Multiscale Robotics Architecture for Micro & Nano Manufacturing

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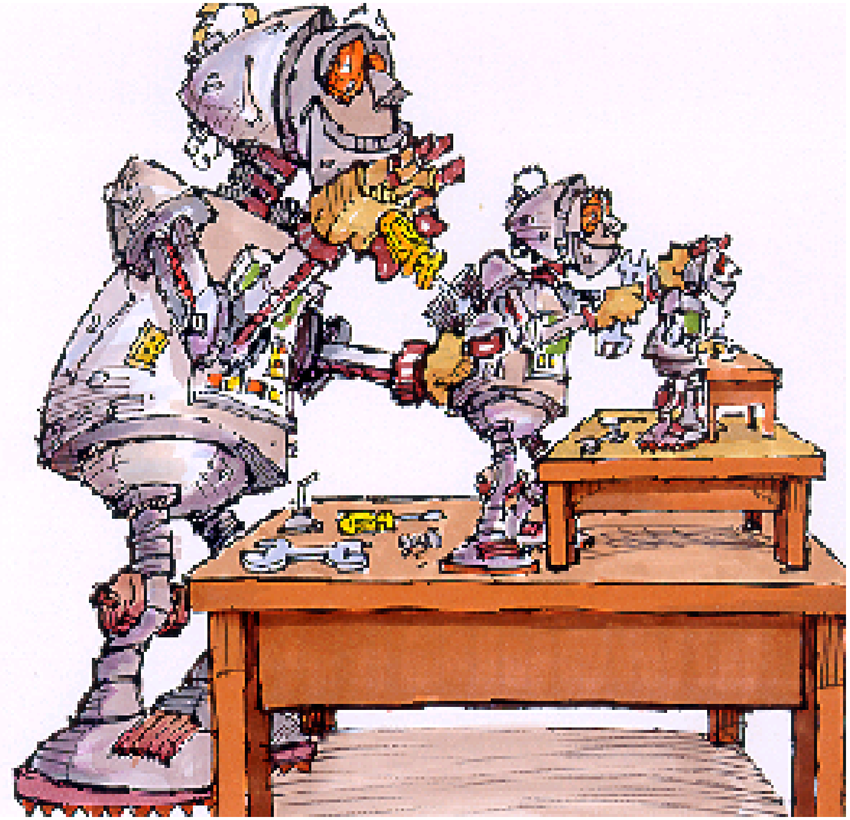
Assembly at small scales not more difficult than conventional assembly if we:

- Measure or predict how what we do at large scales affects the smaller scales (top-down).
- Follow a specific set of top-down design principles while designing manufacturing cell and parts.

What is Multiscale Robotics?

Robotics where the size or tolerance of parts cuts across multiple scales Macro-Meso-Micro-Nano



Related terms

- Precision robotics
- Top-down manufacturing
- Hierarchical manufacturing

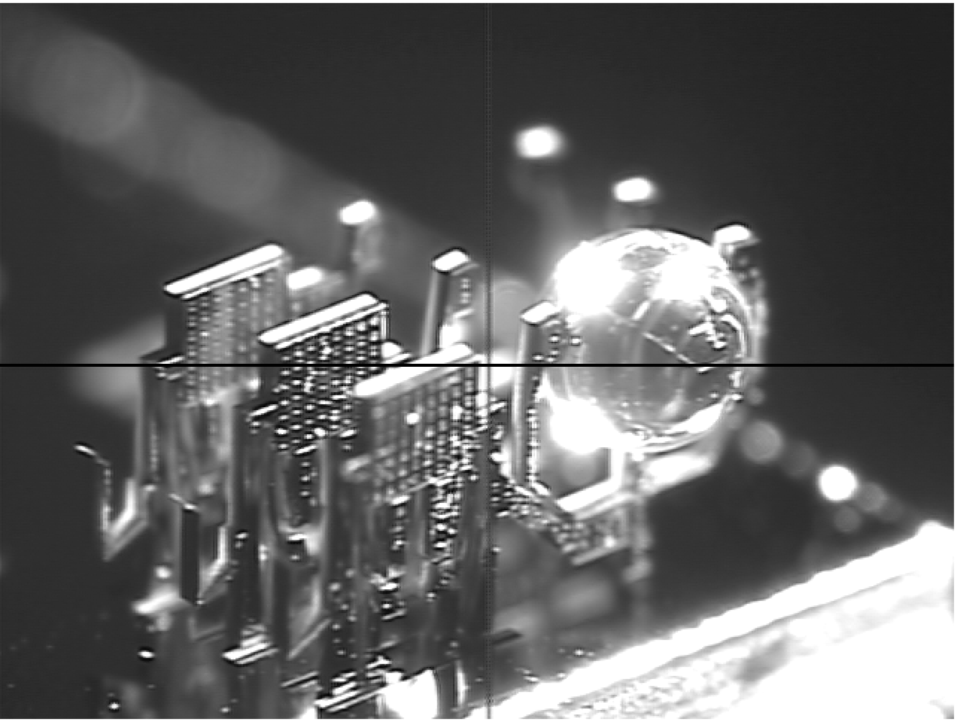
Multiple Scales

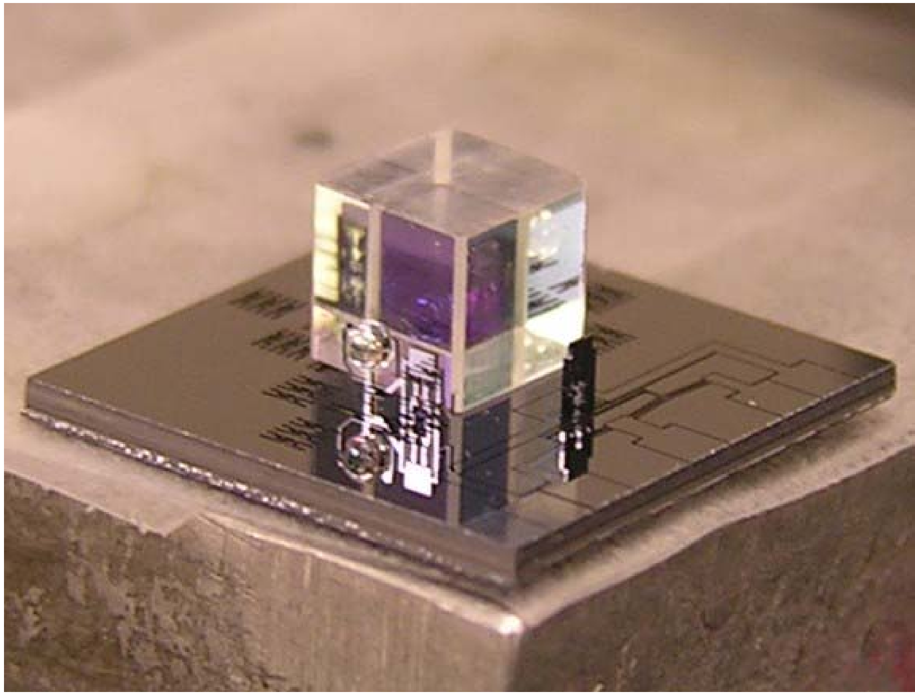
- **Nano** – Part sizes below 500nm, positioning accuracy below 250nm, SEM/TEM.
- **Micro** – Part sizes between 0.5 μm and 500 μm, accuracy between 0.25 μm and 2.5 μm, optical microscope.
- **Meso** – Part sizes between 500 μm and 5 cm, accuracy between 2.5 μm and 25 μm, regular optics.
- **Macro** – Part sizes greater than 5 cm, accuracy greater than 25 μm, regular optics.

