Challenges in Photonic Devices Assembly and Automation Manufacturing

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The Challenges: Key Factors

- Bandwidth hungry world → Increasing demand for photonic devices …
- Increasing demand → Pressures → TTM (Time-to-Market) → CPP (Cost-per-Part)
- The same pressure, e.g., as consumer-electronics or semiconductor industries
- ficonTEC – As the largest supplier of SiP device assembly automation supplier – what do we see?

- Key Factors:
  - Fuzzy specification
  - Lack of standardization
  - TTM (time-to-market) pressure
  - Gap between ‘have vs. needs’
  - Expectations mismatch
  - Vision mismatch
  - Cost pressure
  - Lack of volume/economy of scale

- How can we work effectively under such expectation and environment?
PIC Packaging: Cost Issue

• Since the ‘telecom (photonics) boom’ in the late-90’s, wafer-level technology has made a tremendous progress ...
• For example, exploiting CMOS fab processing for SiP PICs has been progressively cost effective.
• However, not much advancements, if any at all, were made in packaging side during and since the ‘nuclear winter’ ... ‘telecom bust’ era ...
• The same practice and mindset ...
• For example, packaging micro-assembly devices can be as much as 80% of the total cost ...
• In comparison, conventional IC packaging is about 10-12% ...
• The solution is automation ... BUT ...

CW IR Laser source with collimating optics and mirrors, approx 1.5 x 2 x 2,5 mm

12 I/O fibers, 12 fibers spaced 250 µm apart

Chip with Mach-Zender modulators and grating optical couplers, wafer optical circuitry based on CMOS process
EXAMPLE: Device Design/Process for Automation (?)

- Very complex application with active/passive alignment of >30 optical elements for fully integrated transceiver
- Accumulative optical-mechanical tolerances requiring submicron-precision alignment ...
- Handling and bonding <1x1x1mm lenses
- Submicron-precision I/O fiber-optics and fiber-array assembly ...

- Cannot be assembled manually ...
- Only solution is automation ...
- How do we do this?
- What the approaches?
The Elements of CPP (‘Cost-per-Part’)
Equipment Categories

• ‘Customized’ Equipment ($$$$$):
  ✓ Typically for complex/demanding device design/process …
  ✓ Unique applications …
  ✓ Job-shop Business Model

• OTS (‘Off-the-Shelf’) Equipment ($$):
  ✓ Conducive to ‘standardized’ device design and well-defined assembly process …
  ✓ Near ‘system product’ solution

• ‘Platform-based’ Equipment ($$$):
  ✓ Semi-customizing application specific system platforms
  ✓ A hybrid approach (typically ~20/80%)
  ✓ No ‘one platform fits all’ concept …
  ✓ For different applications, there are different platforms …
Customized Equipment

• Some Reasons:
  ✓ Complex/demanding/unique (‘non-standard’) device design/process
  ✓ Perception of “better IP protection” …

• Pros:
  ✓ Highly dedicated machine customized for particular design/process
  ✓ Can be highly process and (possibly) cost effective …

• Cons:
  ✓ High development and (possibly) equipment cost …
  ✓ Long development time … with very limited ‘capable’ supplier base
  ✓ Lack of machine re-utilization
  ✓ Challenges with TTM (time-to-market)
  ✓ May not be well-debugged machine platform

• Business Model:
  ✓ Job-shop
  ✓ Organic-growth (not so scalable)
  ✓ Greater risk with economic downturn
  ✓ May require extensive technology development …
Example: Customized Laser Soldering System

- Industry: Consumer Electronics
- Volume: 2-3B/yr. (minimum)
- CPP: a few dollars
VIDEO: HVM Laser Solder Die Bonding System
Customized Equipment Built for Specific Application

- Leveraging existing technology and platform ...
- But needed to develop other key/new technologies ...
- External tray-loader capability for added-capacity ...
- A 3rd-generation system will be customized for even higher throughput, yield, efficiency, and uptime ...
Standardized Equipment

