

COMPASS

a FormFactor users' group conference



Silicon Photonics - Challenges & Solutions for Wafer-Level Production Tests

Choon Beng Sia Ph.D.

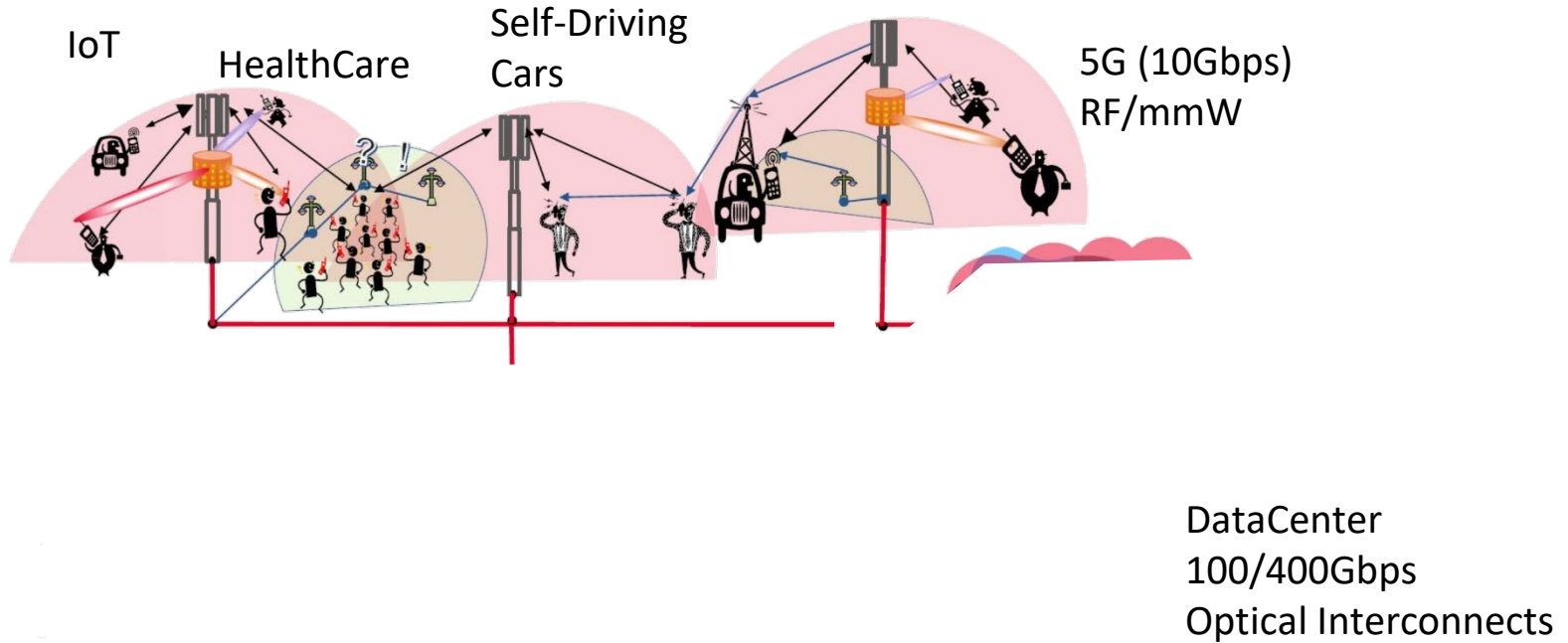
Customer Applications & Production Solution

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Agenda

- Market Trends & Driving Forces
 - Optical Transceivers in Data Centers
 - Why Silicon Photonics?
- Why Wafer-level Photonics Test?
 - Measurement Challenges and Test Engineers' pain points
- FormFactor Wafer-Level Photonics Test Solution
 - Key Advantages & Value Propositions of FormFactor's Photonics Solution
- Summary

Communication Network for 4th Industrial Revolution

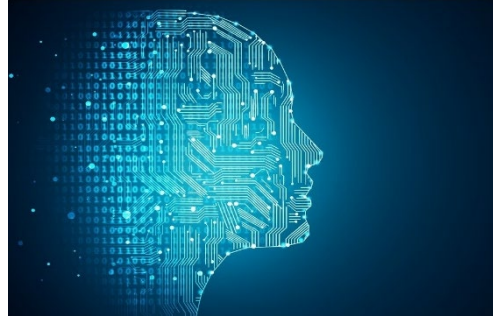


Source: Keysight

The Need for High Performance Data Centers & Network



Big Data Analytics



Artificial Intelligence



Genomics Revolution



Financial Acceleration



Cyber Security



Video Transcoding

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Facebook Invests US\$1B HyperScale Data Center in Singapore

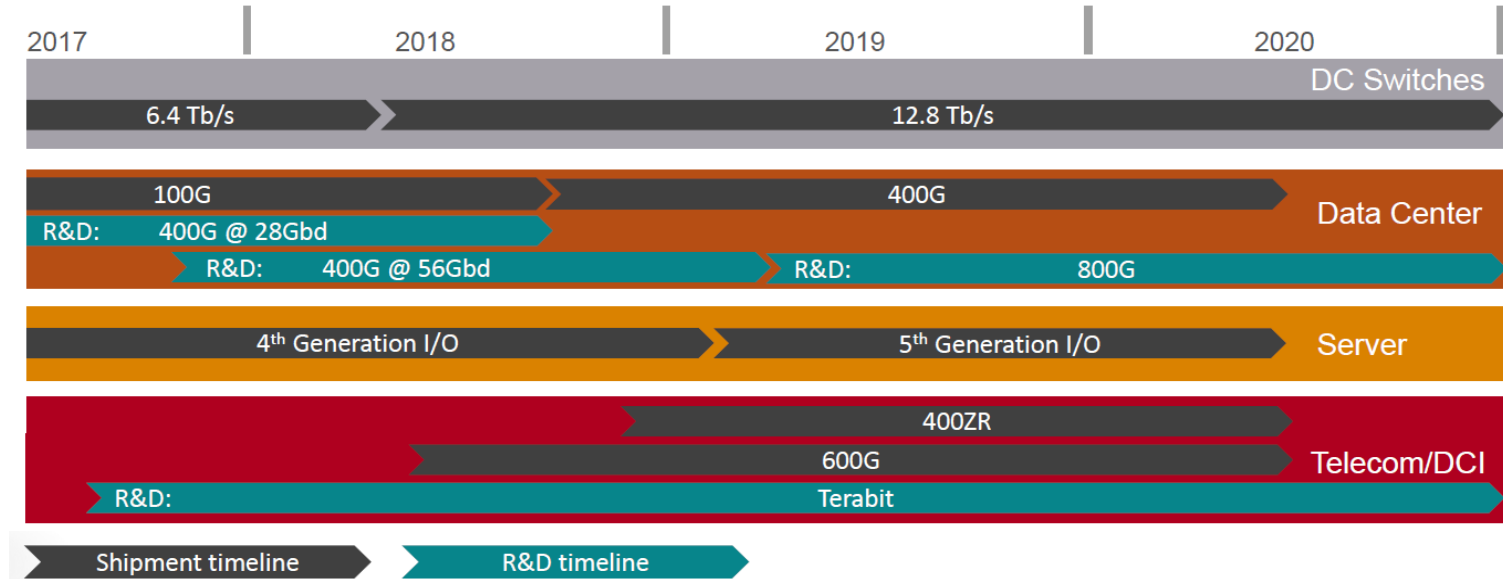
- Facebook's 1st Data Center in Asia.
- 5000 servers
 - Each server supports 100 petabytes or 100,000 TB*



*2015 Facebook Video, 1PB=1000TB

Requirements for Data Center – High Speed Data Rate

- Wired communication network.
 - High Speed, High Data Rate, Low Latency requirements.
- Key market players developing 100-400G optical transceivers.



