SWTEST
PROBE TODAY, FOR TOMORROW
2024 CONFERENCE

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

FORMFACTOR™

ihp

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Overview

- Introduction
- FormFactor edge coupling technology
- IHP wafer-level results
- Summary

IHP
Innovations for High Performance Microelectronics

Frankfurt (Oder)

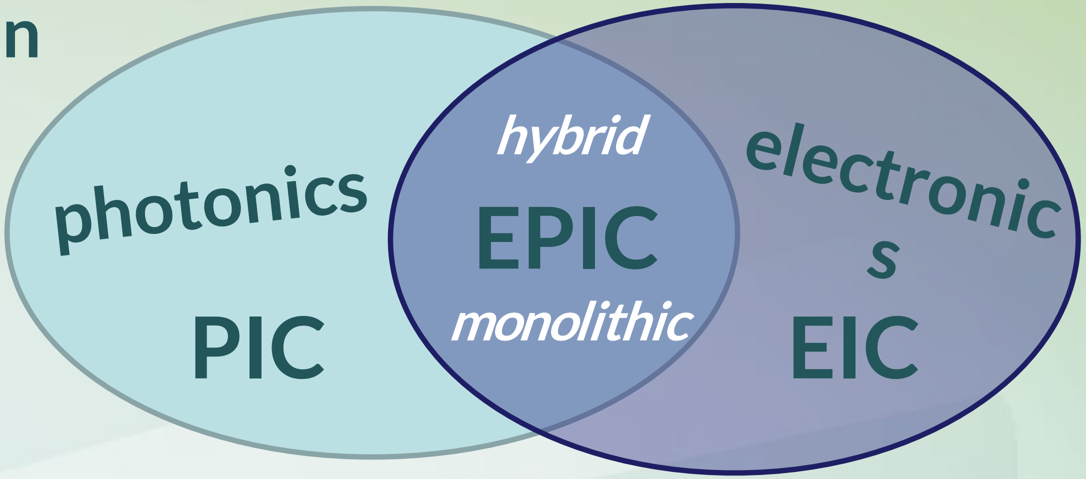
Institute for R&D & Prototyping

- 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

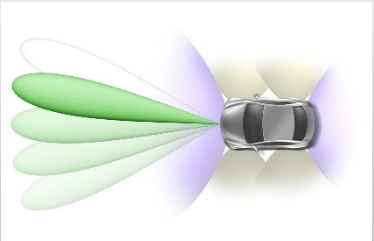
can be combined with electronics.



- 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 !

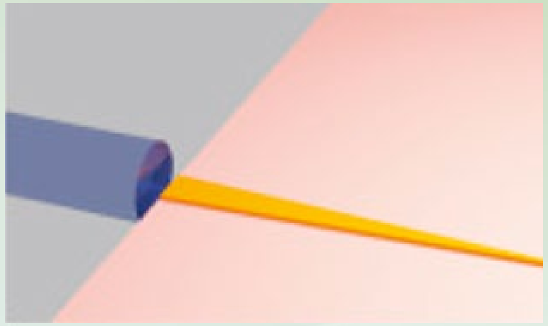
Optical vs. electrical probing

- 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	> 3 dB	<2 dB
Polarization dependance	high	low
Bandwidth	<40 nm	> 100 nm
On- wafer testing	available	Now available

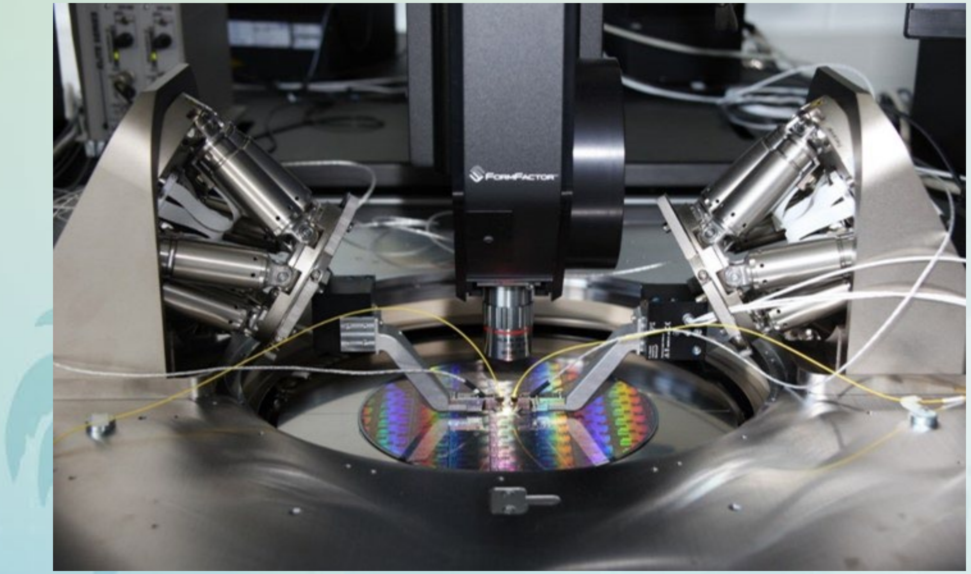
drawbacks

benefits

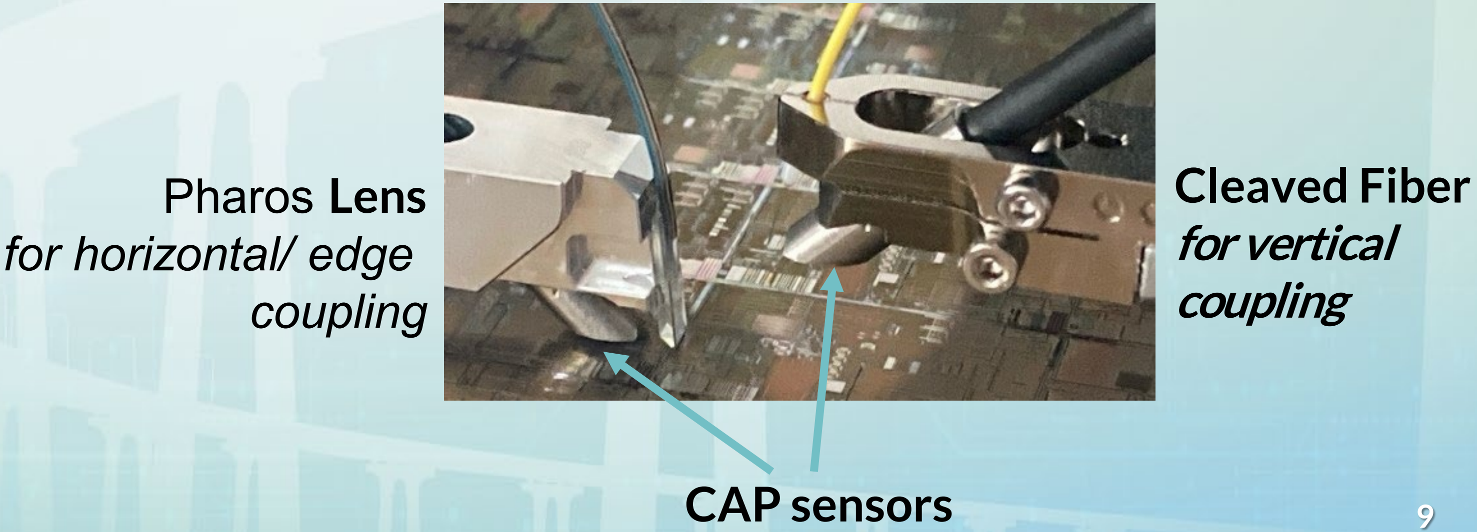
Source of pictures: https://www.sciencedirect.com/science/article/abs/pii/B9780128133538000087

Equipment for on-wafer PIC characterisation

- **300 mm Probe Station FormFactor CM300xi with Loader**
- **6-axis positioners with Nano Cubes (PI)**