Assembly at Different Scales

Assembly scale	Mesoscale	Microscale	Nanoscale
Attribute			
Positioning	Easy	Difficult	Very difficult
Velocity	Cm/s or m/s are not unusual	Slow (μm/s), or (mm/s), vibration suppression	Very slow Nm/s, or μm/s
Force Sensing and Control	Easy / Necessary to avoid part damage and improve manipulability.	Difficult, The range of forces to be sensed could be as low as μN.	Difficult, AFM (atomic force microscope) is used to measure force.
Dominant forces	Gravity, Friction	Friction, Surface forces (stiction, electrostatic, Van der Waals)	Molecular/Atomic forces
Throughput	Serial assembly provides adequate throughput.	Serial assembly is usually not sufficient. Parallel manipulation methods are preferred.	Parallel manipulation methods, or self-assembly are necessary.
Gripper	Mechanical, many examples, RCC, Utah/MIT hand, etc.	Micromechanical, gripper-free manipulation preferred.	Other, optical, proximity force, etc.
Fixturing	Mechanical	Micromechanical fixturing must be used	Chemical
Compliance	Gripper compliance is not necessary if force is measured.	Gripper compliance is usually necessary.	Mechanical compliance does not apply.
Vision	Easy	Difficult (expensive optics)	Impossible in visible wavelengths.

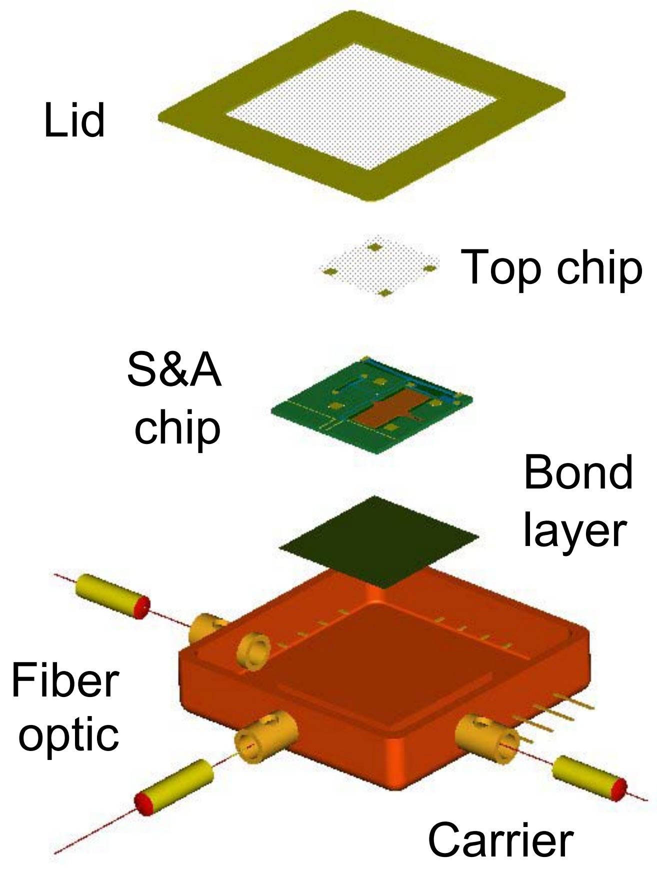
Assembled Microspectrometer



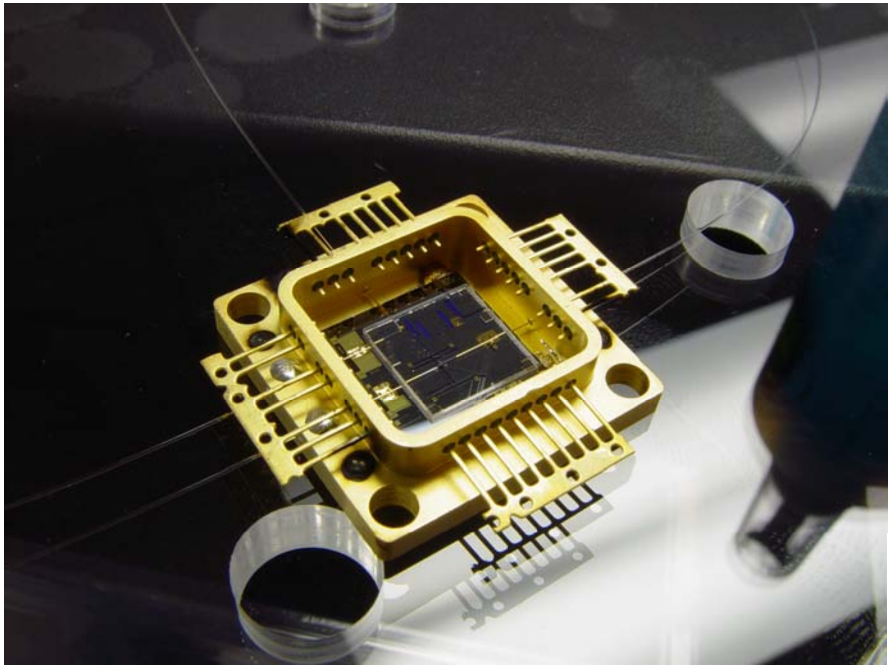


1 cm² die, 3x 500μm tall mirrors, 400 μm ball lens, 3 mm² beamsplitter, MEMS scanning mirror [Lee06]

Microassembly of Fuzing Device



Exploded View



With KAIST and Hanson Robotics Inc.

Low-Volume MEMS Packaging

- Packaging defined as assembly (manipulation) + process (bonding, sealing, etc.)
  - Multitude of commercially available and custom equipment. Generally, commercially available equipment is expensive, lacks versatility, modularity, reconfigurability.
- Create hardware & software to handle process and manipulation of microcomponents allowing:
  - Modularity and reconfigurability in hardware and software.
  - Provide a number of standard process capabilities.

Small Scale Robotics

Design principles for system architecture

- Coarse-fine positioning for multiscale manipulation.
  - Range of fine motion > resolution of coarse motion.
  - Bandwidth of fine motion > resonance of coarse motion.
- Assembly tolerance and precision achieved through fixtures, calibration and servoing.

