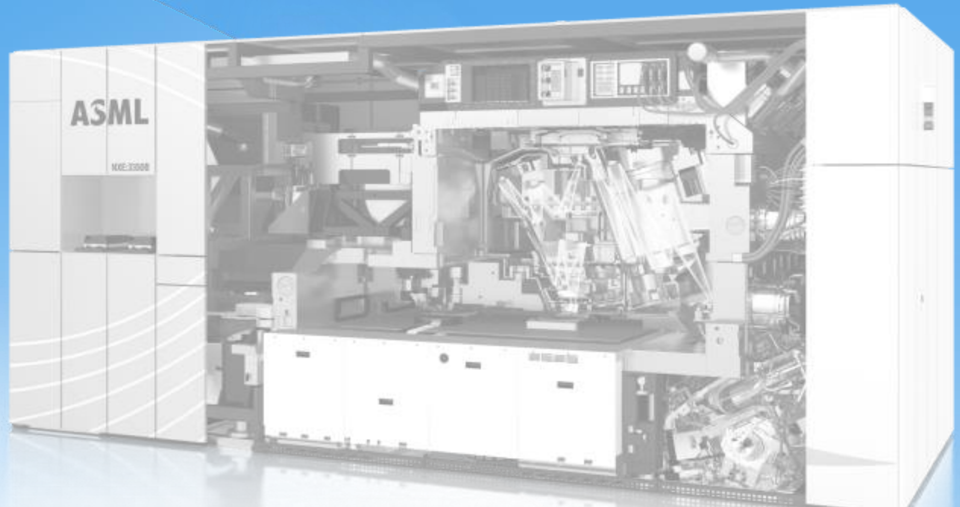


ASML

Developing machines with nanometer accuracy

How COMSOL is used as one of the enablers

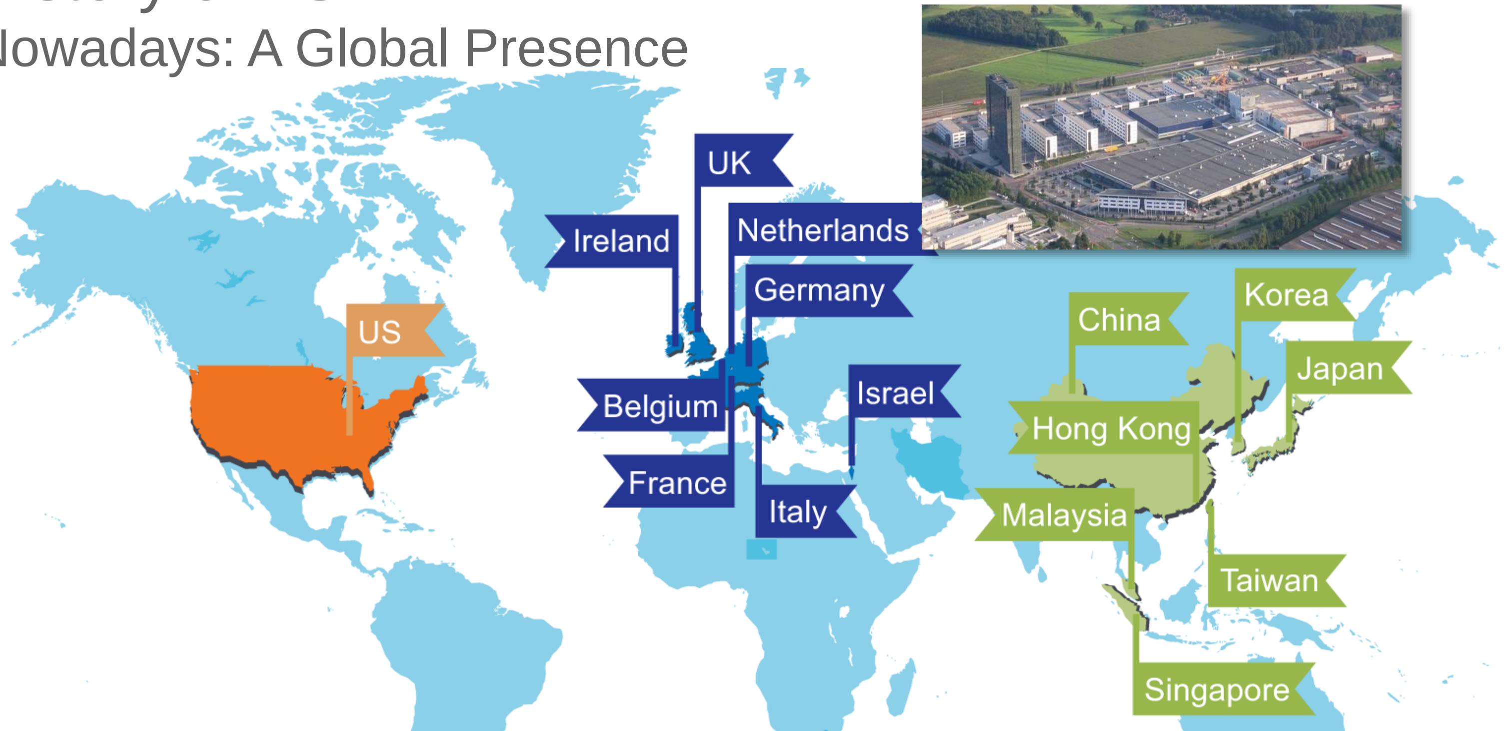
Fred Huizinga
Group Leader Mechanical Analysis
October 2016

History of ASML

Founded in 1984 as a spin-off from Philips

History of ASML

Nowadays: A Global Presence



3,400 employees **8,800 employees** **2,800 employees**

Source: ASML Q2 2016

Over 70 sales and service offices located worldwide

What do we do?

A market of 12 large ASML customers

Company	2015 semi capex (est., $M)
Samsung	13,000
TSMC Group	9,000
Intel	7,200
SK Hynix	4,700
Globalfoundries	4,000
Micron Technology	3,800
Toshiba (incl. SanDisk)	3,095
Sony	1,991
Inotera Memories	1,836
United Microelectronics Group	1,800
SMIC Group	1,500
Infineon Technologies	896

