)/2=2.75dB/faucet

# 3D coupling indicate the waveguide beam direction in Edge coupling (6um) – V-Groove

Power coupling contour in 3D dimension (Color indicates power level)

20um Spiral Scans

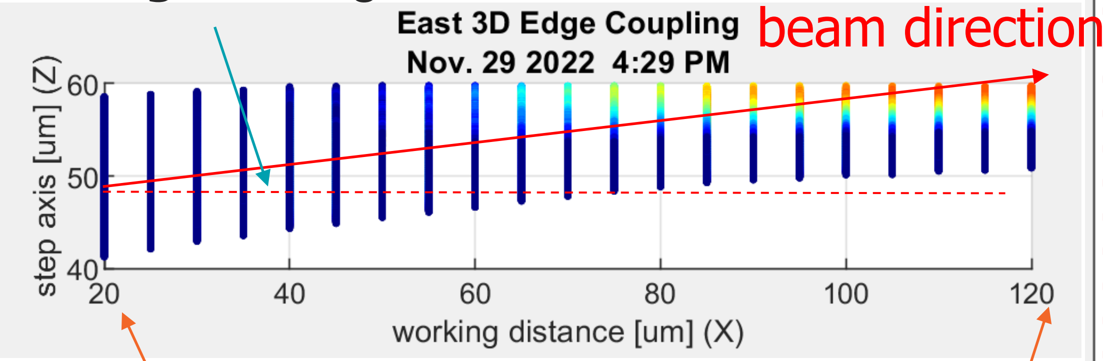
ISO view

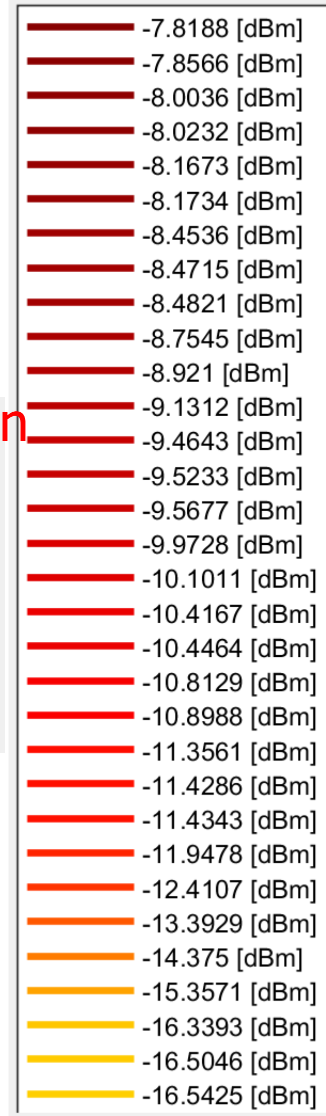


X-Z view

Angle≈6 deg

beam direction





20 um away from Waveguide

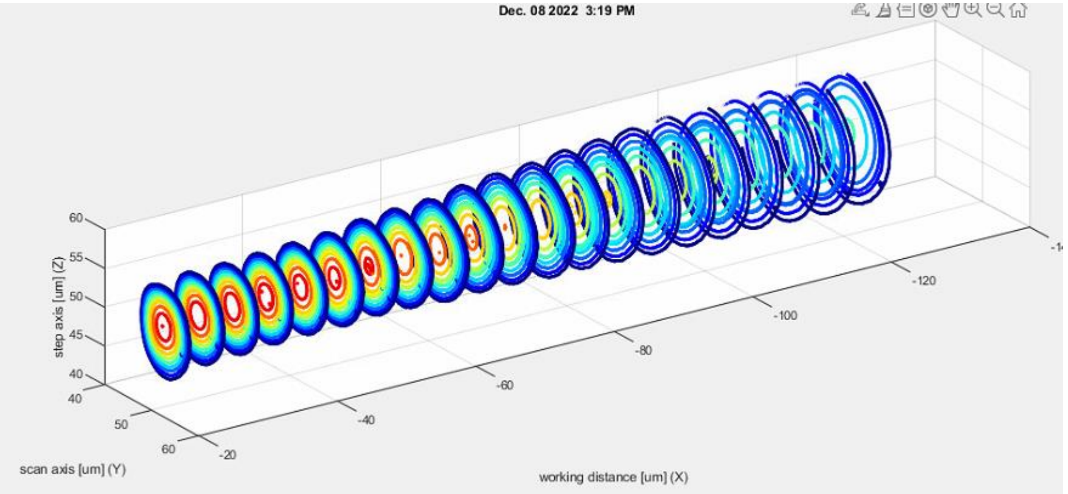
120 um away from Waveguide

# 3D coupling indicate the waveguide beam direction in Edge coupling – Trench

Power coupling contour in 3D dimension (Color indicate power level)

