

The VTT logo consists of the letters 'VTT' in a bold, white, sans-serif font, centered within a solid orange square. The background of the slide features a repeating pattern of stylized, interlocking shapes in orange, blue, white, and black, creating a sense of depth and movement.

VTT

Integration of III-V components on VTT's 3 μ m SOI platform

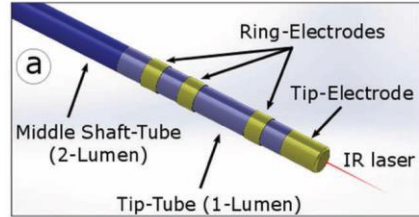
Jae-Wung Lee
VTT

30/05/2024 VTT – beyond the obvious

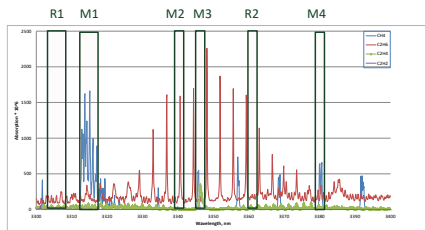
Overview of slides

- **Introduction:**
 - Applications for silicon photonics
 - 3 μm SOI PIC overview
 - Straight waveguides
 - Up-reflecting mirrors
 - Light coupling
- **Integration of RSOA to 3 μm SOI PIC**
 - Hybrid integration development
 - Post alignment confirmation using glass chips for X-/Y- axis
 - Results from glass chips bonding
 - Z-axis misalignment and solution
 - Flip-chip bonding with RSOA
 - Alignment check
 - Optical test and results
- **Q and A**

Main application areas for Si photonics



Health and wellness
 3D sensing and imaging
 Communication & computing
 Industrial sensors
 Military & Aerospace
 Quantum



3 μm SOI ay VTT: Overview

Passive and active PICs in 3 μm thick SOI

Advantages

Broadband, polarization independent and low-loss I/O coupling (horizontal or vertical)

Rib and strip waveguides with low propagation loss (0.04 – 0.15 dB/cm)

Ultra broadband SM operation with rib waveguide mode strippers (1.2 – 6 μm)

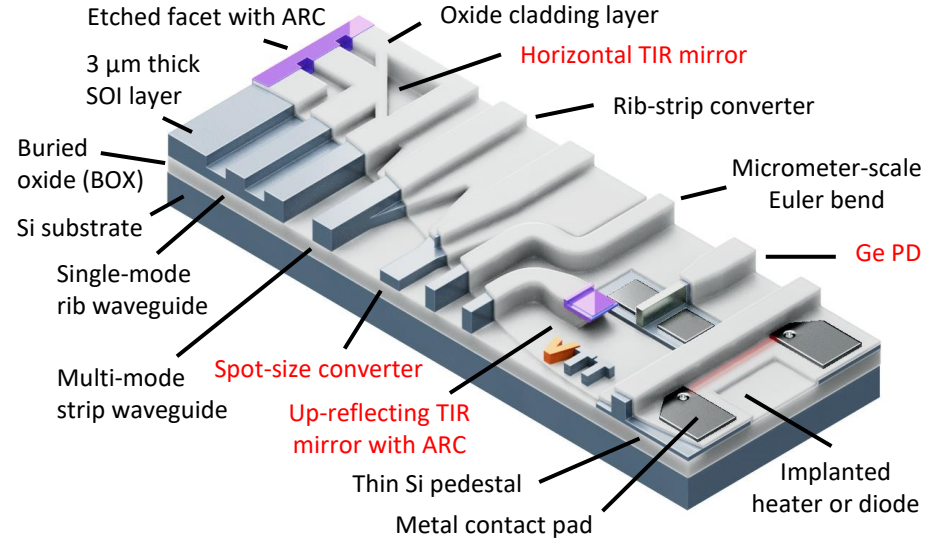
Polarization independent (zero birefringence) and low-loss passives

Ultra-dense integration with Euler bends and horizontal TIR mirrors

Tolerant to ~1 W optical power

Tolerant to fabrication errors

Up to 40 GHz Ge photodiodes



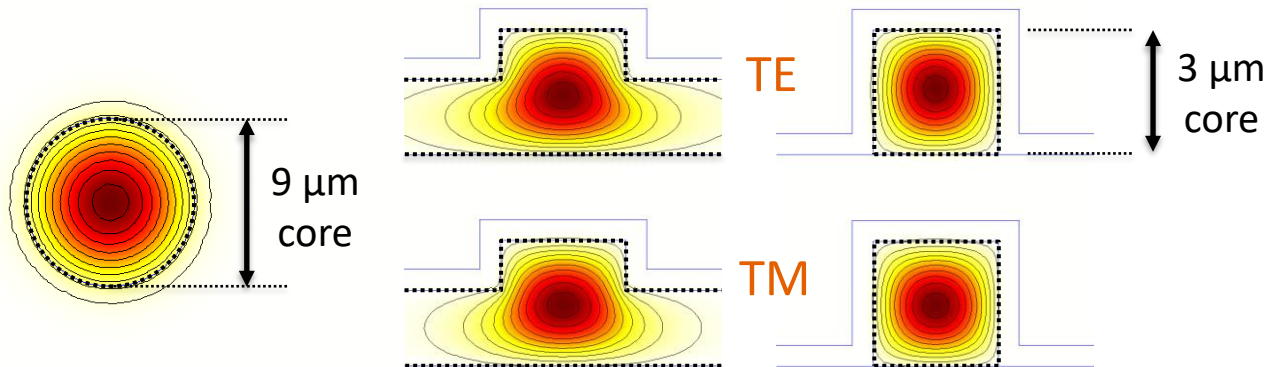
Present limitations

- Lack of fast modulators (GHz)
- Difficult coupling to microrings (too high strip waveguide confinement, too long directional and MMI couplers)
- Topography limits the accuracy of fabrication
- Higher-order mode excitation must be avoided with good designs and accurate I/O alignment

3 μm SOI: Straight waveguides

Ultra-high mode confinement into the Si core

Ultra-broadband, low-loss and polarization independent operation enabled by small mode overlap with side-wall roughness and material interfaces



Norm of the E field plotted as a function of wavelength (material absorption and dispersion ignored)

Reference: Standard single-mode fiber

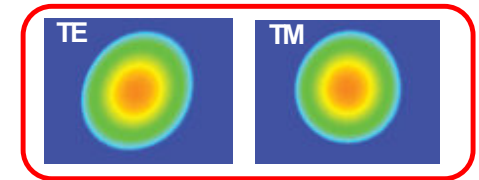
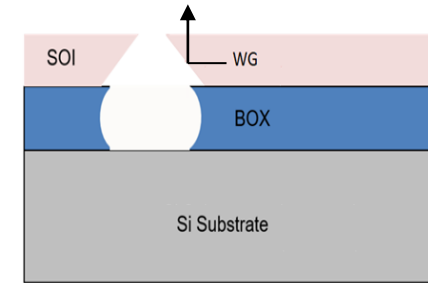
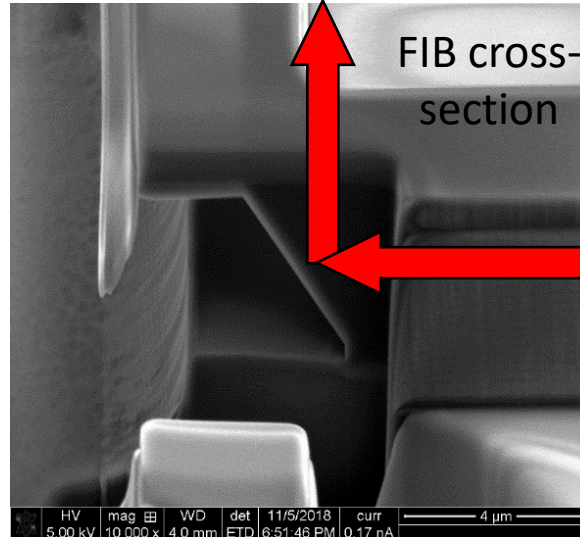
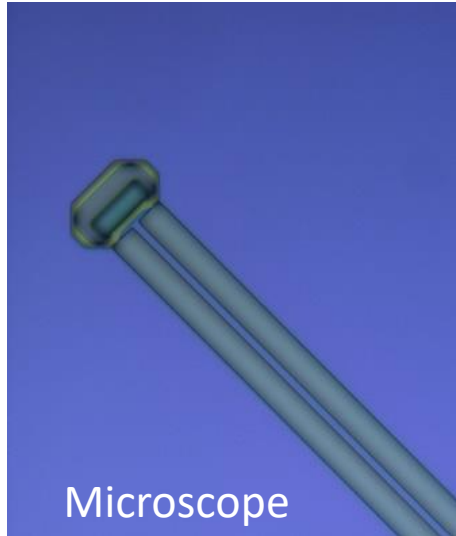
3 μm SOI (SM rib)

3 μm SOI (MM strip)



3 μm SOI: Up-reflecting mirrors

Up-reflecting total internal reflection mirrors for wafer-level testing,
VCSEL & PD integration and vertical fiber coupling
Coupling loss down to 0.5 dB