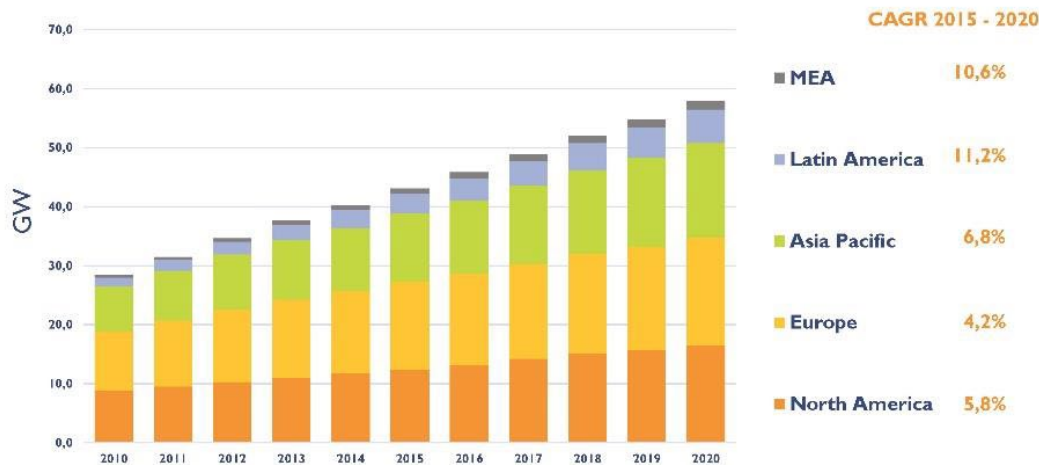
Source: Keysight

Requirements for Data Center – Energy Efficiency

- Biggest challenge for Data Centers – Not Speed but **Reducing power consumption!**
- Power Usage
 - 40% - Server, Switch etc.
 - 40% - Cooling
- *By 2025, Data Centers will consume 20% of Earth's power?

WORLDWIDE DATA CENTER FACILITIES – POWER NEEDS IN GW

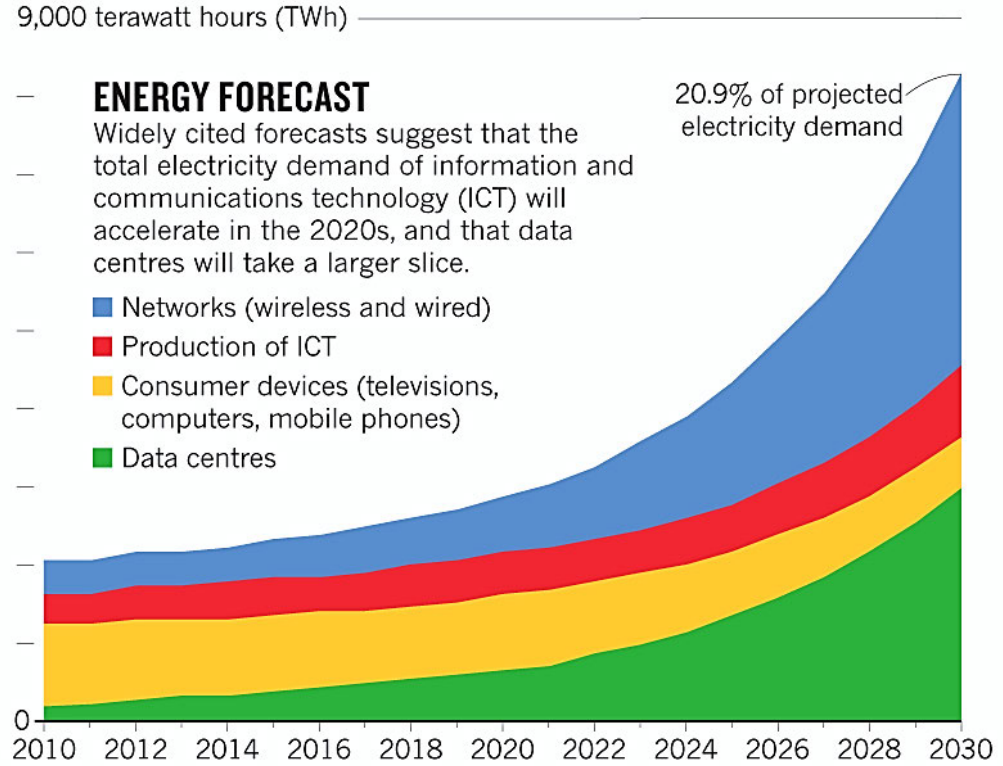
(Source: New Technologies and Architectures for Efficient Data Center report, July 2015, Yole Développement)



With no slowdown in new facility construction, data centers worldwide will have an increasing need for power.

Requirements for Data Center – Energy Efficiency

- *Information Technology forecasted to consume about 21% of the earth's power produced by 2030.
 - Data Centers and Wired Access are largest consumers.
- †Global data centers used... about 3% of the total electricity (in 2016) and this consumption will double every four years.
 - 24% consumption by 2028?
- #Governments are now regulating Data Centers!

