Robotics for Semiconductor Manufacturing: Past, Present, Future

Presented at the
Asilomar Microcomputer Workshop
29 April 2010

by

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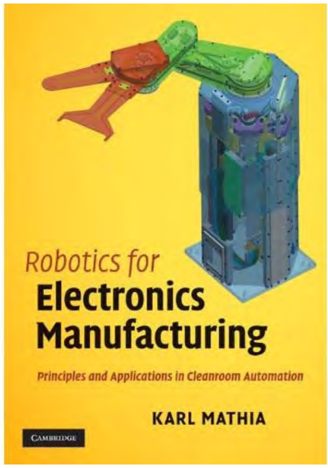

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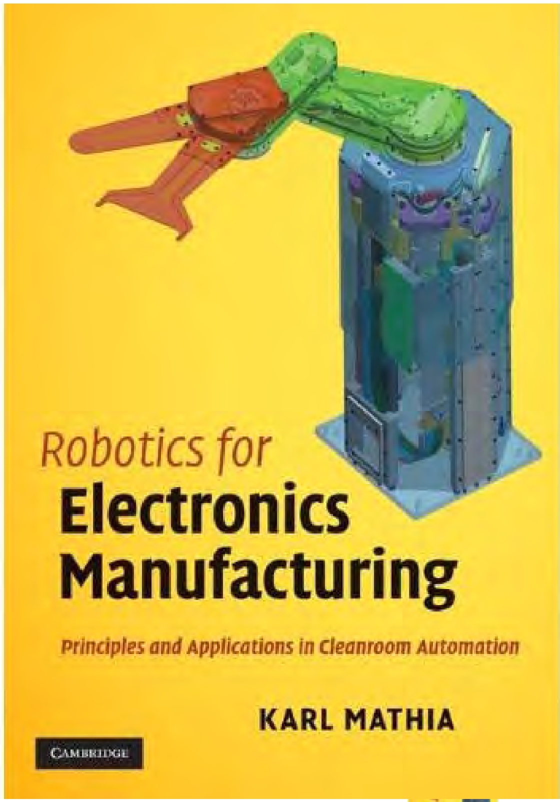
Book

With excerpts from my book

Robotics for Electronics Manufacturing – Principles and Applications in Cleanroom Automation

by Karl Mathia (2010).

Cambridge University Press



Agenda

- How clean are we?
- Trends in Industrial Robotics
- Semiconductor Automation: Past and Present
- Cleanroom Robotics
    - Design of Atmospheric Robots
    - Design Vacuum Robots
- Robot Quality Control
- Trends and Possibilities

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How clean are we?

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- We are not clean enough for modern semiconductor manufacturing
- Human contamination at different levels of motion (*measured particles were 0.3 µm and larger).

Human Motion	**Heat emission (kW)**	**Moisture emission (gram/hour)**	**Particle emission* (particles/min)**	**Breathing requirements (m^3/hour)**
At Rest	0.12	90	100,000	0.50
Light Work	0.18	180	1,000,000	1.00
4.8 km/h	0.3	320	5,000,000	2.15
6.4 km/h	0.4	430	10,000,000	2.55

- Automation, incl. cleanroom robots, is critical.

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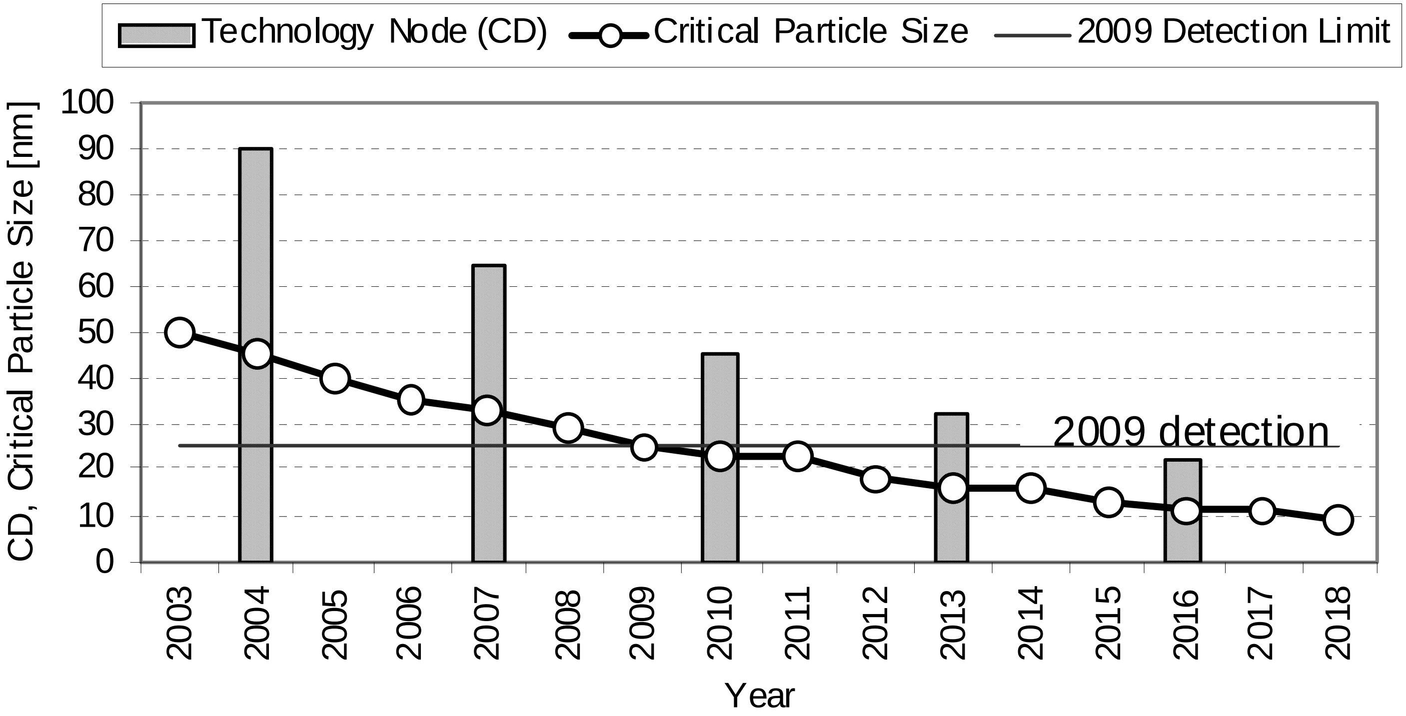
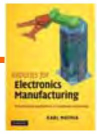
How clean are we?

