Facing Moore's Law with Model-Driven R&D

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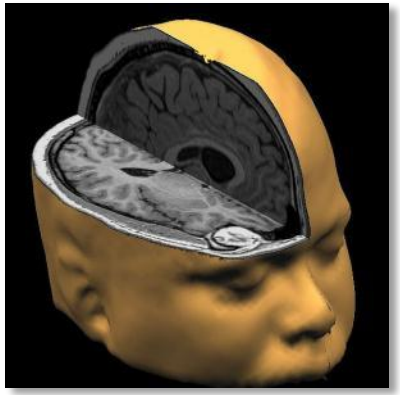
Introducing ASML

It’s hard to imagine a world without chips

Global market 2014: 221 billion chips, $333 billion



ASML makes the machines for making those chips

- Lithography is the critical tool for producing chips
- All of the world's top chip makers are our customers
- 2014 sales: €5.9 bln
- People: ~14,000 FTEs

Founded in 1984 as a spin-off from Philips…

…with global presence!

3,100 employees **8,600 employees** **2,400 employees**

Over 70 sales and service offices located worldwide

Source: ASML Q1 2015

Moore’s law

Driving the semiconductor industry: Moore's Law

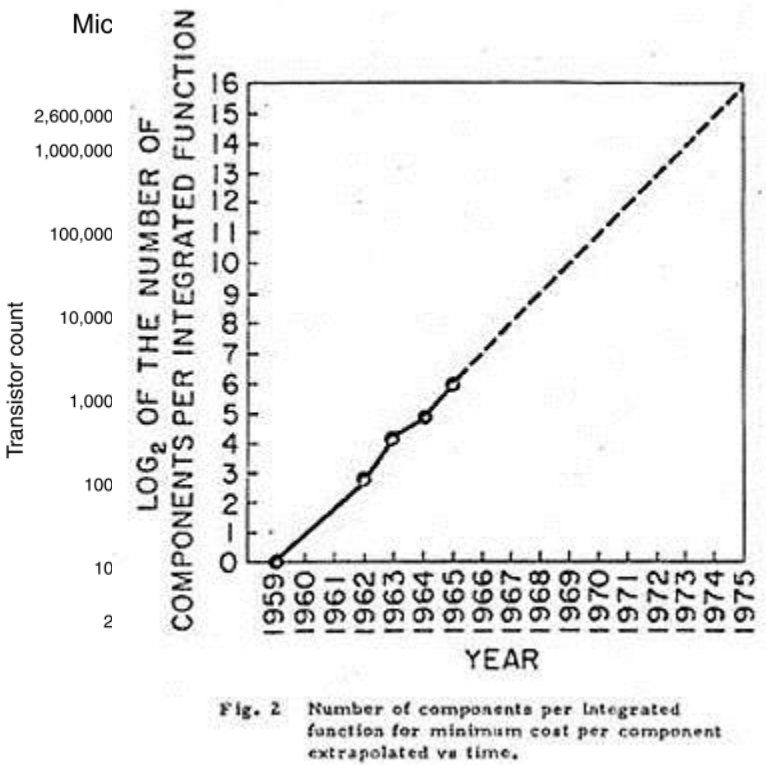
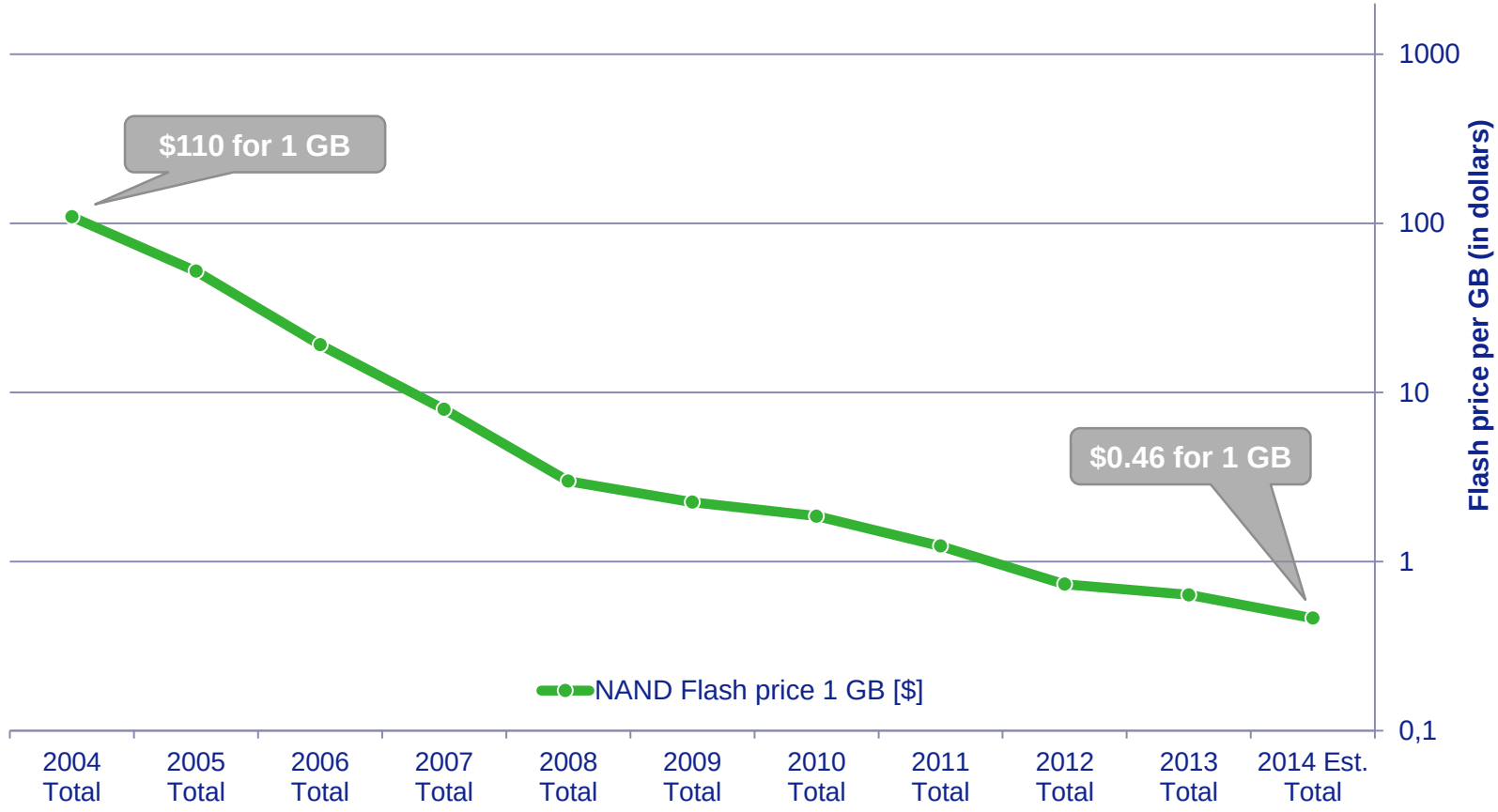