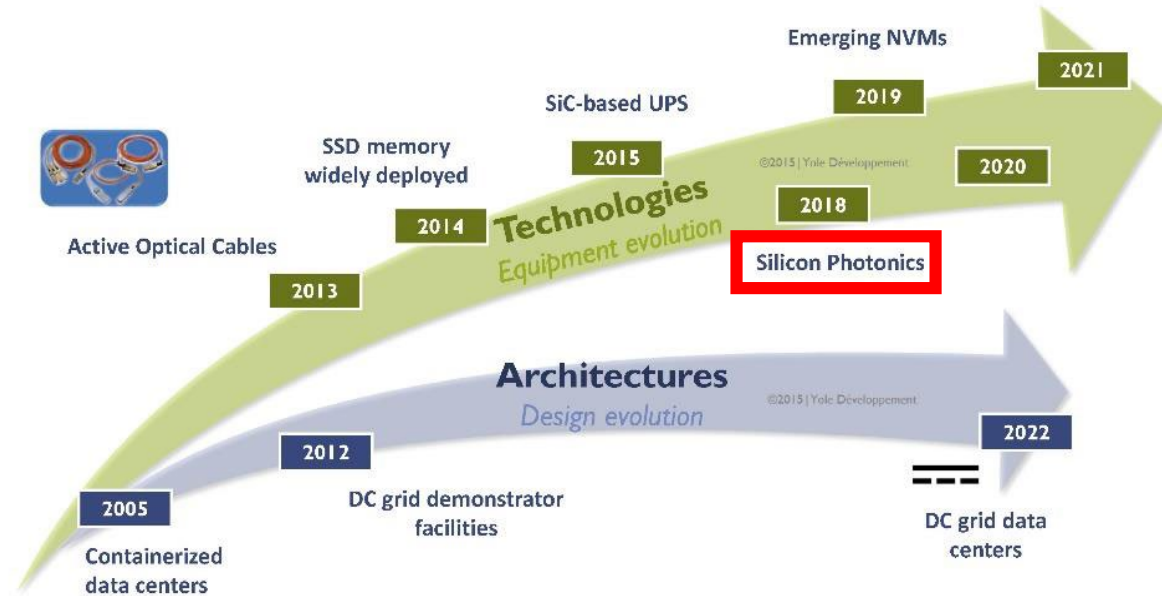


Requirements for Data Center – Energy Efficiency

- A combination of various technologies is needed.
- The urgent need for Energy-Efficient Data Centers is making SiPh technology a rising star in high speed data transfer.

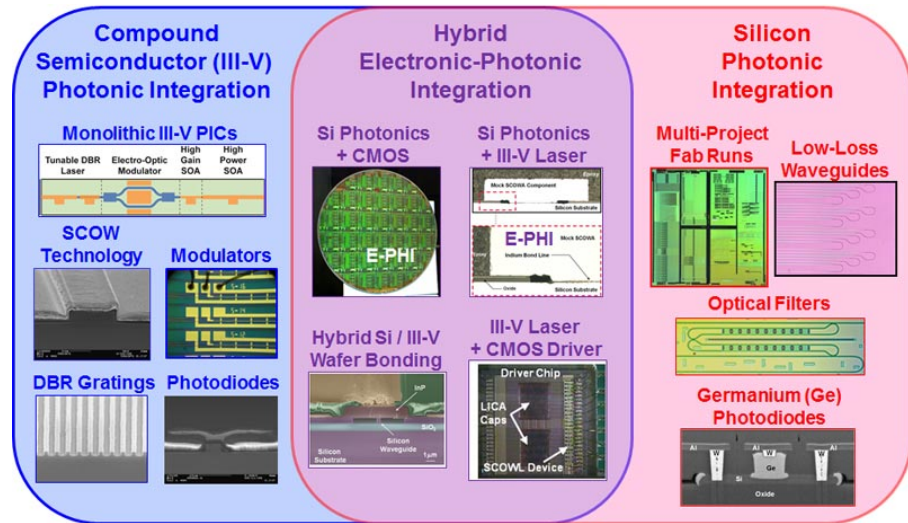
ROADMAP OF THE DATA CENTER TECHNOLOGIES AND ARCHITECTURES

(Source: New Technologies and Architectures for Efficient Data Center report, July 2015, Yole Développement)



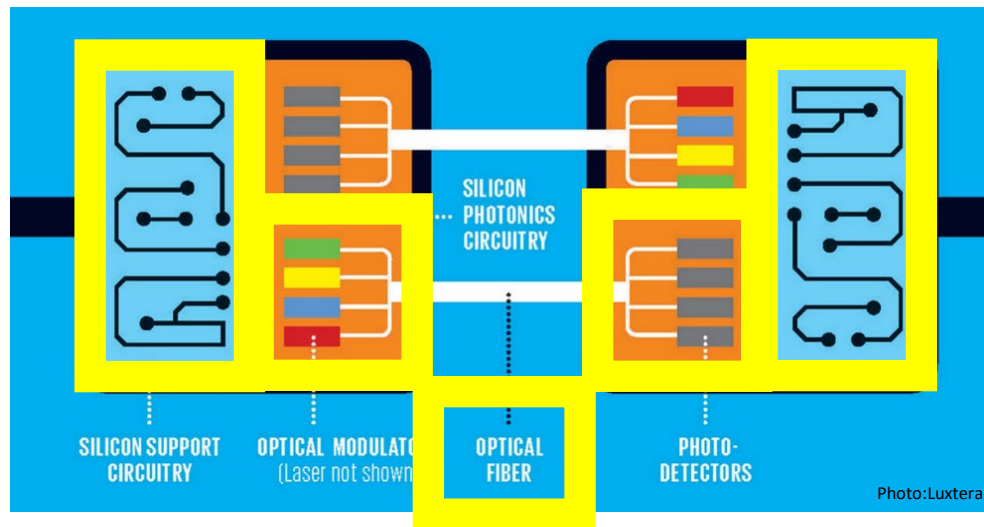
Why Silicon Photonics?

- **Improvements in Thin Film technologies**
 - Ability to grow very High Quality Ge on Si
 - Overcoming lattice mismatch
 - SiGe Photodiodes (3dB BW >30GHz)
- **Exploiting Silicon Technologies**
 - Low-Cost High-Volume Production
 - Low-Power Logic devices
 - High-Speed RFCMOS devices
 - High level of Integration & Scalability
 - Heterogenous Integration/Packaging



SiPh Optical Transceivers for Data Centers

- Using light as carrier of information through optical fiber.
- Components on SiPh Transceivers
 1. CMOS Logic Chip
 - Data Encoding (also decoding)
 2. Optical Transmitter
 - Optical Modulators - Varying voltage modulate Data onto Light
 - Lasers not implemented on Silicon
 3. Optical Receiver
 - SiGe Photo detectors
 - Converts Light to Voltage
 4. CMOS Logic Chip
 - Data Decoding (also encoding)



For a 10Gb/s Link	Copper Interconnect	Optical Fiber
Power Required	10 W	0.2 W
Range	meters	kilometers

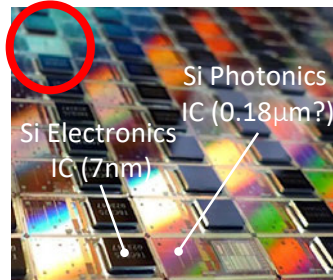
Evolution of Optical Transceivers

- Copper wires → Optical Fibers

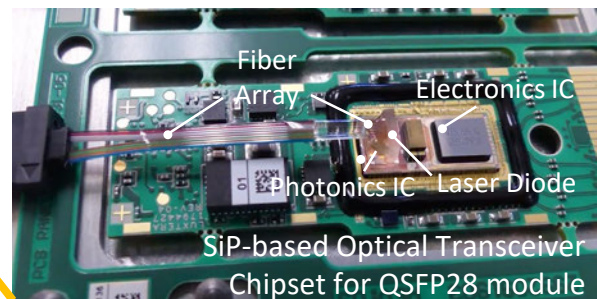
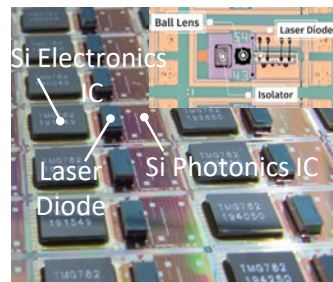


Why Wafer-Level Tests?