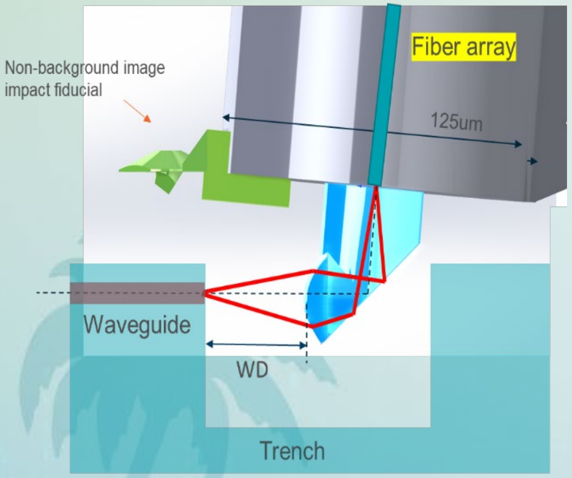


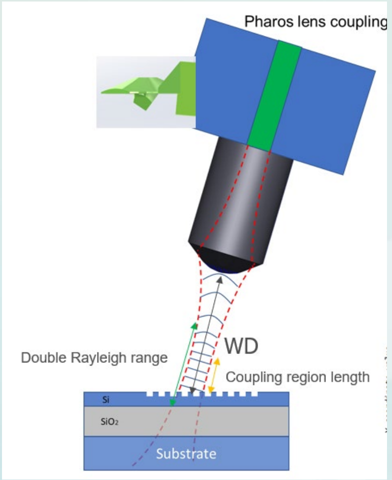
- **Optical Probe**



Pharos Lens for Silicon Photonics Probing

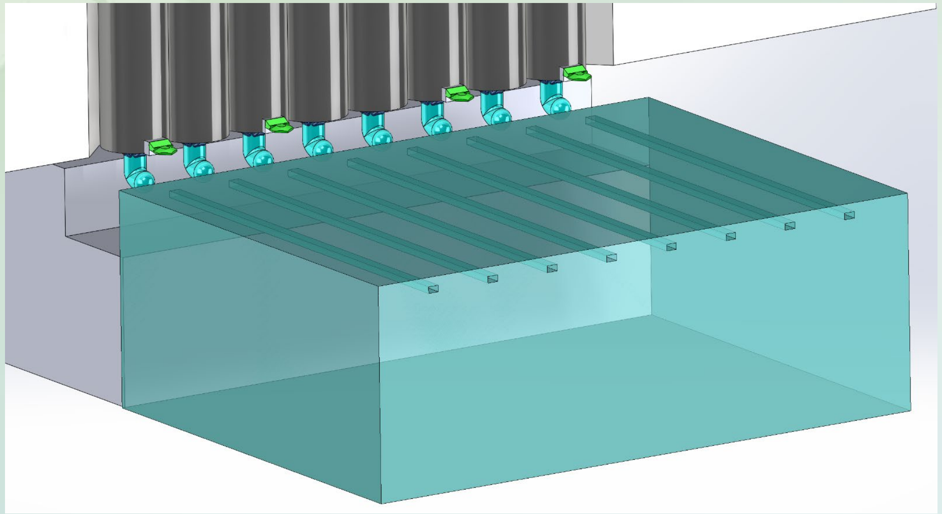
Pharos™ Technology

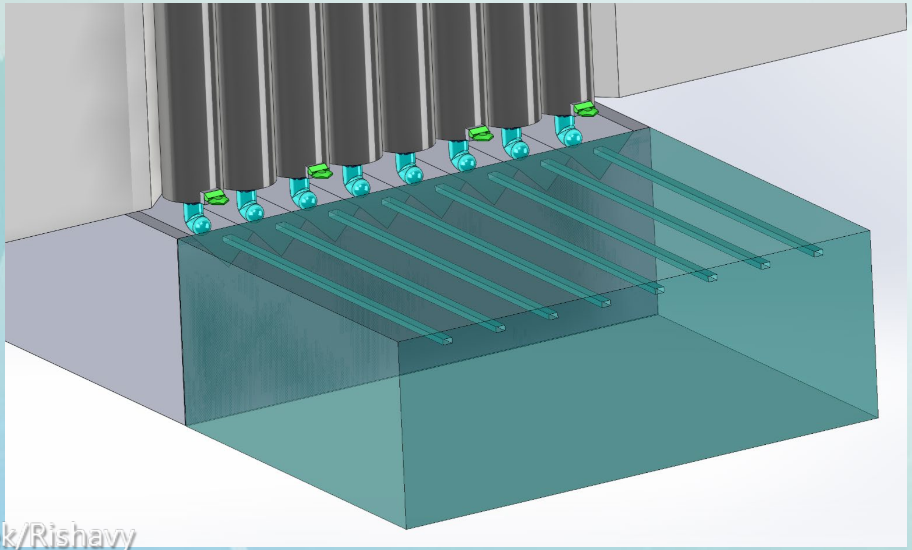


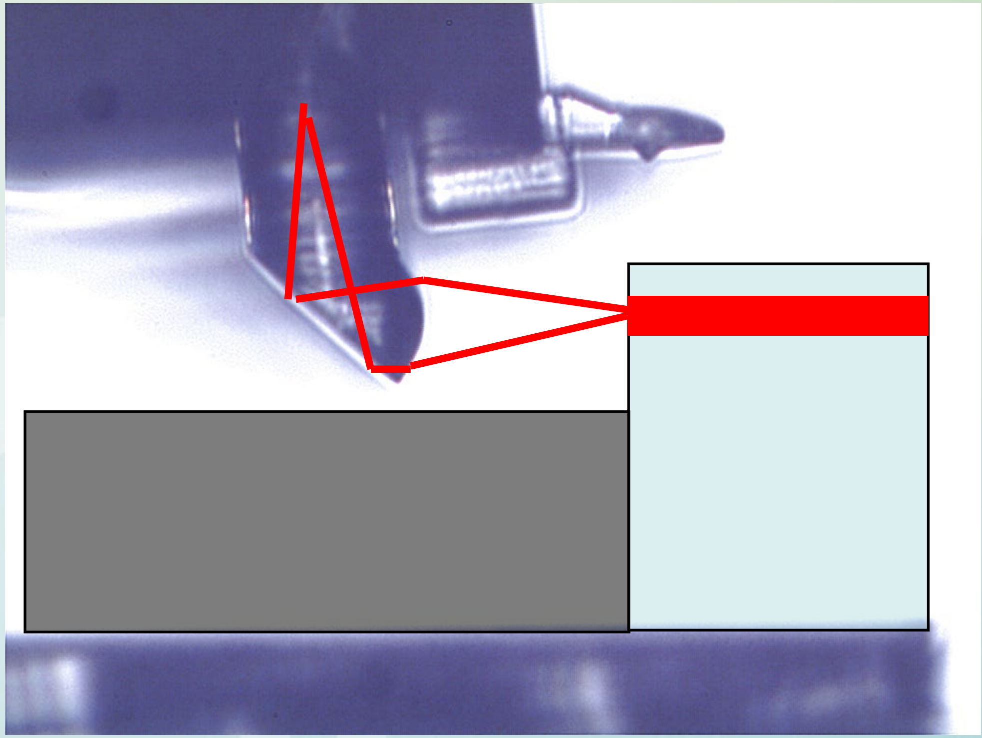


- Wafer level edge and vertical coupling designs
  - Short and long working distance designs
- High coupling efficiency
- High repeatability and stability
- Nearly collimated beam with Plane front wave at grating coupler taper
- Ultra long working distance(WD) possible – ex. up to >800µm
- Tolerant in 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

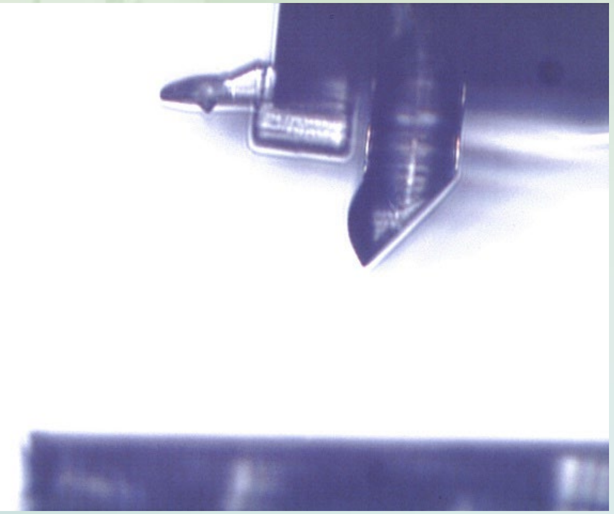




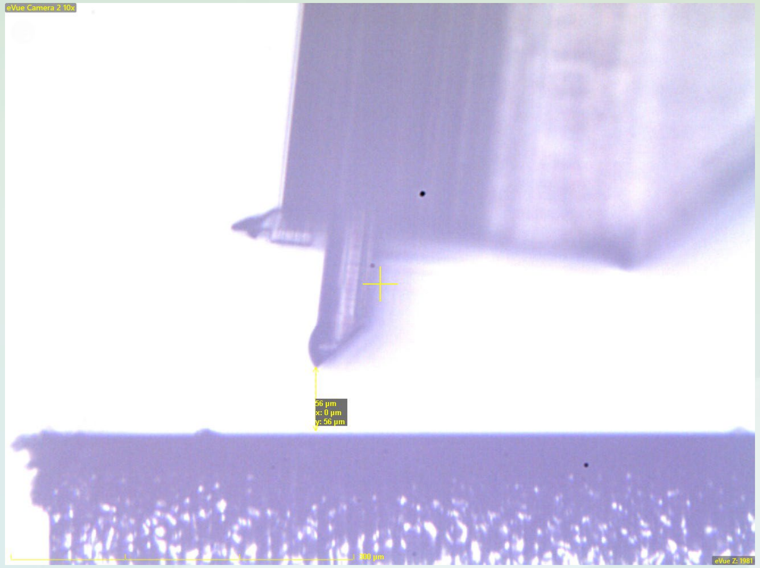


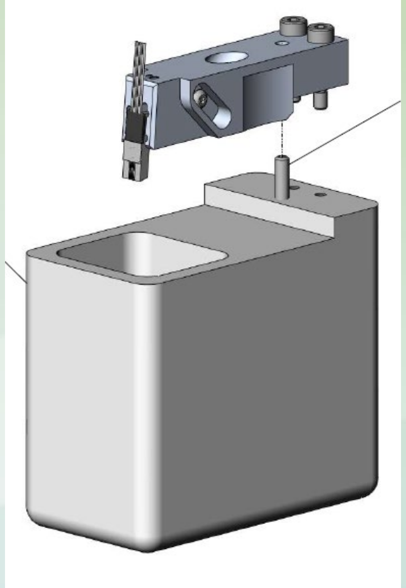
Pharos Lenses for Grating and Edge Coupling

Short Edge Pharos lens (Trench)

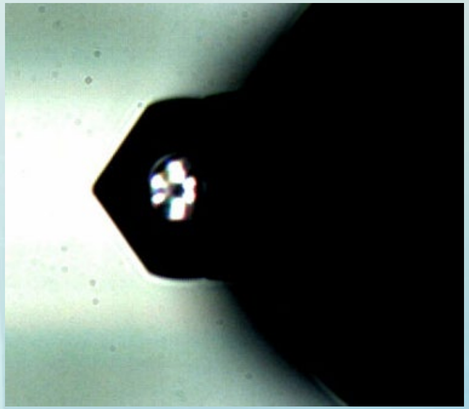


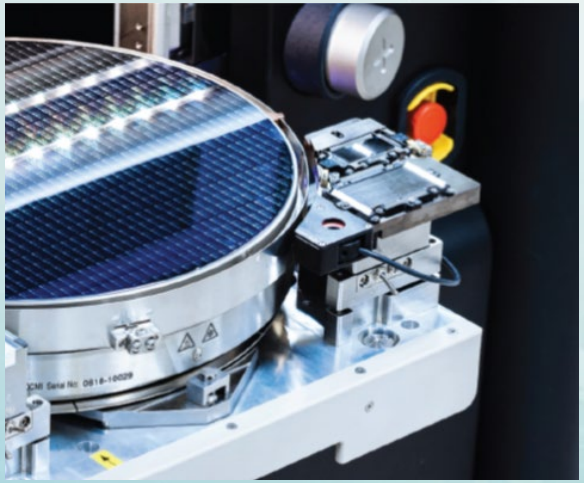
Long Edge Pharos lens (V-groove)