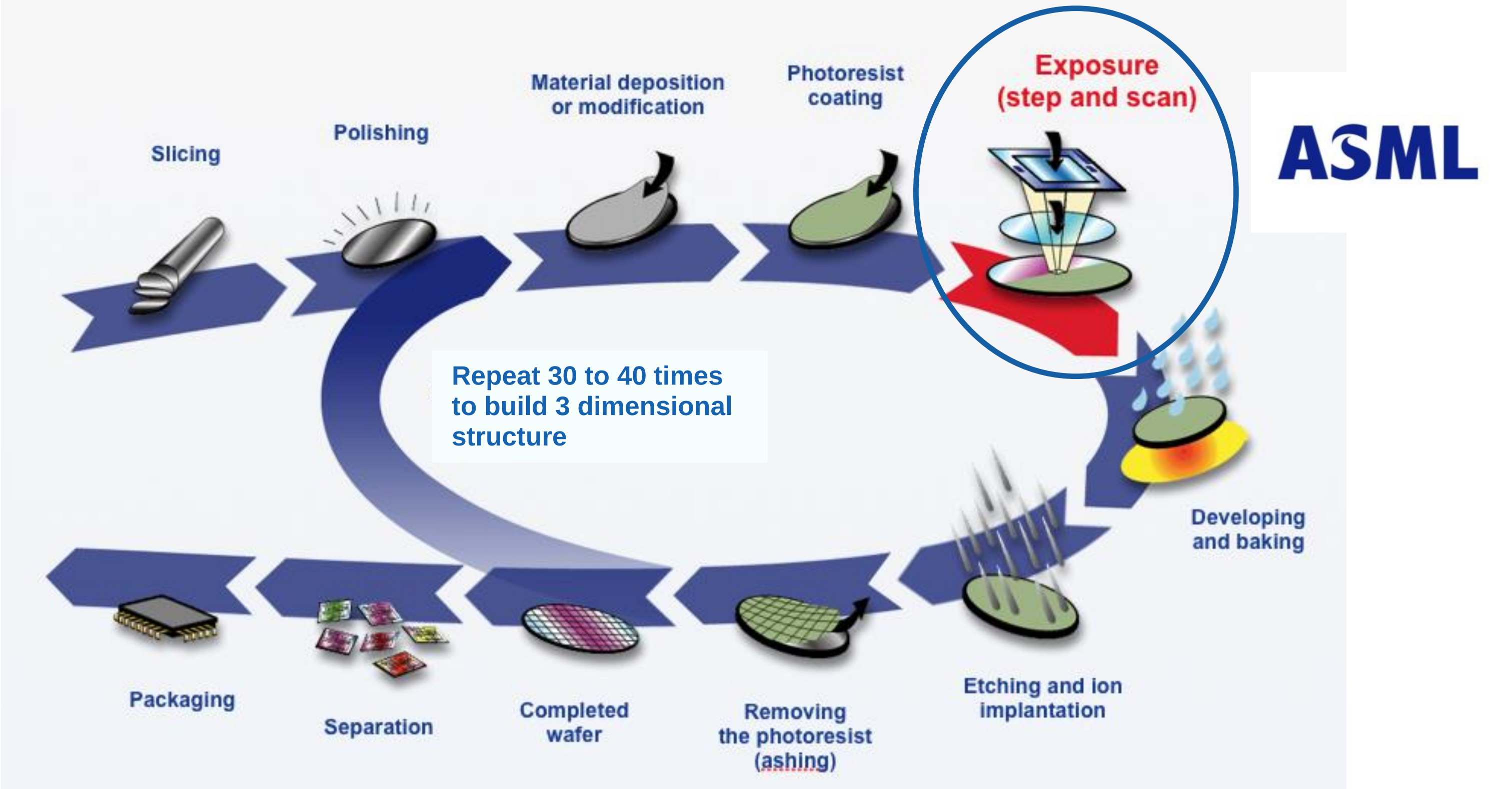
Guidance for next quarter (Q3)

- Q3 net sales approximately € 1.7 billion
- Gross margin around 47%

Full year 2016 sales

- Expected to exceed our 2015 record sales

The Microchip Manufacturing Process
All process steps



ASML

Public

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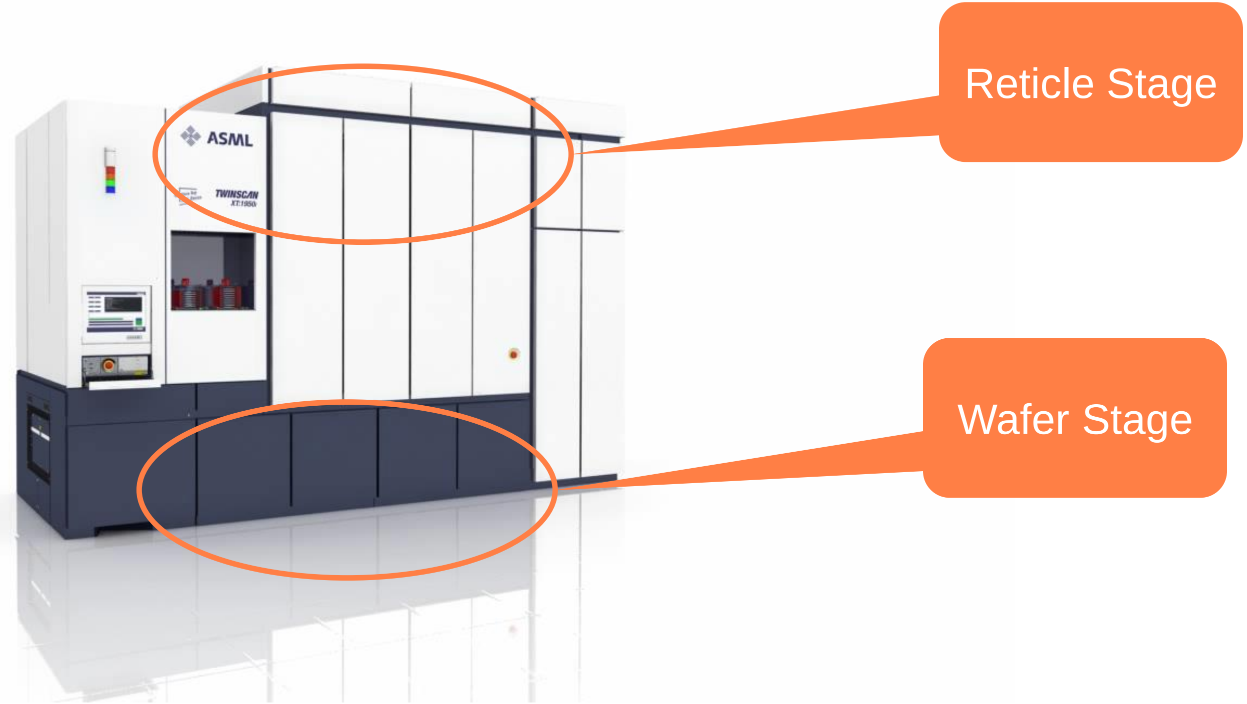
20 October 2016

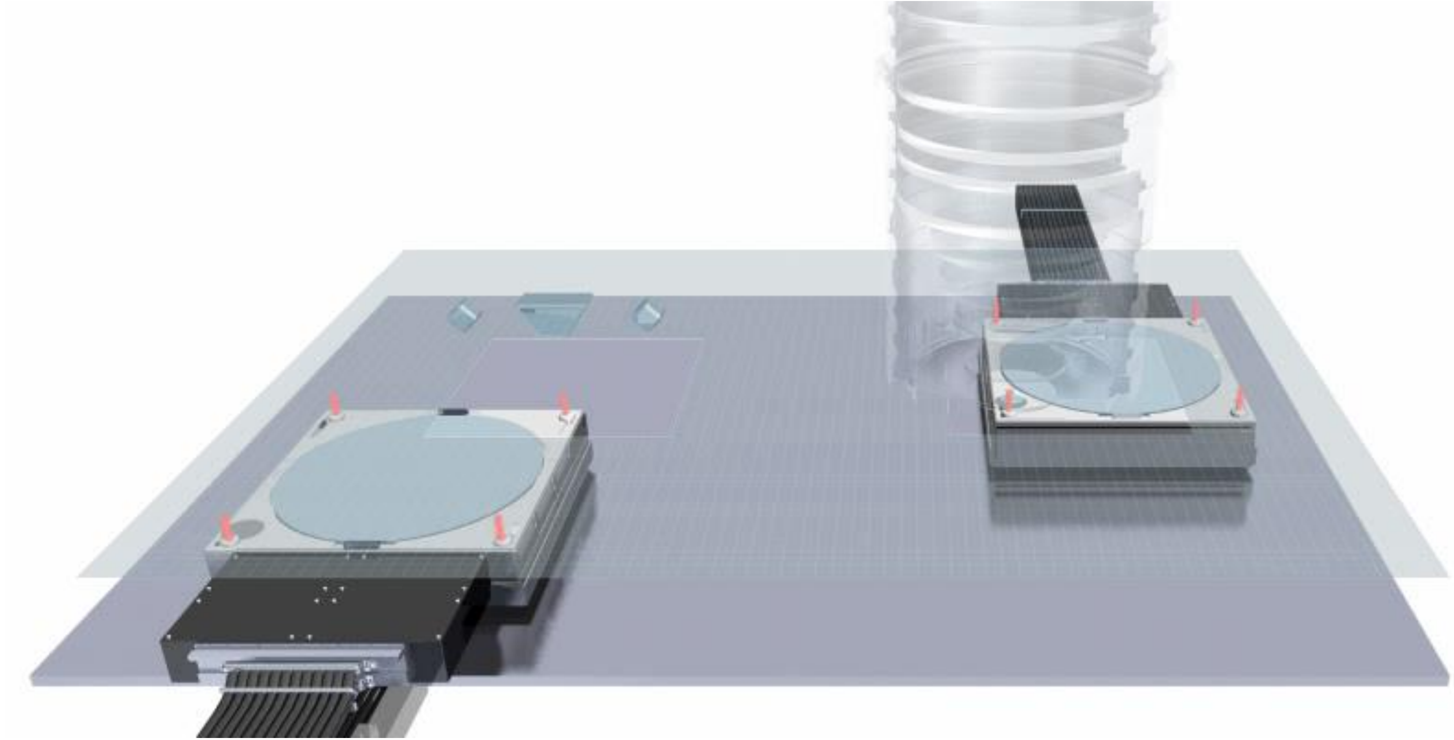
The Microchip Manufacturing Process
The machine in action