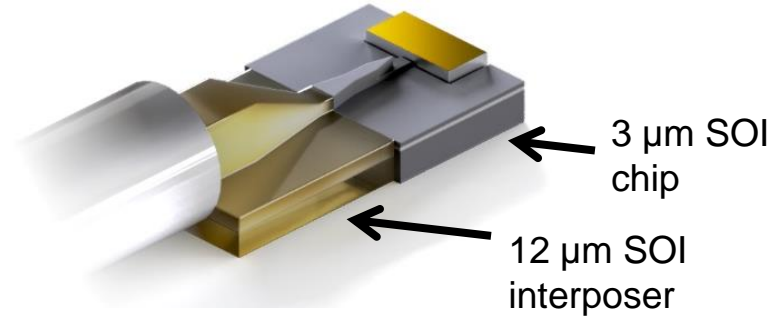
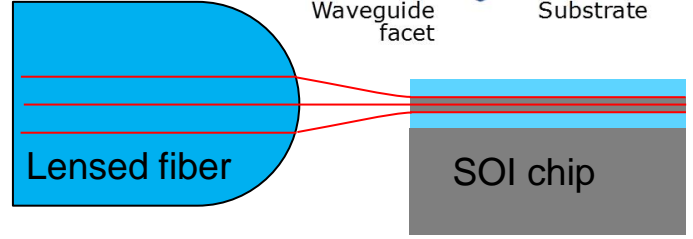
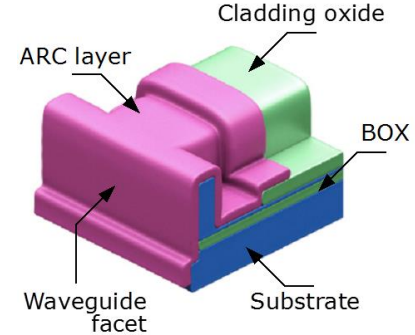
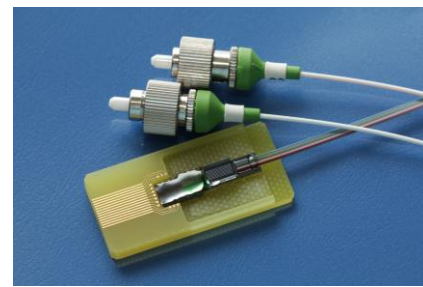
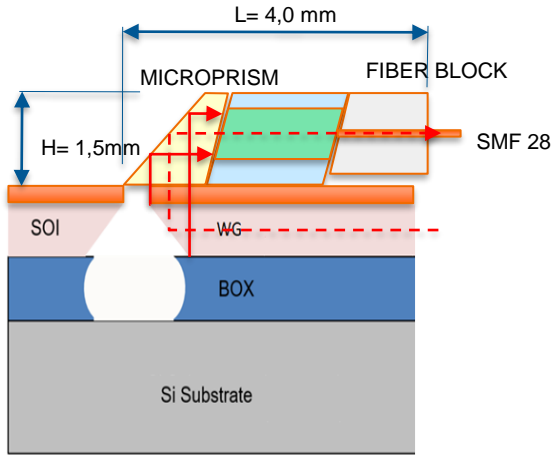


IR-camera images
from top

3 μm SOI: Fiber coupling

Coupling loss from etched facets or up-reflecting mirrors to lensed fiber ~ 0.5 dB

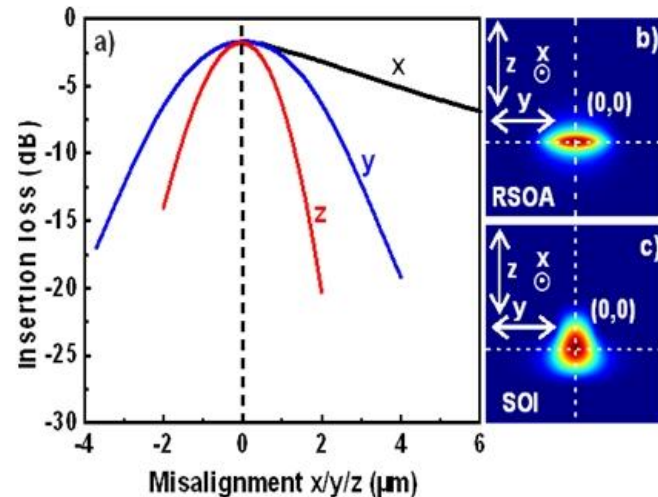
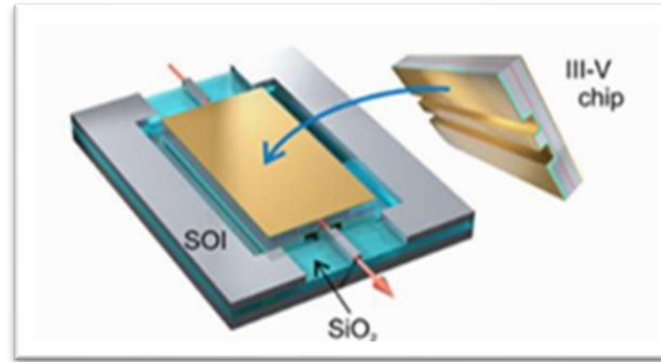
Separate interposers for coupling to standard SMF



Integration of III-V components on VTT's 3 μm SOI platform

Objectives

- Proper solder alloy
- Proper bonding structure
- Proper bonding condition
- Sub-micron post-bond accuracy
- High yield
- Precise optical alignment
- High bonding strength



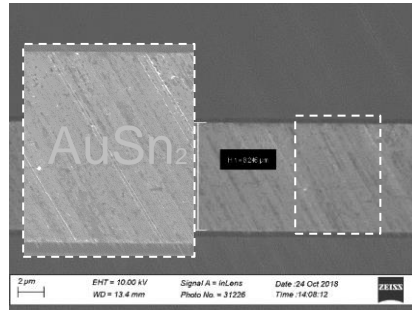
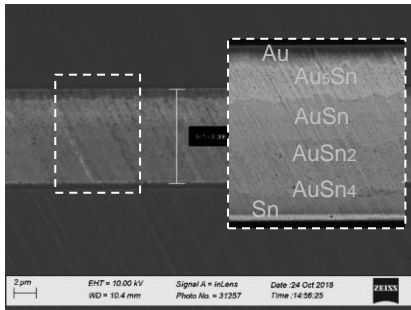
Hybrid integration development (< 1 μ m align accuracy)

Solder development

Bonding scheme

Flip-chip bonding condition

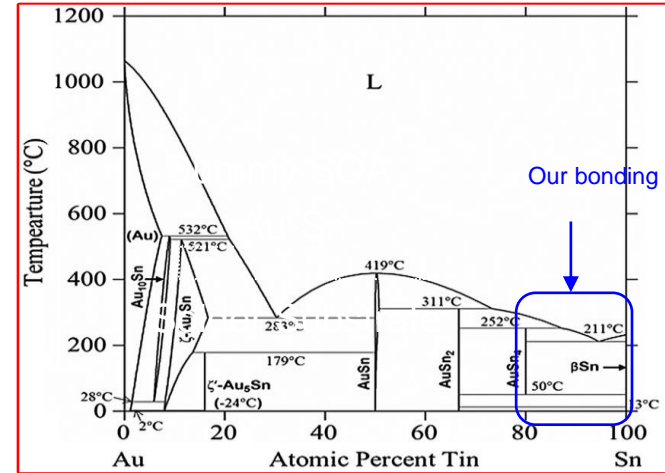
190°C (Chuck) and 220°C (Arm) 250°C (Chuck) and 250°C (Arm)



Things to consider

Stress

Thermal conductivity



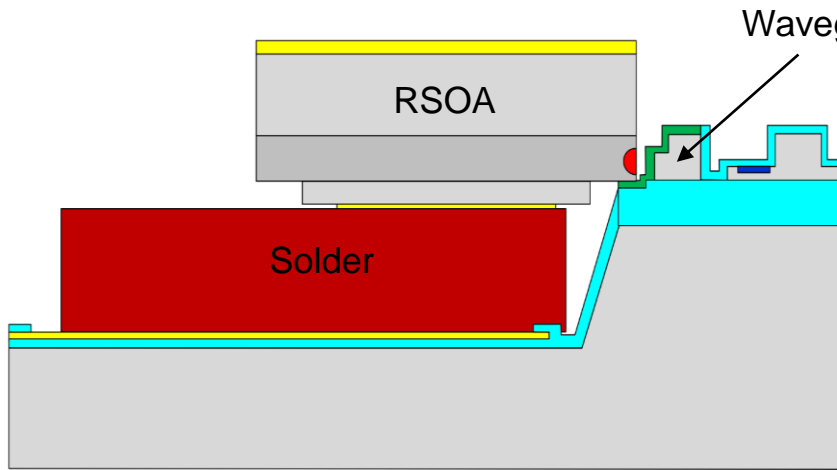
- Our bonding will be done Sn rich area
- Au-Sn solder bonding at 220 ~ 250 °C
- Au-Sn squeezing for Z-axis alignment
- Void free bonding
- Intermetallic form after bonding
- Multiple chip bonding on same Si photonic substrate
- Good shear strength (>>4MPa)

Hybrid integration development

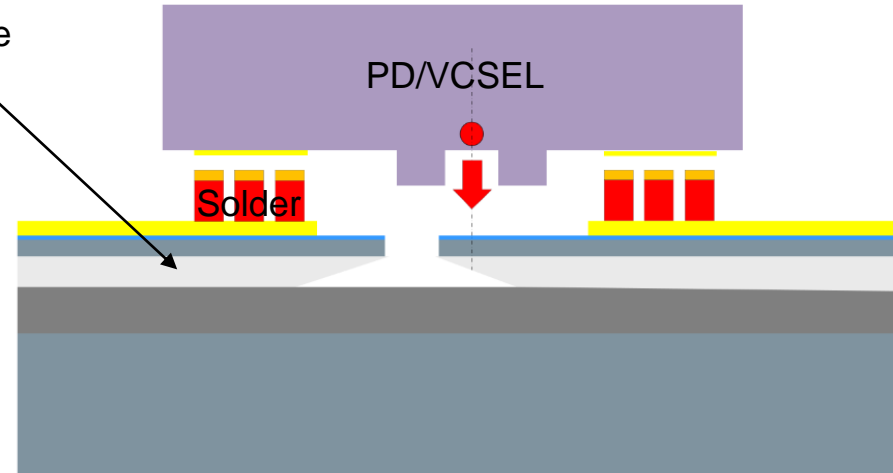
Solder development

Bonding scheme

Flip-chip bonding condition



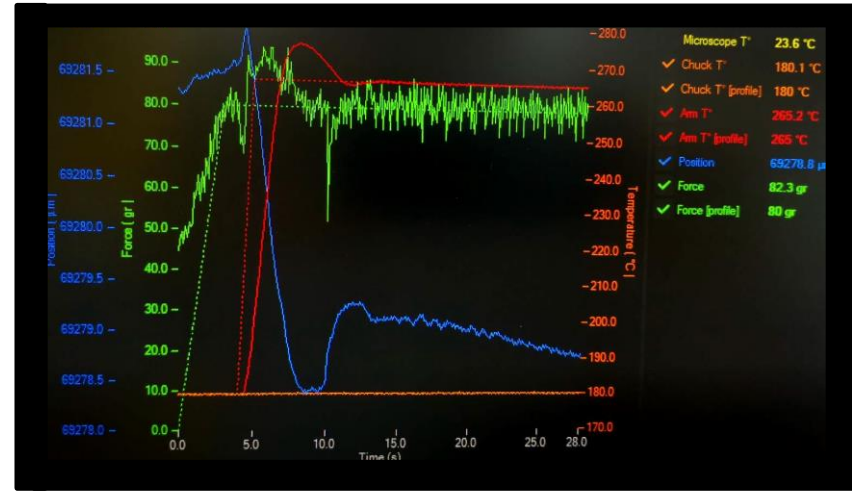
Coupling to edge of the Si waveguide



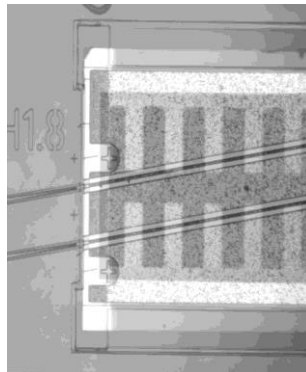
Coupling onto the up-reflecting mirror

Hybrid integration development (< 1 μ m align accuracy)