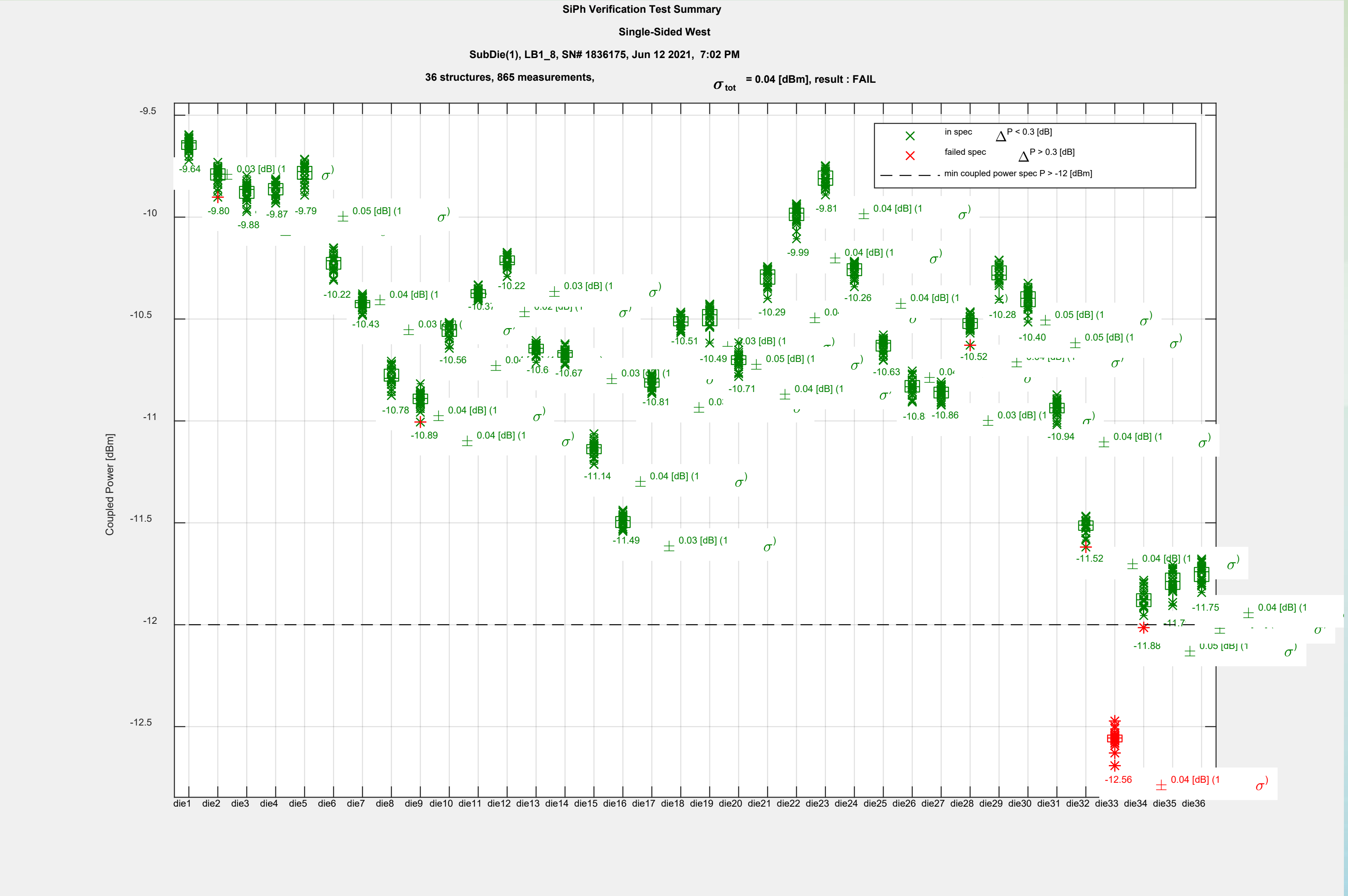
Top View (Fiducial)