Small Scale Robotics (continued)

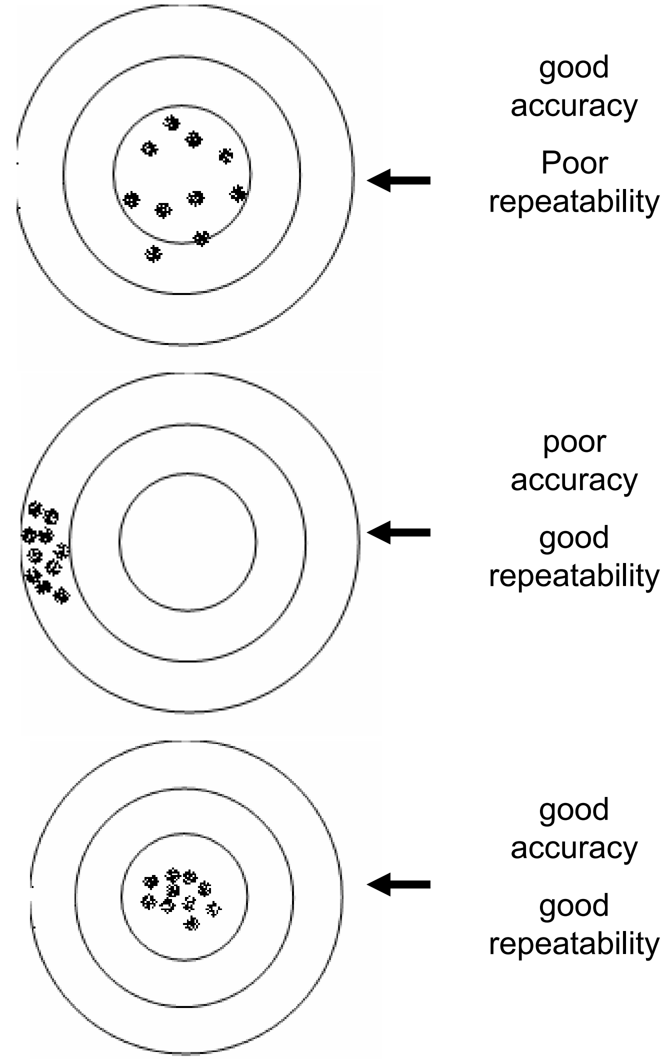
- Use grippers, fixtures or force fields to constrain parts at all times.
- Compliance at micro/nano scale, stiffness at macro/meso scale.
- Close the loop between scales using direct measurements (position, force).
- Affect vibration and motion at lower scales by input shaping at the upper scales.

Precision Concepts

Resolution: smallest position increment that motion system can perform

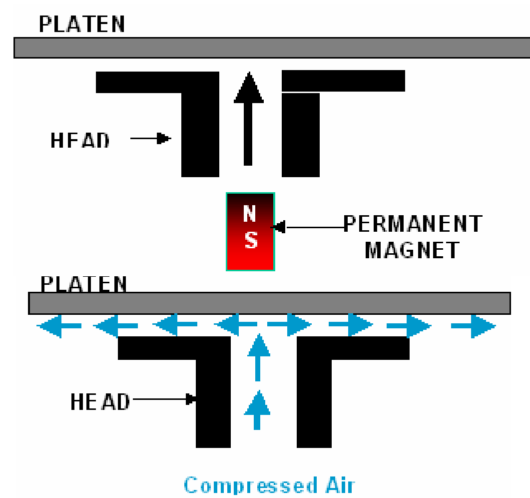
Repeatability: ability to achieve desired position over many attempts

Accuracy: maximum difference between te actual and desired position

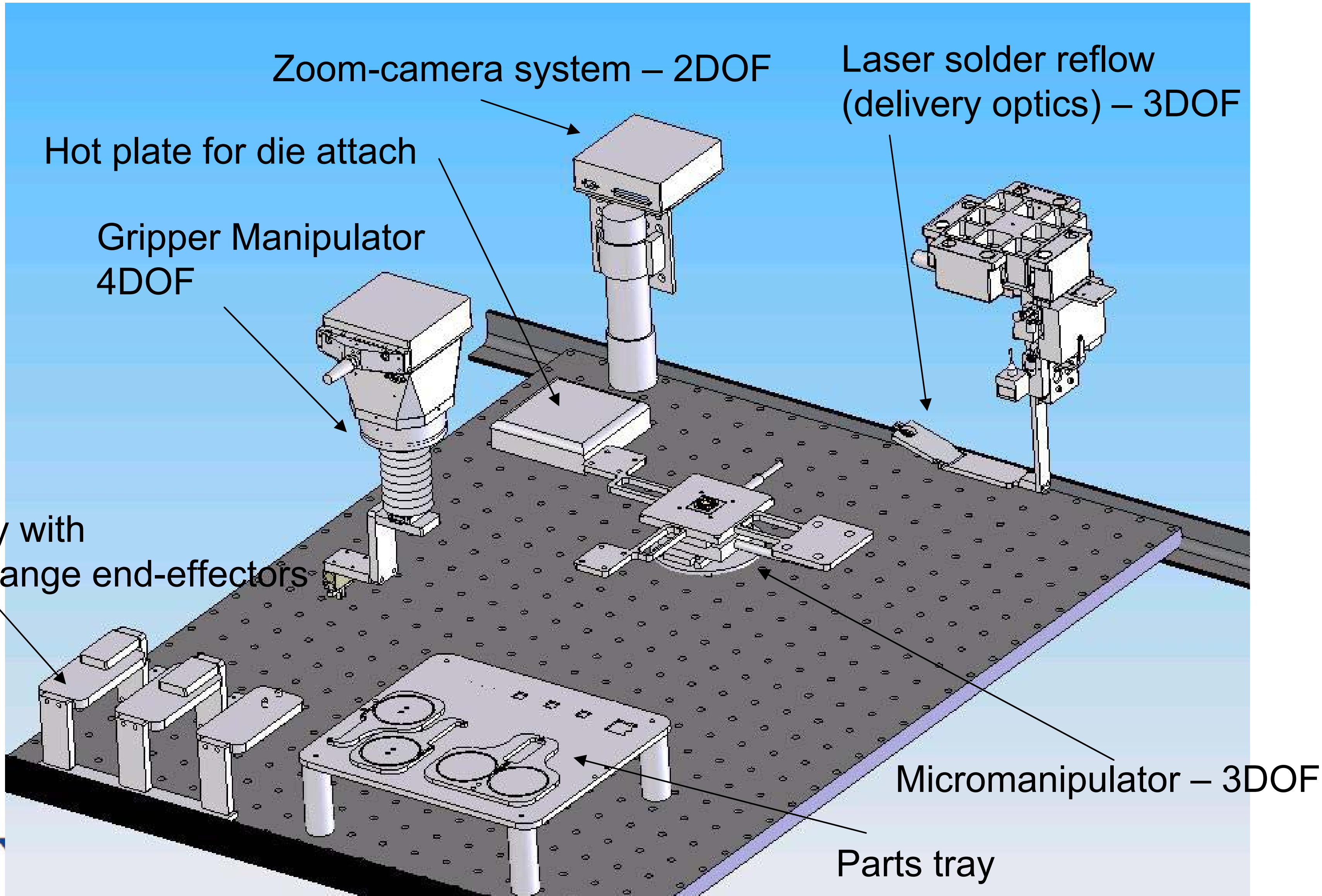


M³ Packaging System: Macro-Meso-Micro

- Multiple Robots within Motoman's Robotworld® Framework
- Platen usage: positioning surface for multiple end-effectors (pucks)
- Pucks: Linear motors riding on 15 μm air bearing