Solder development Bonding scheme Flip-chip bonding condition

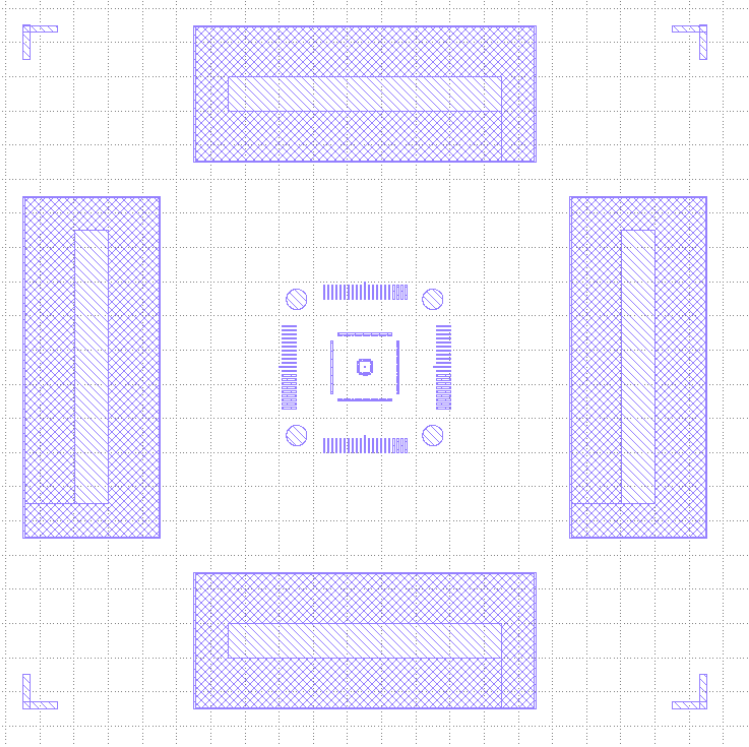
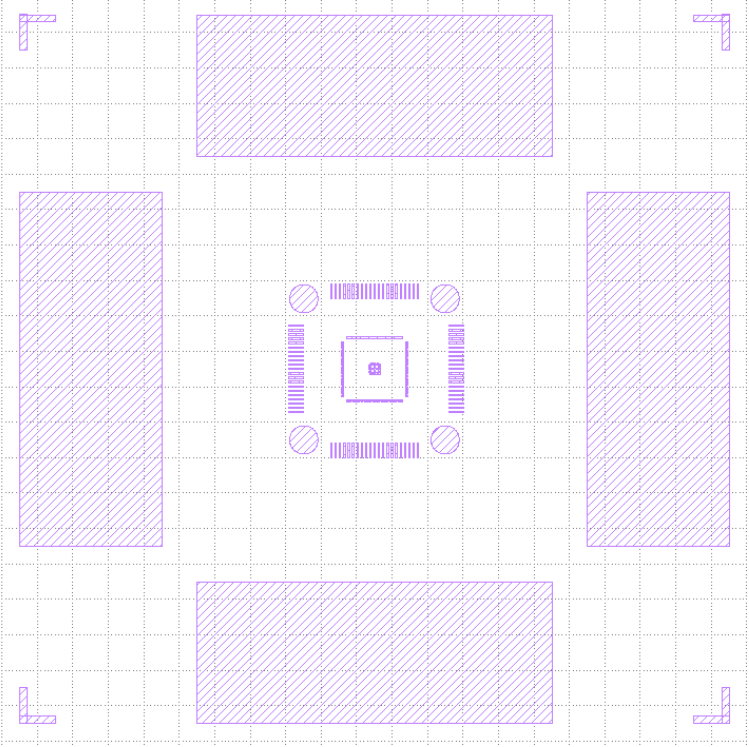


- Our bonding will be done Sn rich area
- Au-Sn solder bonding at 220 ~ 250 °C
- Au-Sn squeezing for Z-axis alignment
- Void free bonding
- Intermetallic form after bonding
- Multiple chip bonding on same Si photonic substrate
- Good shear strength (>>4MPa)

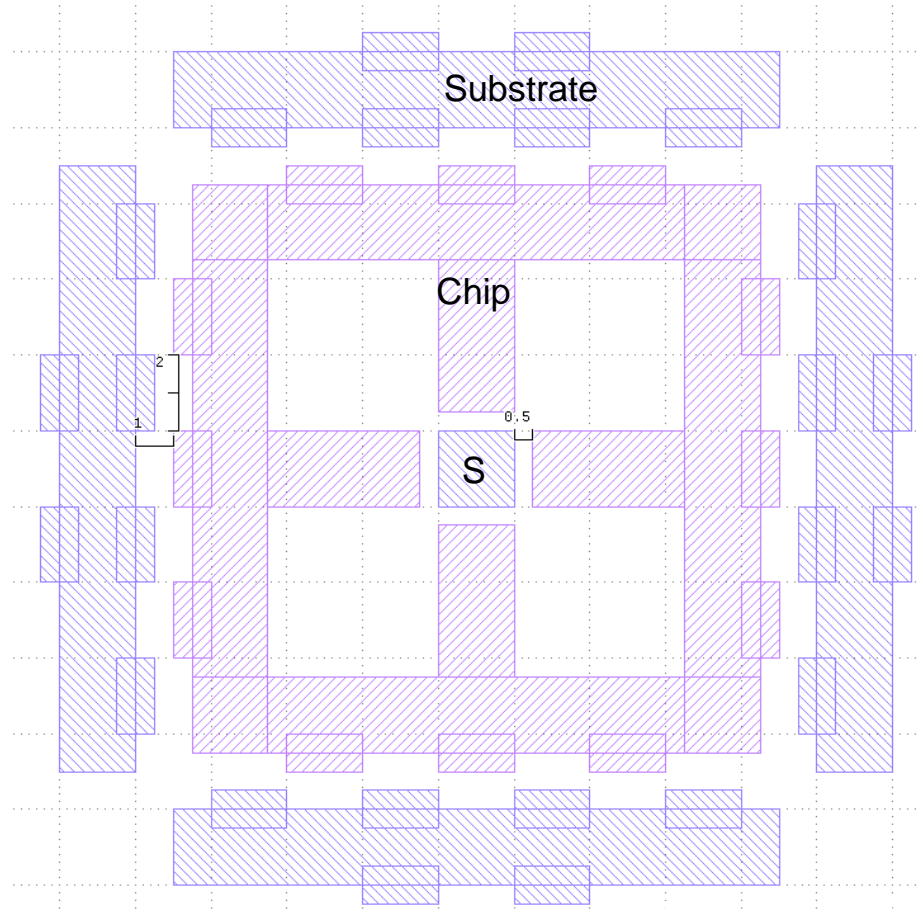


Force
Time
Temperature

Glass chip for post bonding accuracy check: Femto 2



Alignment; $< 0.5 \mu\text{m}$ align accuracy (pass or fail)



Mode: Operation (Process step)
 Group: Bonding
 System: PCB Glass test bonding»PCB bond pos
 Process step: **Bonding (Mount) (T)**
 Align position to be taught