- International Technology Roadmap for Semiconductors
- 2010: CD=45 nm, critical particle size=23 nm
- Class 1: contamination limit=100/m^3

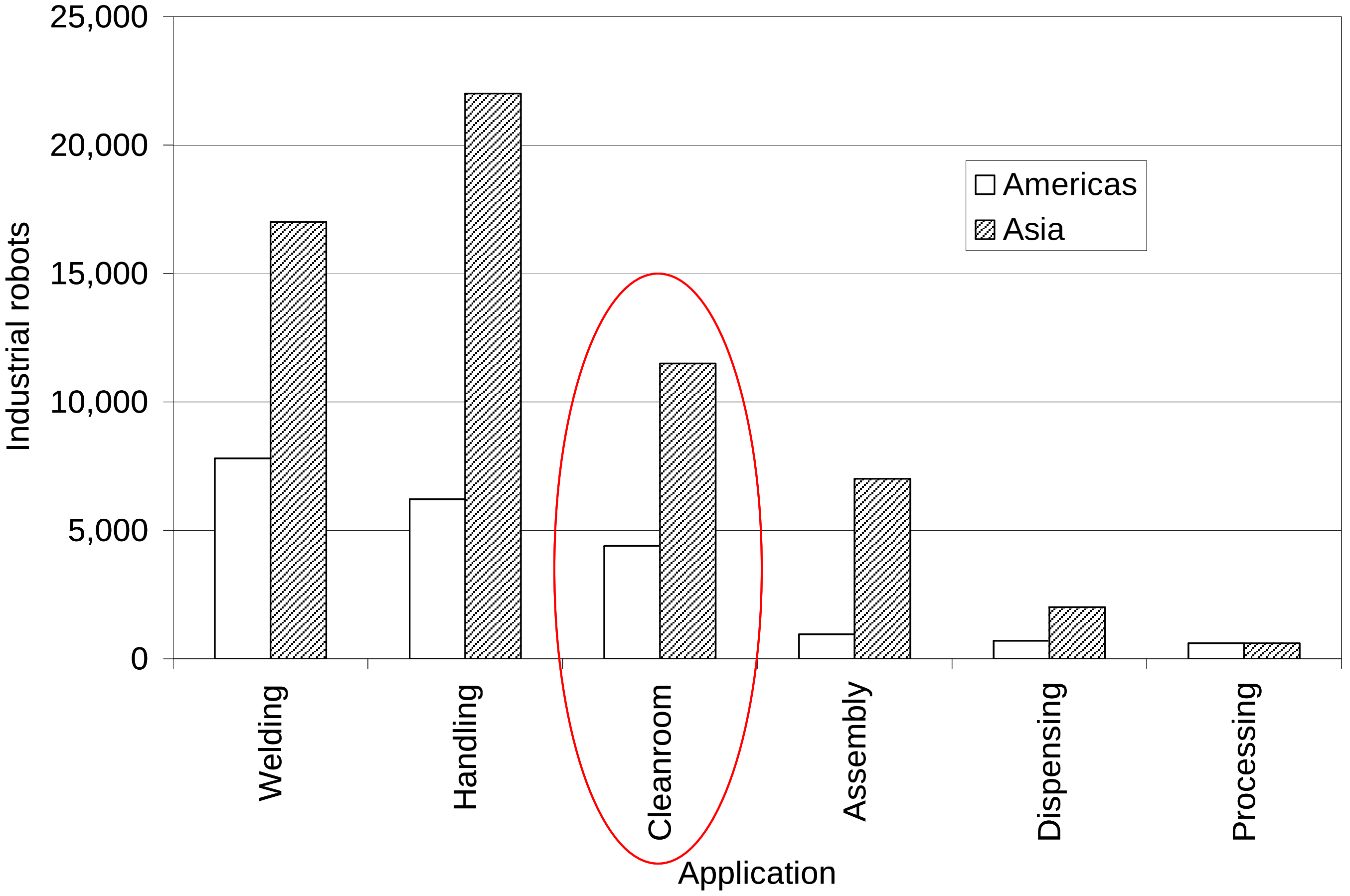




Trends in Industrial Robotics

Shipments of industrial robots by application

Source: World Robotics 2008 (IFR, 2008)



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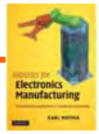

Trends in Industrial Robotics

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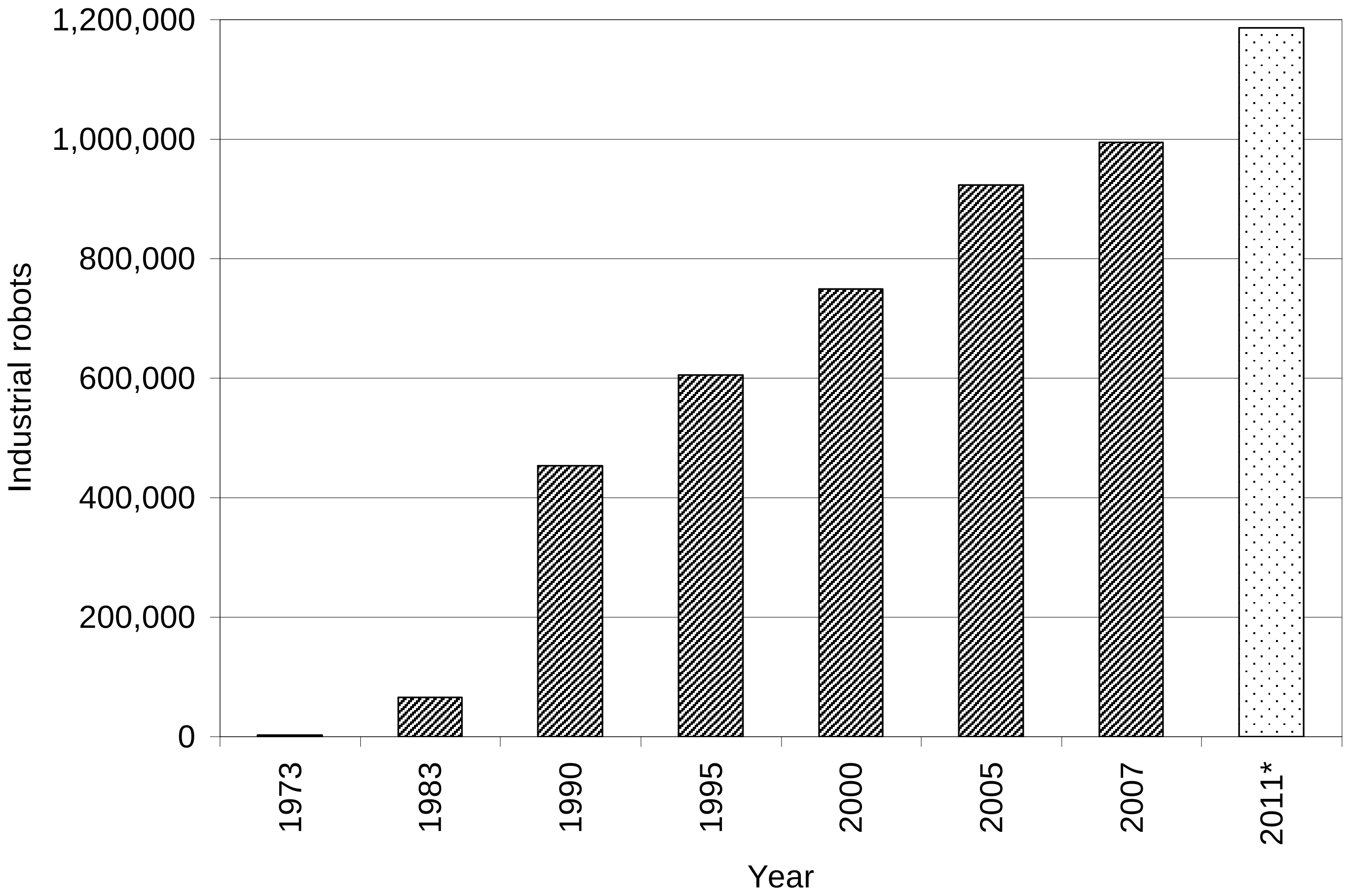
Operational stock of industrial robots (*estimate).