The Microchip Manufacturing Process
The machine in action

Public

Slide 7
20 October 2016



The challenge

Keeping up with “Moore’s Law”

G. Moore, ”Cramming more components onto integrated circuits”, Electronics, Vol. 38, No. 8 (**1965**)

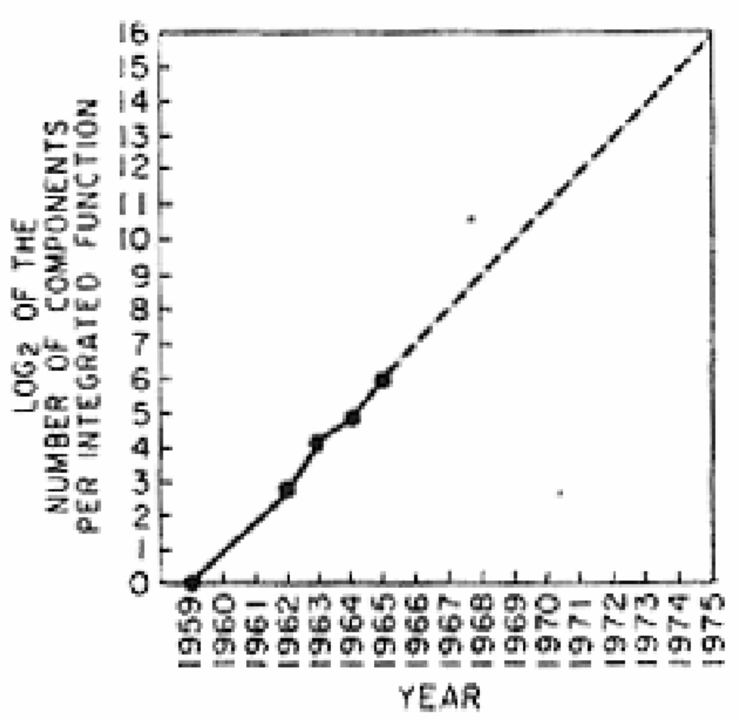
Andy ... ore

Who is Gordon Moore?:

- Born 3 January 1929, San Francisco, California, USA
- Got a BSc (1950) and PhD (1954) in chemistry
- Is one of the founders of both Fairchild Semiconductors (1957) and Intel (1968)
- His is now 87 years old and lives in Hawaii

What did Moore state in 1965?

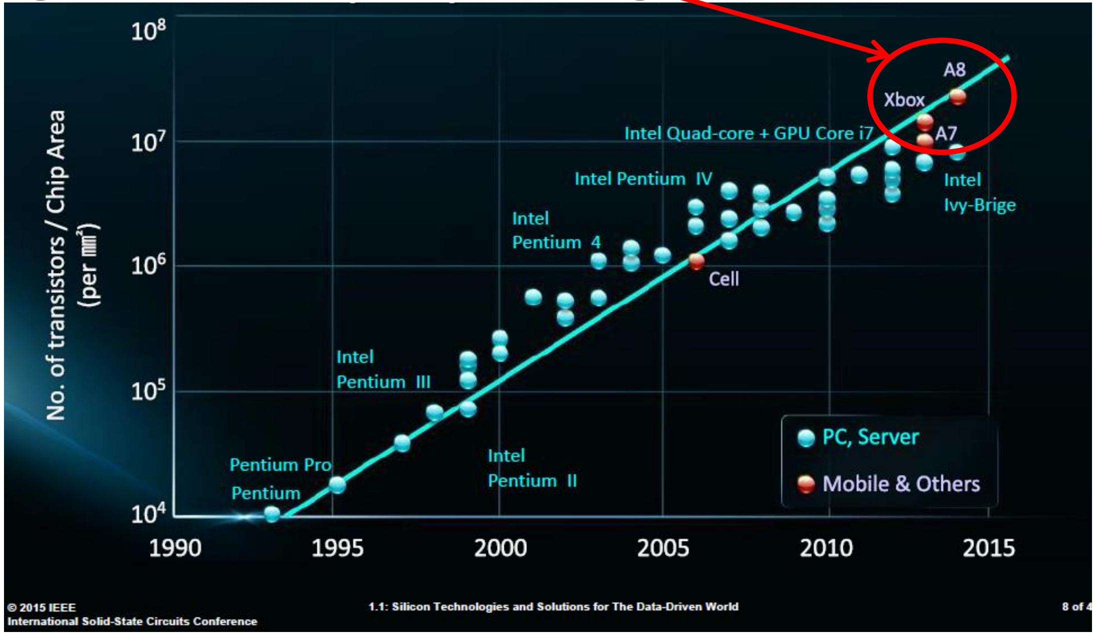
- The **complexity for minimum component costs** will increased at a rate of roughly a **factor of two per year**



Interview with ... ry of ASML: https://www.youtube.com/watch?v=EzyJxAP6AQo

The challenge
Keeping up with "Moore's Law"