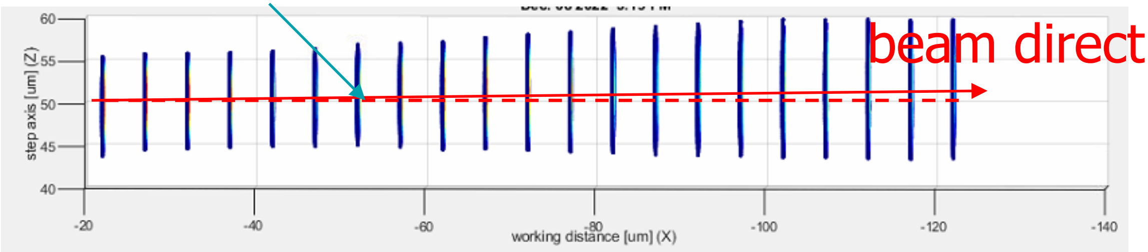
20um Spiral Scans

ISO view

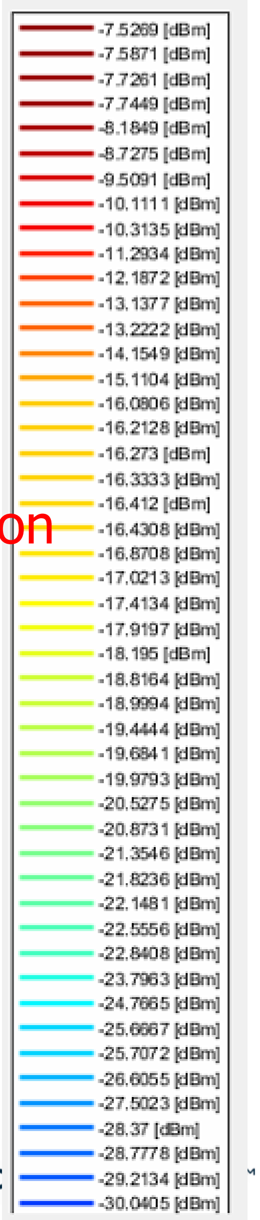


X-Z view

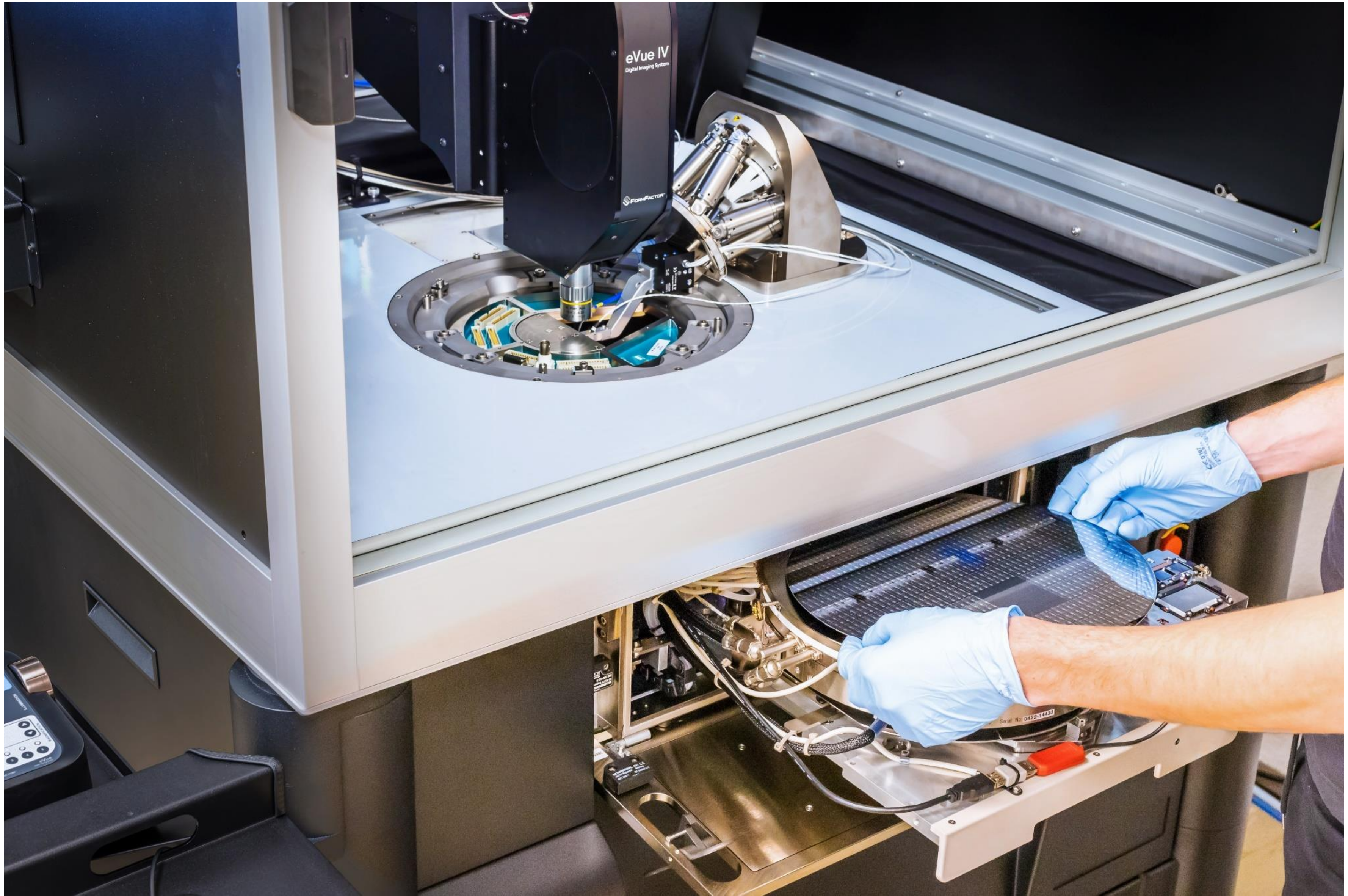
**Angle≈0.89deg**



beam direction

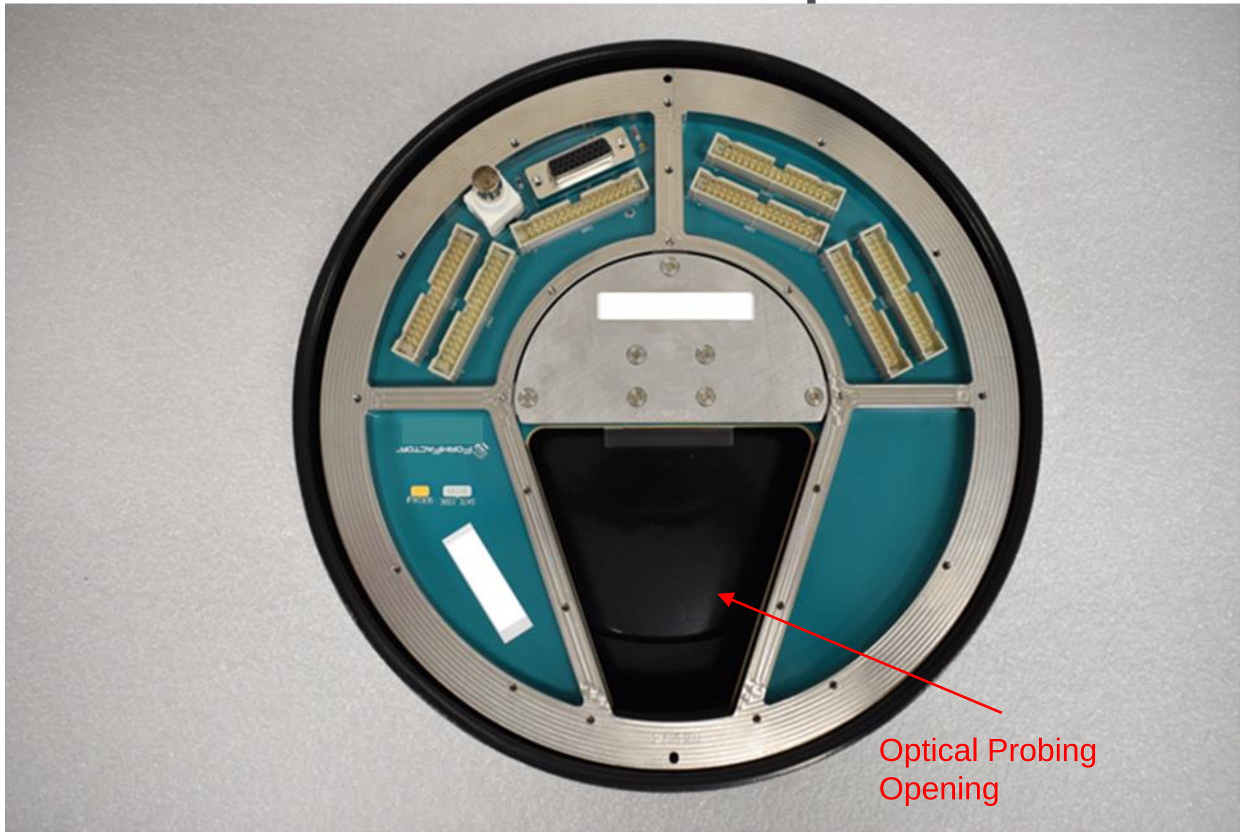


# Probe Card Integration

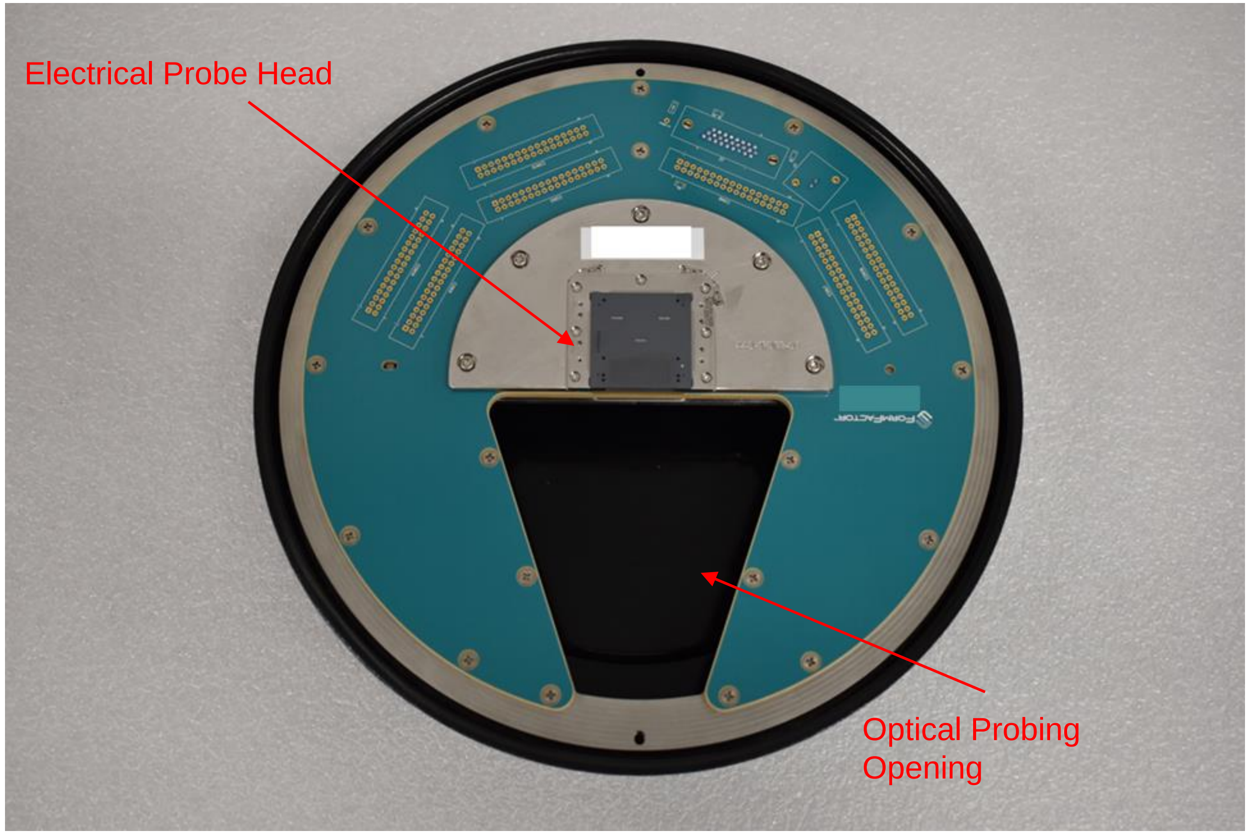