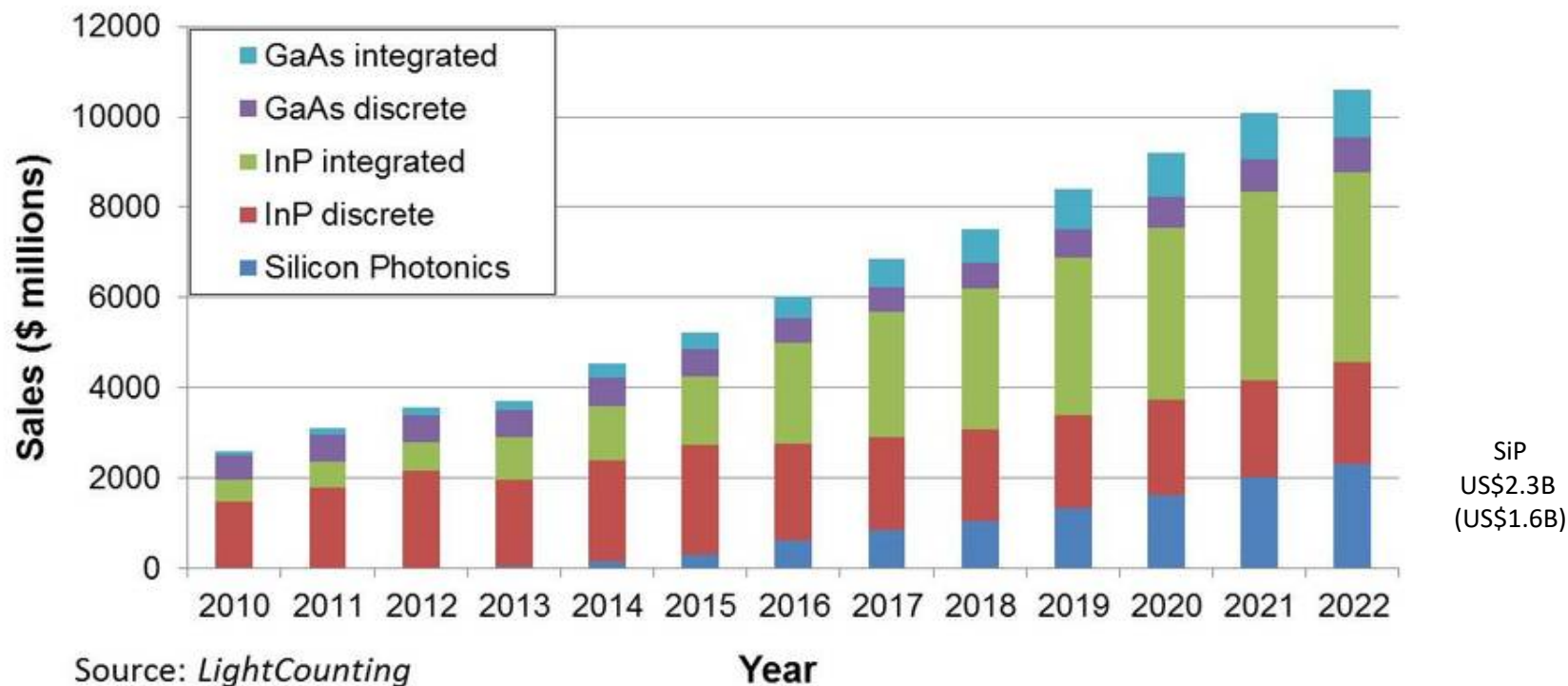
Si Electronics-Die attach onto SiPh-Die (TSV)