Retrospective…
Mobile devices and Gaming Consoles are most demanding

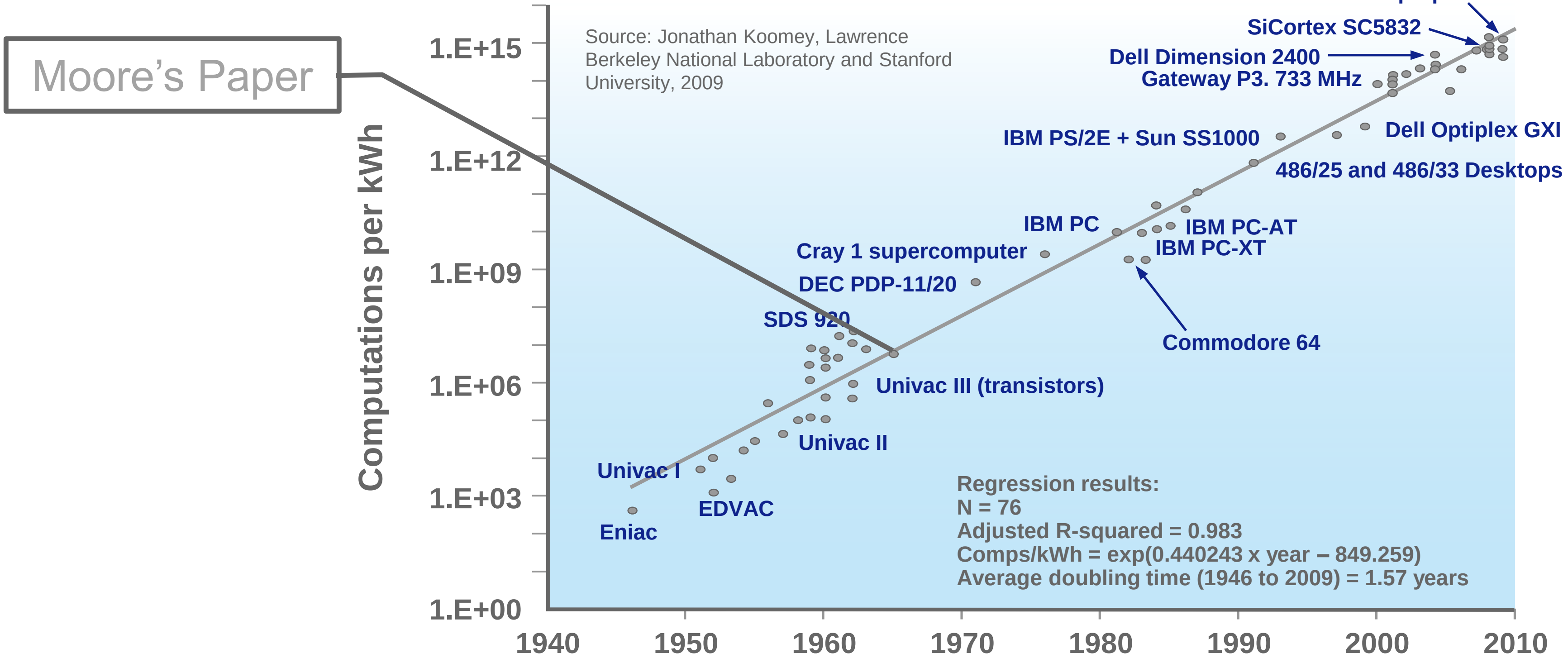


Source: Samsung ISSCC 2015

The challenge

Keeping up with “Moore’s Law”

Computations per Kilowatt hour double every 1.5 years



The challenge
Keeping up with "Moore's Law"

Memory: ×8000
Weight: ÷40000
Price: ÷50000
Processing power: ×6 – 230
Electrical Power: ÷30000

1976

Cray 1, the first supercomputer:
- 8 MB memory
- 5.5 tons
- 150 kW (Freon cooled)
- $8.86 Million ($25 Million today)
- 3.4 – 134 Mflops

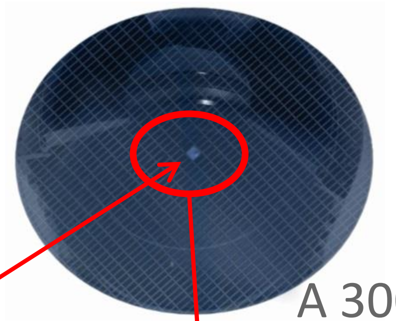
2013

Today's phone:
- 64 GB memory
- 130 g (incl. 13 megapixel camera with full HD video)
- 1-6 W
- $ 500,00
- 791 Mflops

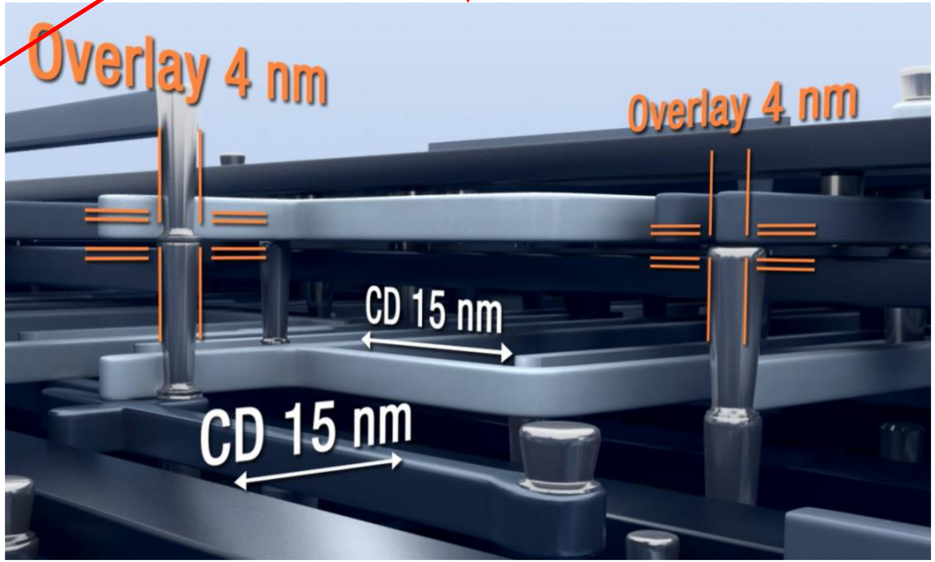
The challenge
How to keep up with Moore's law

The iPhone A8 Processor

CD= Critical Dimension



A 300 mm Wafer

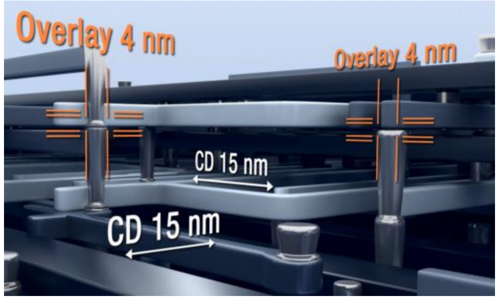


The challenge
How to keep up with Moore’s law

Designing for nanometer accuracy; to create some awareness…

Have a 300 mm wafer magnified to approximately the size of The Netherlands, then…

- CD would be about 15 mm
- And overlay accuracy 4 mm



The challenge

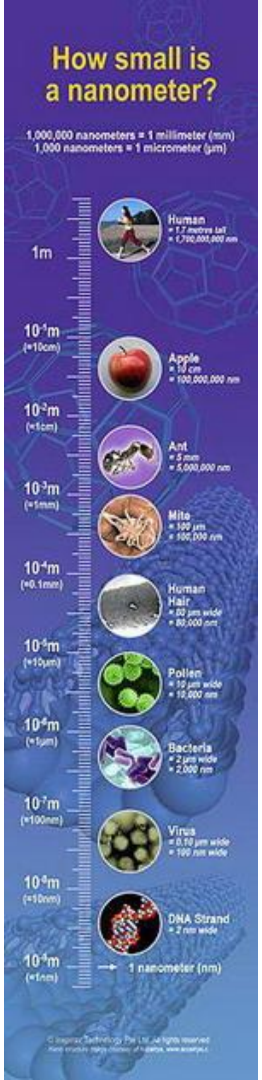
How to keep up with Moore's law

Designing for nanometer accuracy; to create some awareness…

- A **human hair** measures about 80 micrometer, 5300 times bigger than CD
- A **flue virus** measures about 100 nm, almost 6 time bigger than CD
- Overlay performance for EUV is 1 nanometer, less than **5 Si atoms!**

→ Dust is "killing" for the lithography process!