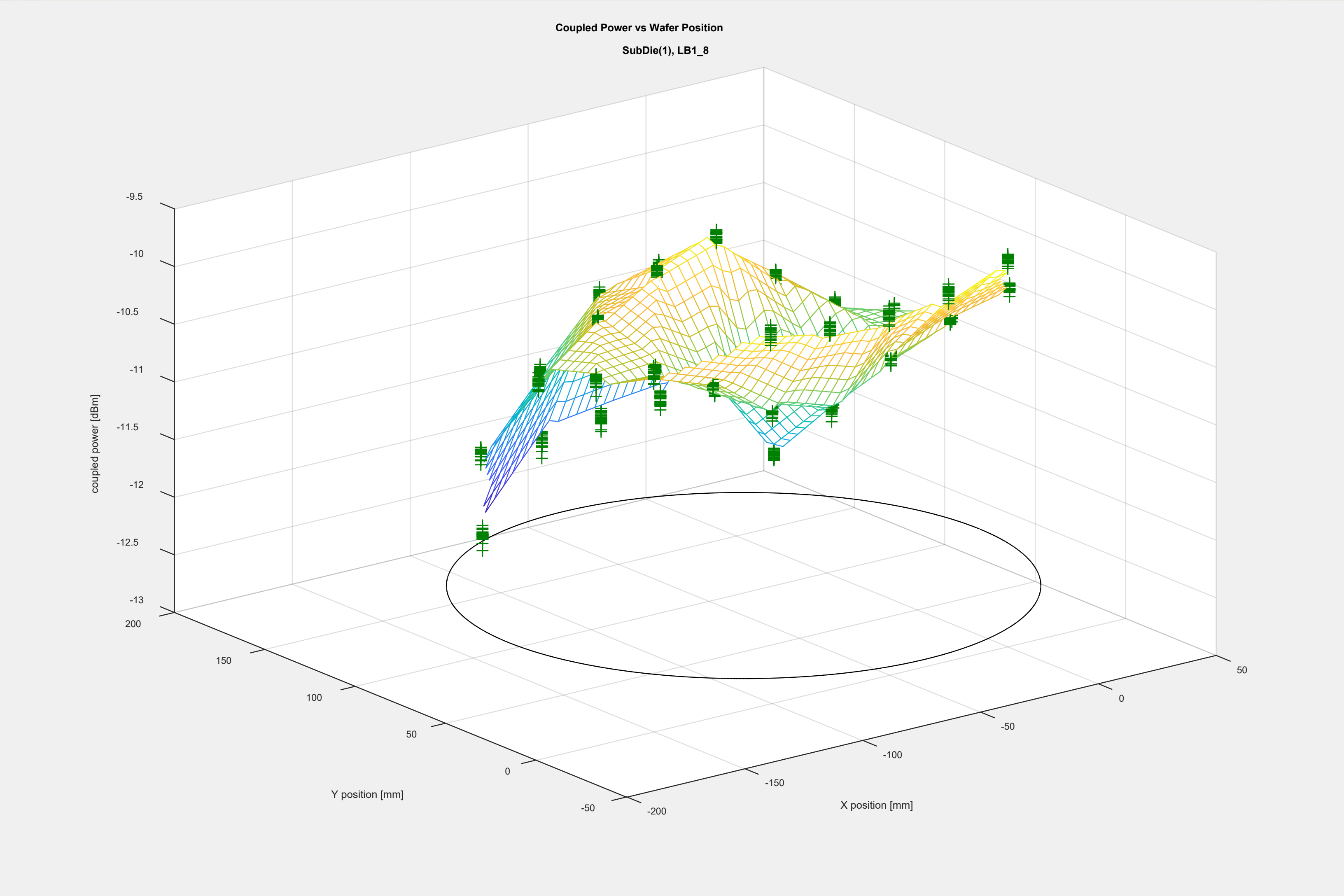
OptoVue Pro

Coupled Power by Structure – LB1_8



36 die
1 subdie
4 channels
24 passes

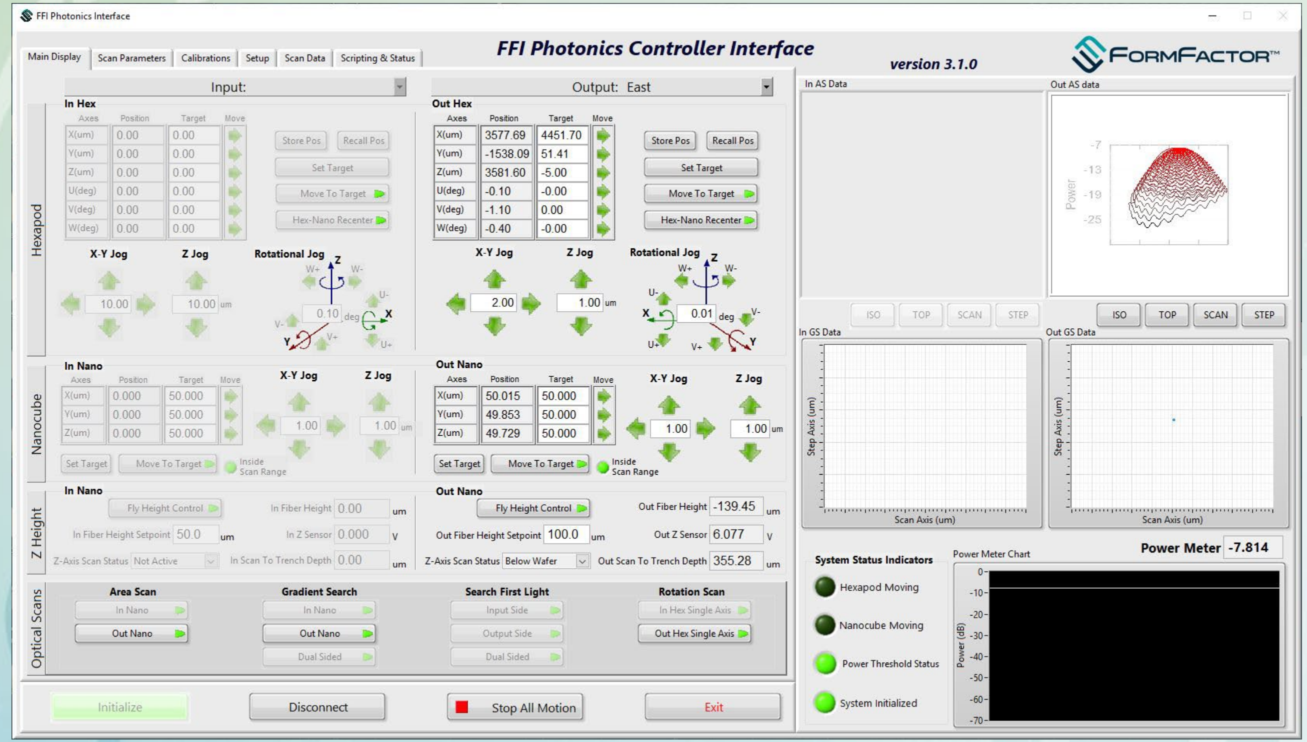
Coupled Power vs Wafer Position – LB1_8



36 die
1 subdie
4 channels
24 passes

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

One scanning example



FFI Photonics Interface

FFI Photonics Controller Interface version 3.1.0

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

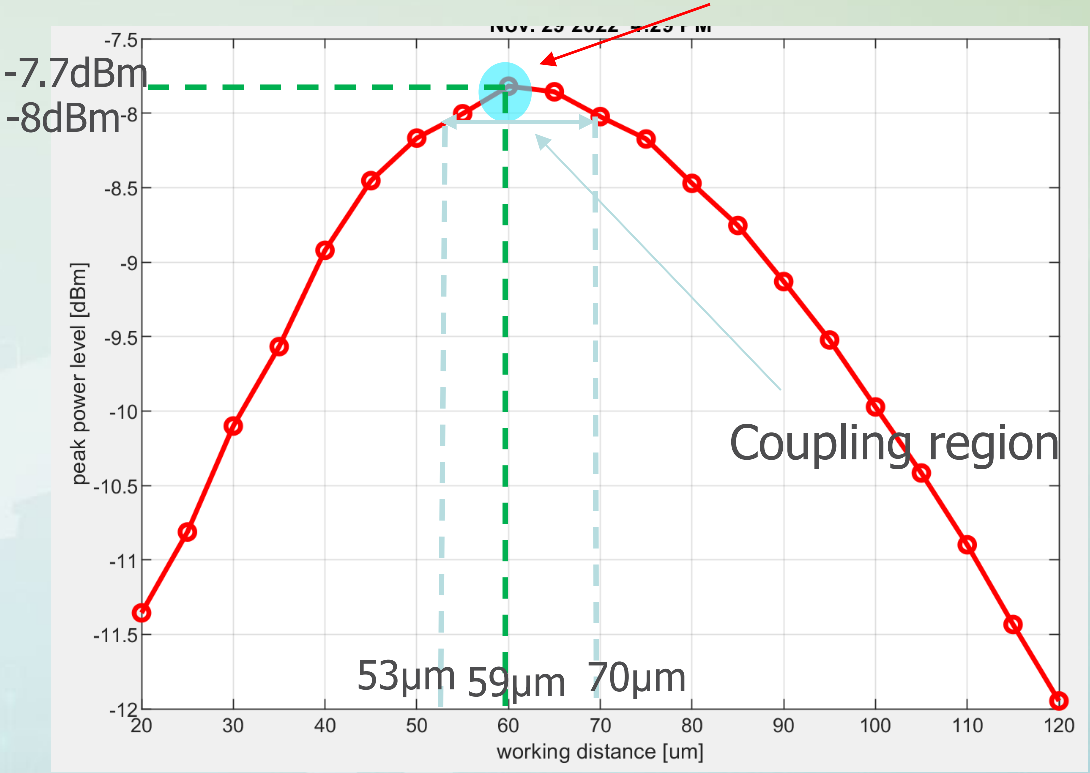
Out Z Sensor 6.077 V

Z-Axis Scan Status Below Wafer

Out Scan To Trench Depth 355.28 um

Power Meter -7.814

Max coupling at 59um which agrees with simulation



Input power -2.2 dBm

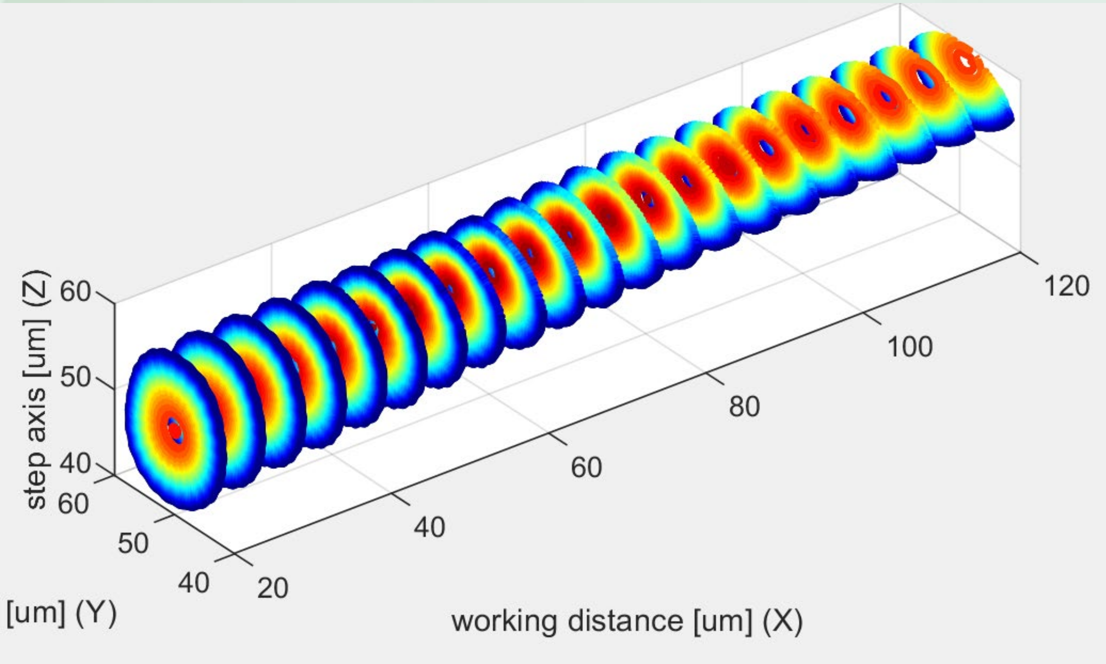
Power coupler loss (7.7-2.2)/2=2.75dB/facet