Continuous Wave Laser Diode on SiPh-Die

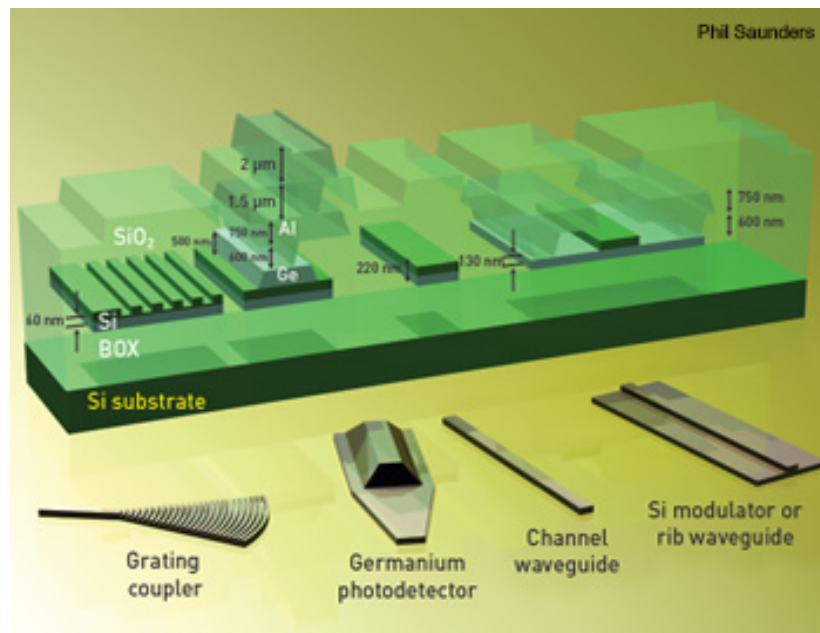


Integrated Photonics Transceivers



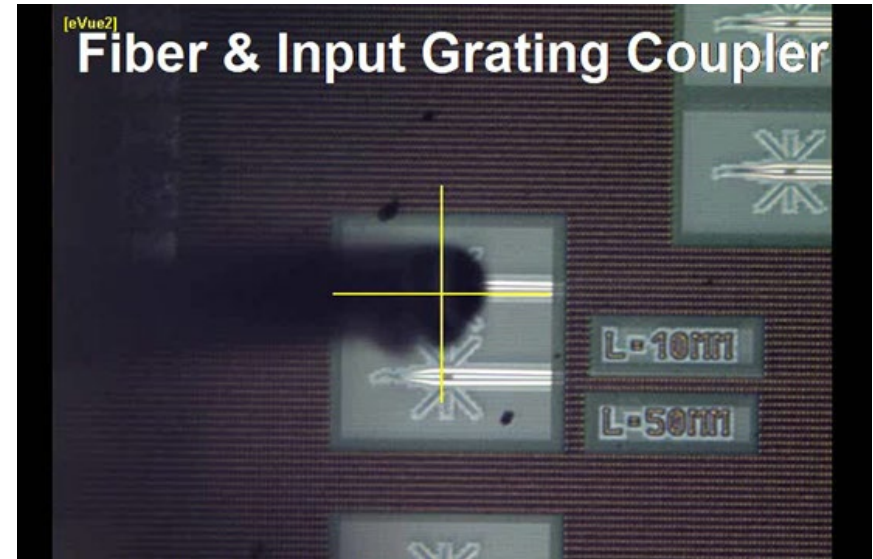
General Devices for Photonics ICs

- Passives
 - Grating Couplers (3-6dB)
 - Low loss waveguides
 - Splitters
 - Wavelength selective combiners/splitters
 - Isolators/Circulators
 - Comb generators
- Actives
 - Photodetectors (3dB bandwidth >30GHz)
 - Modulators
 - Lasers (single frequency, tunable, mode locked)
 - Switches
 - Amplifiers



Measurement Challenges faced by Our Photonics Customers

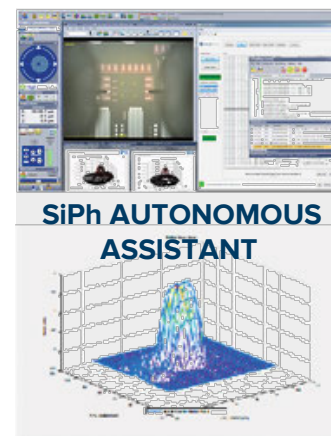
- Test Challenges
 - Fast & reliable fiber-to-device alignment
 - Highly accurate & repeatable data
 - Toggle easily between OO/OE/EE Test Setups.
 - DC, RF and Multi-contact probes
 - Manual & Motorized Positioners
 - Handle Single & Multiple Wafers
- Test Engineers' Voice
 - “We need a Silicon Photonics probing solution that allows us to quickly start making measurements to validate our designs or bring them to market without initiating a long development project to enable wafer-level test”.



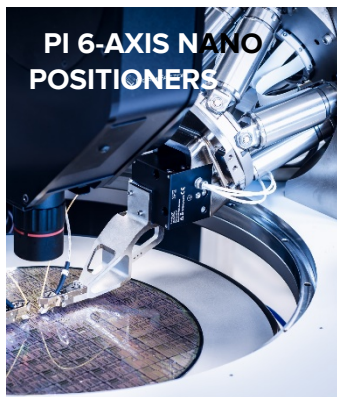
FFI SiPh Wafer-Level Measurement Solution



**KEYSIGHT PHOTONIC
APPLICATION SUITE**



**SiPh AUTONOMOUS
ASSISTANT**



**PI 6-AXIS NANO
POSITIONERS**

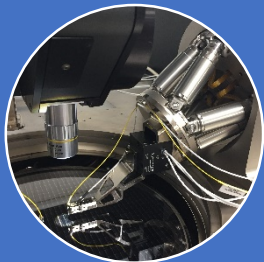


WAFER-LEVEL RF TEST SOLUTION



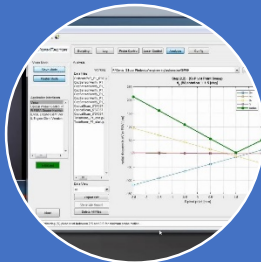
**CM300XI
PROBE SYSTEM**

FFI SiPh Wafer-Level Measurement Solution



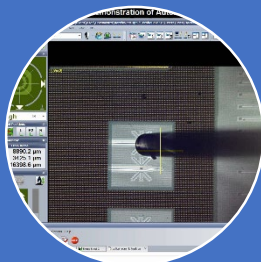
Integration

Custom designed mounts, fiber arms and holders ensure guaranteed integration on FormFactor's CM300 probe station. SiPh-Tools integrates the optical positioning system for automated alignments



Calibration

FFI has developed a unique set of calibration fixtures that enable easy setup of fiber holders. Using machine vision, automated calibrations minimize time to measurement



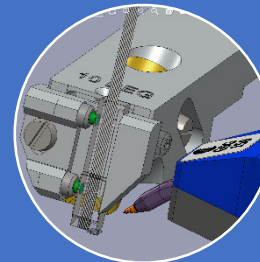
Verification

Using a defined set of critical verification parameters, FFI validates actual system performance prior to shipment and on-site. Ensuring your system is ready to start working for you



Flexibility

Our interchangeable fiber holders enable changing between wide range of incident angles for both single fibers and fiber arrays.



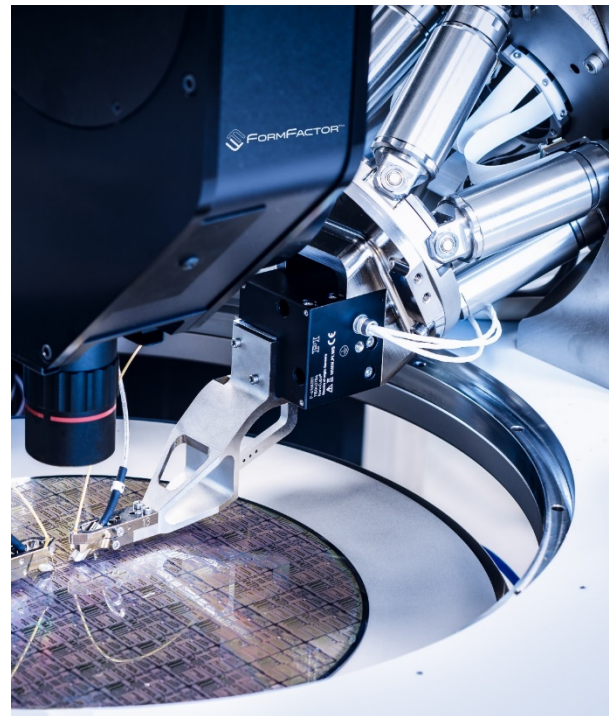
Interoperability

FFI's unique fiber holder design has been validated with FFI's wide range of Analytical Probes. Our design guide provides layout parameters for RF, DC and Optical couplers