• Some Reasons:
  ✓ Well understood (‘standard/legacy’) device design/process
  ✓ Conducive to ‘standardized’ assembly process (i.e., “Machine is physical manifestation of the process …”)

• Pros:
  ✓ Likely lower equipment cost as a result of ‘productization’ & economy of scale
  ✓ Faster leadtime → favorable scenario for TTM
  ✓ Lower technical risk
  ✓ More supplier base/availability …

• Cons:
  ✓ High initial ‘product development’ cost … i.e., investment
  ✓ Long development time/cycle … only incremental technology upgrade
  ✓ Lack of machine re-utilization for different applications

• Business Model:
  ✓ System ‘product’ offering → packaged system solution → lowers the barrier-to-entry
  ✓ Scalable
  ✓ May require some level of technology development
FL300-12: Semi- & Fully-automated Assembly Systems

- Fiber-optic components assembly
- Submicron precision motion system
- Ultra-high precision vision system
- Manual-loading, automated assembly

12-axis + 1-axis System Setup
FL300: Wide Range of Applications

- Fiber-optic components assembly
- OE devices
- Integrated optics
- Silicon-photonics
500-Series Automation Platforms

AL500 – Assembly System

TL500 – Test & Measurement System
IL500 – Inspection System

BL500 – Die Bonding System
VIDEO: BL500 Precision Die-Bonding System
BL500: Alignment & Post-bond Shift Result (±0.5µm)
‘Platform-base’ Equipment

• Some Reasons:
  ✓ Prototype/pilot-production phase device design/process
  ✓ Ready to transition to production … existing platform (20/80%)

• Pros:
  ✓ Leveraging hardened system-level platform
  ✓ Preconfigured for certain type of application(s)
  ✓ Effectively optimized for given design/process
  ✓ Conducive to machine reutilization …
  ✓ Can be leveraged for economy of scale …

• Cons:
  ✓ Higher initial cost & long leadtime, pending app
  ✓ Application can fall in-between platform types

• Business Model:
  ✓ Process-engineering … allow to focus on process developement, not platform
  ✓ Reasonably scalable and larger initial investment …
  ✓ May require technology development in focused area(s) …
VIDEO: AL2000-AA Optical Components Assembly Platform
VIDEO: AL2000-AA Optical Components Assembly – OSA Close-Up
AL2000-AA Optical Component Assembly Platform – In-Package
VIDEO: AL2000-AA Optical Components Assembly – In-Package
Submicron Precision Alignment Engine

- 6-axis “single-stack” configuration
- 50nm BDR & incremental motion
- Travel: 100mm (XY) & 50mm (Z) & ±5° (θ_{xyz})
- Single MPOP (Mechanical Point-of-Pivot)

- Optical encoder
- Counter-balanced for load capacity
- Linear stage with cross-roller bearing
- Flexible configuration

- 3-axis single-stack configuration
AL1000 Motion System Configuration

AL1000 = Gantry + Alignment Engine

Micron-precision Gantry Motion System

Configurable Sub-micron Precision Alignment Engine
Demo Video: Alignment Engine Configurations
Passive Approach (Split Optic)

Flipped Chip (Die) → Split Prism

Use Stages to Adjust X, Y, & Theta Axis for Precision Alignment (<1 µm) and LOCK X, Y & Theta

Probe Moves Out => Bond Head Finishes the Bonding (Moves Only in the Z-Axis)

RESULT
Can be Better Than ±1 µm
Application: BL500 Assembly Technology

- Flipped or non-flipped Chip (Die)
- Bond Head
- Substrate
- Lower Chuck
- Use stages to adjust X, Y & theta axis for precision alignment (<0.5µm) and lock X, Y & Theta
- Close gap => Bond head finishes the bonding (moves only in the z-axis by ~10µm)
- Result: Can be better than ±0.5µm

- Passive optical distance sensing alignment technology
- 30nm resolution
- Measure between LD facet and submount
- Post-bond shift measurement
GRIPPERS: AL2000(i) Optical Components Grippers