Source: Building quantum states with individual silicon atoms, Scienedaily.com,



Source: www.nanodic.com

ASML

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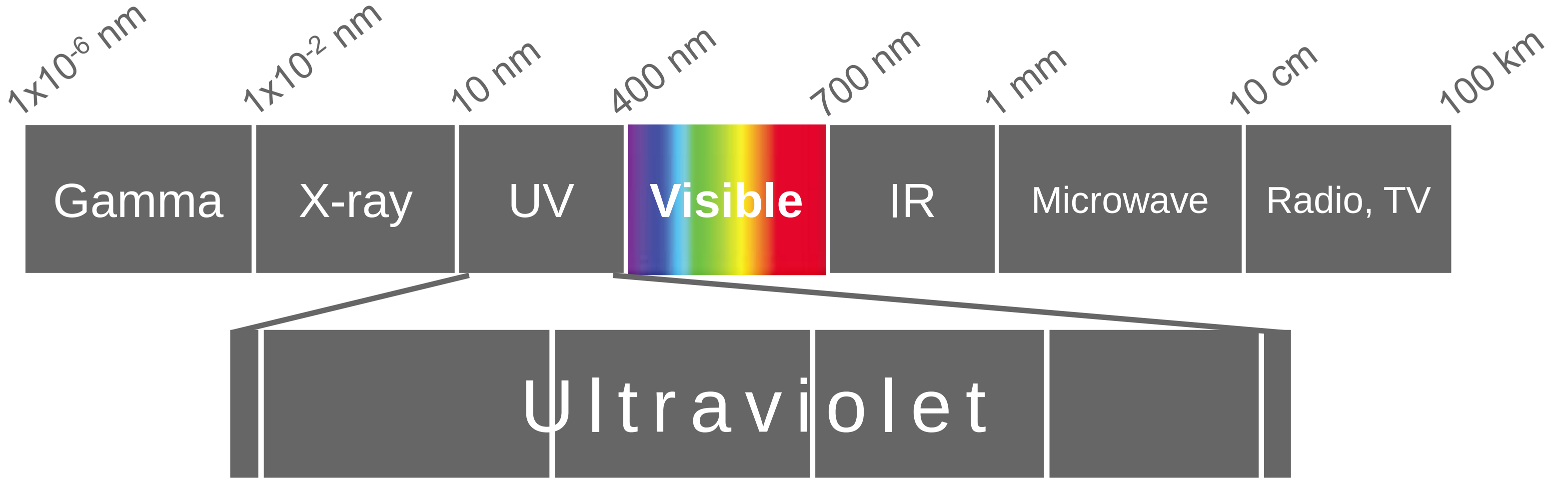
The challenge
How to keep up with Moore's law

$$CD = k_1 * \frac{\lambda}{NA}$$

How to print smaller lines → shorter wavelength of the light



Wavelength	**13.5 nm**	**193 nm**	**248 nm**	**365 nm**	**436 nm**
Year	2011	2003	1992	1986	1984
Platform	EUV	Immersion	PAS 5500	PAS 5000	PAS 2000

TWINSCAN NXT:1980Di

How to keep up with Moore's law

The future of lithography: EUV

Wavelength:
13.5 nanometers

Resolution:
≤ 22 nanometers

Overlay:
1.0 nanometers

Wafer size:
300 mm

Productivity:
125 wafers per hour

13.5 nm, close to X-rays (starts at 10nm). Major implications for the design of the machine