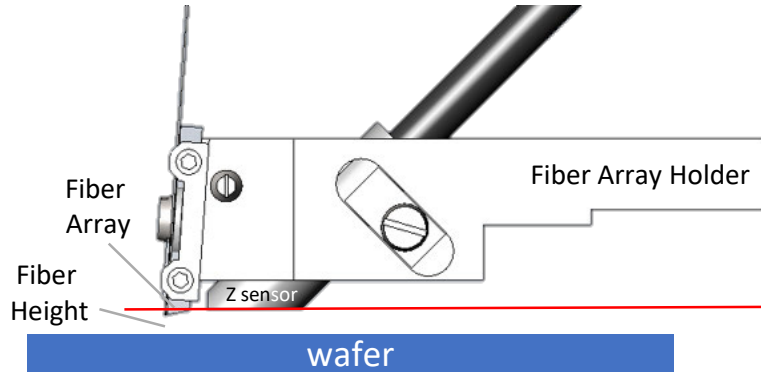
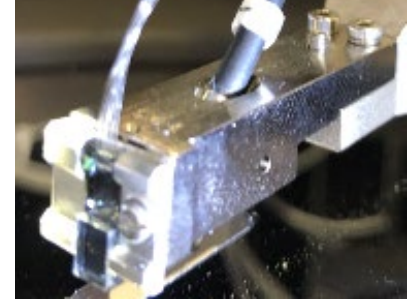
Calibration

- SiPh Calibration Kit, Tools and Fixtures
 - Custom Calibration Wafers for precision setting of Fiber height.
 - Fixture for easy of installation & adjustment of Fibers and Fiber Arrays.
 - Illumination positioner for Vision-based Optical Calibrations.
- SiP-Tool Software automates...
 - Z Sensor, Fiber Height, 6-axis+Piezo positioner calibrations
 - θ_{XYZ} Calibrations of Fibers & Fiber Arrays.
- These are Know-How that other solution providers offering PI solution will take some time to develop!

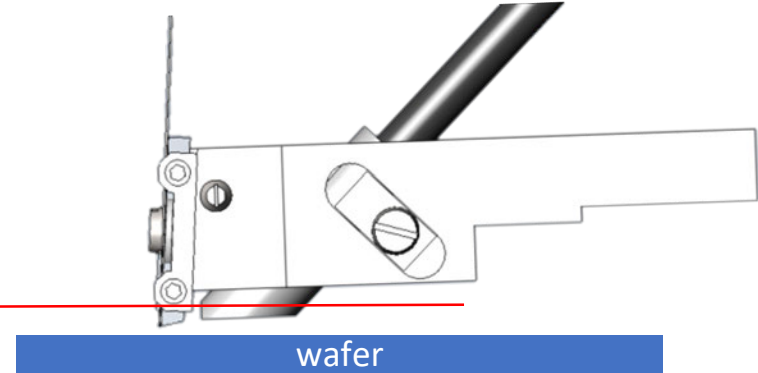


Calibration – Example θ_Y & Z Displacement Sensor

- Measurements at different incident angles= $Y \pm 1^\circ$ i.e. θ_Y .
 - Quick Investigation of grating coupler's performance.
- θ_Y rotation affects Fiber Height & Measurement Accuracy!
- Z sensor must be calibrated at different θ_Y to maintain Fiber Height accurately.



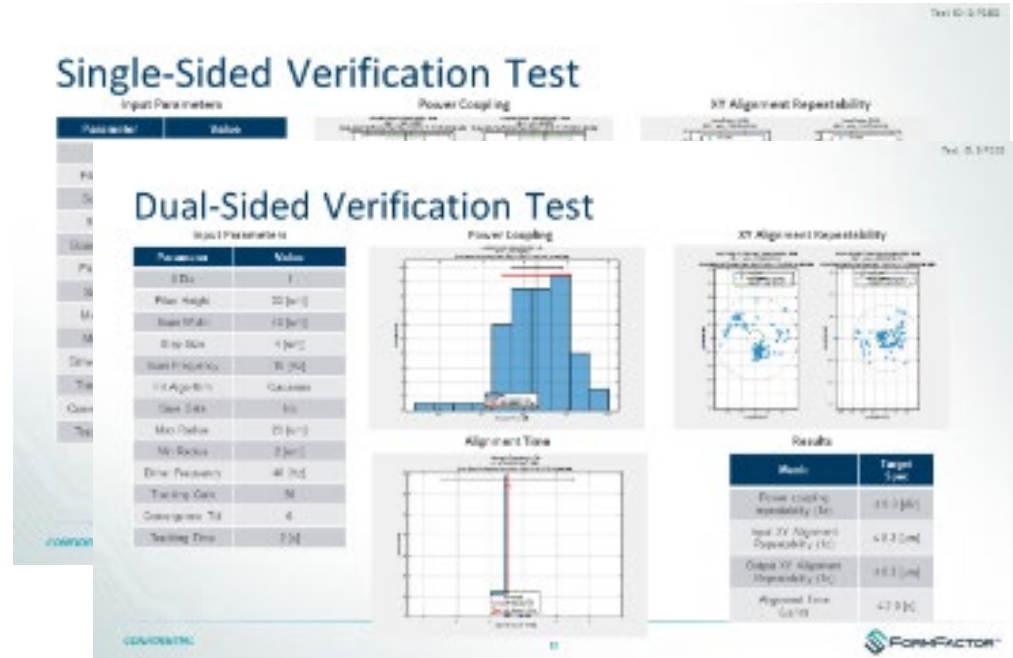
Fiber Array @ Y° Incident Angle



Fiber Array @ $Y-1^\circ$ Incident Angle

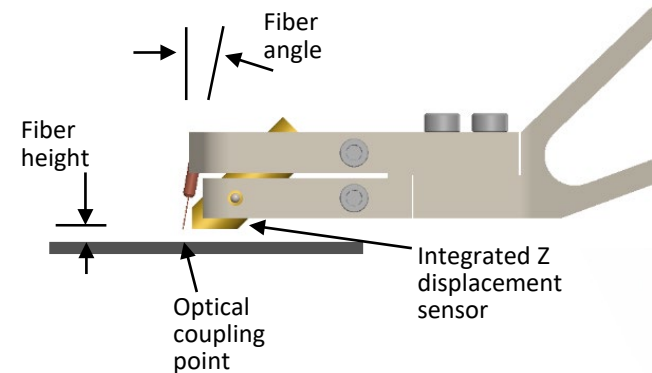
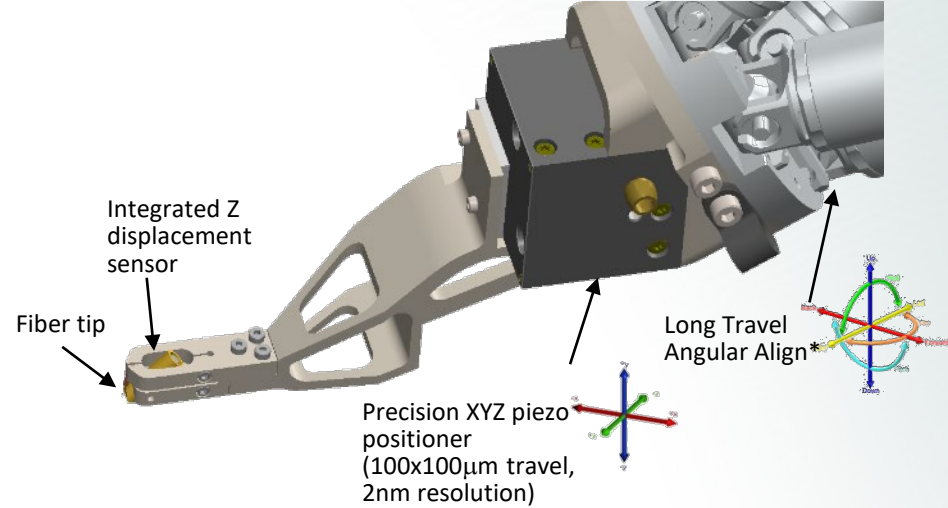
Verification