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

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

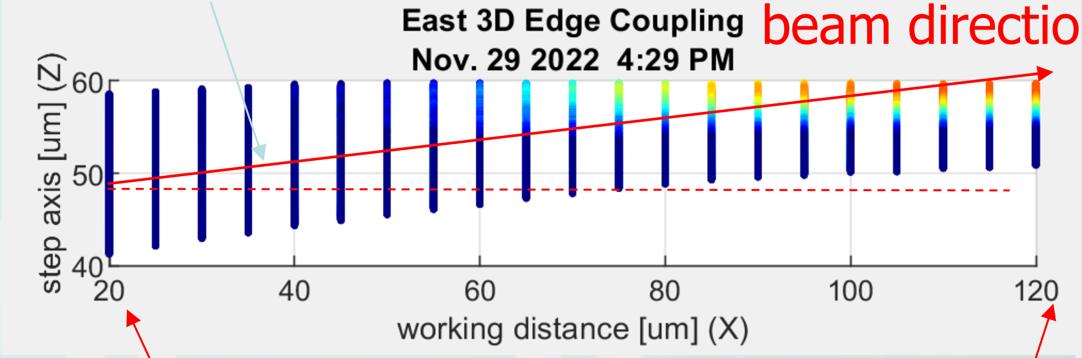
20um Spiral Scans

ISO view



X-Z view

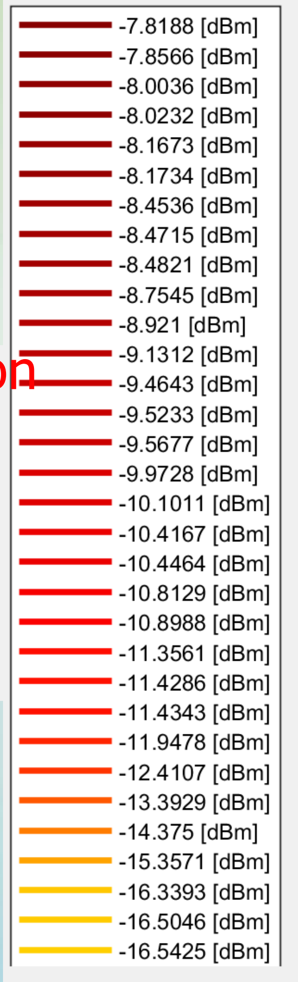
Angle≈6 deg



beam direction

20 um away from Waveguide

120 um away from Waveguide

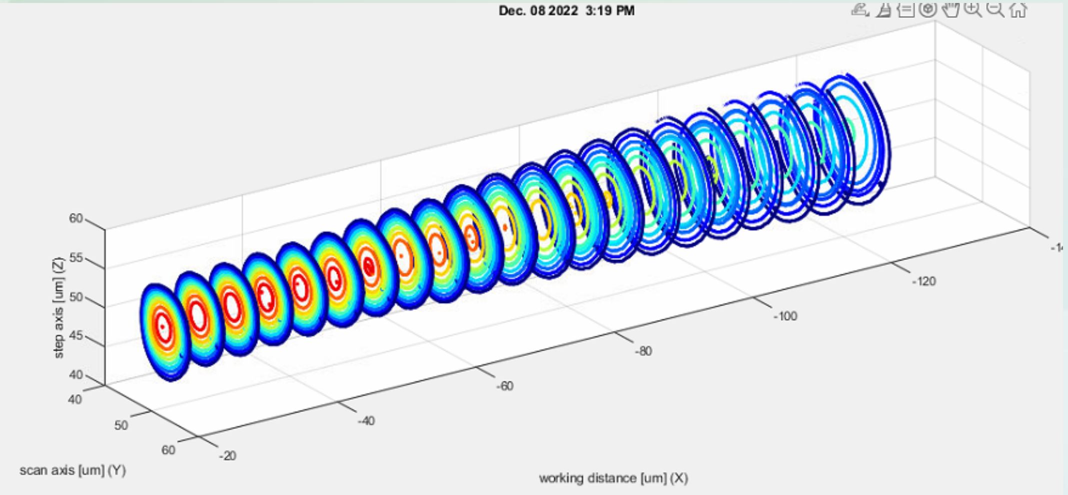


3D coupling indicate the waveguide beam direction in Edge coupling – Trench

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

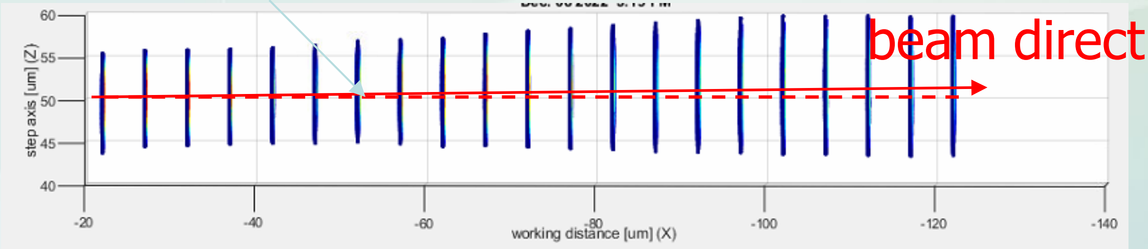
20um Spiral Scans

ISO view

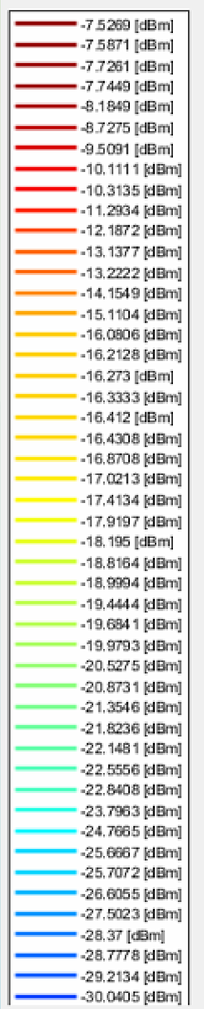


X-Z view

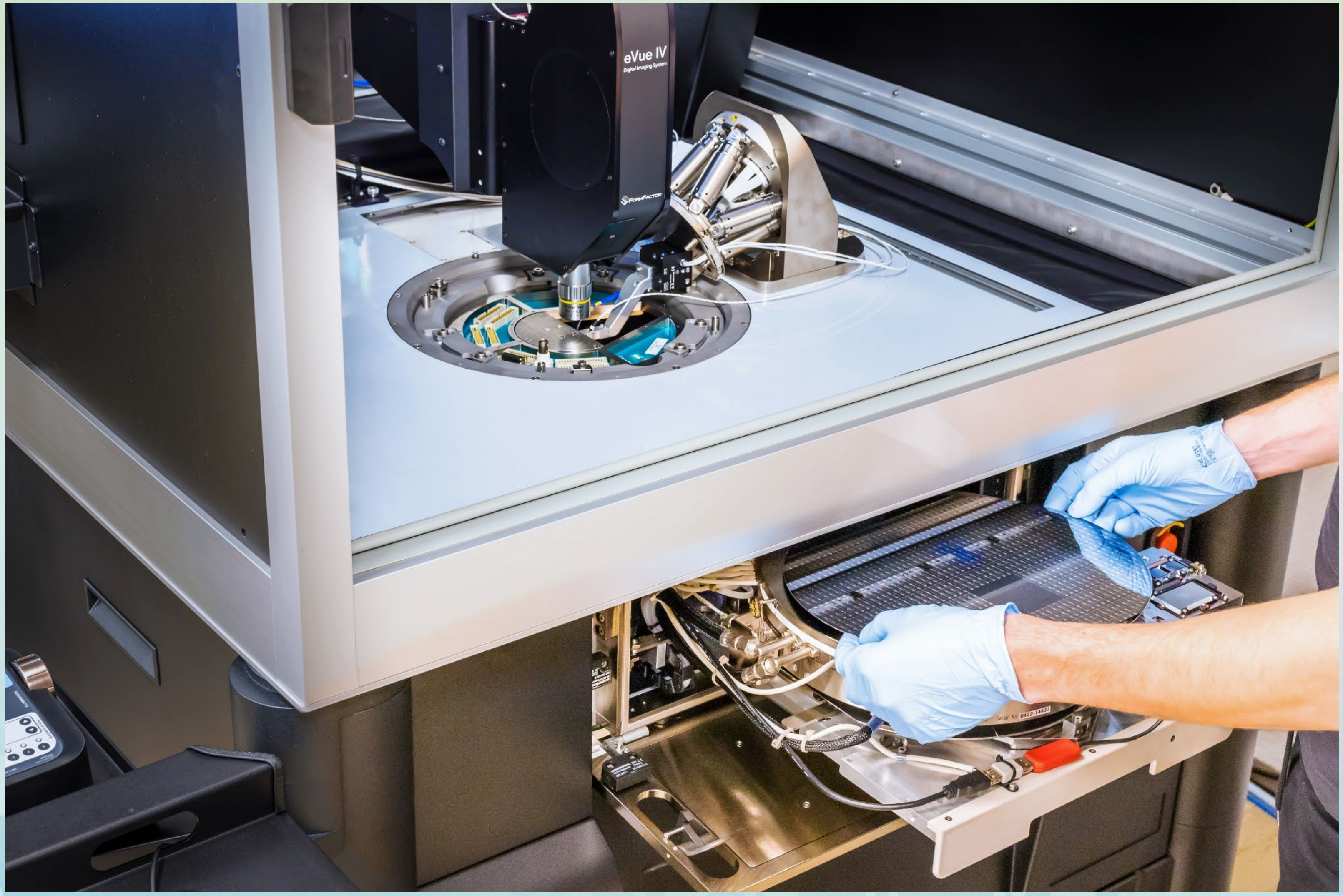
Angle≈0.89deg



beam direction