# FFI Apollo Probe technology adapted for SiPh probing

## Probe Card Top View



## Probe Card Bottom View

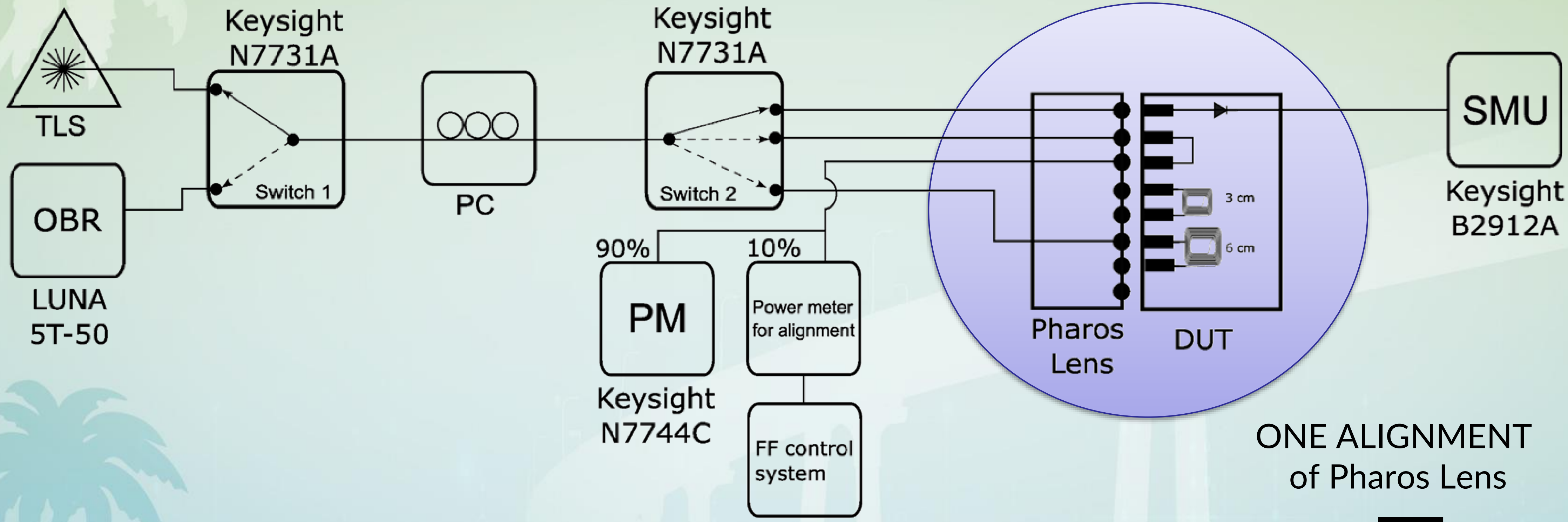


# Probe Card Integration with Edge Coupling Pharos

FFI Apollo and Pharos Probe Technology is currently being used for production testing of edge coupled wafer level V-groove Co-Packaged Optics devices