M³ System Diagram



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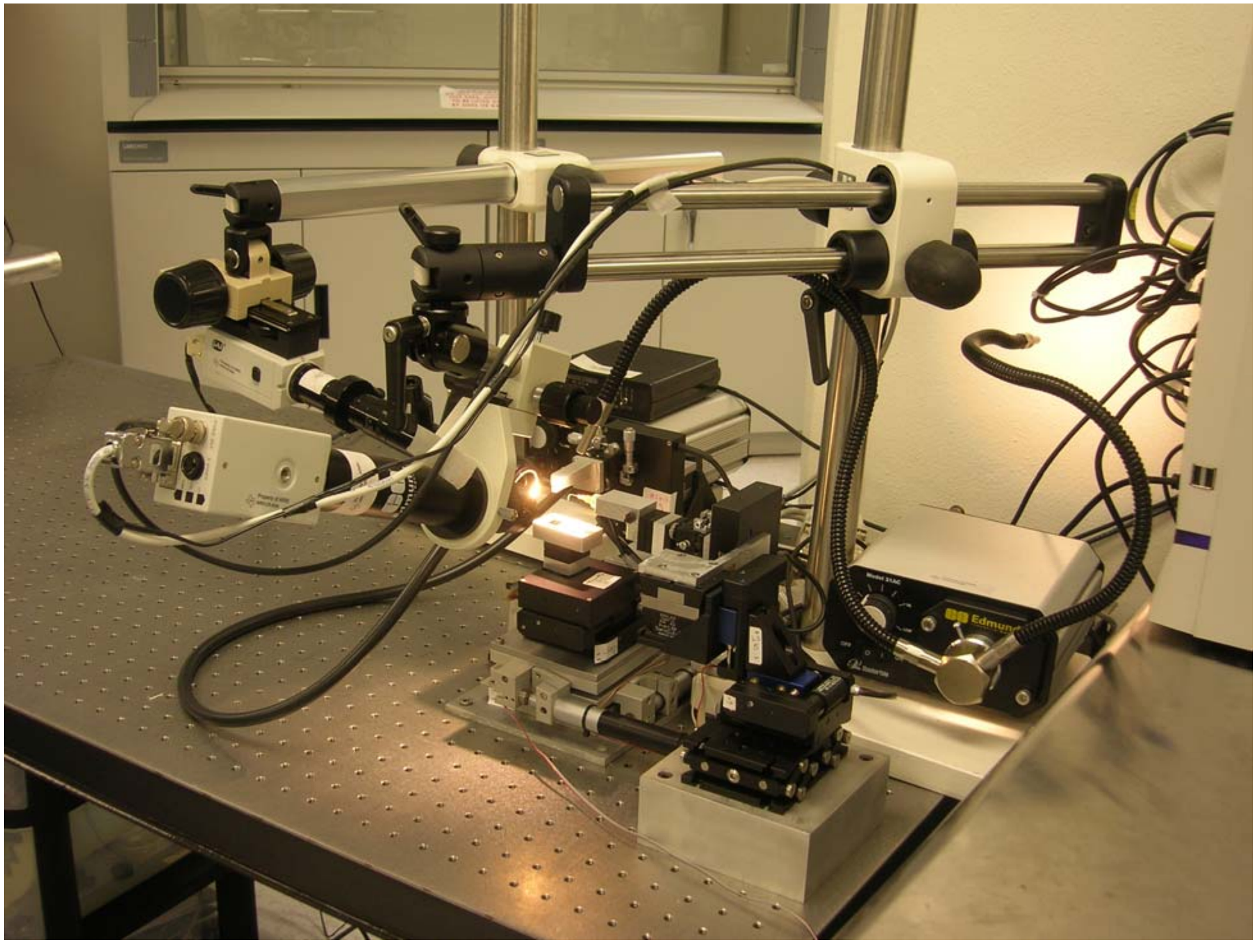
μ^3 Microassembly Station: Meso-Micro-Nano