Micro Mechanical Grippers

Lens in front of LD

Micro Vacuum Grippers

700µm
AL2000(i) Key Technologies and Capabilities

- Active component placement
- Passive component placement
- EO Test & Measure
- Soldering
- Epoxy Delivery & UV Curing

ficonTEC Proprietary
AL1000 with feeder
AL1000 with feeder

- Z-Head
- Z-Head
- Feeder
- 3 Axis Gantry
- Tool Holder
- 6-Axis Alignment System
- Conveyor Unit
- Bottom Camera
- Trays
- Downholder
- Damping Unit
- Granite Base

[Image of AL1000 with feeder diagram]
Feeder for Auer Carrier

- Operator Protection Cover
- Linear Axis for Z-Movement
- Feeder Door
- Mounting Unit
- Exit Cover (Pneumatic Slider)
- Auer Carrier Magazine Platform for Magazine Ejection Unit
- Z-Axis Movement
Conveyer Unit

- Auer-Boat Carrier on Loader
- Feeder
- Linearguide
- Oval Vacuum Suction Pad
- Centering Pins
PRODUCTION CALIBER, USER-FRIENDLY, POWERFUL AUTOMATION SOFTWARE
Flexibility vs Speed

- **A Matter of ‘Volume’ …**
  - A few tens/hundreds → Flexible, manual/semi-automated approach
  - A few hundreds/thousands → Flexible, semi-/fully-automated
  - 10K to million(s) → Full-automation, less-flexible

- **BTW, What is the volume?**
  - Hopefully driven by market-demand and cost … not ‘industry pushed’
  - And/or our ability to product effectively?

- **Different Approach**
  - Design for flexibility – higher product mix and machine reutilization
  - Design for speed – dedicated application
  - Platform/modular approach – addresses both
  - ROI is important in all cases

- **Scale-down Known Automation Principles**
  - A ‘trend’ to start with high-capabilities …
  - … to quantify and define key process parameters
  - Scale-down and streamline for cost-effective, robust equipment
Why Lack of Standardization?
- Legacy behavior from telecom-boom’s IP mentality/paranoia ...
- NIHS (‘not-invented-here’ syndrome)
- Lack of volume … relatively low compared to other industries

Can address those concerns and still standardize?
- Doable, as seen by other industries …
- Still can protect IP and benefit from standardization?

Device Design and Process Conducive for Automation …
- Streamline/optimize the whole chain for automated manufacturability
- Engage automation supplier early on in the process

AIM Can Help …
- The ‘M’ part of AIM is focused on design for manufacturability …
- And, automation is just a part of it …
Concluding Remarks

- What is the (real) volume?
  - Varying market studies and forecast …
  - Customers’ forecast vs market study …

- Standardization in Photonic Device Packaging?
  - Probably makes more sense for SiP applications …
  - But integrated micro-optics device assembly … too many variations

- Integrated Systems Automation Solution?
  - Most of the key technologies are available now …
  - Some key technologies need to be developed → AIM
  - Will stay modular ($$$) until we can see standardization …

- How AIM Can Help …
  - HVM will become more critical factor with increasing volume demand …
  - And downward cost pressure …
  - Design/process conducive to test/assembly automation …
  - Designed for HVM (high-volume manufacturing) from the start …
Development to Production

**Device Development**
- Package Design
- Device and process experimentation/characterization
- First-generation prototyping
- Customer-directed customizations

**Assembly Process Development**
- Process Testing/Validation
- Package Design Refinement
- Small Prototype runs
- Initial product qualification
- Tooling design finalization
- Final system requirements definition

**Pilot Production**
- Pilot runs w/ final package design
- Final process sequencing
- Final product qualification
- Transfer process to custom platform
- Qualify custom platform

**Standard or Lower-cost Customized Platform**

**Production**
OPEN DISCUSSION

Any ("good") Questions? 😊