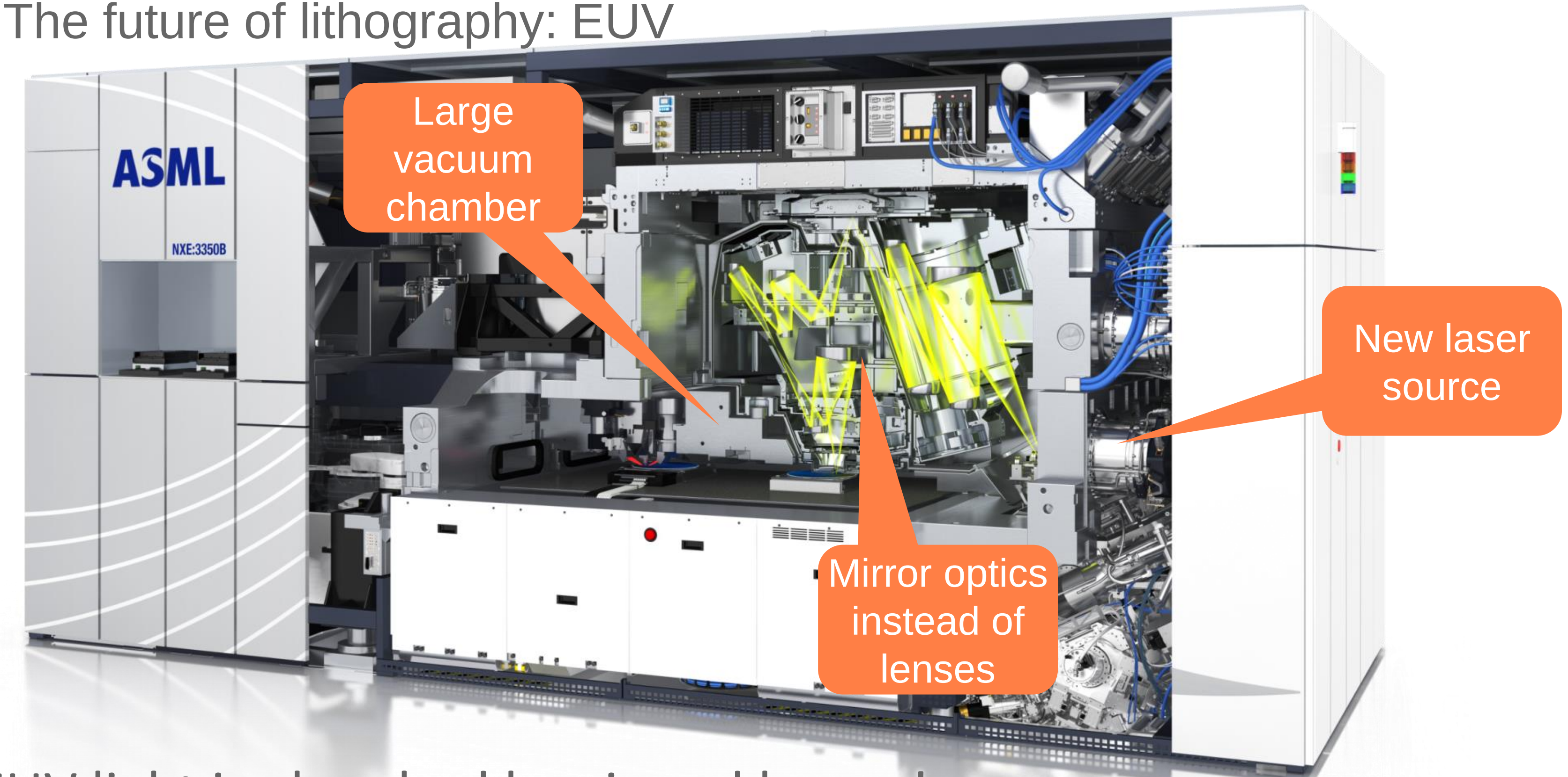
1984
PAS 2000
ASML's first stepper

2015
TWINSCAN NXT:1980Di
Our most advanced immersion system

2015
TWINSCAN NXE:3350B
Production-ready EUV system

How to keep up with Moore's law

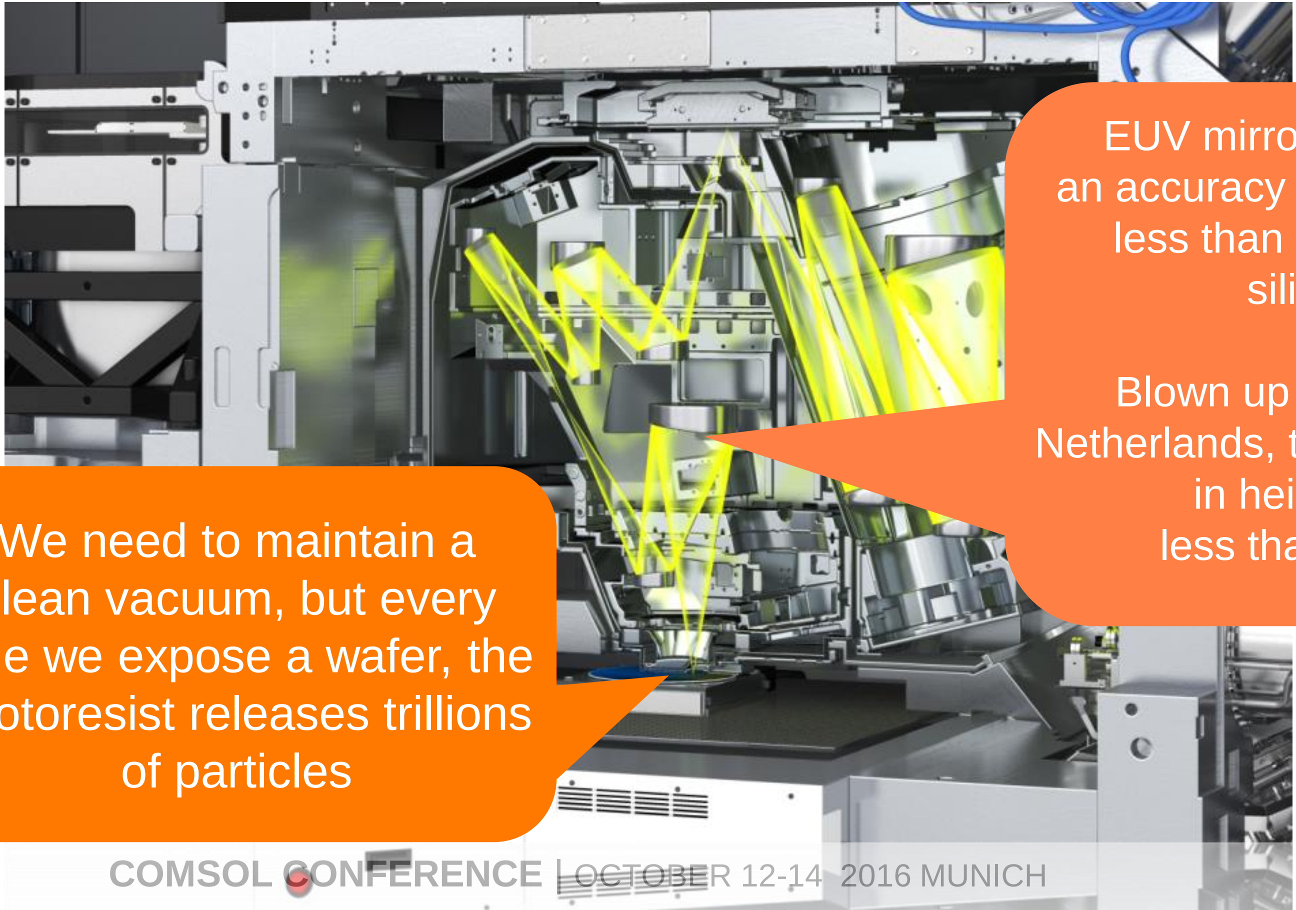
The future of lithography: EUV



EUV light is absorbed by air and lenses!

How to keep up with Moore’s law

The future of lithography: EUV



EUV mirrors are polished to an accuracy of ~50 picometers – less than the diameter of a silicon atom.

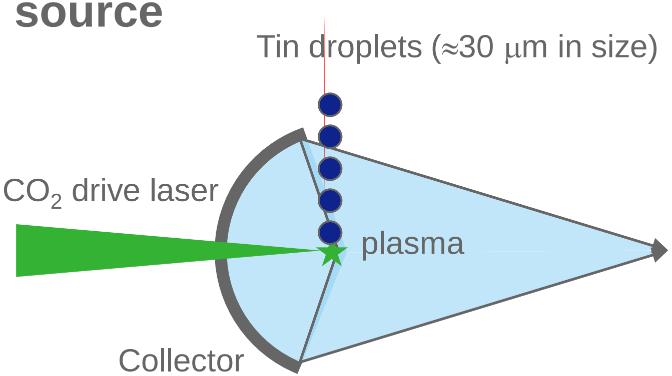
Blown up to the size of the Netherlands, the biggest difference in height would be less than a millimeter.

We need to maintain a clean vacuum, but every time we expose a wafer, the photoresist releases trillions of particles

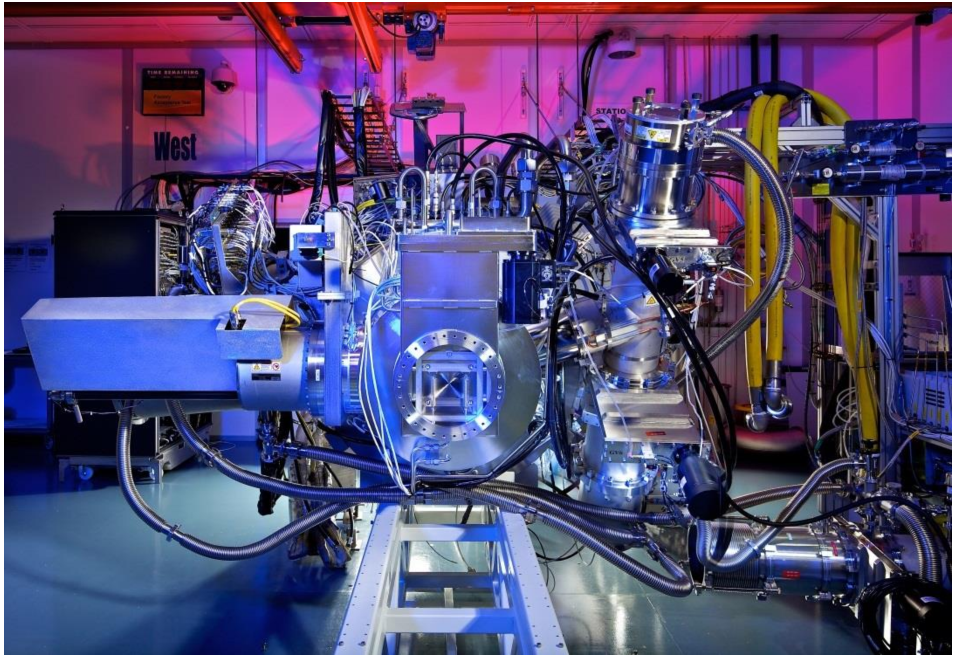
CARL ZEISS SMT

How to keep up with Moore's law
The future of lithography: EUV

Laser-Produced Plasma (LPP) source



- Each tin droplet is precisely hit by a drive laser pulse to bring it in a plasma phase
- 40,000 times per second…



Use of CAE within Development & Engineering

Physics / areas of application

ELECTRICAL	MECHANICAL	FLUID	CHEMICAL	OTHER
AC/DC	Structural Mechanics	CFD	Molecular Dynamics	Motion & Thermal Control
Wave Optics	Structural Dynamics	Molecular Flow	….	Optimization
Ray Optics	Heat Transfer	Microfluidics		….
….	Multibody Dynamics	….		
	Fatigue	….		
	Acoustics			