Source: World Robotics 2008, IFR, 2008



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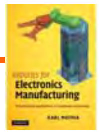
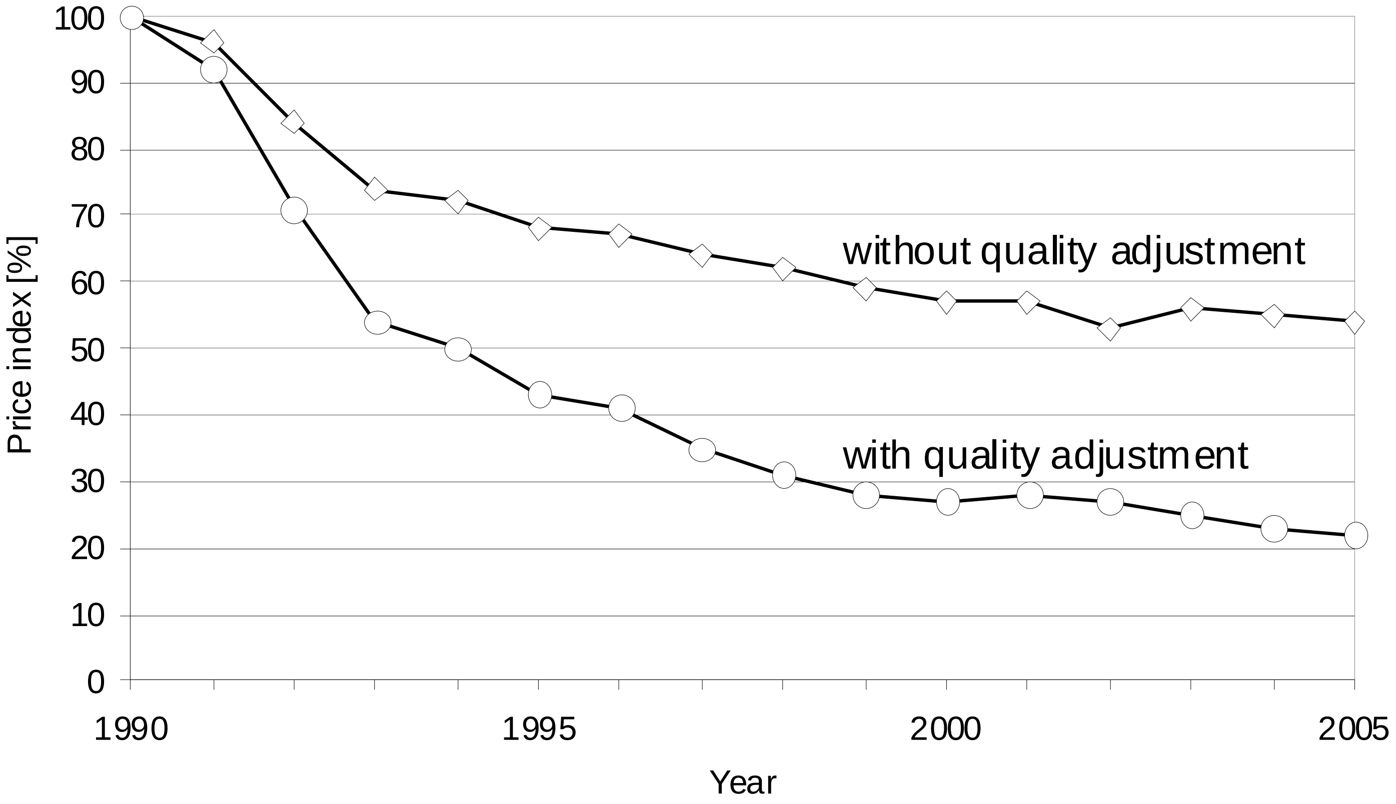


Trends in Industrial Robotics

Price index for industrial robots 1990-2005

Source: World Robotics 2005 (IFR, 2006)