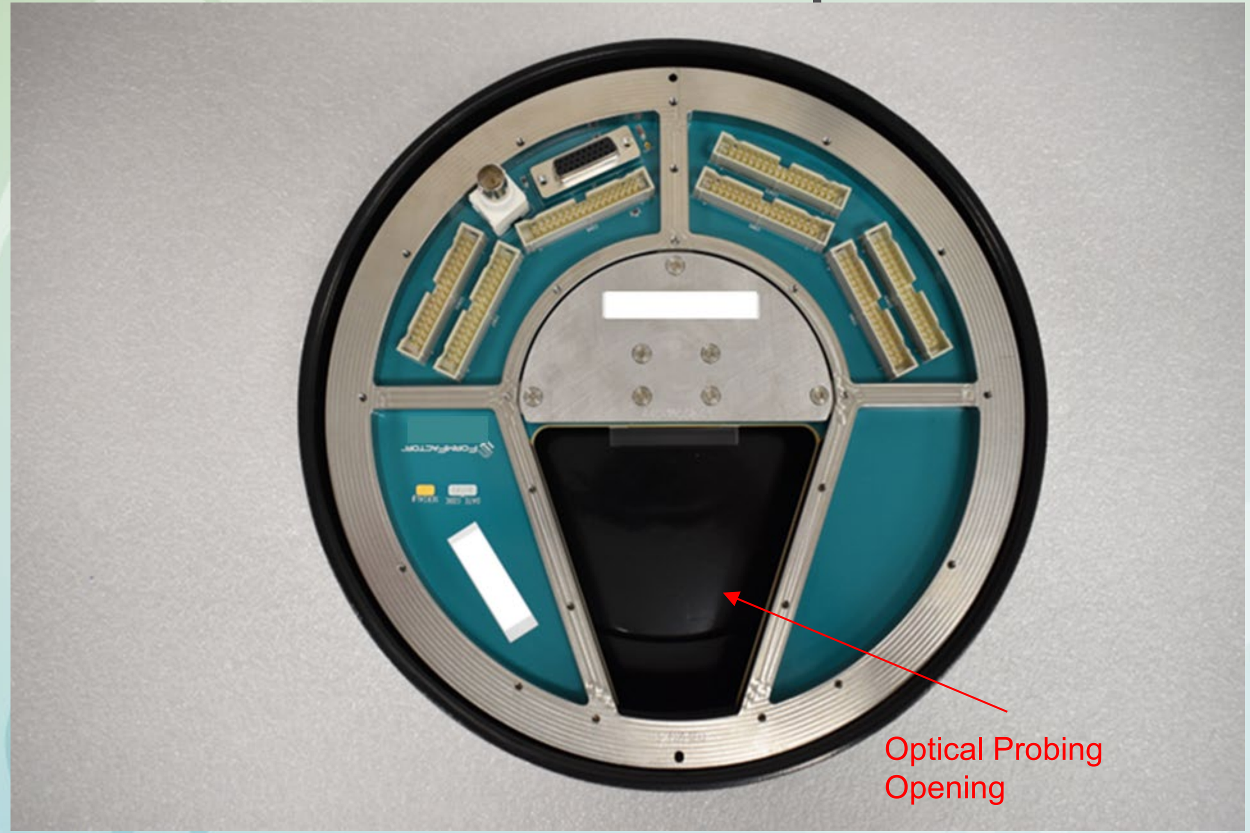


Probe Card Integration

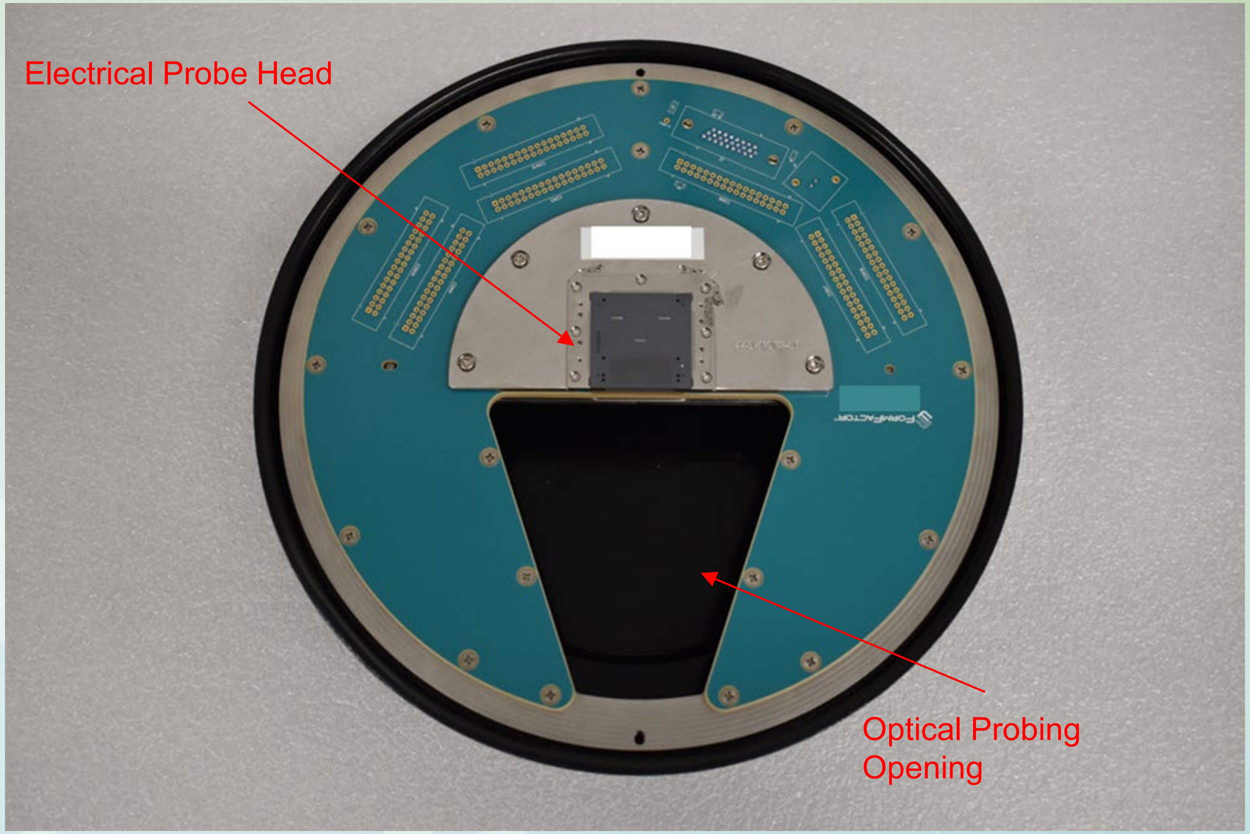


FFI Apollo Probe technology adapted for SiPh probing

Probe Card Top View



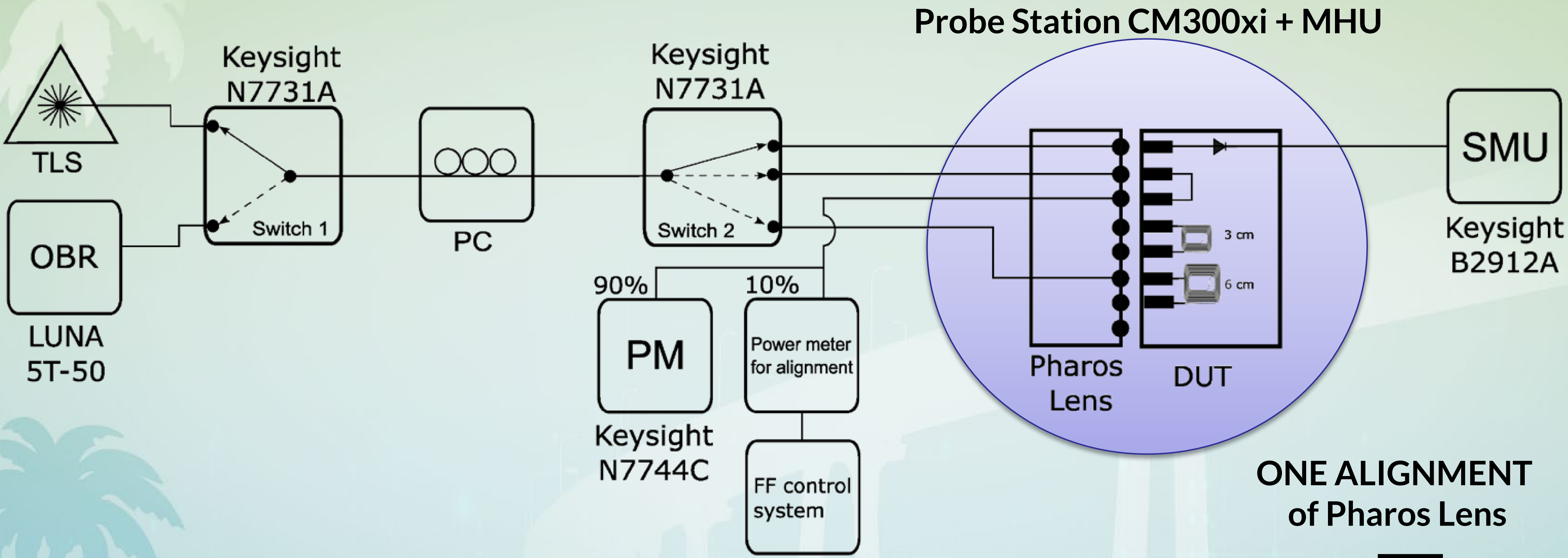
Probe Card Bottom View



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

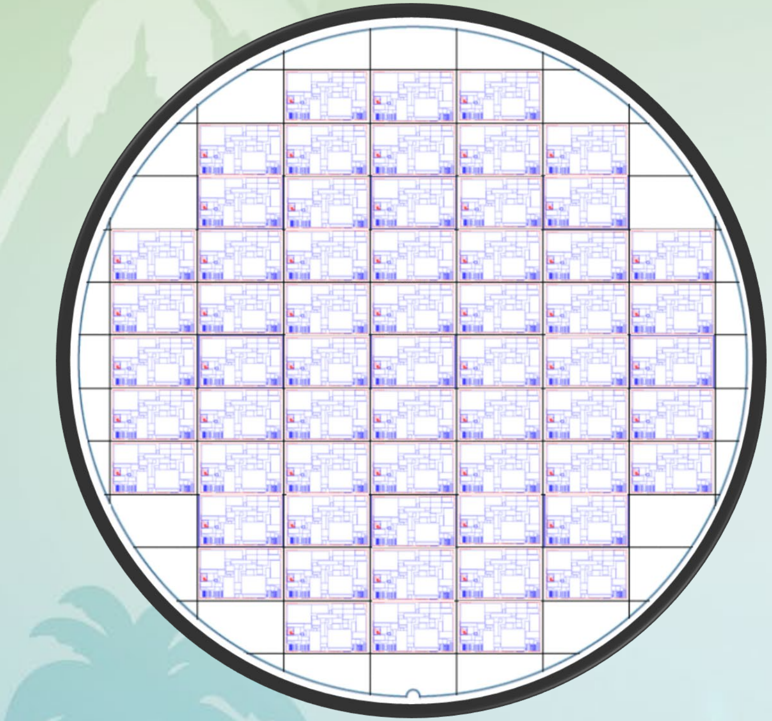
Test setup at IHP



ONE ALIGNMENT of Pharos Lens

- Coupling loss
- Waveguide loss
- Photodiode responsivity

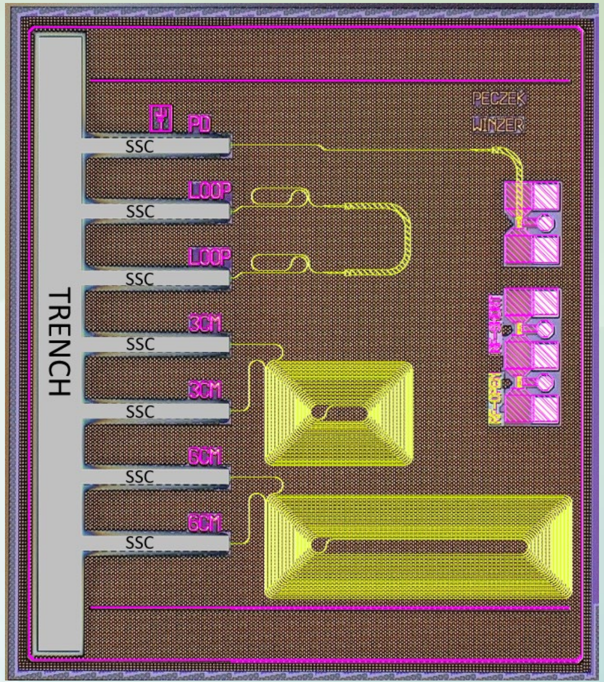
Device under test

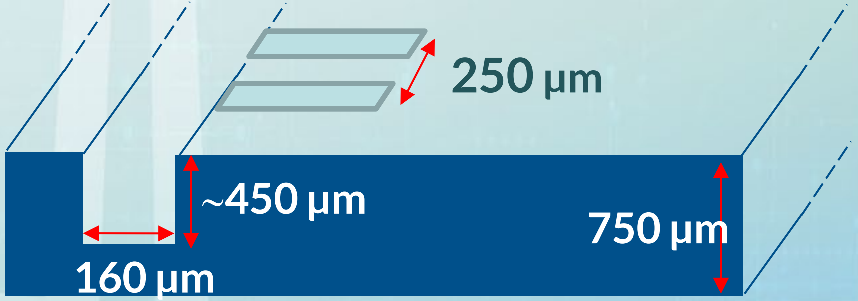


200 mm PIC wafer

Up to 61 dies

Photograph of the test chip with overlapped layout

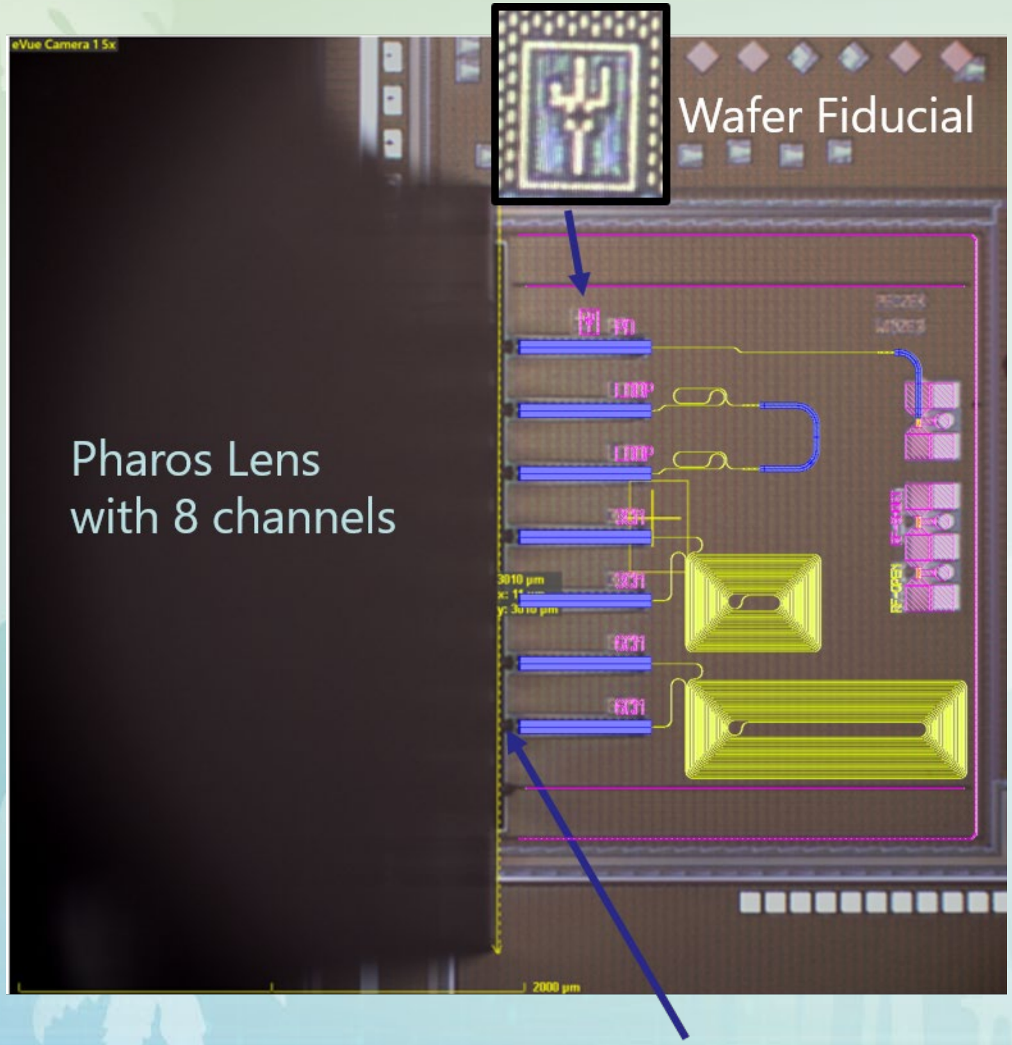




Test chip consist on:

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

Design and fabrication requirements



Probe Fiducial

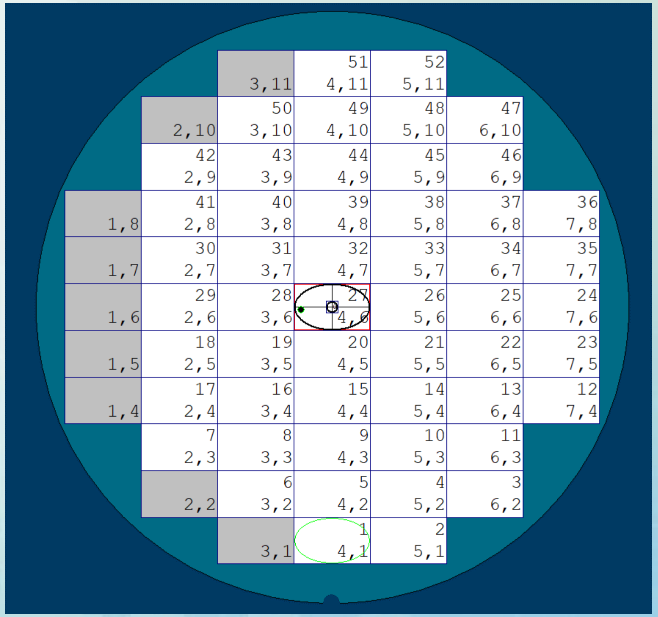
Requirements:

- 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.



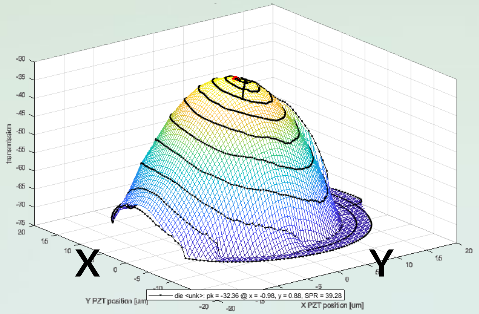
		3,11	51 4,11	52 5,11		
	2,10	50 3,10	49 4,10	48 5,10	47 6,10	
	42 2,9	43 3,9	44 4,9	45 5,9	46 6,9	
1,8	41 2,8	40 3,8	39 4,8	38 5,8	37 6,8	36 7,8
1,7	30 2,7	31 3,7	32 4,7	33 5,7	34 6,7	35 7,7
1,6	29 2,6	28 3,6	27 4,6	26 5,6	25 6,6	24 7,6
1,5	18 2,5	19 3,5	20 4,5	21 5,5	22 6,5	23 7,5
1,4	17 2,4	16 3,4	15 4,4	14 5,4	13 6,4	12 7,4
	7 2,3	8 3,3	9 4,3	10 5,3	11 6,3	
	2,2	6 3,2	5 4,2	4 5,2	3 6,2	
		3,1	1 4,1	2 5,1		