Not pretending to be complete

Use of CAE within Development & Engineering
Software used

ELECTRICAL | MECHANICAL | FLUID | CHEMICAL | OTHER

HyperLith™
ANSYS
ANSYS FLUENT
MATLAB The Language of Technical Computing
Mentor Graphics
COMSOL
GROMACS FAST. FLEXIBLE. FREE.
Opera Simulation Software COBHAM
Photon ENGINEERING
OpenFOAM
Altair HyperWorks
CD-adapco
Mathcad
LightTrans VirtualLab™
SIEMENS
esi
Zemax
Sigmadyne™ SigFit

Not pretending to be complete

Use of CAE within Development & Engineering
Trends and developments

- More complex systems, while ever tighter requirements have to be met. At the same time **Time to Market** should be shorter while quality should not be compromised → **Time to Maturity** mindset
- Requirements on System/Module level are a fraction of the requirements on Machine level → analysis on sub-nanometer level (moving into analysis on pico-meter scale)
- Evolution from “single physics” to “multi physics”
- Verification by physical testing becomes more difficult, not feasible or even not possible.
- Higher demand on CAE: Bigger models, more advanced models, more simulations

Use of CAE within Development & Engineering

How do we anticipate

PEOPLE development

PSE CERTIFIED

- Develop Engineers that are “CAE competent” and let them analyze their own designs (up to a certain level) → Co-operation with NAFEMS on training and PSE Certification*
- Provide user friendly “Simulation App’s” to Design Engineers

*NAFEMS Juli 2016 Benchmark magazine

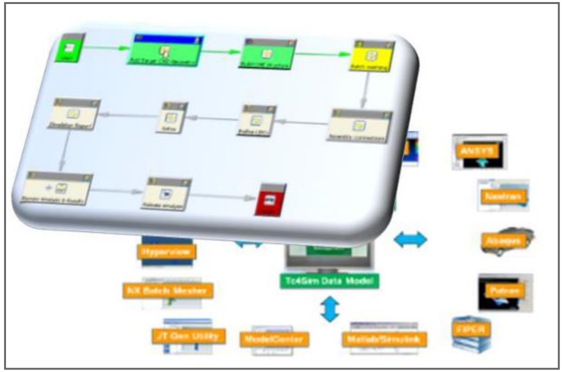
Use of CAE within Development & Engineering
How do we anticipate

PROCESS

- Tighter Integration of Virtual Verification into the development process
- Define/optimize the CAE “WoW”

(“Way-of-Working”, not )

- SPDM (Simulation Process and Data Management)

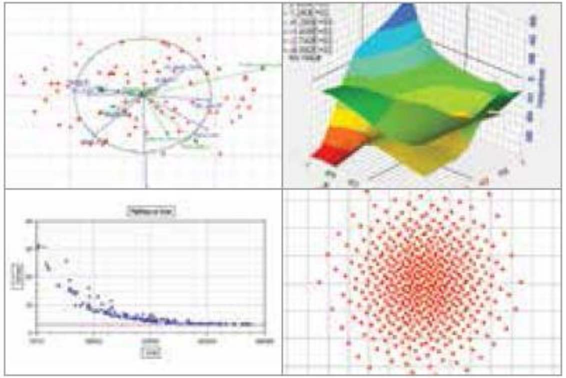


Use of CAE within Development & Engineering

How do we anticipate

TOOLS & METHODS

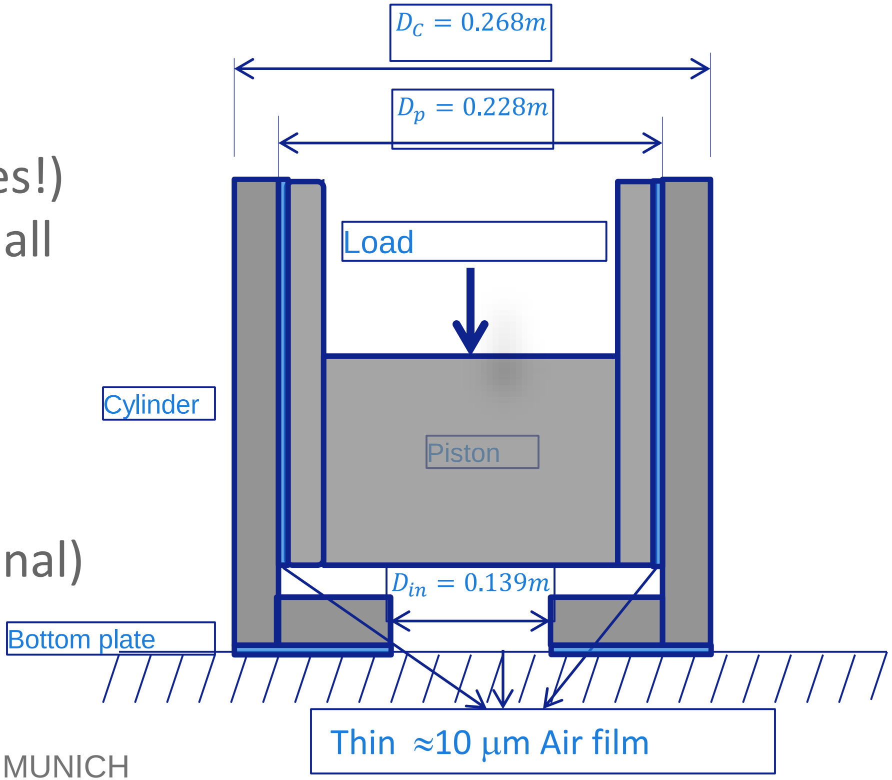
- Increase “Analysis Maturity” to enable more verification by analysis
- HPC Cluster. Currently several thousands of cores and a number of GPU enhanced nodes in addition. Used globally.
- Optimization and stochastic analysis
- Multi-physics analysis → **COMSOL Multiphysics**



Use of COMSOL within Development & Engineering

Example: Air Bearing Analysis

- Air Bearings are used in our machines at many places because of
  - High stiffness → high positional accuracy is attainable
  - No friction → no wear (no particles!)
  - High load bearing capacity in a small volume
  - Thermal isolation
  - …
- Typical design criteria
  - Stiffness (translational and rotational)
  - Gap size under load (“fly height”)
  - Air consumption

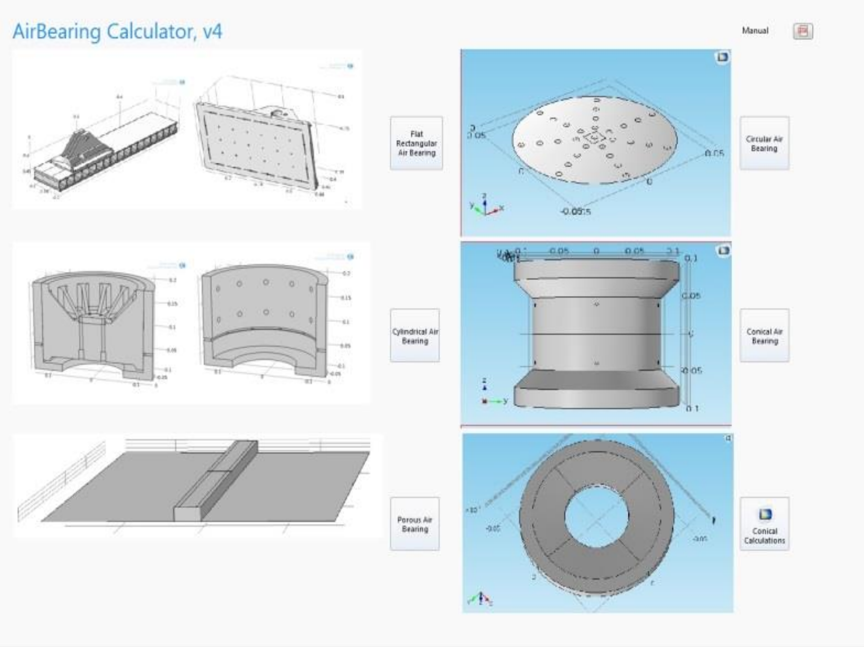


Use of COMSOL within Development & Engineering

Example 2: Air Bearing Analysis

Air film only analysis (structure assumed to be very stiff) with **Air Bearing Calculator**