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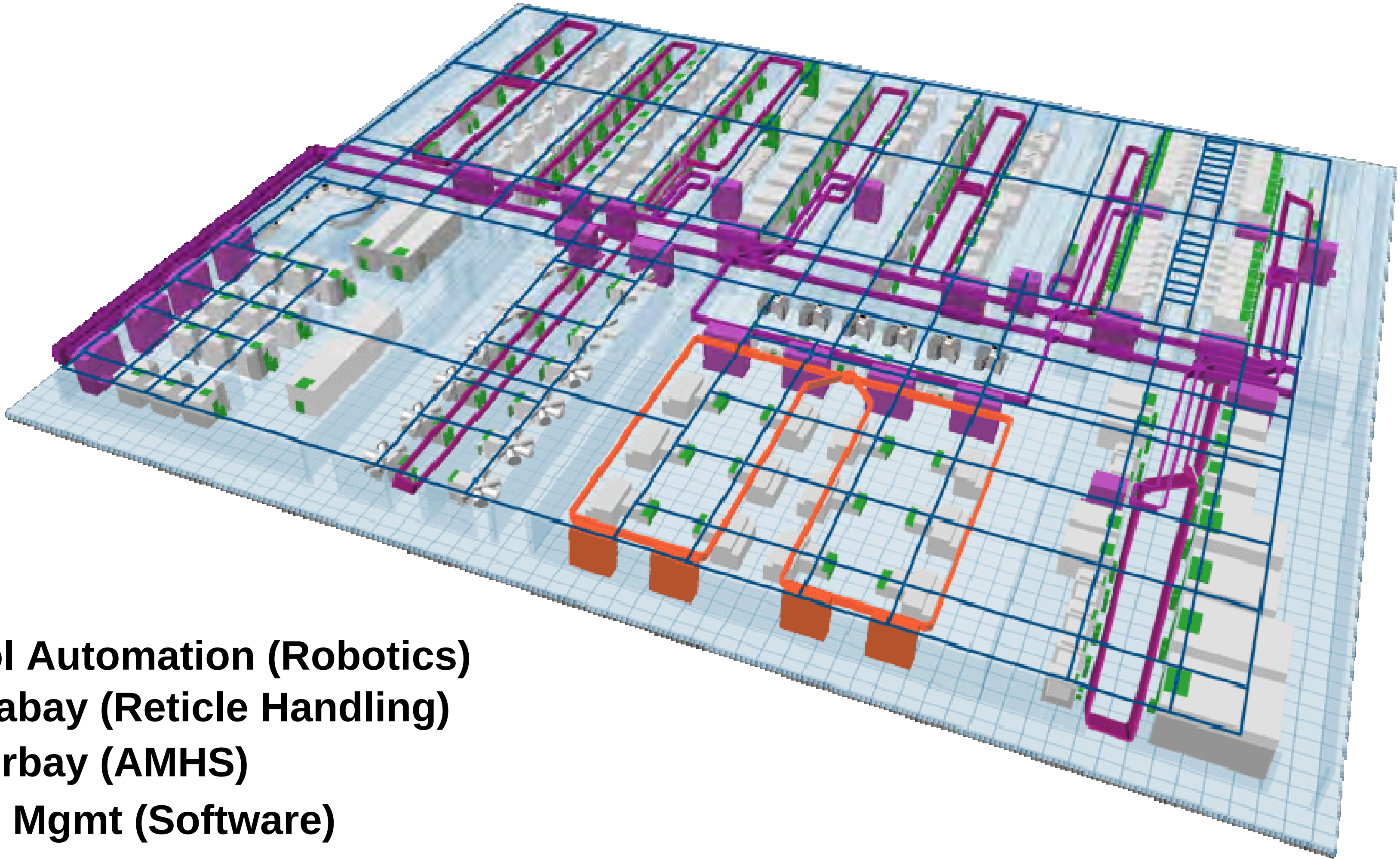
Semiconductor Automation



- 🟩 **Tool Automation (Robotics)**
- 🟧 **Intrabay (Reticle Handling)**
- 🟪 **Interbay (AMHS)**
- 🟦 **Fab Mgmt (Software)**
- 🟦 **Services (Operators)**

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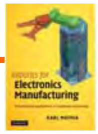
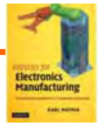


Atmospheric Robots

- Substrate handling at ambient atmospheric pressure in tools
- 3 to 5 axes of motion
- SCARA-type arm is the most common kinematics
- Handle a variety of substrates (150–300 mm wafer, reticles)



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Atmospheric Robots

Design for cleanliness and product safety:

- Clean materials
- Preventing electrostatic charges
- Clean drive trains
- Surface finishes
- End-effectors

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Atmospheric Robots

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Clean materials:

Minimize particle contamination from contact, friction, out-gassing

- Stainless steel: excellent, expensive
- Aluminum: cheap, popular
- Plastics: small parts, harsh environm.
- Ceramics: excellent, very expensive
- Composites: instead of metal, ceramics

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Atmospheric Robots

Clean materials: wear resistance comparison for selected materials

Material	**Wear rate** ($\mu m \cdot hour^{-1}$)	**Dynamic friction coeff.** ($m \cdot s^{-1}$)
Plastics (not reinforced)		
PEEK, pure	17.75	0.42
Composites:		
PEEK, carbon-fiber reinforced	2.16	0.29
PEEK, glass-fiber reinforced	2.36	0.26
Vespel CR-6100[1]	0.69	0.20
PFA, carbon-fiber reinforced	1.19	0.18

PEEK (polyetheretherketone): thermoplastic

Vespel® (polyimide): plastic

PFA (perfluoroalkoxy): plastic

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Atmospheric Robots

Preventing electrostatic discharges (ESD):

Risk is ESD-event between sensitive devices and a robot end-effector

- Product damage
- Robot malfunction or failure
- Electromagnetic interference, impact on sensors and communications