# Test setup at IHP

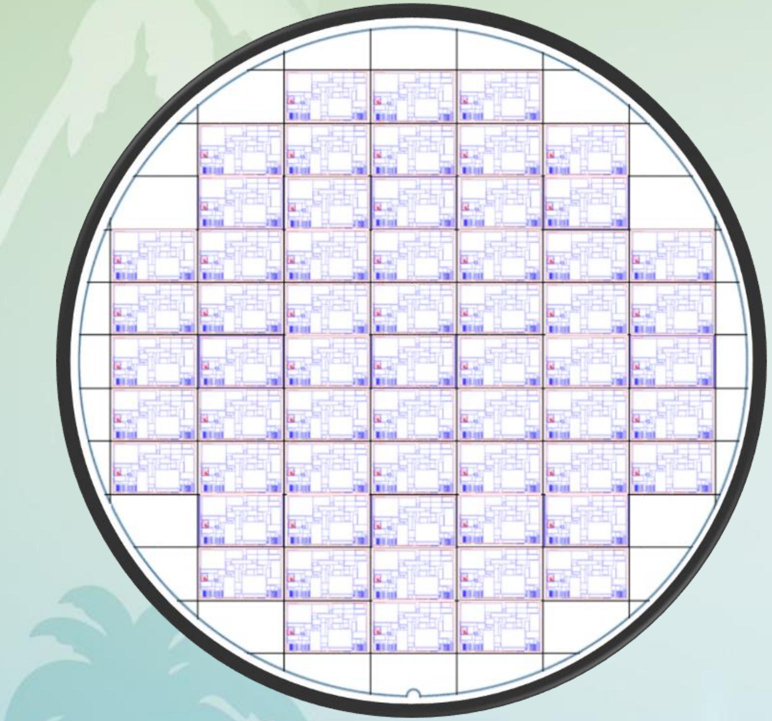
Probe Station CM300xi + MHU



ONE ALIGNMENT
of Pharos Lens

- Coupling loss
- Waveguide loss
- Photodiode responsivity

# Device under test



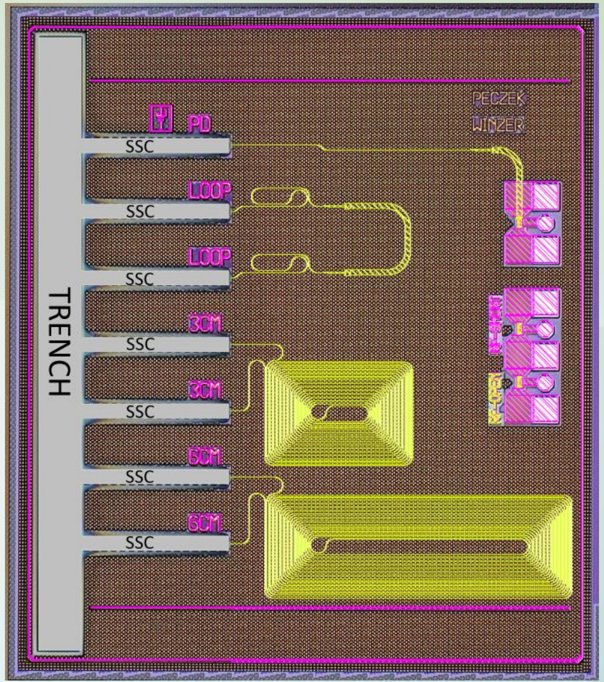
200 mm PIC wafer

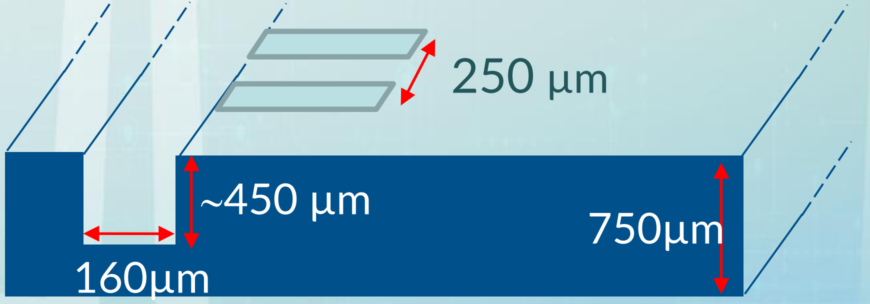
Up to 61 dies

Test chip consist on:

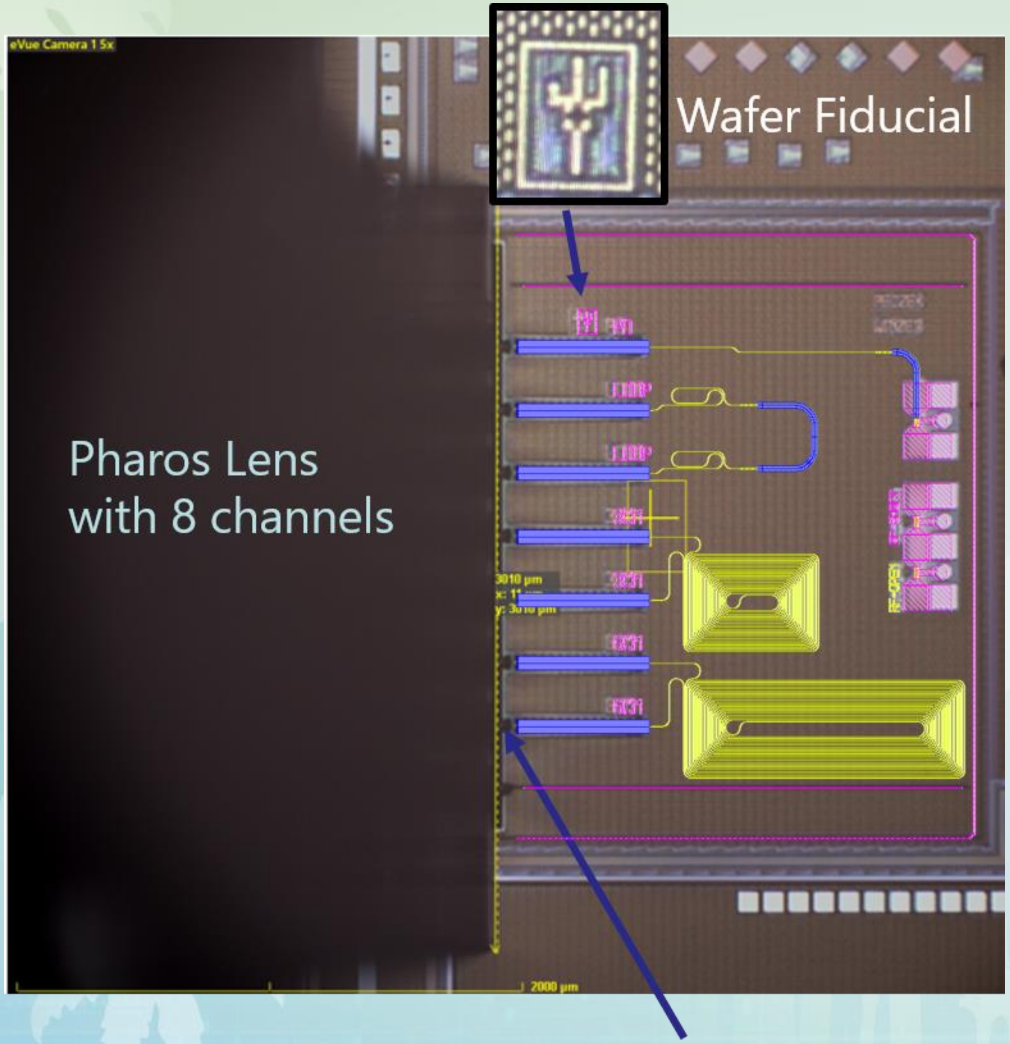
- Ge photodiode
- Waveguide loop
- 3 cm long waveguide
- 6 cm long waveguide

Photograph of the test chip with overlapped layout





# Design and fabrication requirements



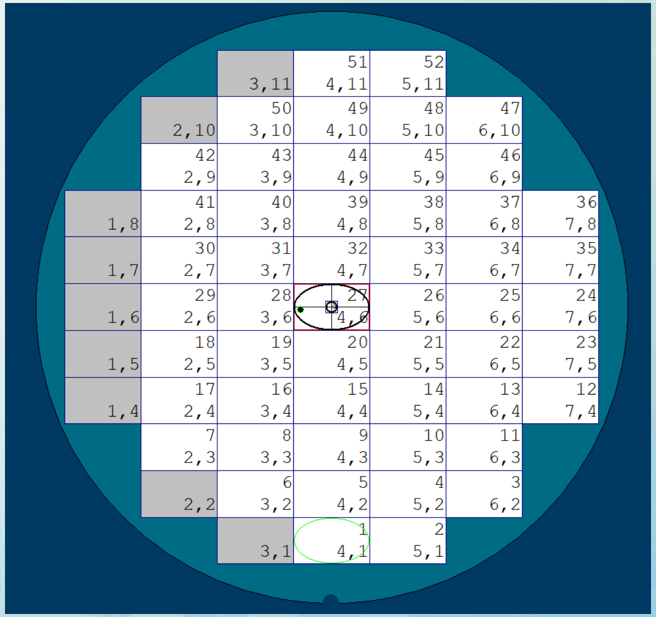
Requirements:

- Trench width > 95 µm
- Trench depth > 60 µm
- Wafer fiducial present
- Pharos spot size range 2-10.2 µm

# Testing step by step

1. System Calibration → *Essential for accuracy and automation*
2. Trench quality control → *Important to not damage the Pharos Lens*
3. Selecting the test dies
4. Calibration of the optical path and measurement instruments
5. Preparation of the measurement project (IC-CAP Keysight)
6. Running the measurement sequence …

….. and waiting for the results.