- Takes away the effort of FEM modelling, analysis set-up and post-processing



← Main page: Select configuration:

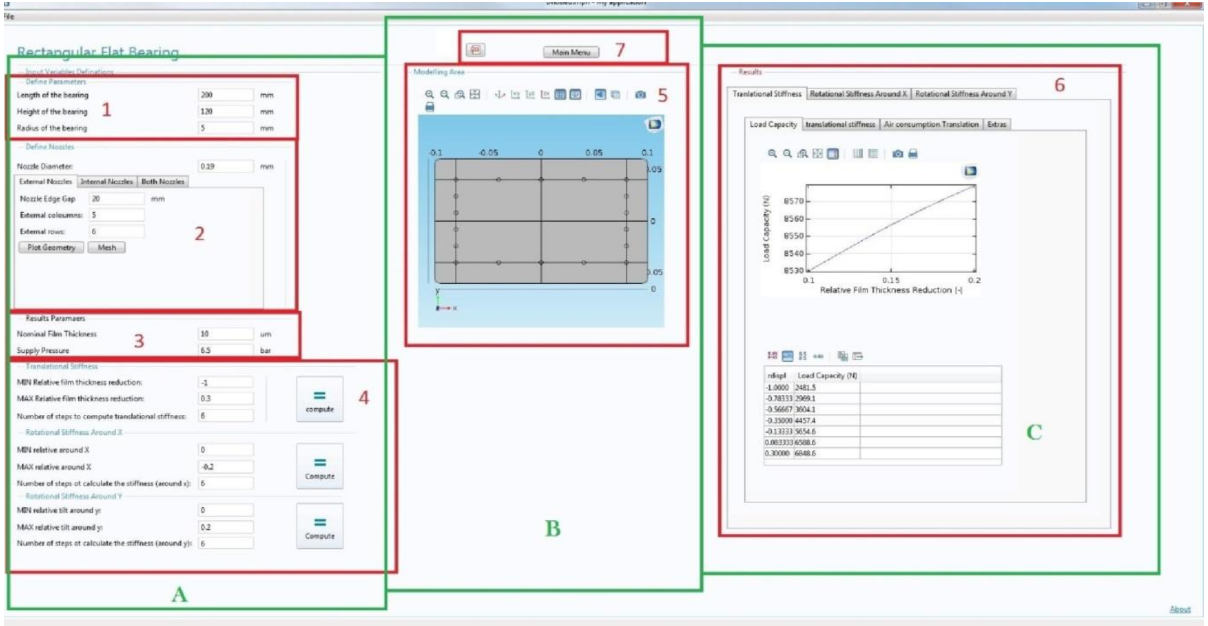
1. Rectangular/Cylindrical flat Air Bearing
2. Cylindrical/Conical Air Bearing
3. Under development: Flat Porous Air Bearing

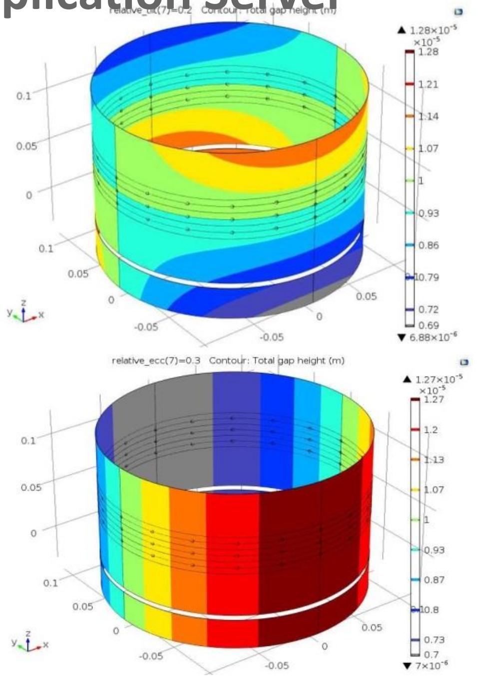
Use of COMSOL within Development & Engineering

Example: Air Bearing Analysis

Air film only analysis (structure assumed to be very stiff)

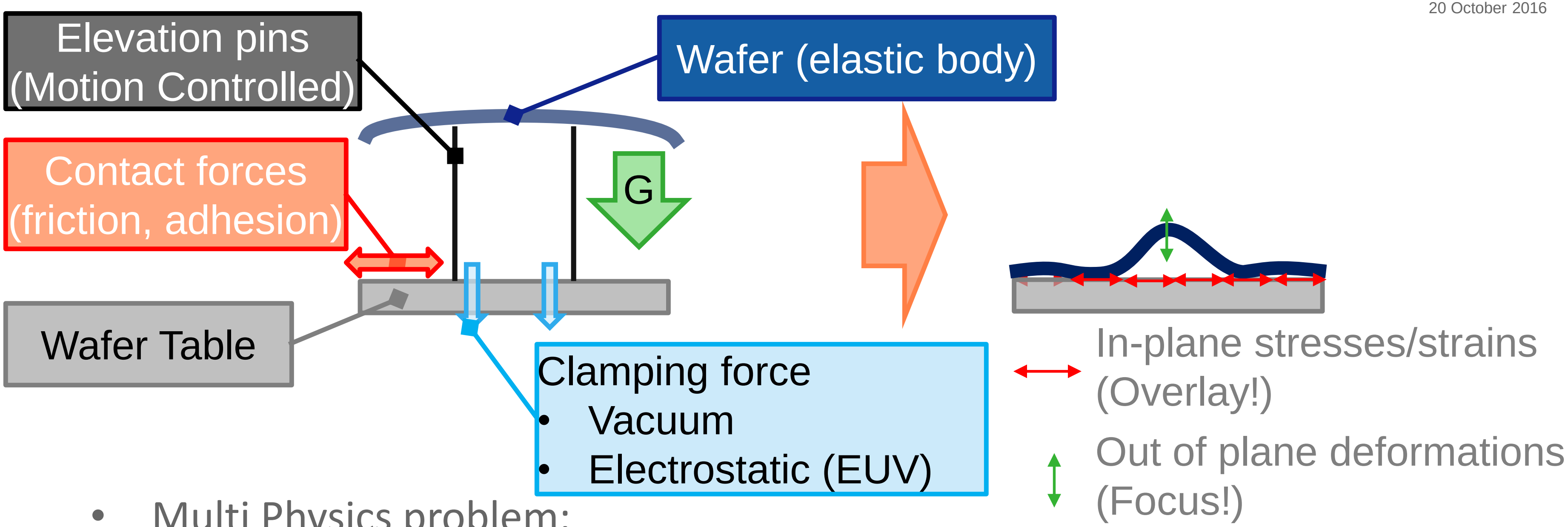
- Input dimensions and other variables and results page
- Will be made available to more engineers via **COMSOL Application Server**





Use of COMSOL within Development & Engineering

Under development: Wafer Load Simulation



- Multi Physics problem:
  - (Wafer) Dynamics
  - Flow
  - Contact mechanics
  - Thermal
  - Electrostatics
  - Motion Control

Questions?

ASML