Prevention: grounding, conductive surface

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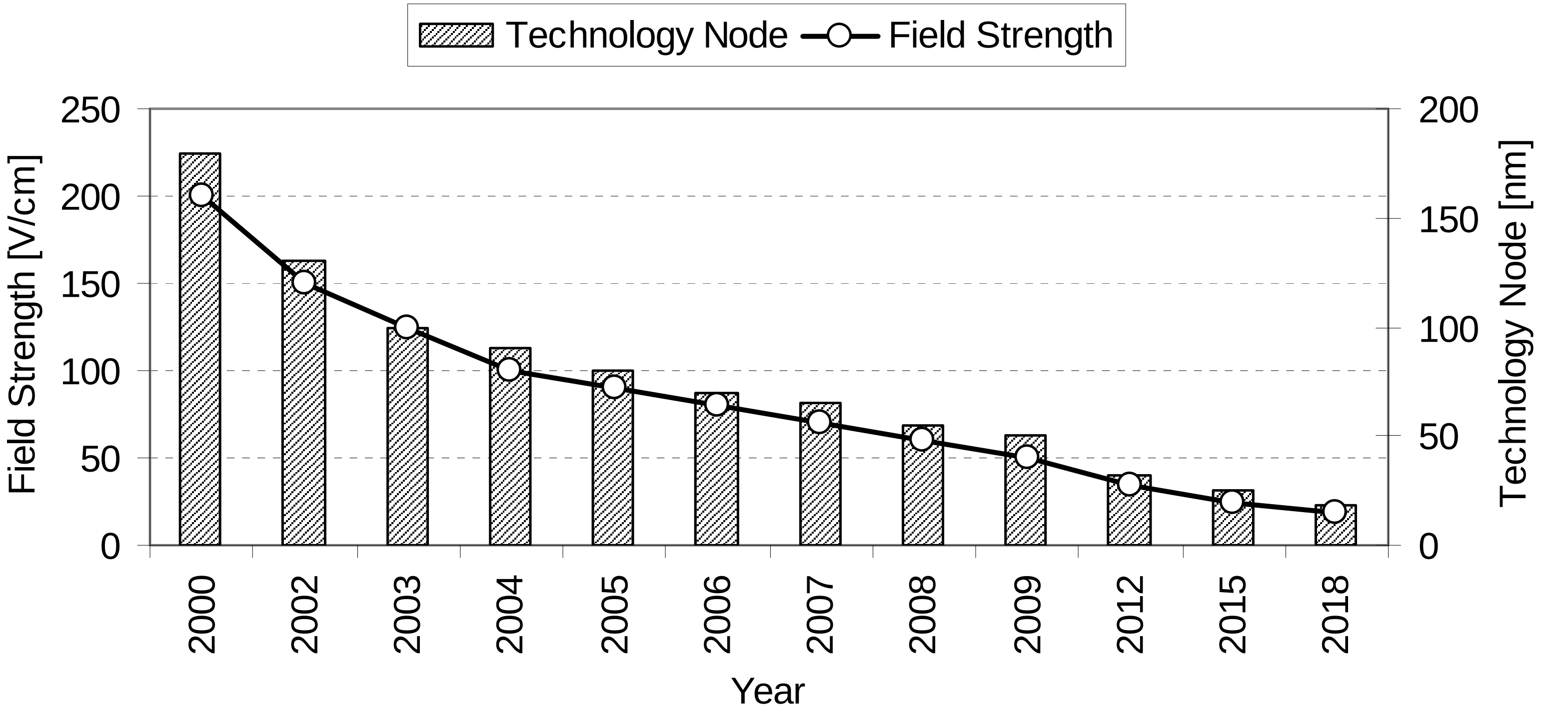
Atmospheric Robots

Electrostatic field limits per technology node (ITRS)



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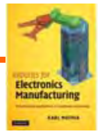
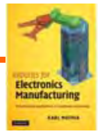


Atmospheric Robots

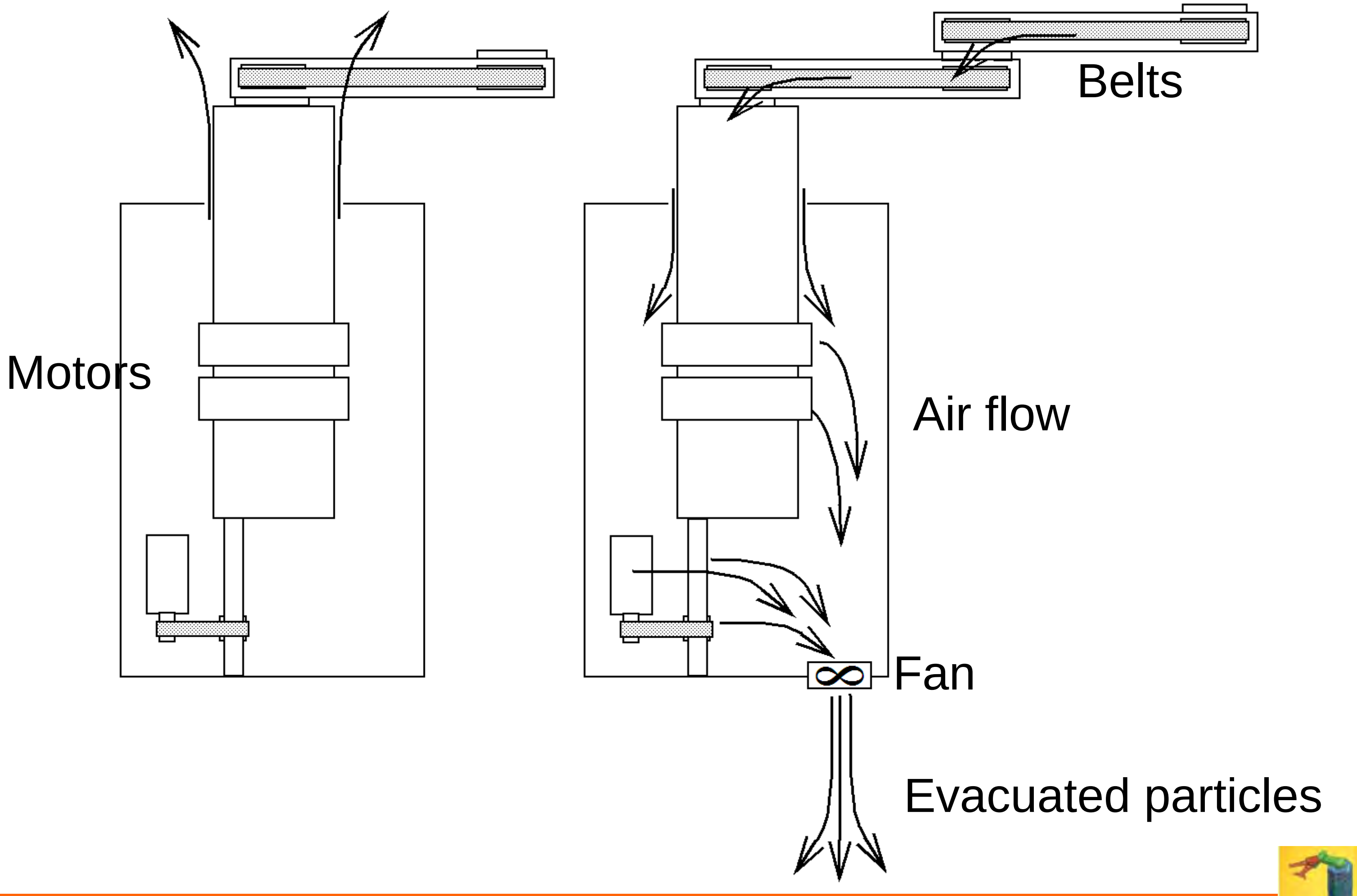
Clean drive trains:

- All parts below substrate/wafer
- Evacuate generate particles
- Minimize number of moving parts
- Motor selection (brushless or direct drives…)
- Careful selection of belts and pulleys
- Maintainability of drive train (access,…)



Atmospheric Robots

Evacuating airborne particles



Belts

Motors

Air flow

Fan

Evacuated particles

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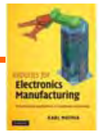
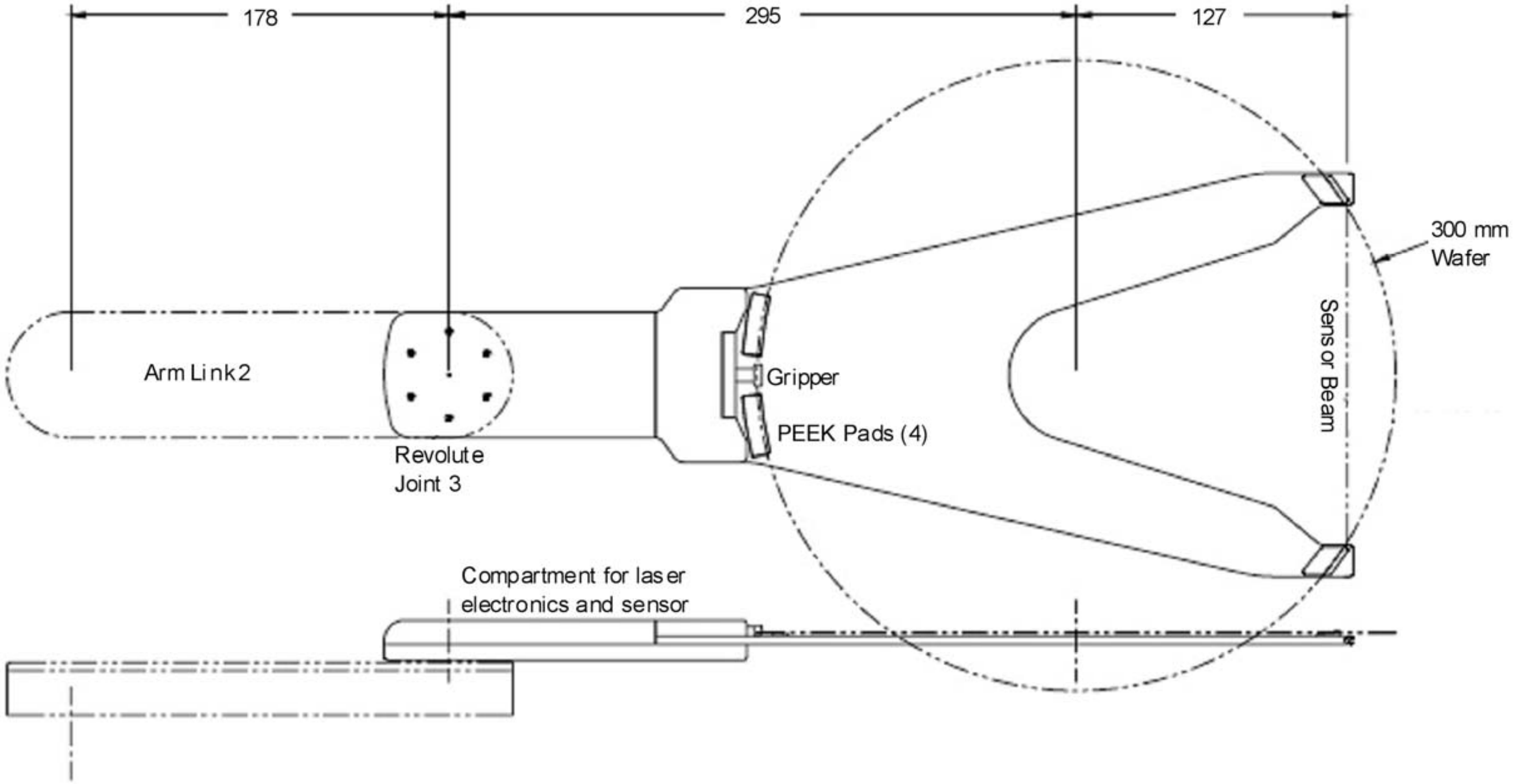


Atmospheric Robots

End-effectors: edge-gripper, minimal contact



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Vacuum Robots

- Substrate handling in vacuum
  - ≤10^{-8} Torr pressure
  - Dynamic vacuum barrier (seal) transfers motion into vacuum
  - Suitable materials (outgassing)
- Low profile:
  - Small chamber (pump-down time)
  - SEMI standard compatibility
- Suitable controls:
  - Prevent wafer slippage without vacuum gripping, smooth trajectories
  - Provide required wafer throughput