Continue Stop

X	452.917	Y	25.646	Z	0.695
P	1.767	W	90.095	W _F	0.273
M _x	0.000				

Camera / Light Actions Measure

Measure positions XY table

X	0.0198	+		X	0.0199
Y	-0.0157	/	0.0001	Y	-0.0156
Z	0.2060	-		Z	0.2061
P	0.0000	*		P	0.0001

Reset Notice pos. Calculator

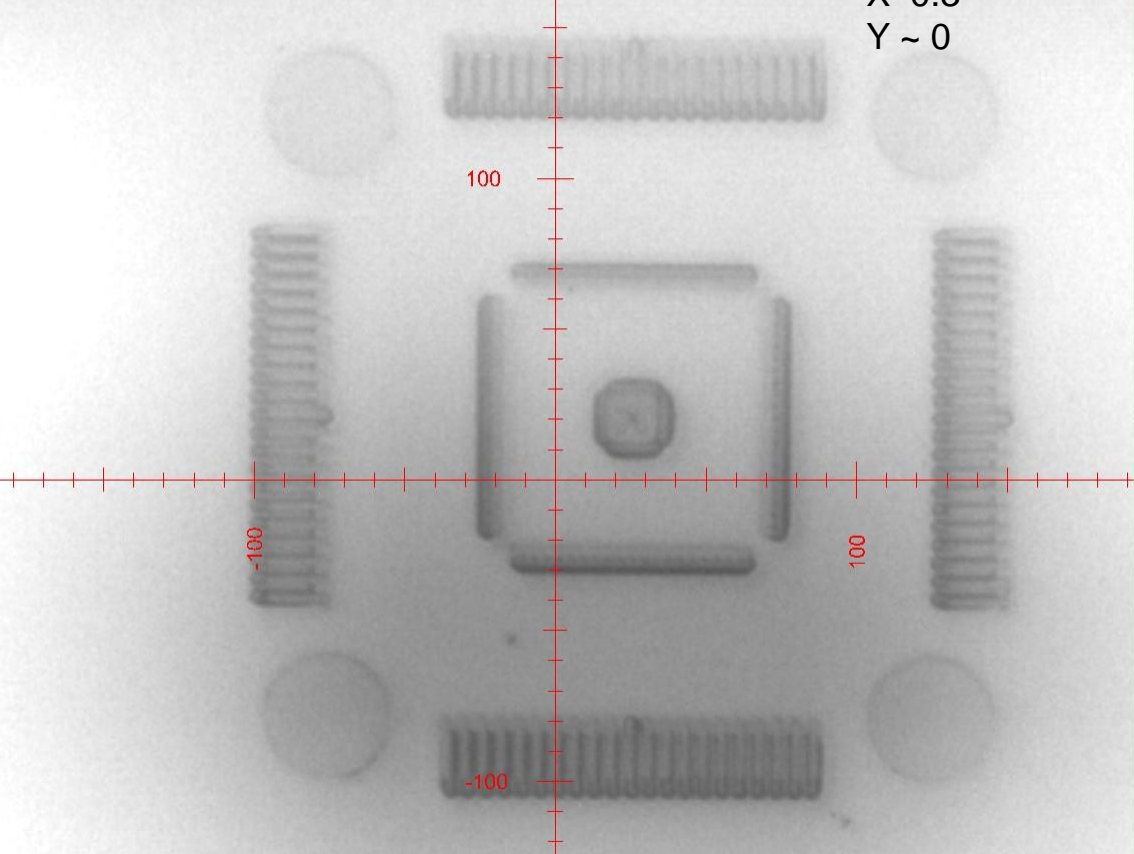
Speed buttons for base position
 Z=0 P=0

Speed buttons for measure position = 0
 X Y Z P

Speed buttons for noticed position
 X Y Z P

Speed buttons for calculated position
 X Y Z P

Bonding results



Misalign
 X 0.3
 Y ~ 0

Video

Sensors

Vacuum		
— Vacuum Arm1	<input type="radio"/>	
— Vacuum Tool tip	<input checked="" type="radio"/>	82.3%
— Vacuum Clamping	<input type="radio"/>	
— Vacuum GelPack	<input type="radio"/>	
— Vacuum Transfer	<input checked="" type="radio"/>	91.4%
— Vacuum FA15/16 Channel-1	<input checked="" type="radio"/>	90.3%
— Vacuum FA15/16 Channel-2	<input type="radio"/>	
— Vacuum FA15/16 Channel-3	<input type="radio"/>	
— Vacuum Handling	<input type="radio"/>	
Heater		
— Temperature CHM FB6		60°C
— Temperature FA15/16		60°C
— Flow Flushing target		0.0l/min
— Flow (Total) Formic Acid Controller		0.0l/min
— Flow (Acid) Formic Acid Controller		0.0l/min
— Current Heater FA15/16		32.50A
Thermocouples		
— Thermocouple A (T-1 Machine)	-	
— Thermocouple B (T-2 Machine)	-	
— Thermocouple C (T-3 Machine)	-	
— Thermocouple D (T-4 Machine)	-	
— Temperature MP1		23.2°C
— Temperature MP2		23.7°C
— Temperature MP3		25.7°C
— Temperature MP4		21.4°C
Forces		
— Force Comp.	-	
— Force W	-	
— Force W-Dest		0.00N
— Force W-Tool		0.00N
— Force Load cell		0.00N
Positions		
— Position Z-TD	-	
— Position W-TD	-	
— Temperature Offset-X		-0.5µm
— Temperature Offset-Y		-0.8µm



Mode: Operation (Process step)
 Group: Bonding
 System: PCB Glass test bonding»PCB bond pos
 Process step: **Bonding (Mount) (T)**
 Align position to be taught

Continue Stop

X	452.927	Y	26.912	Z	0.695
P	2.190	W	90.095	W _F	0.273
M _x	0.000				

Camera / Light Actions Measure

Measure positions XY table

X	0.0000	+		X	0.0001
Y	0.0000	/	0.0001	Y	0.0001
Z	0.2062	-		Z	0.2063
P	0.0000	*		P	0.0001

Reset Notice pos. Calculator

Speed buttons for base position

Z=0 P=0

Speed buttons for measure position = 0

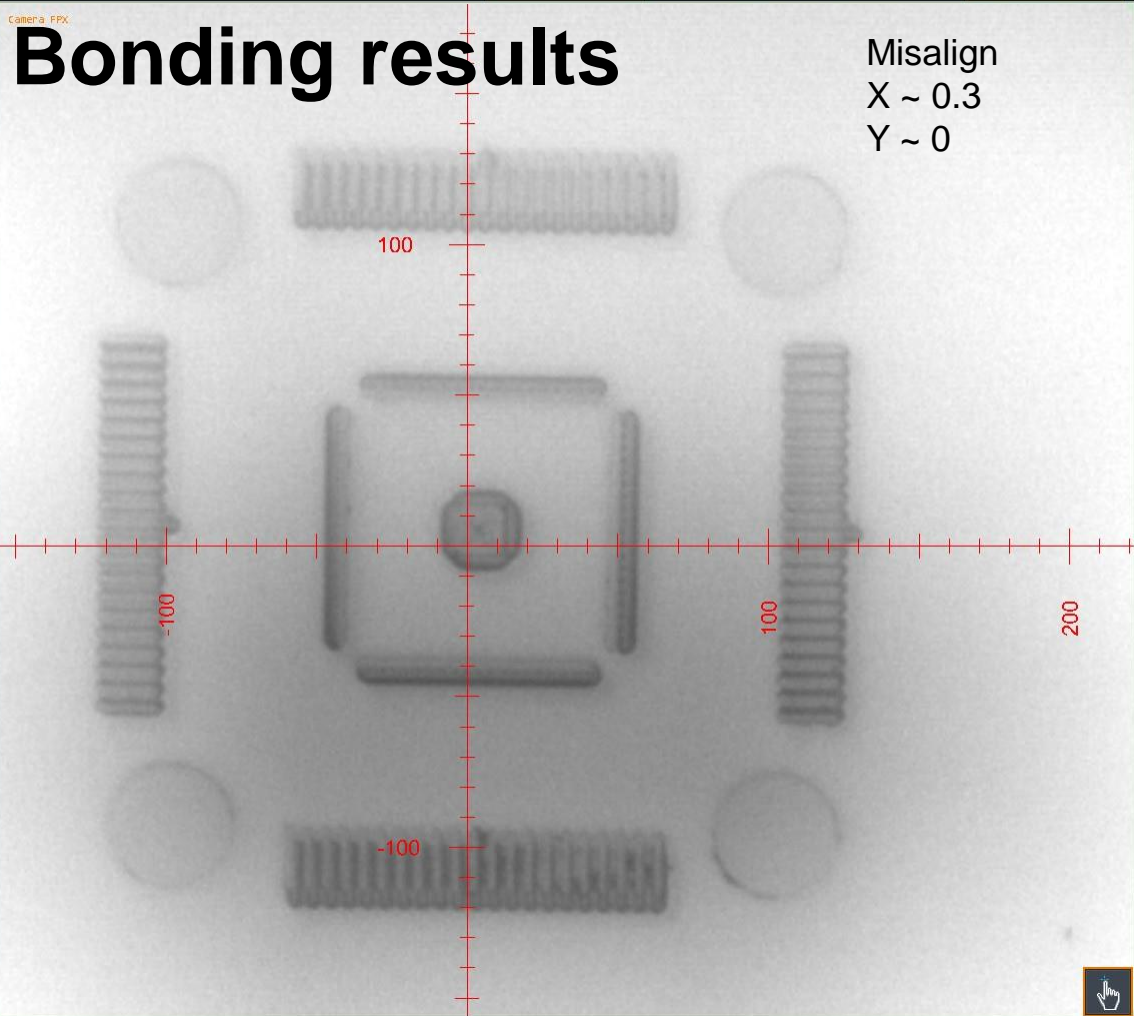
X	Y	Z	P
---	---	---	---

Speed buttons for noticed position

X	Y	Z	P
---	---	---	---

Speed buttons for calculated position

X	Y	Z	P
---	---	---	---



Vacuum

- Vacuum Arm1: 82.4%
- Vacuum Tool tip: 91.0%
- Vacuum Clamping: 90.4%
- Vacuum GelPack: 91.0%
- Vacuum Transfer: 90.4%
- Vacuum FA15/16 Channel-1: 91.0%
- Vacuum FA15/16 Channel-2: 90.4%
- Vacuum FA15/16 Channel-3: 91.0%
- Vacuum Handling: 90.4%

Heater

- Temperature CHM FB6: 60°C
- Temperature FA15/16: 60°C
- Flow Flushing target: 0.0l/min
- Flow (Total) Formic Acid Controller: 0.0l/min
- Flow (Acid) Formic Acid Controller: 0.0l/min
- Current Heater FA15/16: 32.52A

Thermocouples

- Thermocouple A (T-1 Machine): -
- Thermocouple B (T-2 Machine): -
- Thermocouple C (T-3 Machine): -
- Thermocouple D (T-4 Machine): -
- Temperature MP1: 23.3°C
- Temperature MP2: 23.8°C
- Temperature MP3: 27.0°C
- Temperature MP4: 21.4°C

Forces

- Force Comp.: -
- Force W: -
- Force W-Test: 0.00N
- Force W-Tool: 0.00N
- Force Load cell: 0.00N

Positions

- Position Z-TD: -
- Position W-TD: -
- Temperature Offset-X: -0.5µm
- Temperature Offset-Y: -0.9µm



Mode: Operation (Process step)
 Group: Bonding
 System: PCB Glass test bonding»PCB bond pos
 Process step: **Bonding (Mount) (T)**
 Align position to be taught

Continue Stop

X	452.893	Y	25.601	Z	0.695
P	1.823	W	90.095	W _F	0.273
M _x	0.000				

Measure positions XY table					
X	0.0000	+		X	0.0001
Y	0.0000	/	0.0001	Y	0.0001
Z	0.2066	-		Z	0.2067
P	0.0000	*		P	0.0001