Consolidate controls via Labview® Interface from single PC

- Gripper Mounting
- Rotation Centering
- Calibration
- Visual Servoing

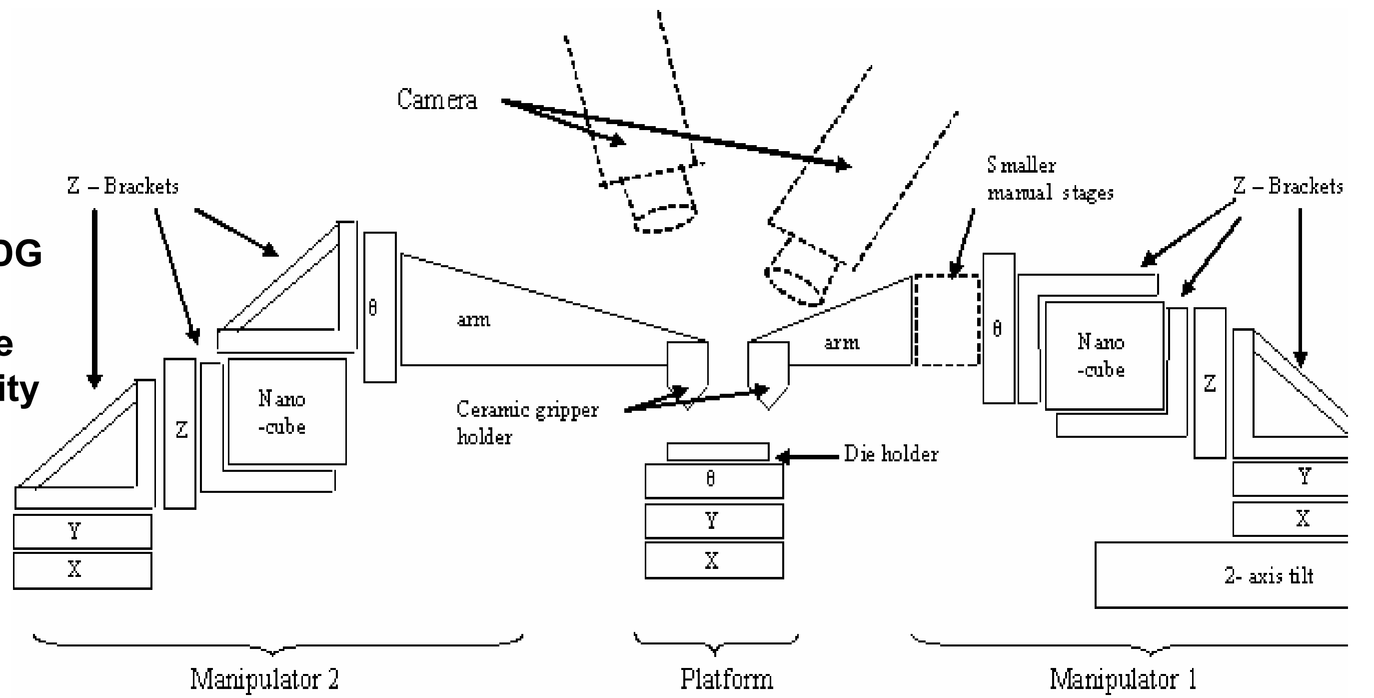
μ^3 System Diagram

2x PI Nanocube:
x,y,z - 100μm³ work volume
<10 nm repeatability

8x Pi – translation – M112.1DG
6.8 nm move resolution
2.5x2.5x2.5 cm³ work volume
2 μm bidirectional repeatability

3x PI – rotation – M116.DGH
0.00018 deg resolution
200 arcsec repeatability

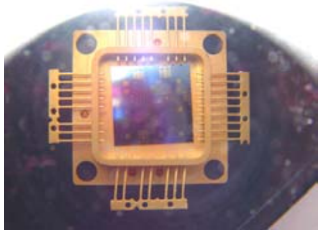
2x PI – tilt - M-044.D01



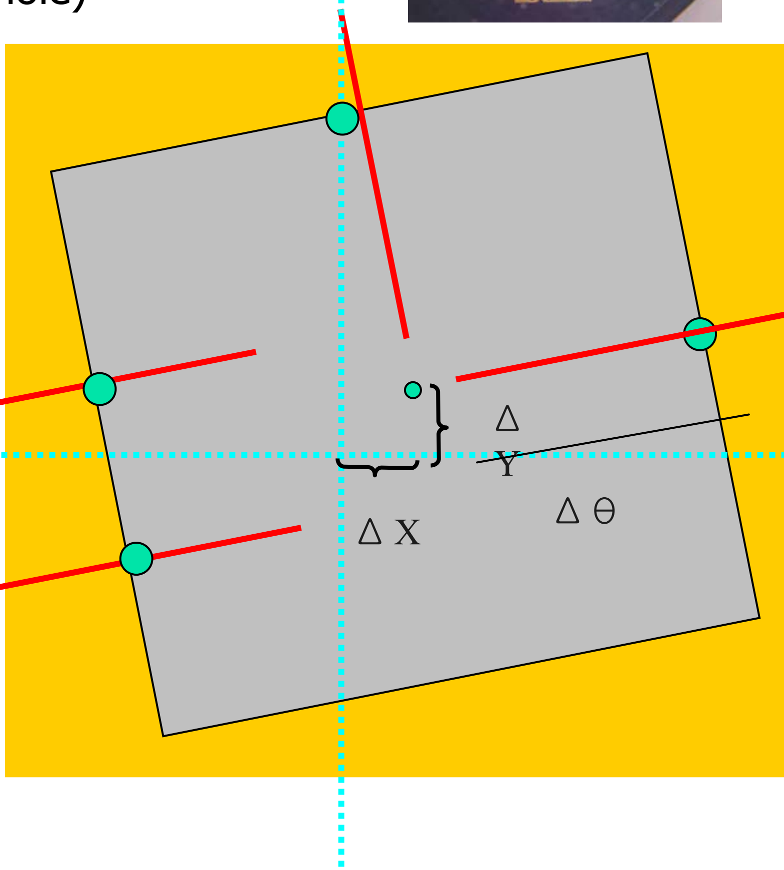
15 PI motorized DOF
Station + 4 manual DOF

S&A MEMS: Tolerance Budget

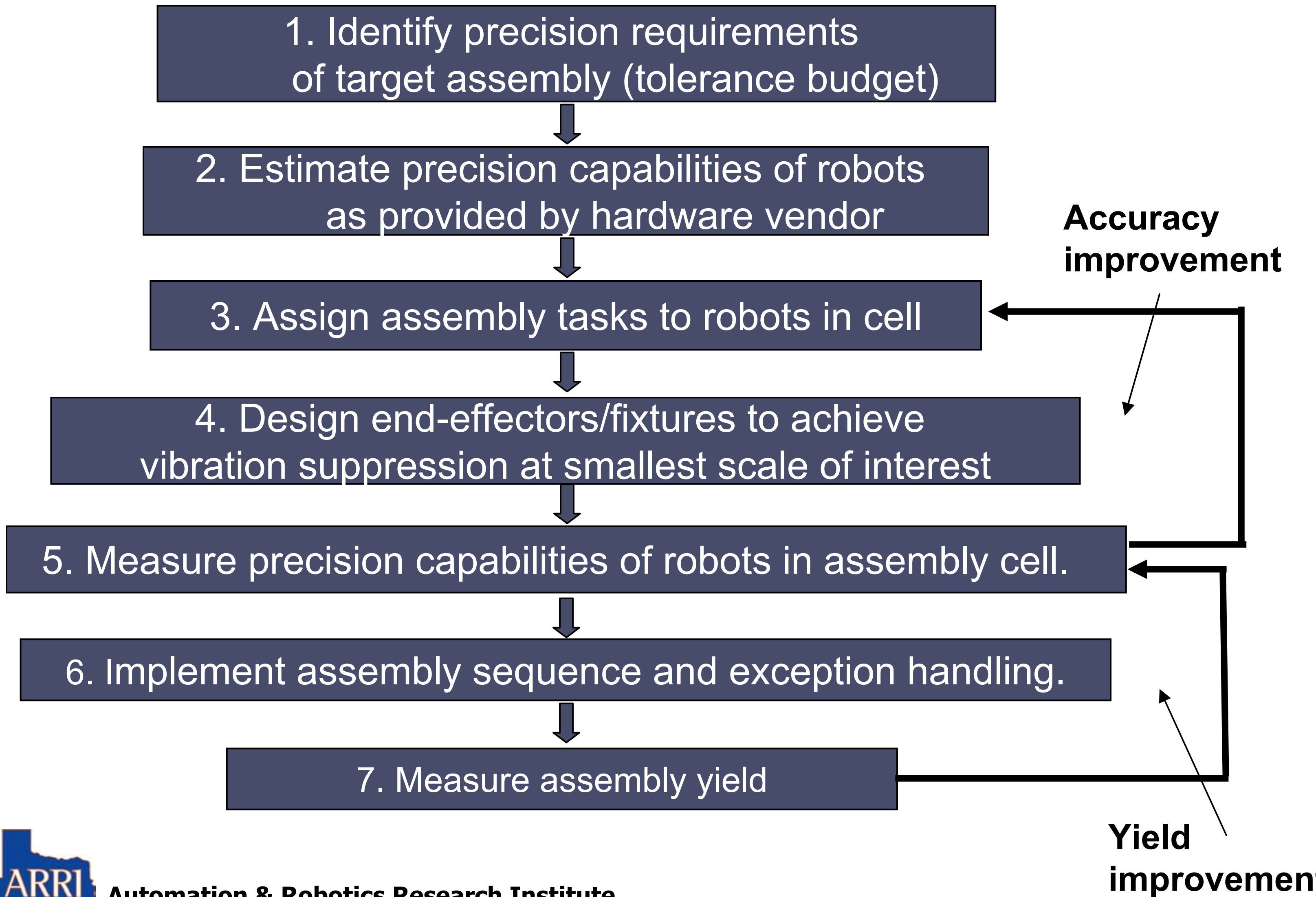
- Driving the precision requirements for this application:
  - Die to package: 50 μm @ 0.5 deg
  - Fiber to package: 300 μm @ 1.75 deg
  - Fiber to trench: 4 μm @ 0.2 deg (peg in hole)