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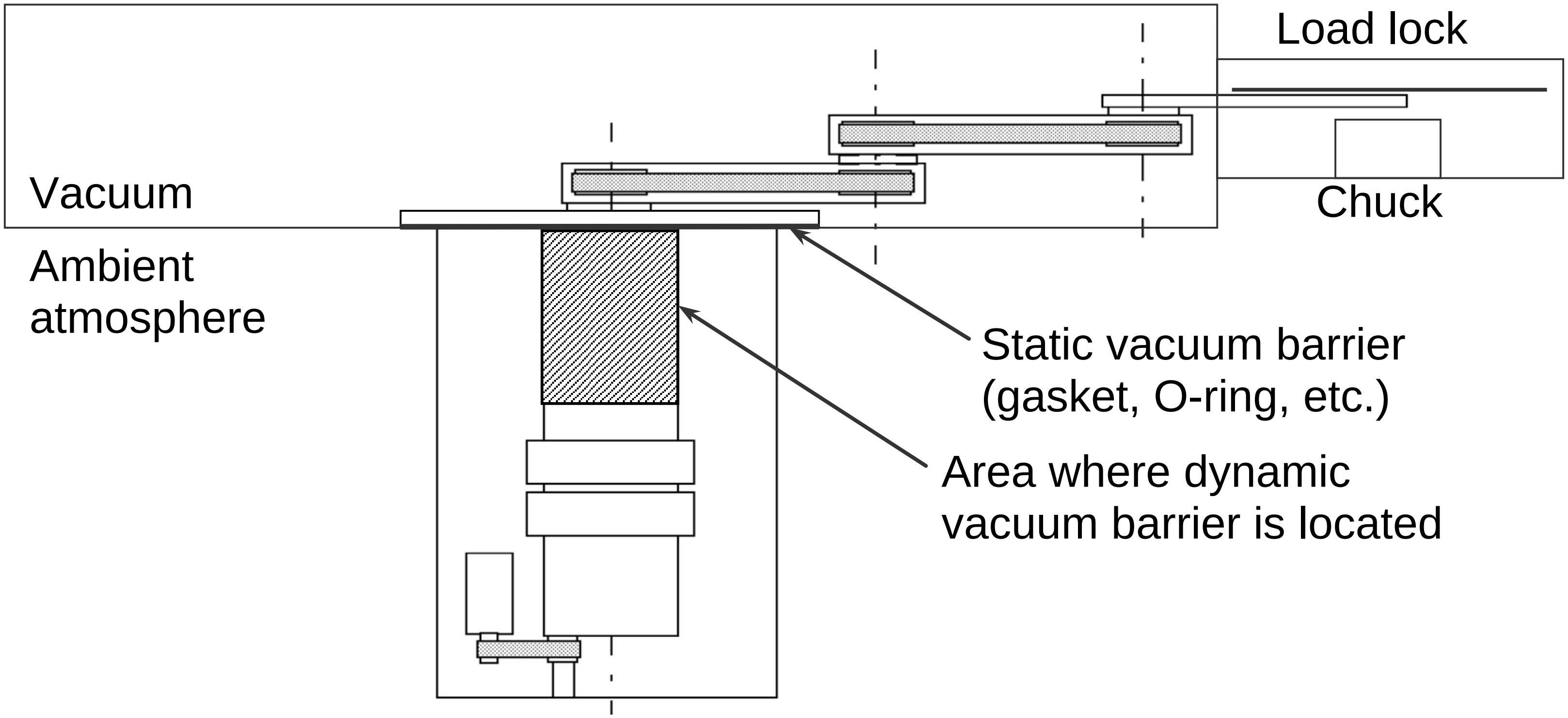
Vacuum Robots

Vacuum robot inside vacuum cluster tool



Vacuum chamber

Load lock

Vacuum

Chuck

Ambient
atmosphere

Static vacuum barrier
(gasket, O-ring, etc.)

Area where dynamic
vacuum barrier is located

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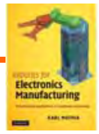

Vacuum Robots

Design for cleanliness and product safety

Vacuum integrity:

- Static vacuum barrier
- Dynamic vacuum barrier
  - Magnetic feedthrough
  - Metal bellow
  - Magnetic coupling
  - Motors with integrated vacuum barrier
  - Lip seal
  - Harmonic drive

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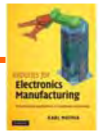

Vacuum Robots

Estimated vacuum level and market share of manufacturing processes

Process	Estimated Market share	Typical Vacuum Level
Etch	28%	medium
Chemical vapor deposition	30%	medium to low
Molecular beam epitaxy	3%	ultra-high
E-beam	11%	ultra-high to high
Sputtering		ultra-high
Physical vapor deposition		high
Atomic layer deposition	1%	medium
Ion implant	11%	High
Inspection and metrology	9%	High
Ashing	3%	high to low

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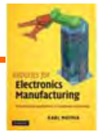
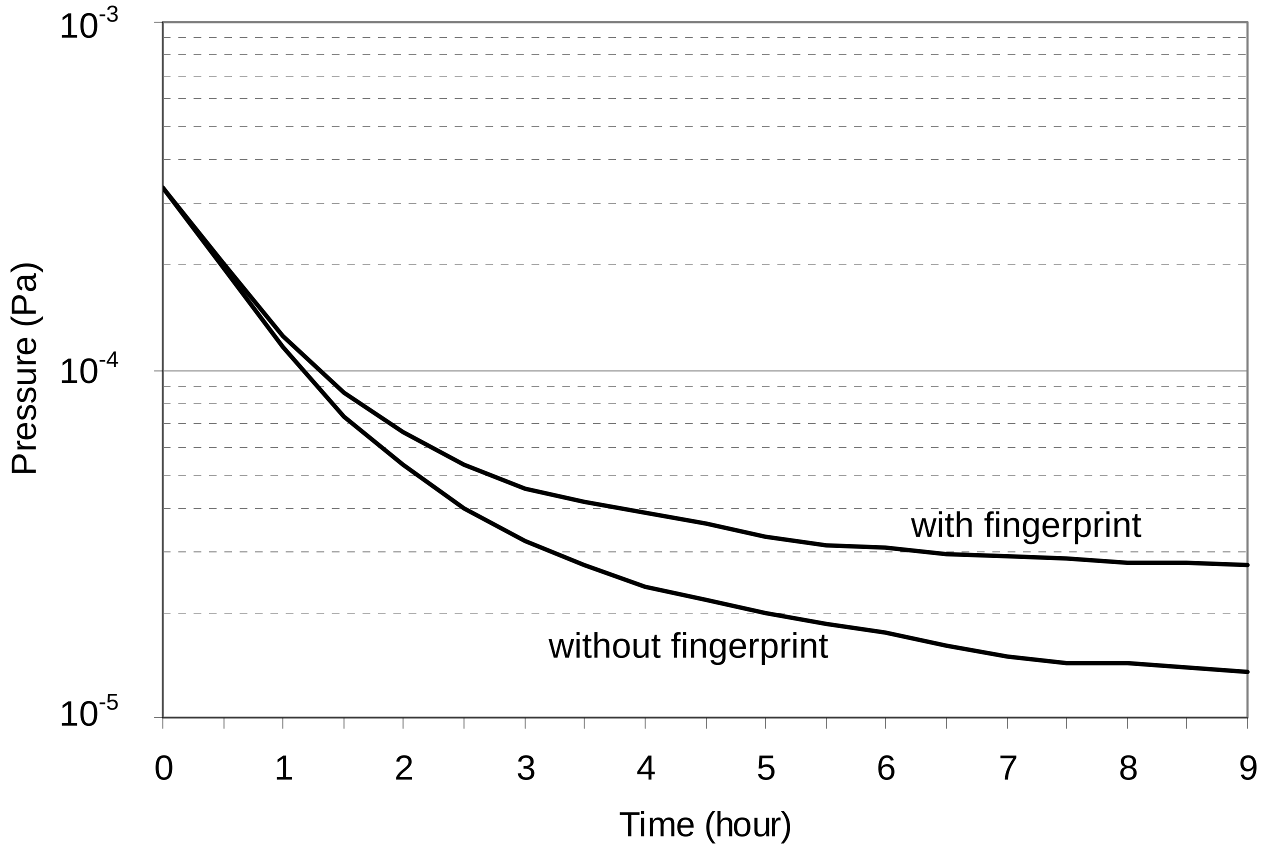
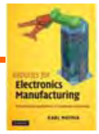