Reset Notice pos. Calculator

Speed buttons for base position

Z=0 P=0

Speed buttons for measure position = 0

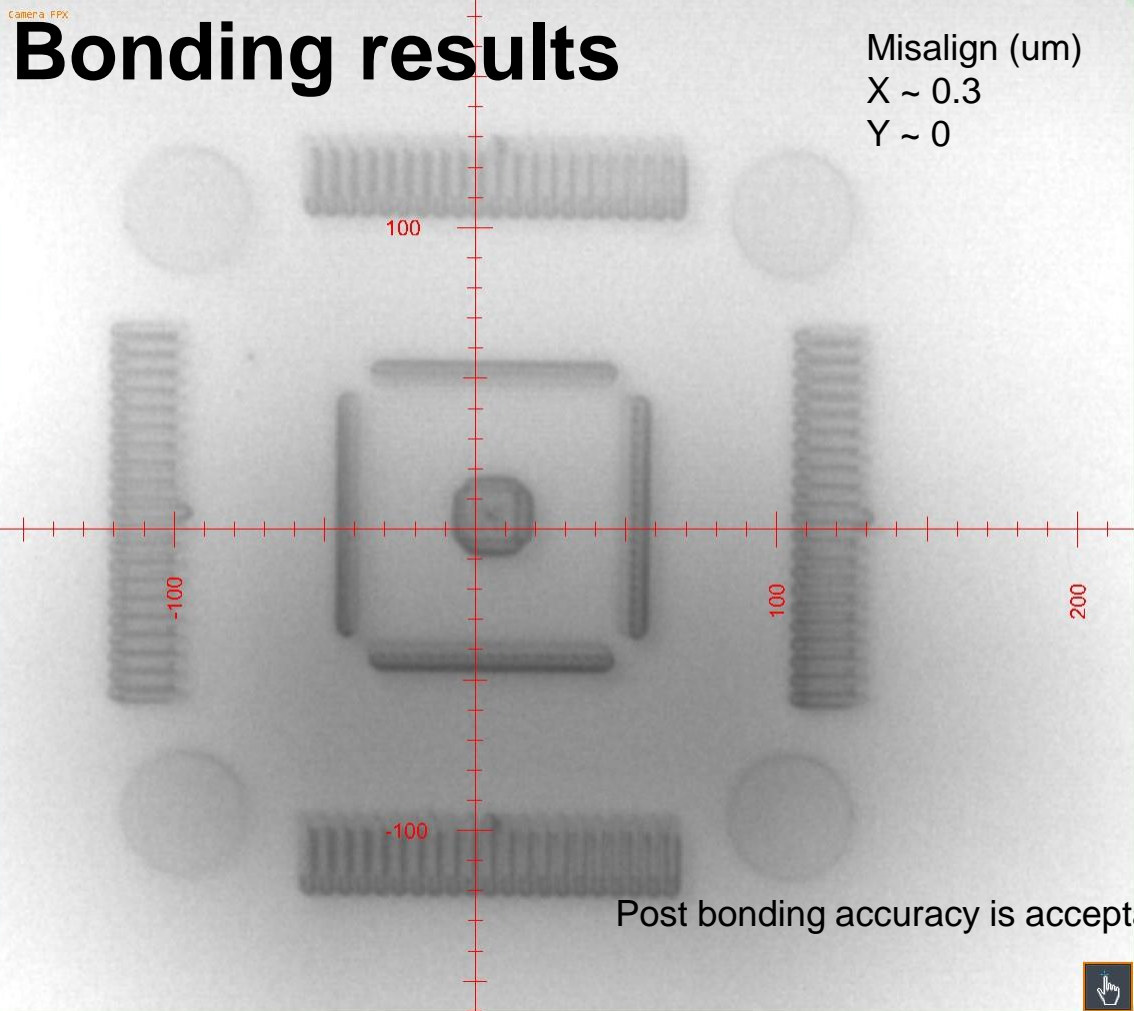
X	Y	Z	P
---	---	---	---

Speed buttons for noticed position

X	Y	Z	P
---	---	---	---

Speed buttons for calculated position

X	Y	Z	P
---	---	---	---



Vacuum

- Vacuum Arm1
- Vacuum Tool tip 84.4%
- Vacuum Clamping
- Vacuum GelPack
- Vacuum Transfer
- Vacuum FA15/16 Channel-1
- Vacuum FA15/16 Channel-2
- Vacuum FA15/16 Channel-3
- Vacuum Handling

Heater

- Temperature CHM FB6 60°C
- Temperature FA15/16 60°C
- Flow Flushing target 0.0l/min
- Flow (Total) Formic Acid Controller 0.0l/min
- Flow (Acid) Formic Acid Controller 0.0l/min
- Current Heater FA15/16 32.54A

Thermocouples

- Thermocouple A (T-1 Machine) -
- Thermocouple B (T-2 Machine) -
- Thermocouple C (T-3 Machine) -
- Thermocouple D (T-4 Machine) -
- Temperature MP1 23.4°C
- Temperature MP2 23.9°C
- Temperature MP3 **27.4°C**
- Temperature MP4 21.3°C

Forces

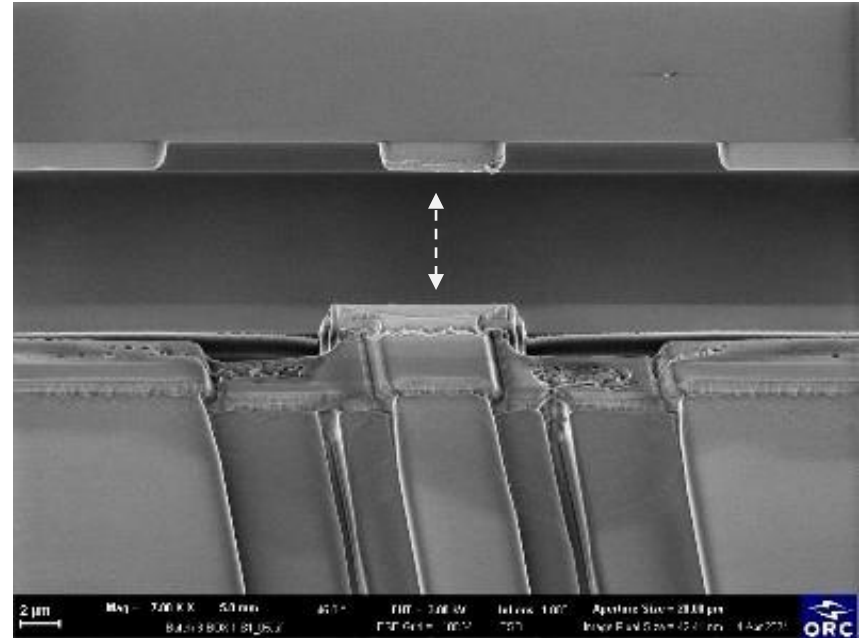
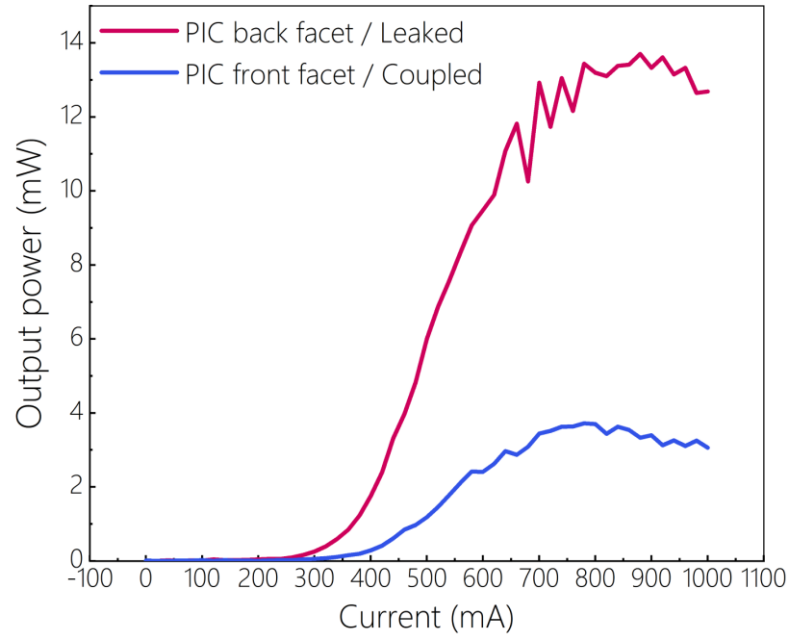
- Force Comp. -
- Force W -
- Force W-Tool 0.00N
- Force W-Tool 0.00N
- Force Load cell 0.00N

Positions

- Position Z-TD -
- Position W-TD -
- Temperature Offset-X -0.4µm
- Temperature Offset-Y -1.0µm

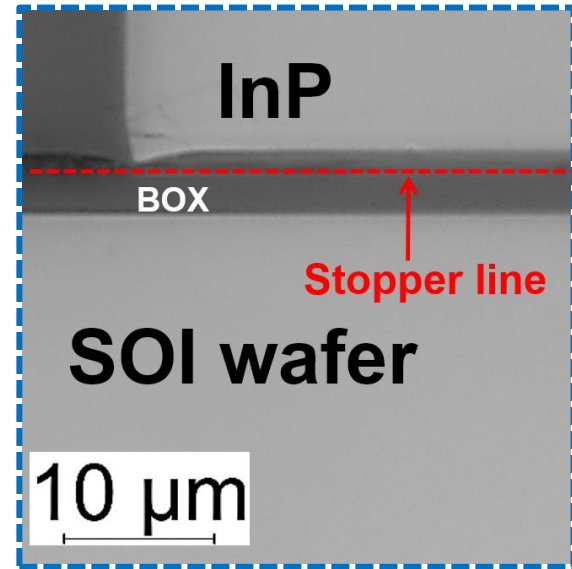
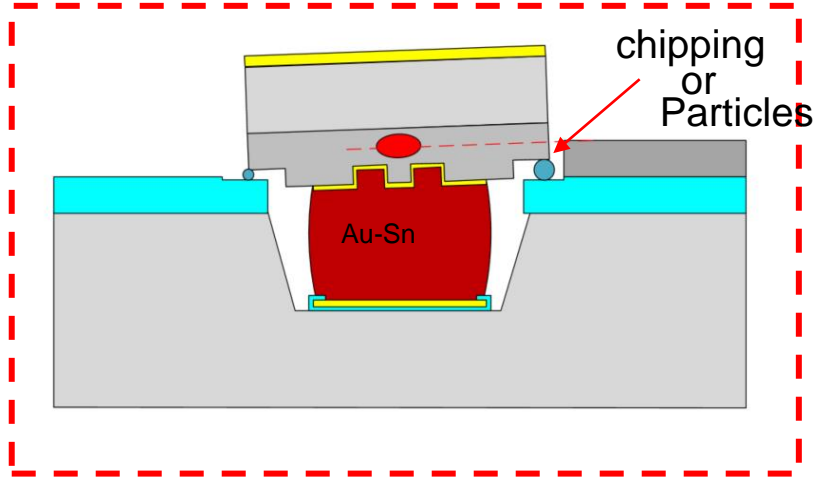
Post bonding accuracy is acceptable < 500 nm

Very low optical coupling due to....