	ΔX	ΔY	ΔZ	Δθ (YAW)	Δφ (PITCH)	ΔΨ (ROLL)
DIE TO PACKAGE	50	50	25	0.5	-	-
FIBER TO PACKAGE	300	300	186	1.73	1.73	-
FIBER TO TRENCH	4	4	25	0.2	-	-
TOP CHIP TO DIE	50	50	25	0.22		
INDIUM PREFORM	127	127	-	-	8	8



Designing Multiscale Assembly Cells



Multiscale System Design Rules Based on Accuracy/Repeatability/Resolution

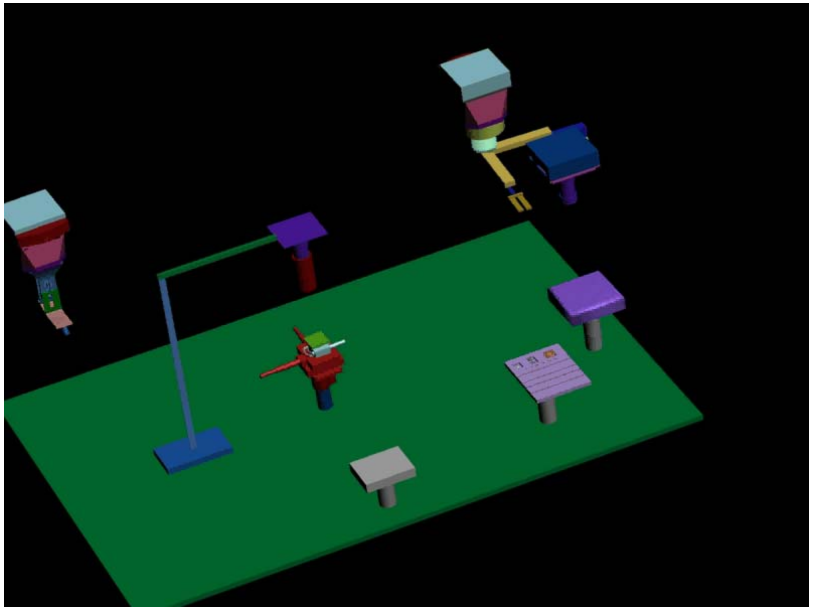
manipulator accuracy < tolerance required → use fixtures

manipulator repeatability < tolerance required → use calibration

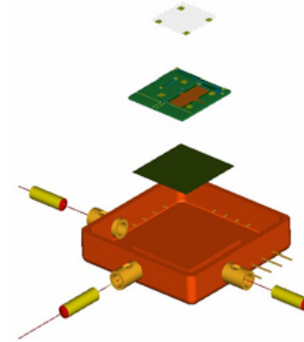
manipulator resolution < tolerance required → use visual servoing

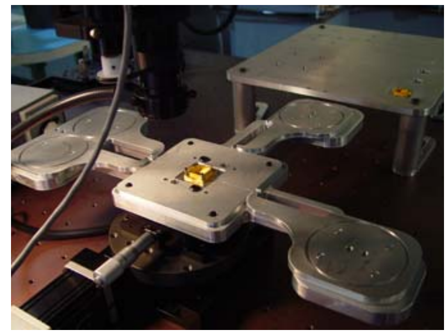
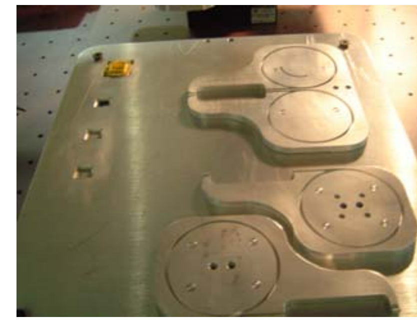
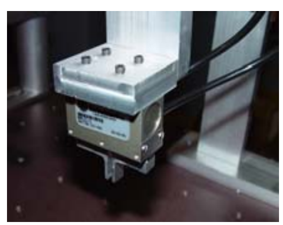
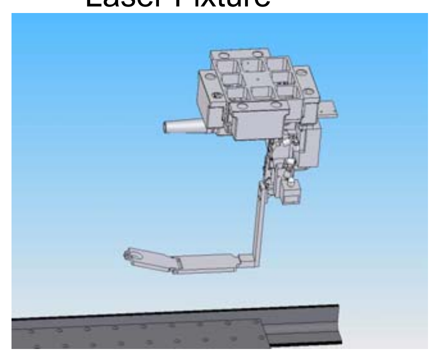
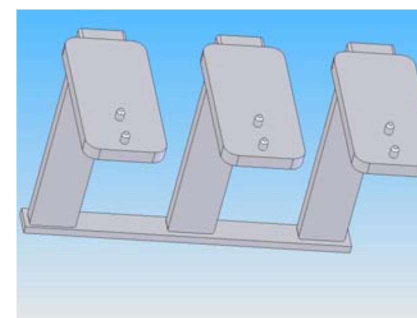
Robot Assignment

Manipulator or process	Tooling	Calibra-tion	Servo-ing	Fixture
COARSE I	Zoom camera	No	No	N/A
COARSE II	Most tools	Yes	No	N/A
FINE I	Laser	No	No	N/A
FINE II	Spool plate	Yes	Yes	N/A
Fiber – package insertion	N/A	No	No	Yes (pick & place)
Fiber-trench insertion	N/A	Yes	Yes	No
Die Pick/Place	N/A	Yes	No	Yes (pick)
Package Pick/Place	N/A	Yes	No	Yes (pick)
Preform-Package insertion	N/A	Yes	No	Yes (pick & place)