Vacuum Robots

Robot assembly and handling:

- Gloves, hairnets, gowns, shoe covers





Trends and Possibilities

<u>Future possibilities: 450 mm wafers</u>

- Will 450 mm happen? (So far Intel, TSMC, and Samsung support it.)
- Risk: who will pay for the wafer size transition? (300 mm is not paid for yet [SEMI])

Consequence for robotics: technical challenge is moderate. Scale up the robots and increase their reliability.

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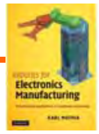
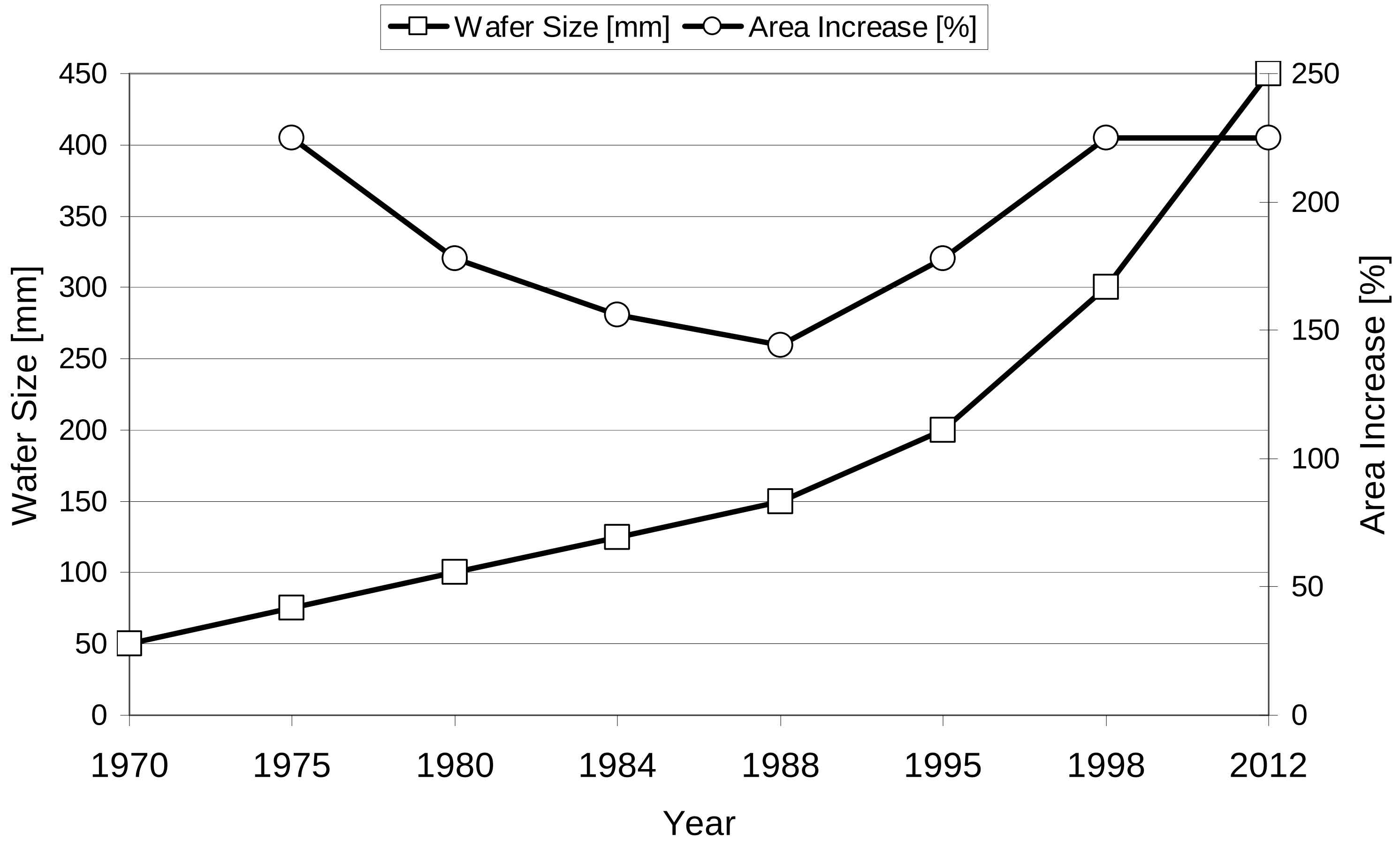
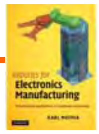


Trends and Possibilities

Wafer size transitions





Trends and Possibilities

Future possibilities: 3-dimensional devices

- Are 3D devices a possibility, with an increased number of metal layers and denser 300 mm circuitry?
- Risk: more process steps, increased processing time, therefore a higher risk of reduced yield.
- Cost per wafer would increase (cost per process step is assumed constant)

Consequence for robotics: same form factors, but higher speed, tighter cleanliness requirements

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Trends and Possibilities

Future possibilities: new materials

- Non-Silicon materials (GaAs,…) are fragile
- Small wafers (e.g. GaAs): LED mfg is typical, may become high-volume niche with larger substrates
- Glass substrates?
- Cross contamination (example: copper)

Consequence for robotics: same form factor, but increased reliability

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Trends and Possibilities

Conclusion: no significant hardware challenges

Instead, software challenges:

- Smart/intelligent features: algorithms, software
- Increase autonomy, reduce human labor
- Examples: plug’n’play system startup, automatic calibration, remote diagnostics, parameter monitoring and failure prediction, unscheduled (not scheduled) maintenance

Consequence for robotics: similar hardware, but smarter software

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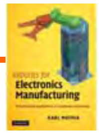

Q & A

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