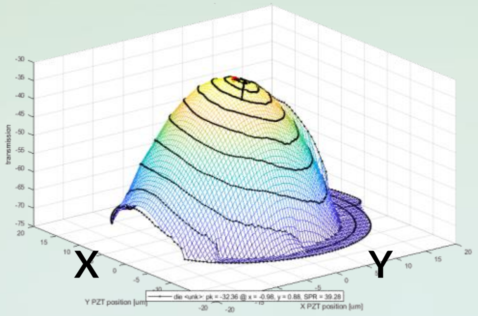


Grey chips excluded from tests due to trench imperfections

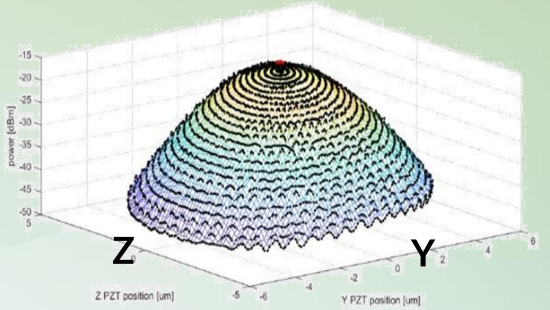
# Alignment

Fully automated, algorithm-based with user-defined parameters

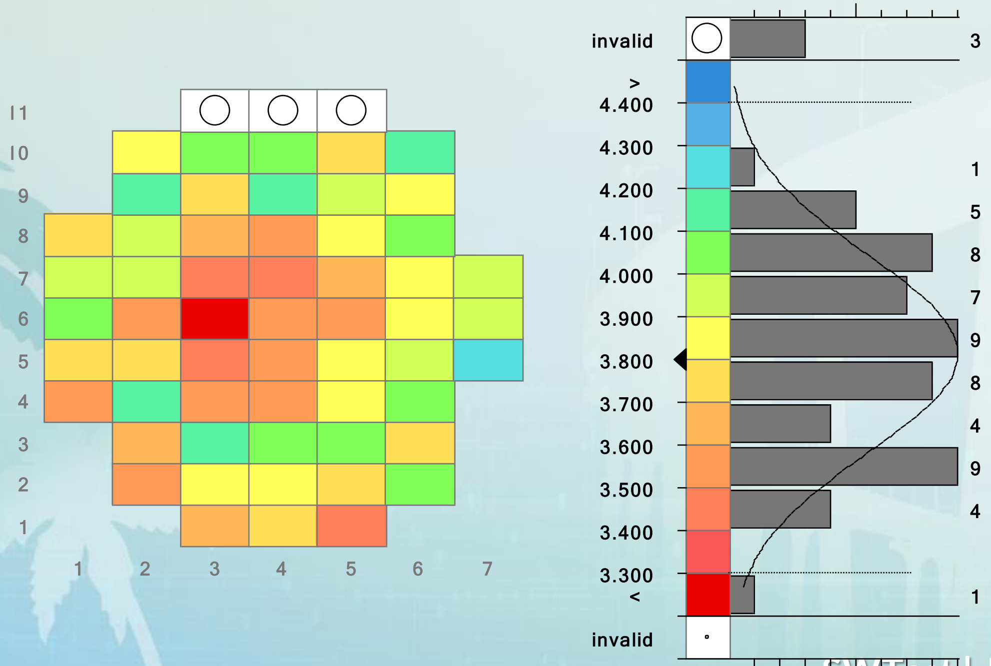
## Grating coupler



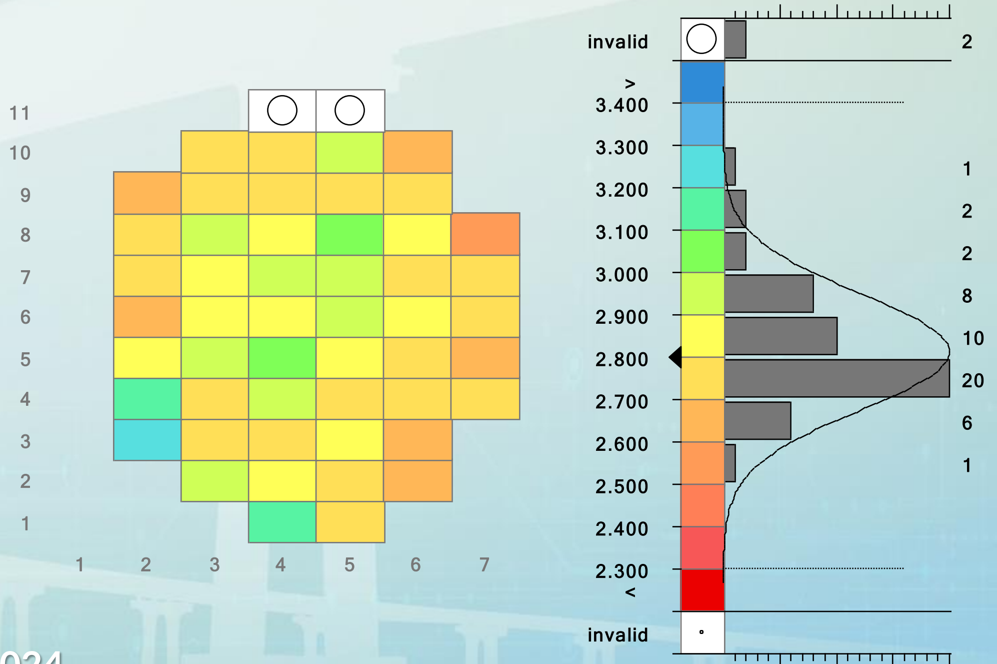
## Edge coupler



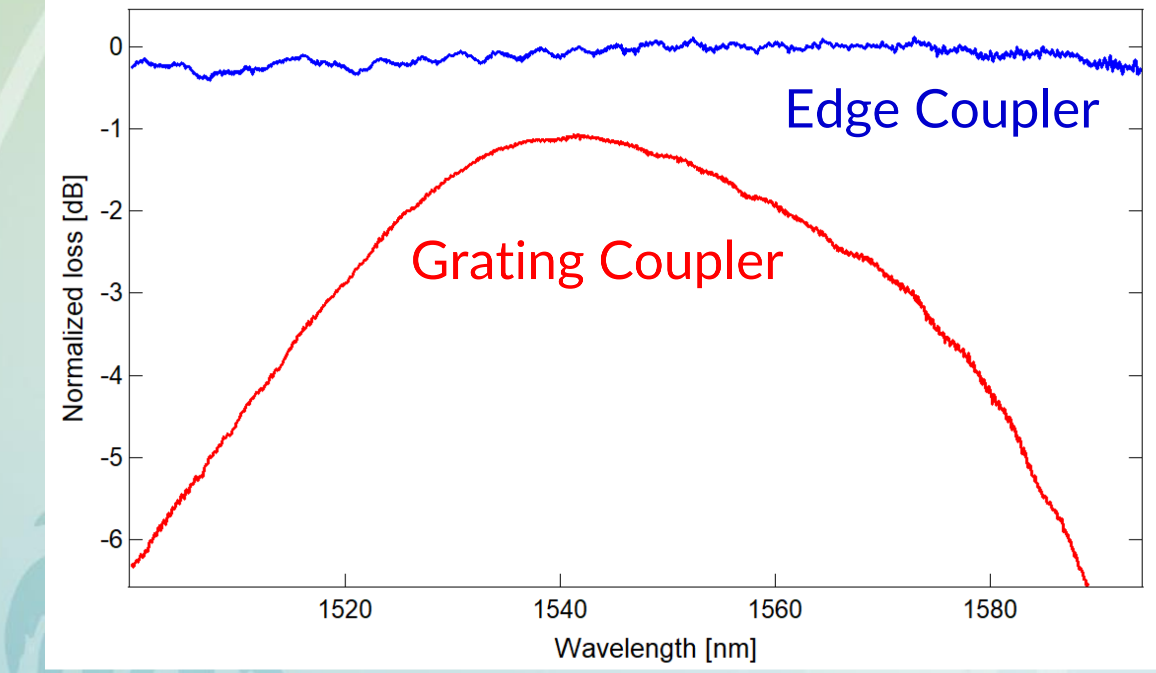
Mean coupling loss: 3.9 dB ± 0.2 dB

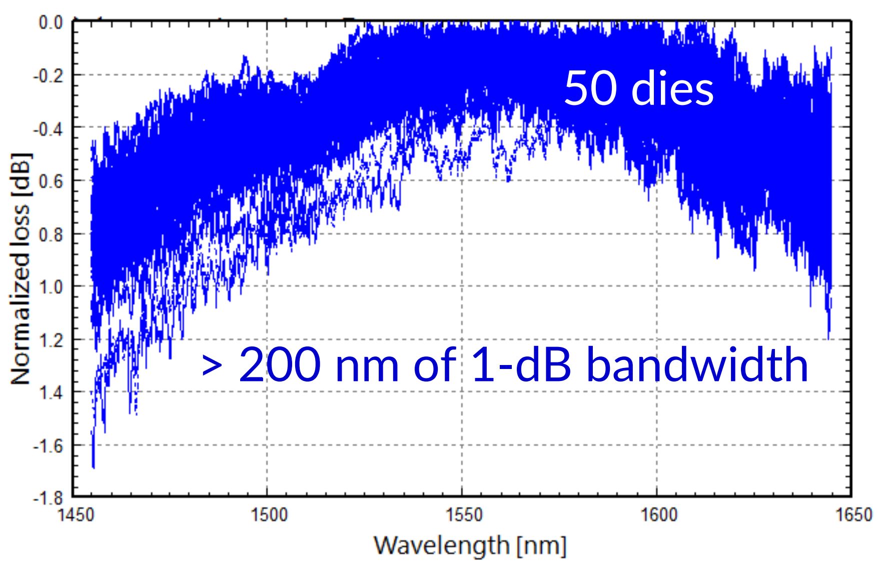