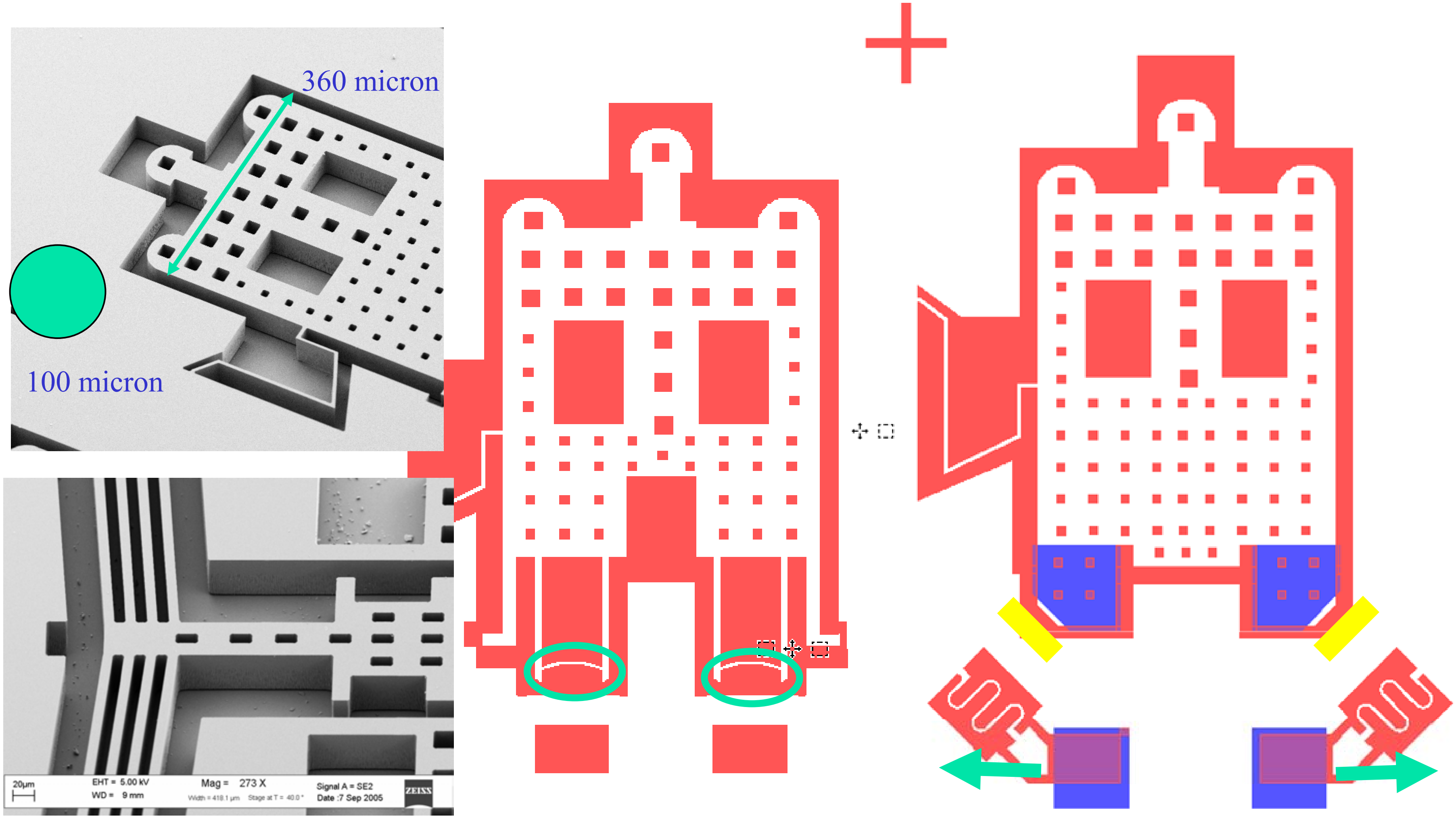


Tools and End-Effectors

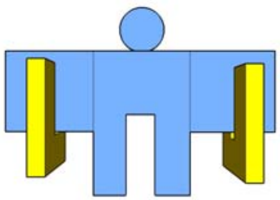


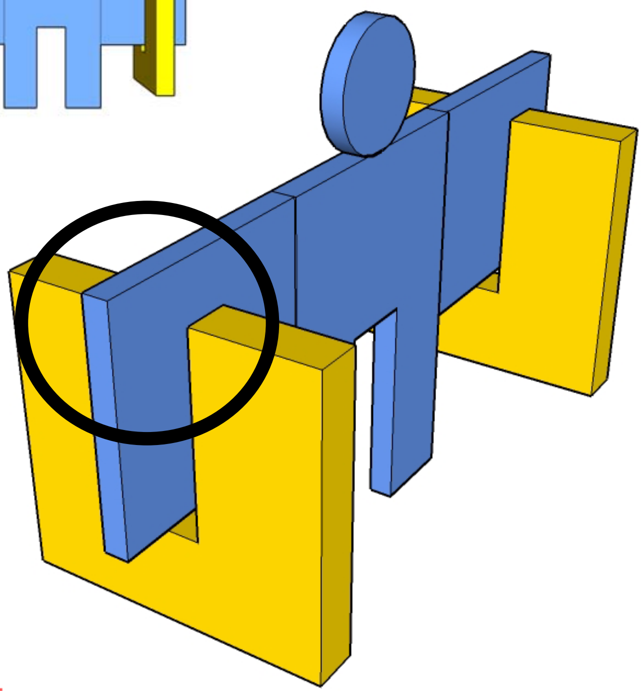
Vacuum Pick-up (die) 	Carrier Pick-up 	Fiber Insertion Platform 	Parts Tray 
Indium Pick-up 	Fiber Gripper 	Laser Fixture 	Tool Stand 