- Validates System Performance before Delivery & after Installation.
- Verification Tests
 - Alignment Time
 - Power coupling repeatability
 - Input XY Alignment Repeatability
 - Output XY Alignment Repeatability
- FFI is setting new standards in Wafer-level Photonics tests.



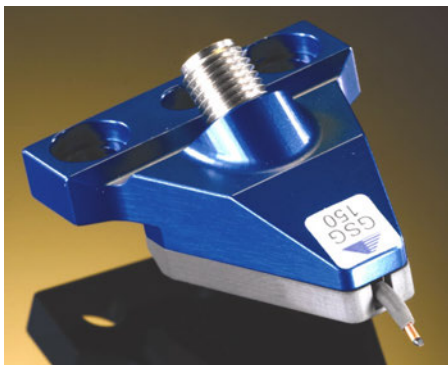
Flexibility

- Unique fiber arm design provides flexibility
 - Engineering Tests
 - Production Tests
- Replaceable fiber holders support
 - Single Fiber
 - Fiber Array
- Wide Range of Incident Angles available
 - Incident angles of 6° to 20° in 1° increments
- FFI's experience working with both Production & Engineering customers.



*The travel ranges of the individual coordinates (X, Y, Z, θ_X , θ_Y , θ_Z) are interdependent. Actual travel relative to wafer will vary.

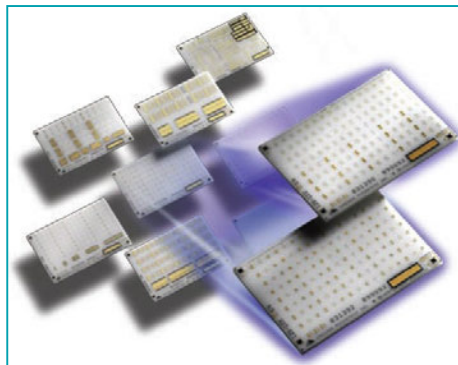
RF probes, Multi-contact Probes, Calibration Substrates



Single/Dual
RF Probes



Multi-contact
RF Probes



RF Calibration
Substrates

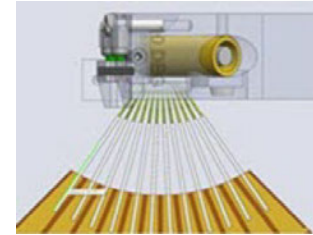
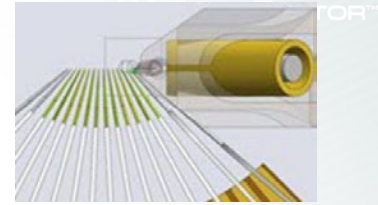
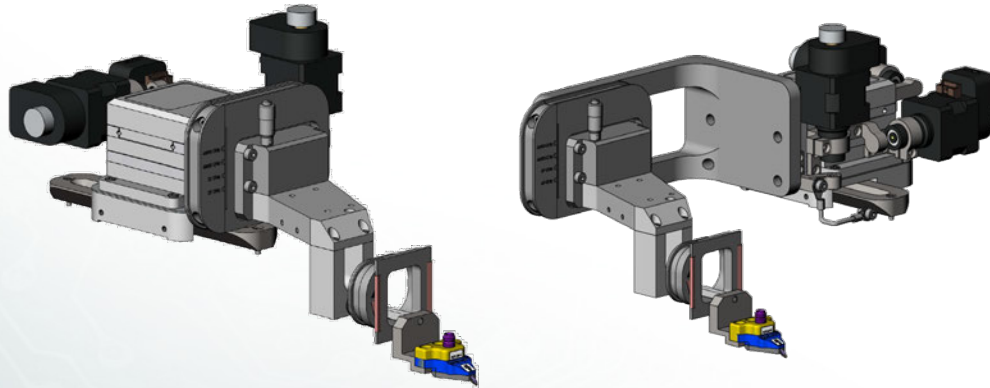