Mean coupling loss: 2.8 dB ± 0.1 dB

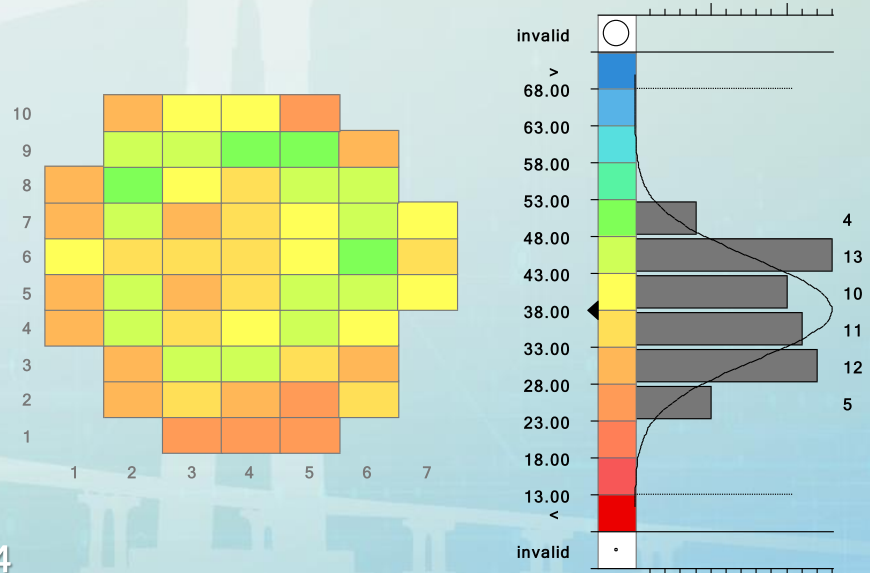


# Optical bandwidth
## Wafer level distribution





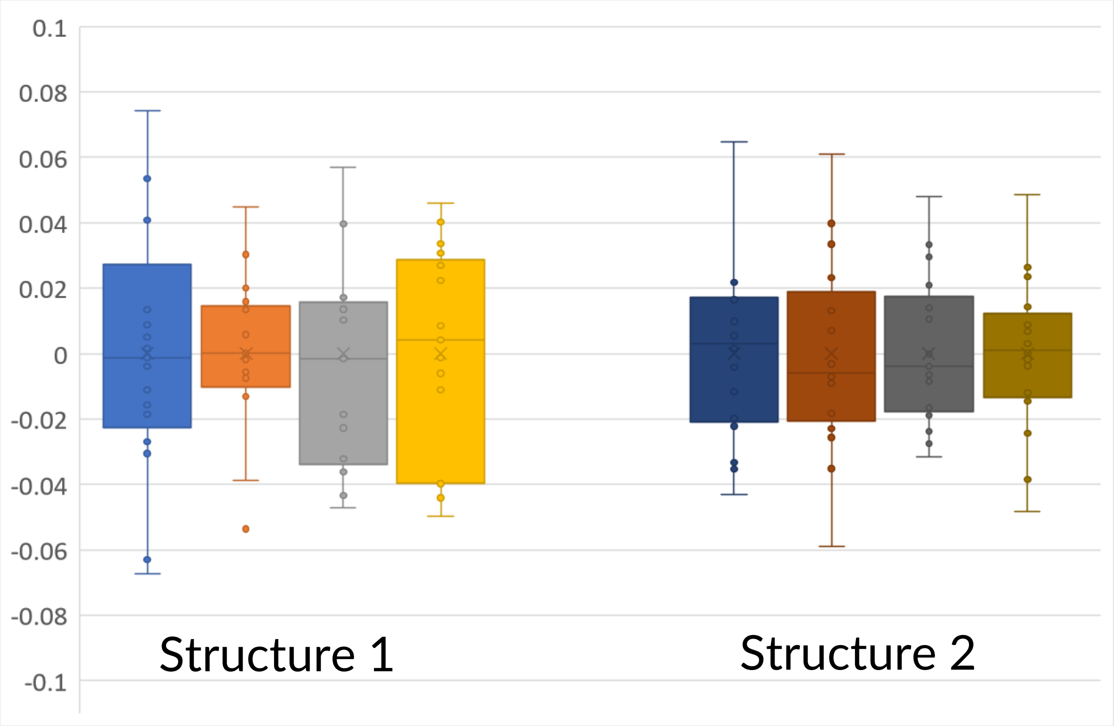
1-dB bandwidth of 38 nm ± 7nm (wafer variation)

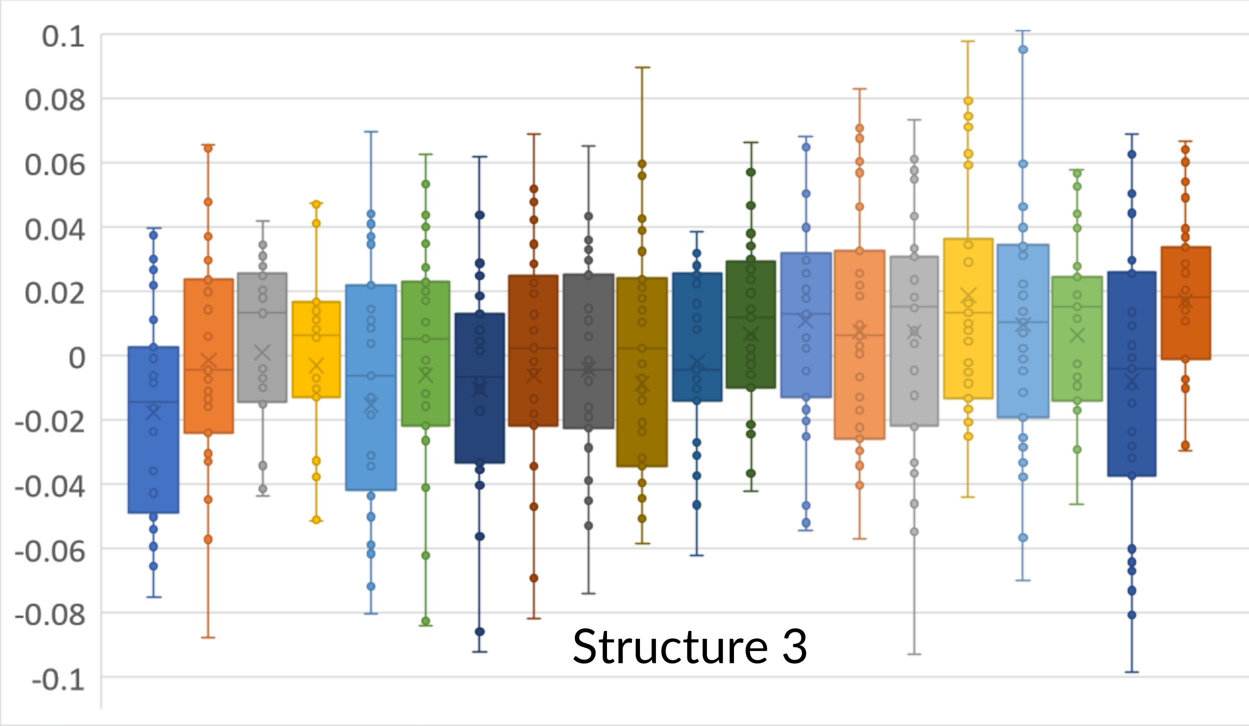


# Repeatability

Coupling via grating coupler
- over 4 dies
- 2 test structures
- repeated 17 times

Coupling via edge coupler
- over 31 dies
- 1 test structure
- repeated 20 times





**sigma ~ 0.02 dB**

**sigma ~ 0.02 dB**

# Measurement time

# Summary

- Fully automated edge coupling was demonstrated on 200 mm wafer
- The system includes advanced, automated calibration routines for high accuracy PIC characterization
- Comparison with established grating coupler probing shows no significant drawback.

# Thank you for your attention !

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dan.rishavy@formfactor.com