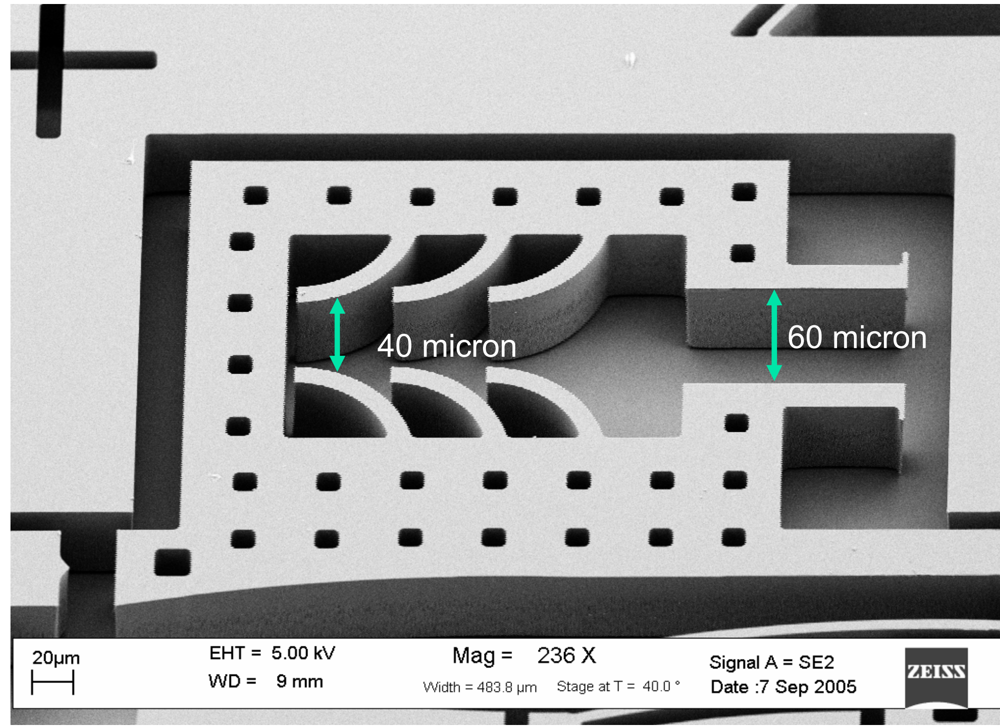
Snap fastener design

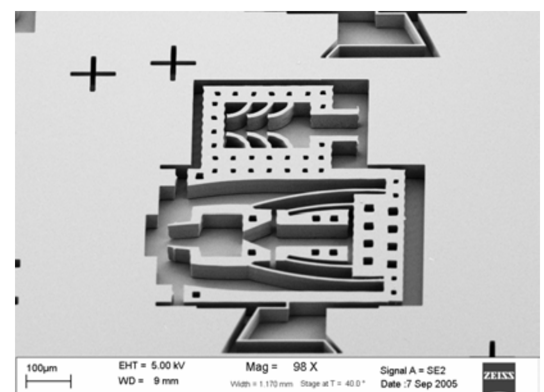


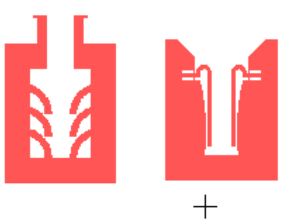
3D Microstructures











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Strategic Alliance

ARRI - - - - - - - - - → ***from concept to production*** - - - - - - - - - → ***BMC***

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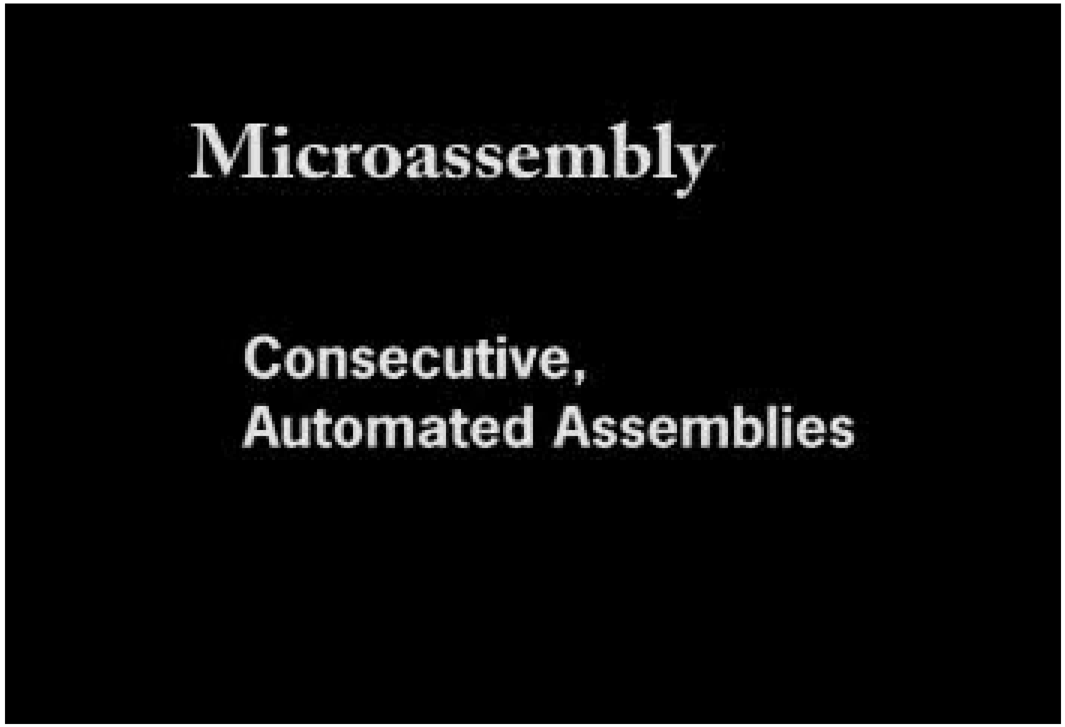
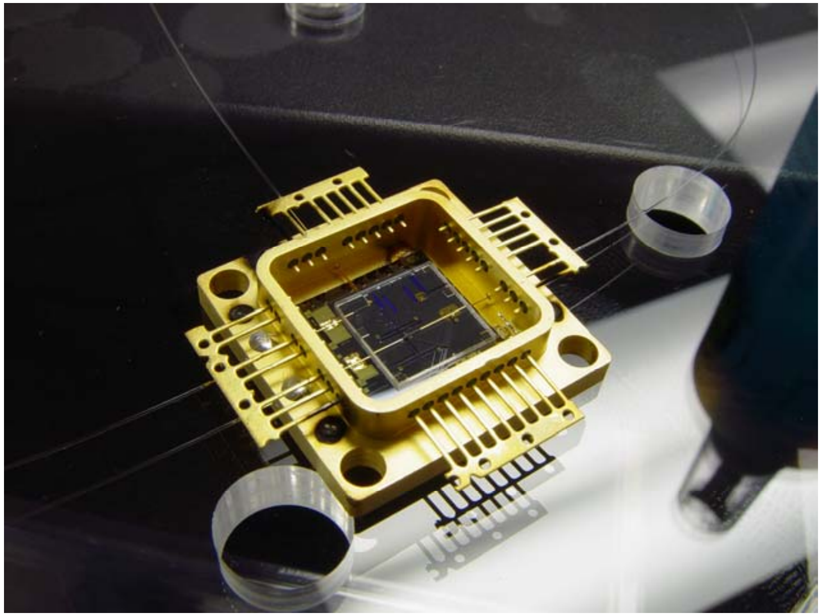
Serial Assembly Scripting



Assembly Yield: 90+% with well designed parts and appropriate tolerance and calibration precision

M^3 in Operation

Packaging Sequence



Assembled MOEMS

Assembly at small scales not more difficult than conventional assembly if we:

- Measure or predict how what we do at large scales affects the smaller scales (top-down).
- Follow a specific set of top-down design principles while designing manufacturing cell and parts.