RF Calibration
Software

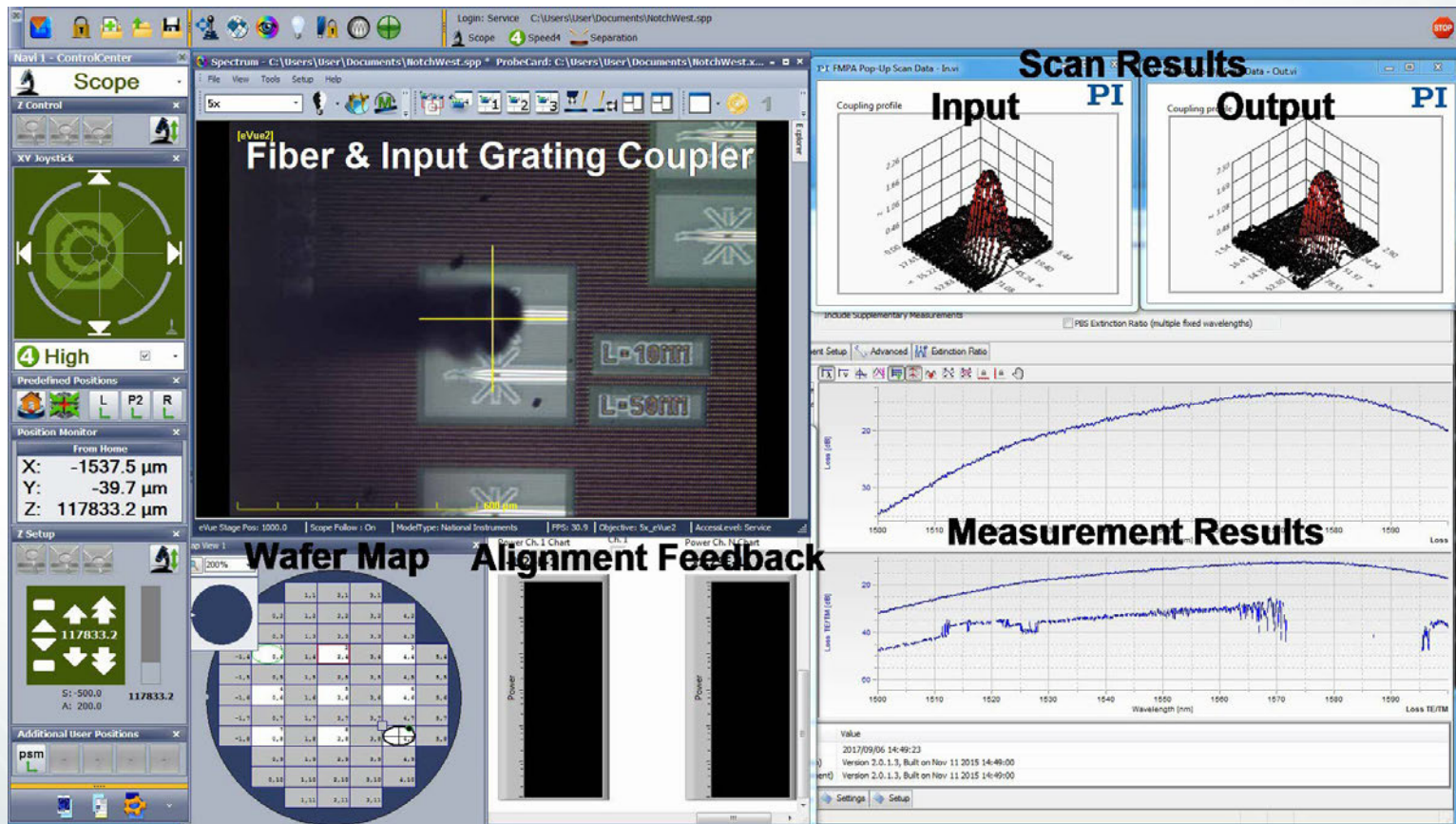
- FFI is the Market Leader in Wafer-Level RF Test.
- RF probes, calibration substrates and software provide a complete OE test solution for our photonics customers.

Interoperability

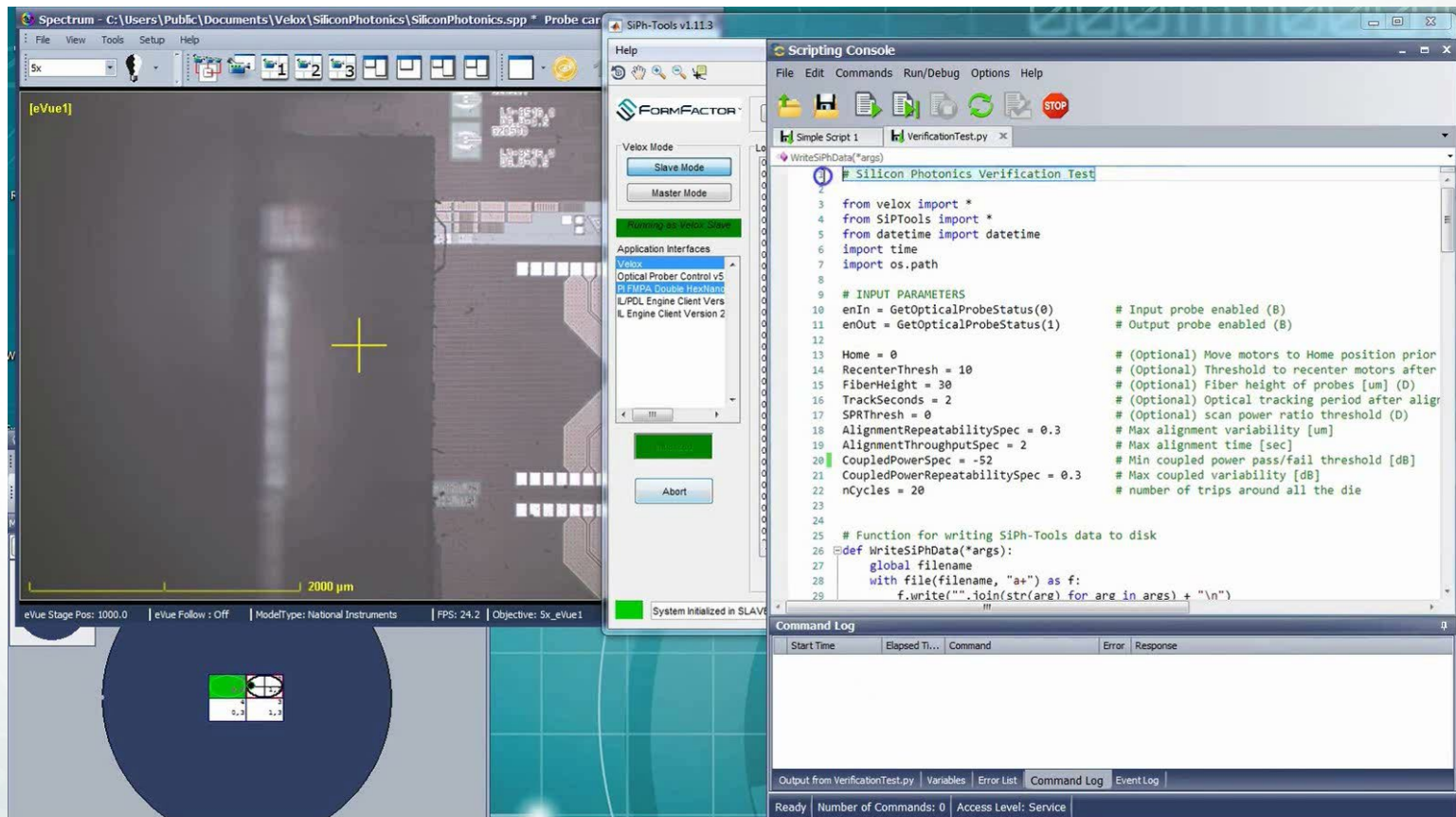
- FFI's Single Fiber & Array holders - Compatible with library of DC, RF and multi-contact probes & motorized positioners.
- 1st to develop SiPh devices layout design rules
 - Min. distance for optical grating couplers & electrical test pads with different probes etc.
- Leveraging on our experience to help customers ensure their devices are Design-for-Test.



Single Fiber Alignment & Measurement Demonstration FACTOR™



Fiber Array Alignment Demonstration



Summary

- Improving Data Center Power Efficiency is driving the Strong Demands for Silicon Photonics Integrated Circuits.
- Total available market is still increasing for Integrated Photonics Transceivers, US\$10B, CAGR 35% (up to 2022 forecast).
- FormFactor provides a Market-Leading & Proven Photonics Wafer-level Test Solution for Test Engineers.