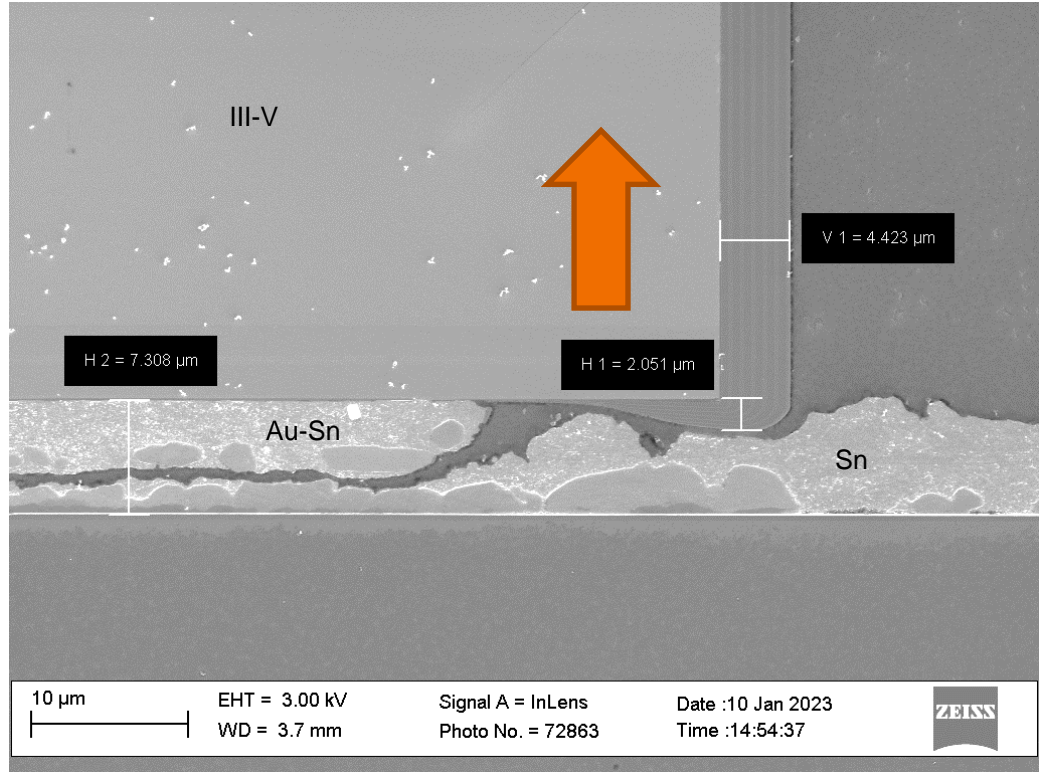
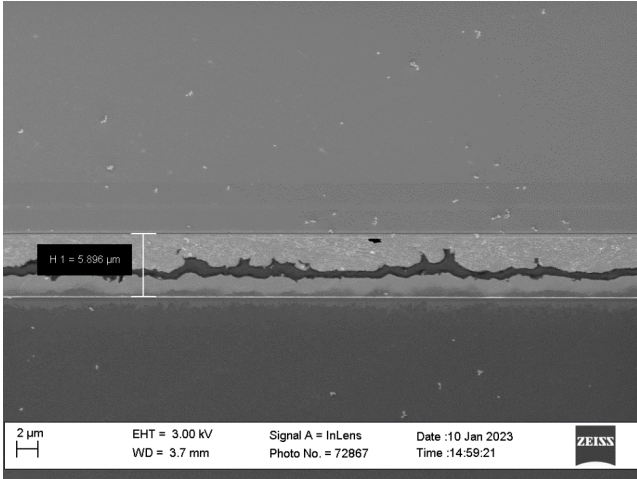


Hybrid integration development

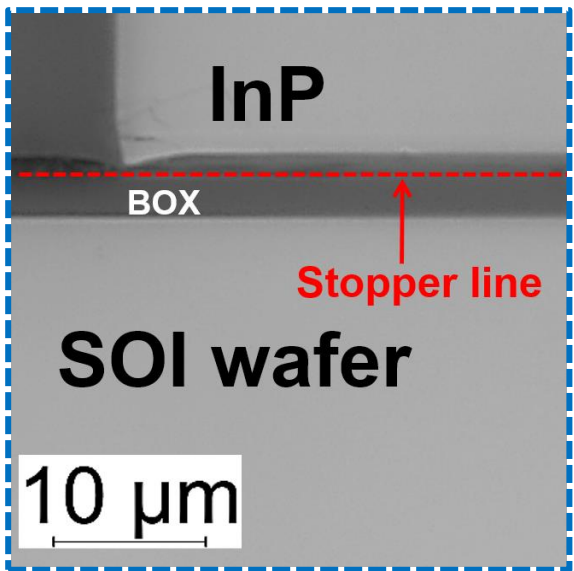
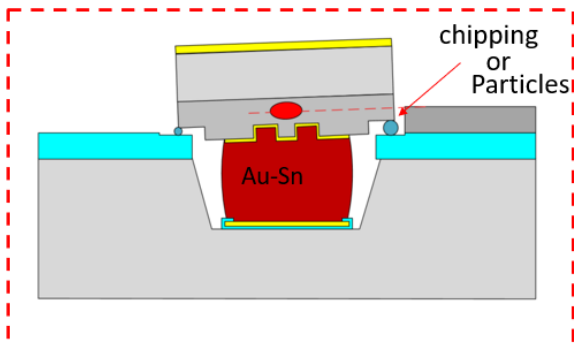
ISSUES : Z-axis mis-alignment due to particles or/and chipping



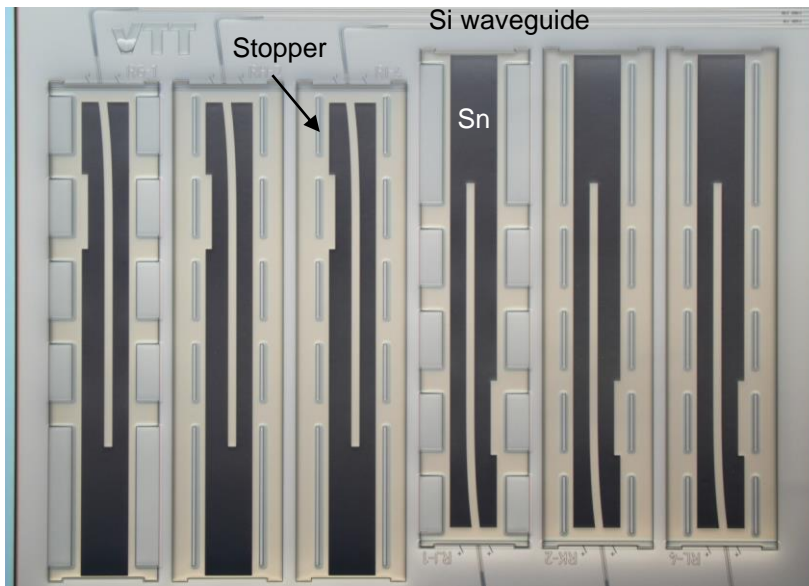
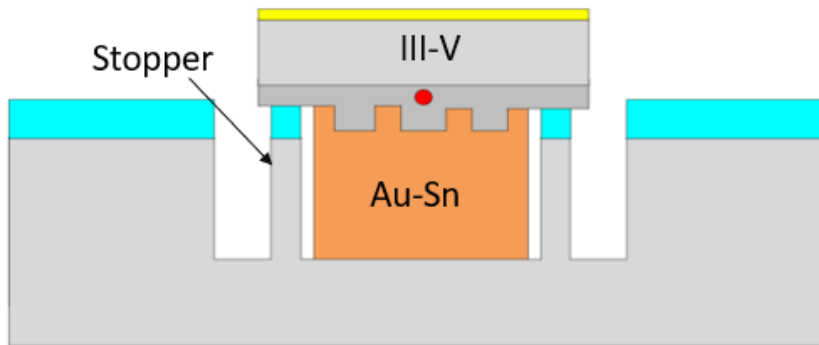
Discussion : Optical performance needed to be improved