Grey chips excluded from tests due to trench imperfections

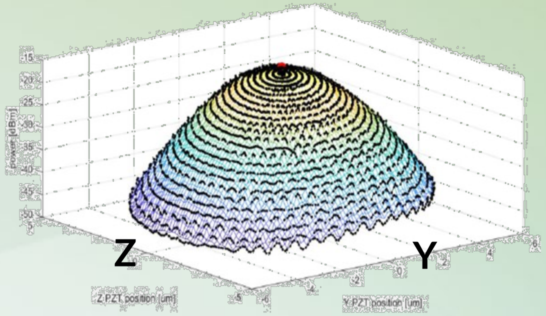
Alignment

Fully automated, algorithm-based with user-defined parameters

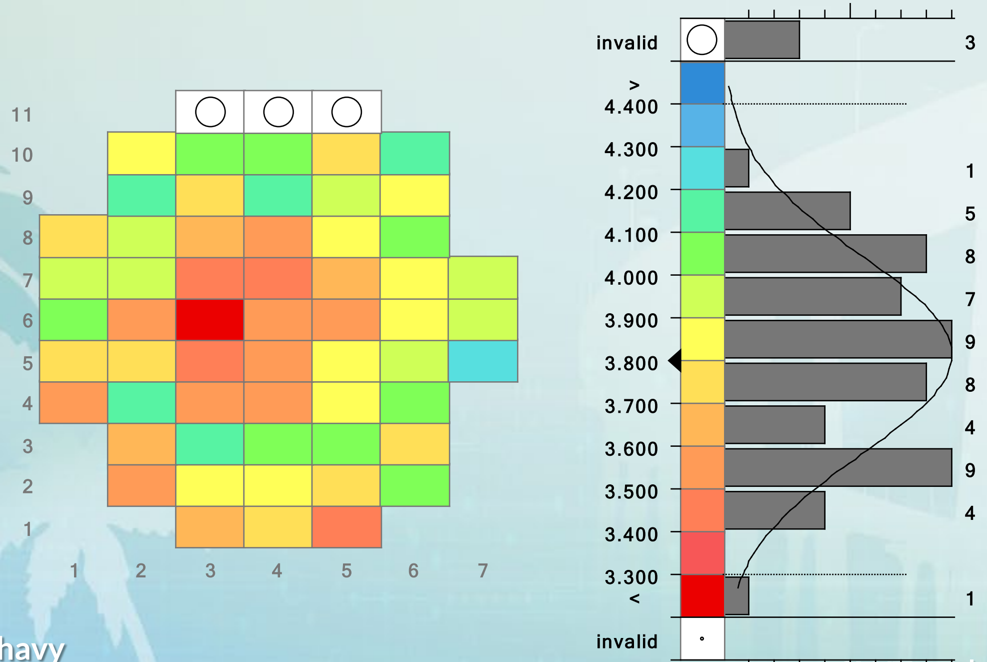
Grating coupler



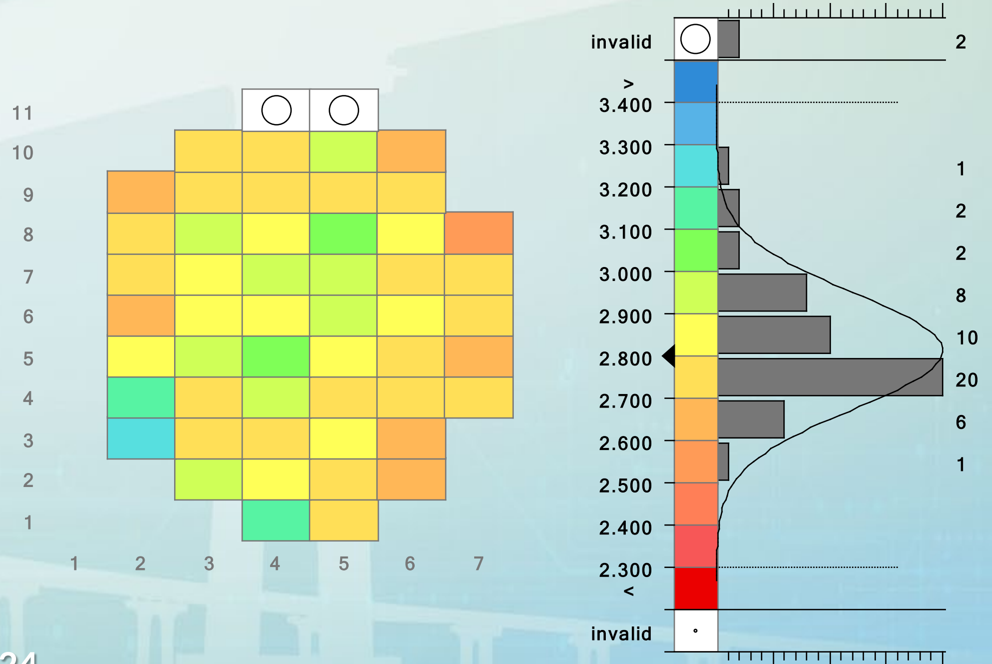
Edge coupler



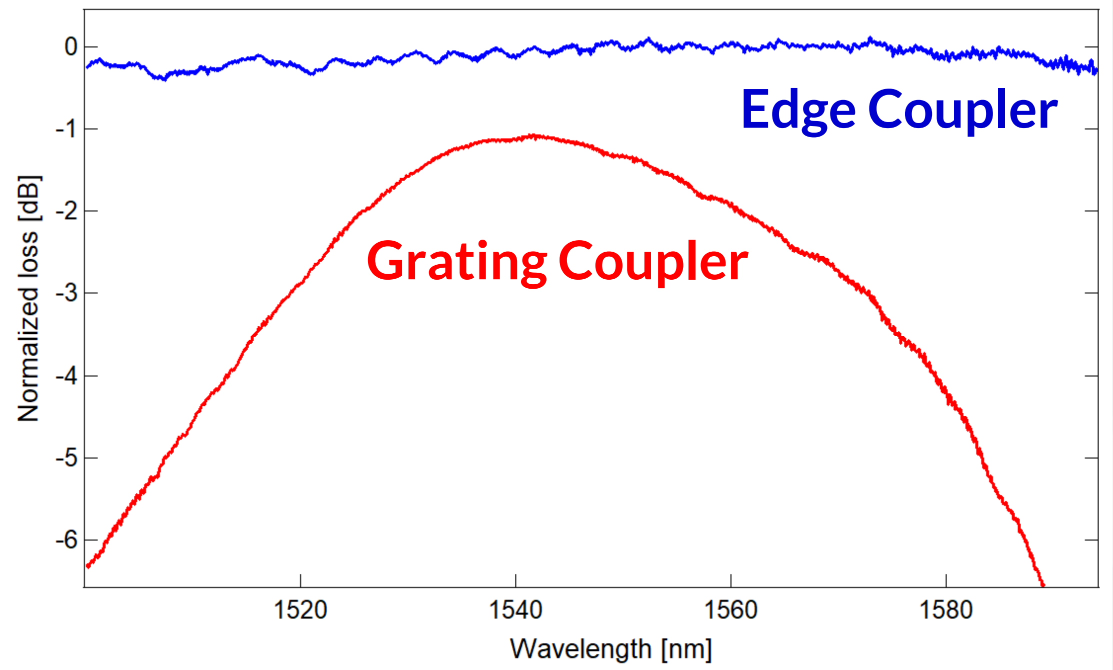
Mean coupling loss: 3.9 dB ± 0.2 dB

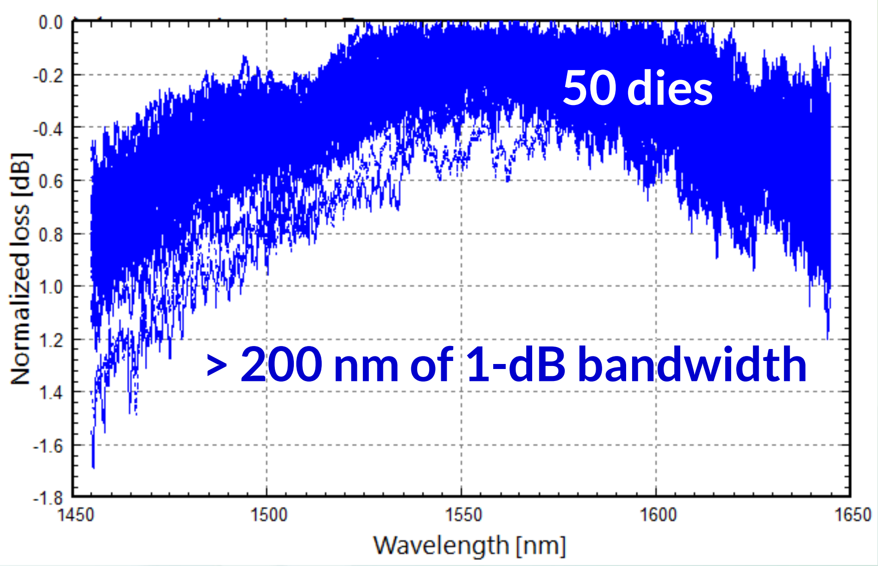


Mean coupling loss: 2.8 dB ± 0.1 dB

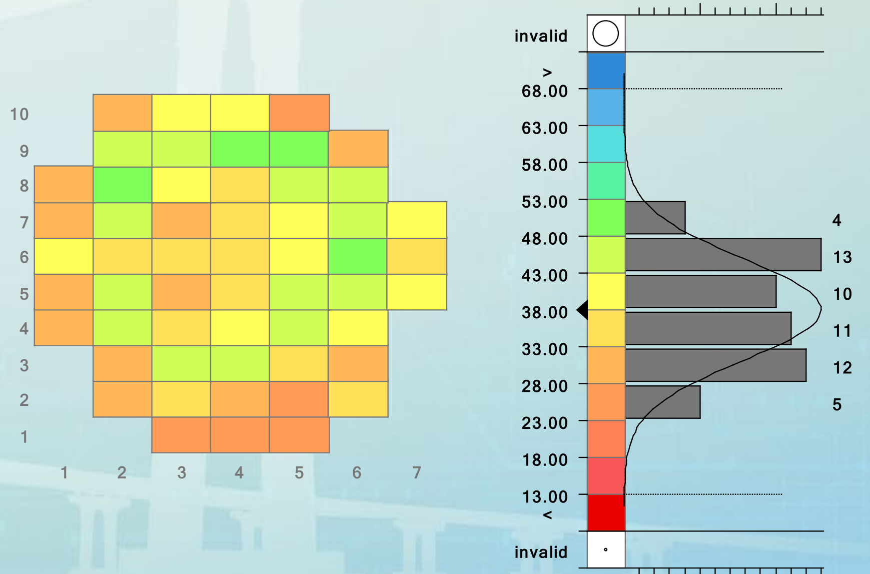


Optical bandwidth
Wafer level distribution



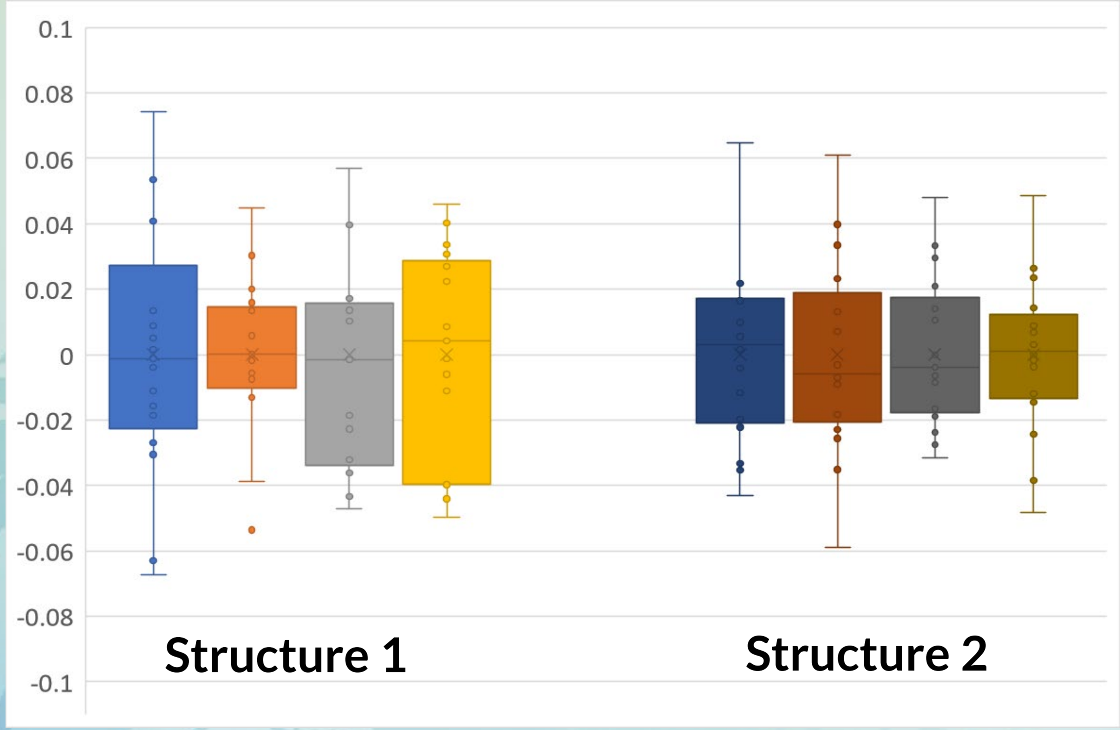


1-dB bandwidth of 38 nm ± 7nm (wafer variation)



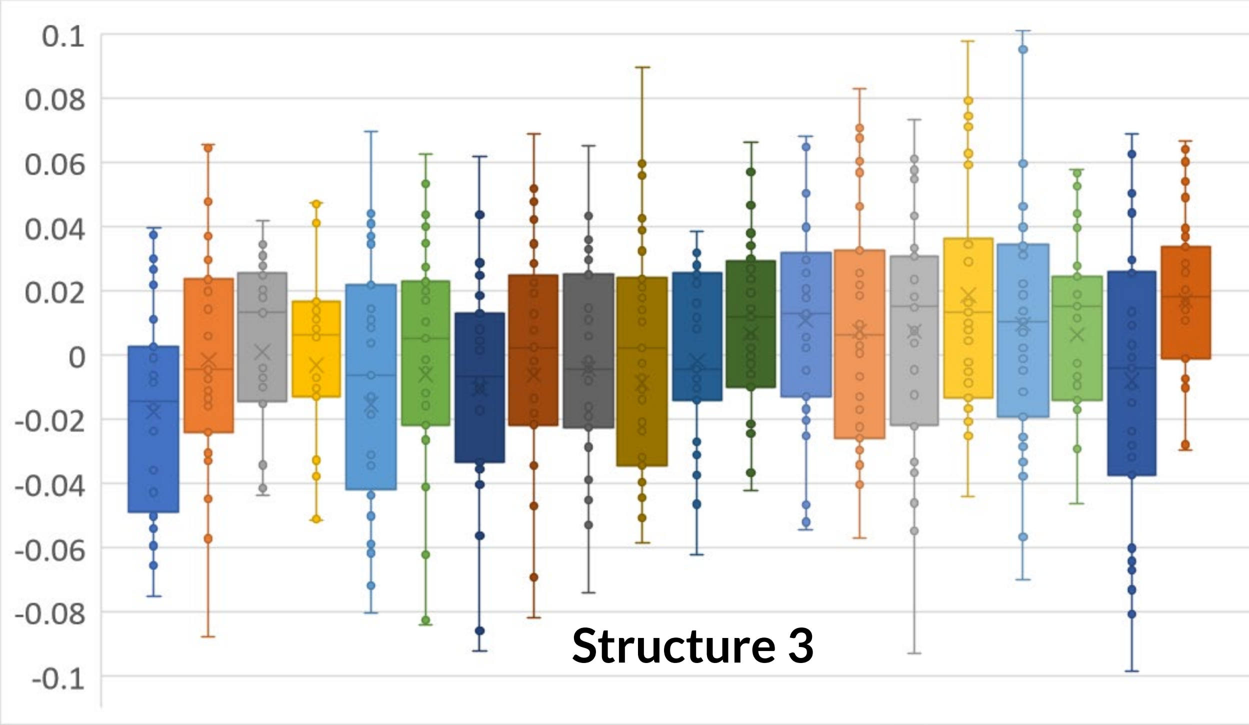
Repeatability

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



sigma ~ 0.02 dB

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



sigma ~ 0.02 dB

Summary

- Fully automated edge coupling was examined on 200 mm wafer
- The system includes advanced, automated calibration routines for high accuracy PIC characterization
- From our experience, a comparison of established grating coupler probing with edge couplers shows no significant drawback.

Thank you for your attention !

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dan.rishavy@formfactor.com