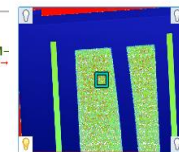
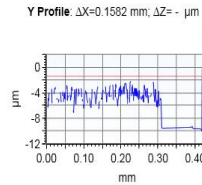
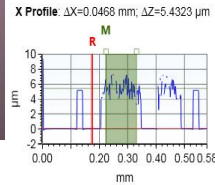
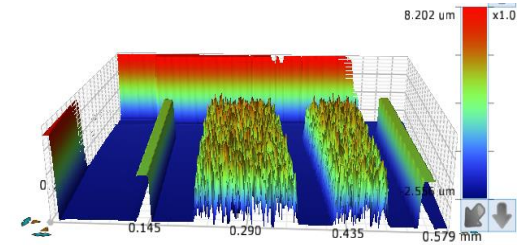
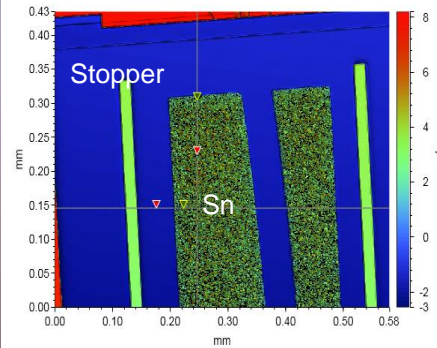
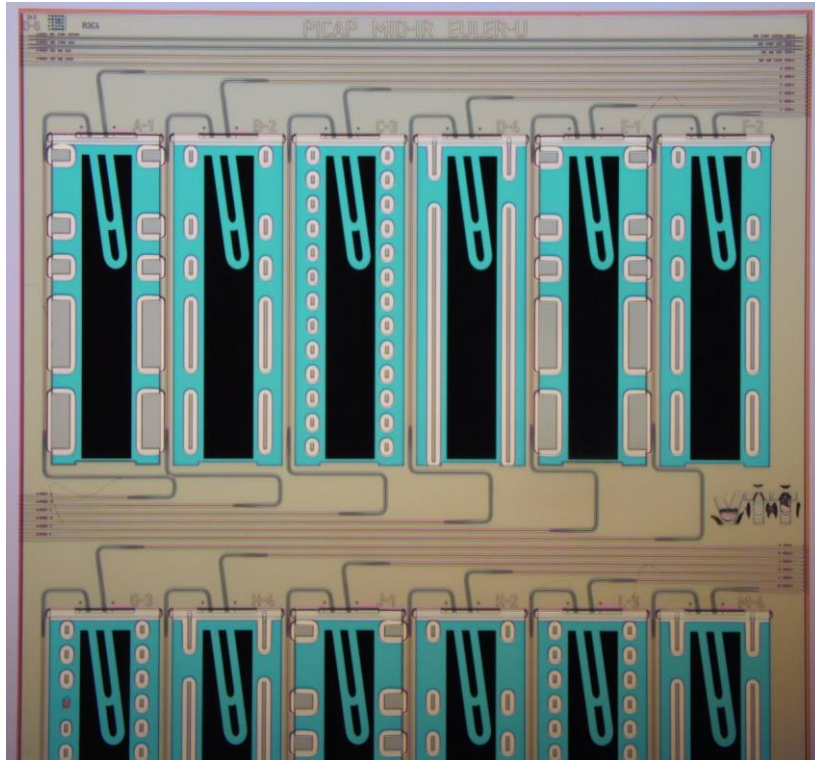
Solution



MPW12



Flip-chip bonding : Solder Mount

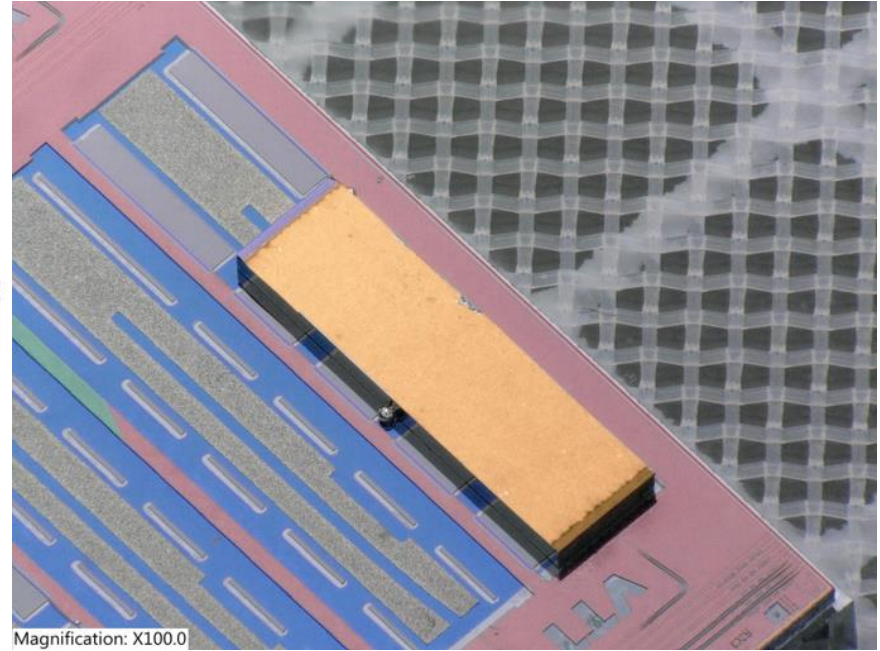
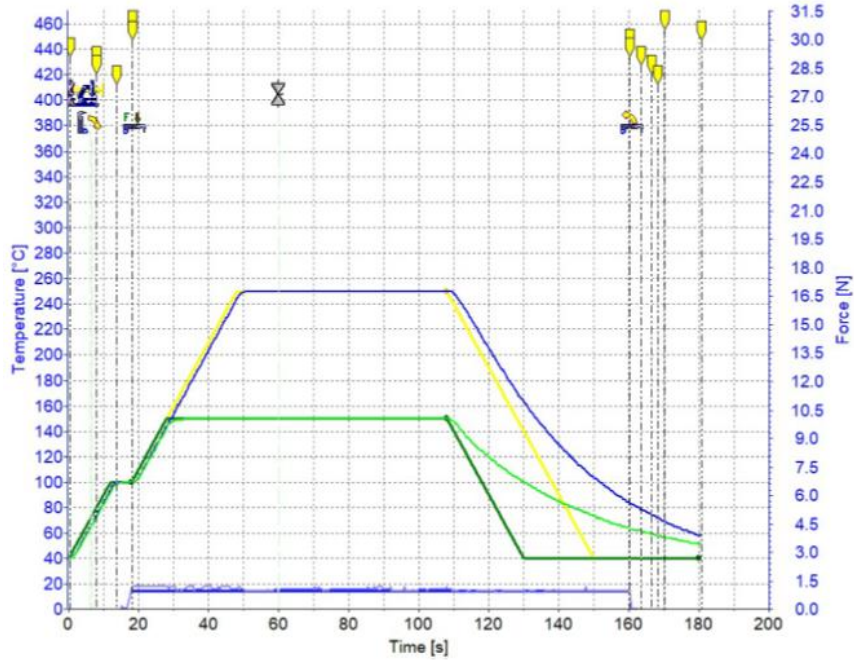


Trace Only

Contour+Trace



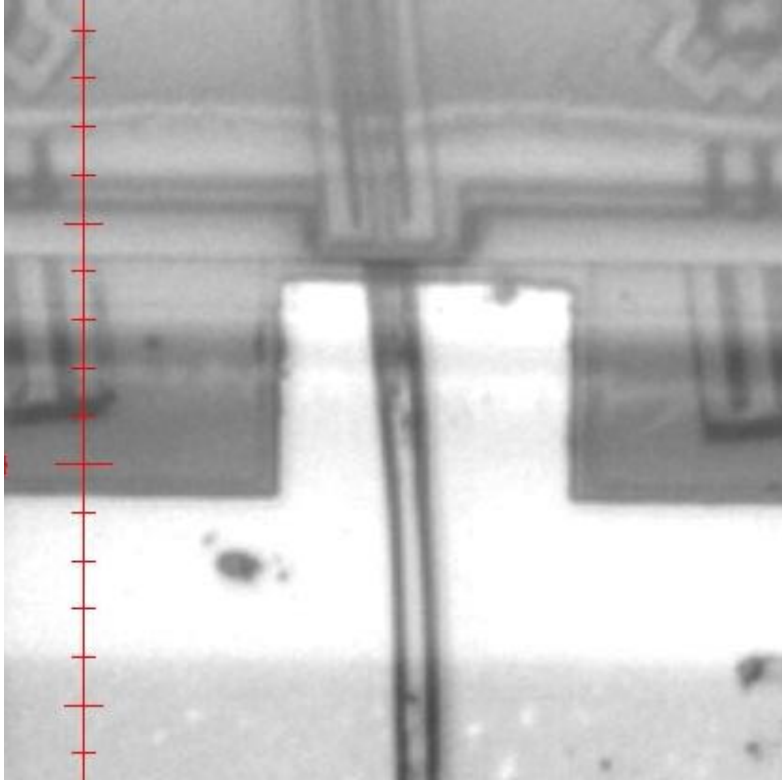
Flip-chip bonding



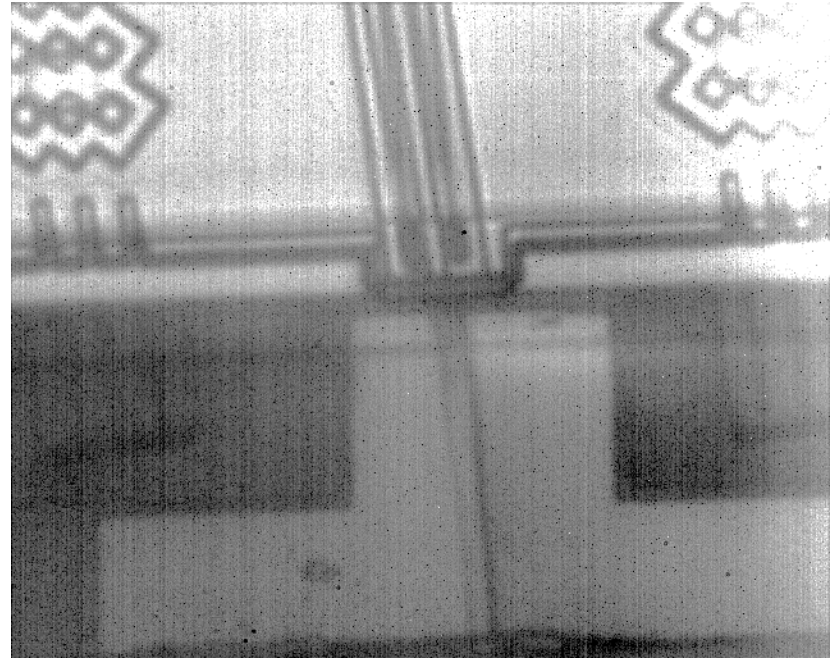
Flip-chip bonder optimization needed

RSOA flip-chip bonding results

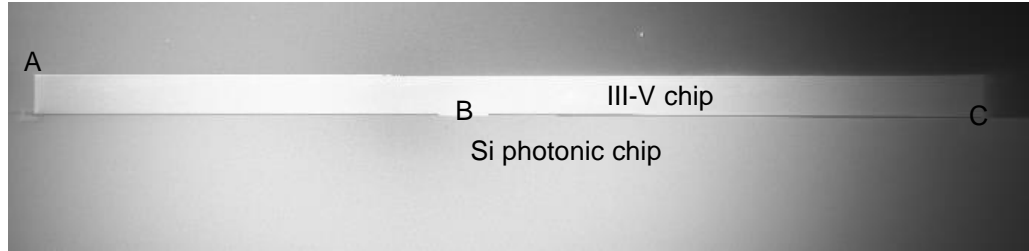
Alignment before bonding (Femto 2 optical image)



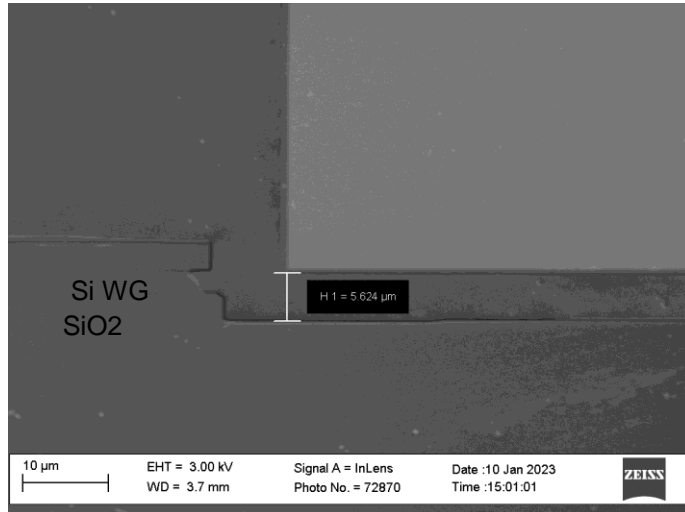
Alignment after bonding (IR image)



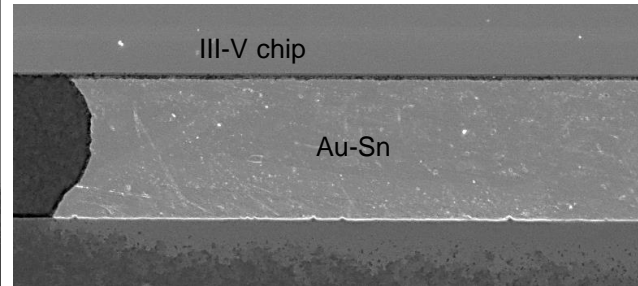
Cross SEM images



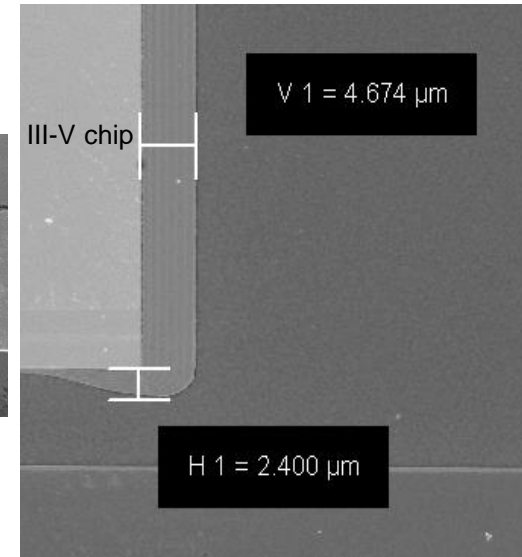
A



B



C





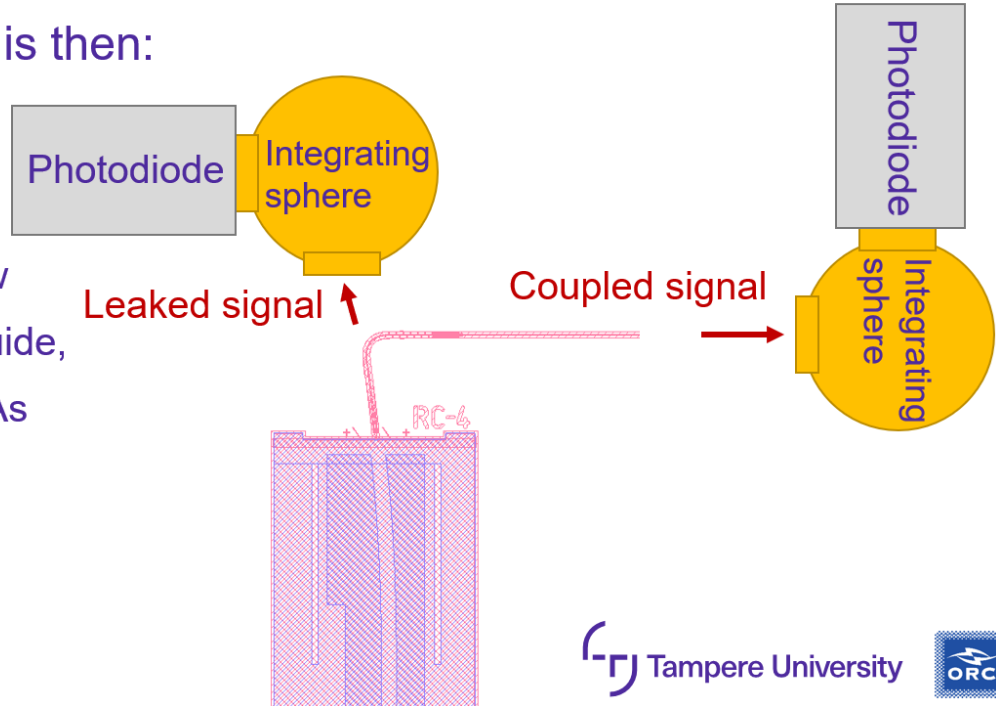
Outline of the measurements

- Pulsed current (100 kHz, 10% duty cycle) was injected to RSOA with probe needles
- "Leaked signal" and "coupled signal" was measured utilizing an integrating sphere
- Estimated "coupling efficiency" is then:

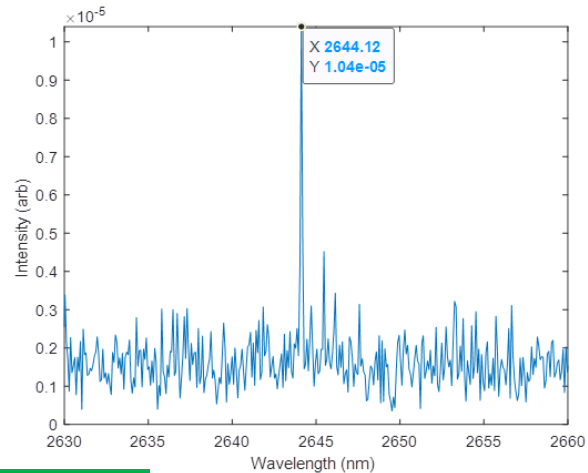
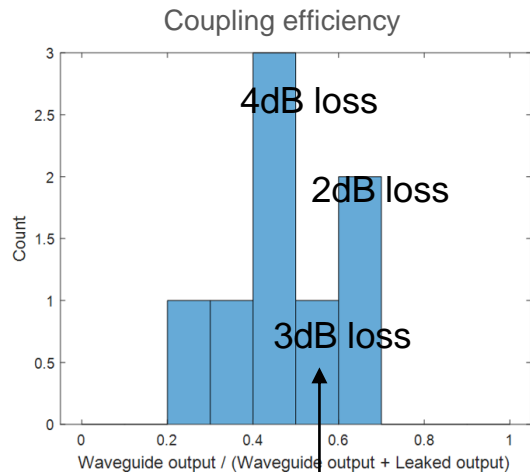
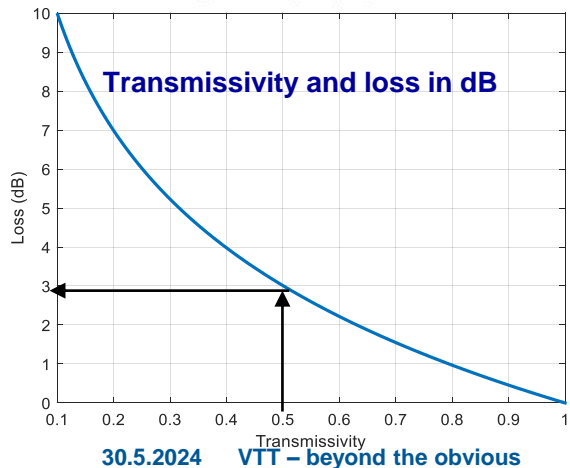
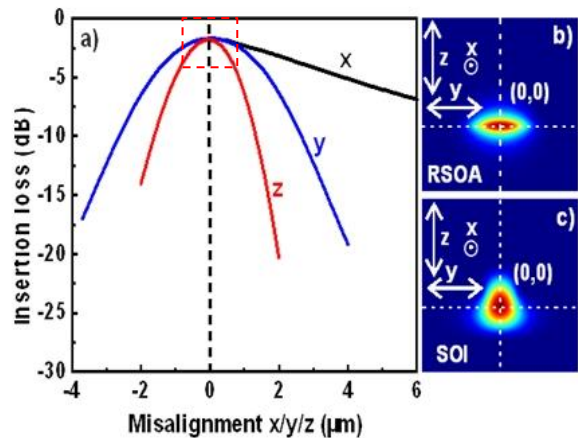
$$\frac{\text{Coupled signal}}{\text{Leaked signal} + \text{Coupled signal}}$$

- This is not the actual coupling efficiency, but gives some idea of how much light is coupled into the waveguide, and allows one to compare the RSOAs
- "Total signal" was also calculated:

$$\text{Leaked signal} + \text{Coupled signal}$$



Achievements till now



Basic loss ~2 dB due to mode mismatch
 +
 Optical misalign ➔ 1 dB loss

+
 Other issues :AR coating

Thank you very much

Q and A