Fig. 2 Number of components per integrated function for minimum cost per component extrapolated vs time.

Gordon Moore (1965): Number of transistors per chip doubles every year.

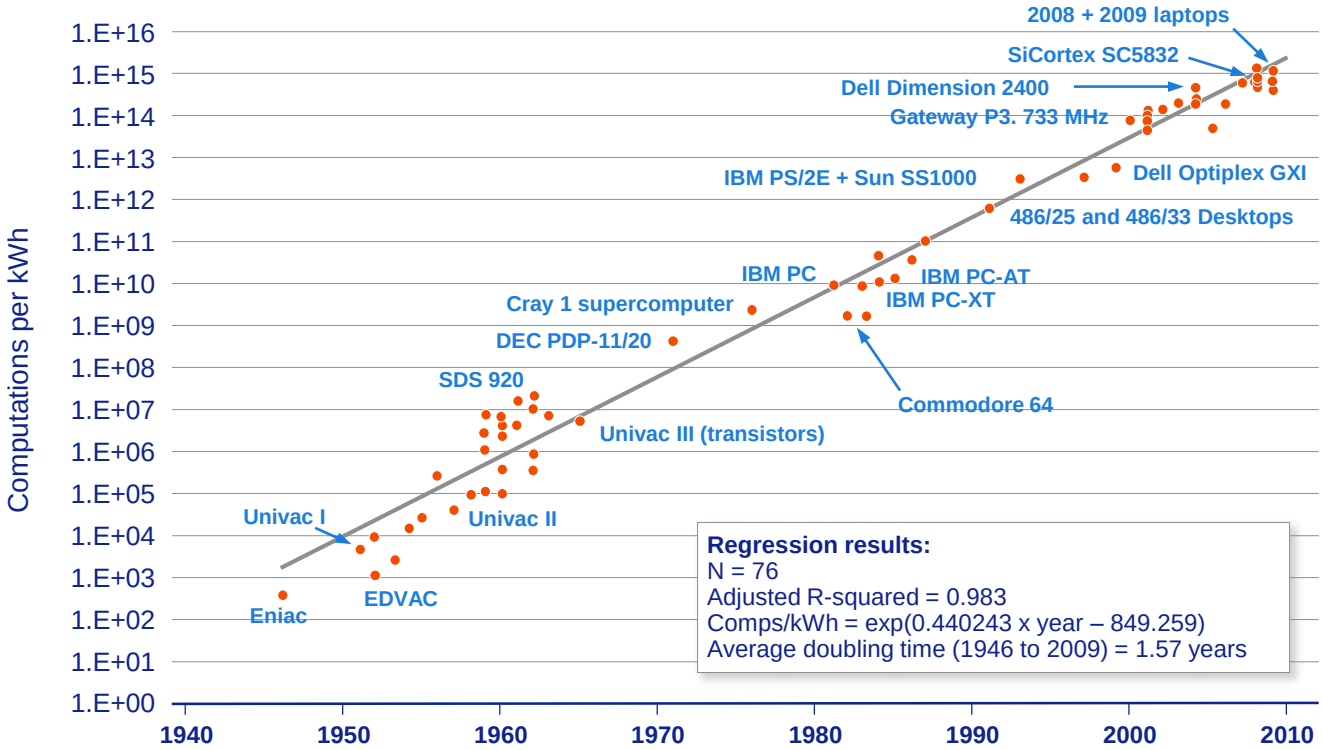
Later adjusted to two years, the trend has held for half a century

Moore's Law makes chips cheaper…



… and more energy-efficient

Computations per Kilowatt hour double every 1.5 years

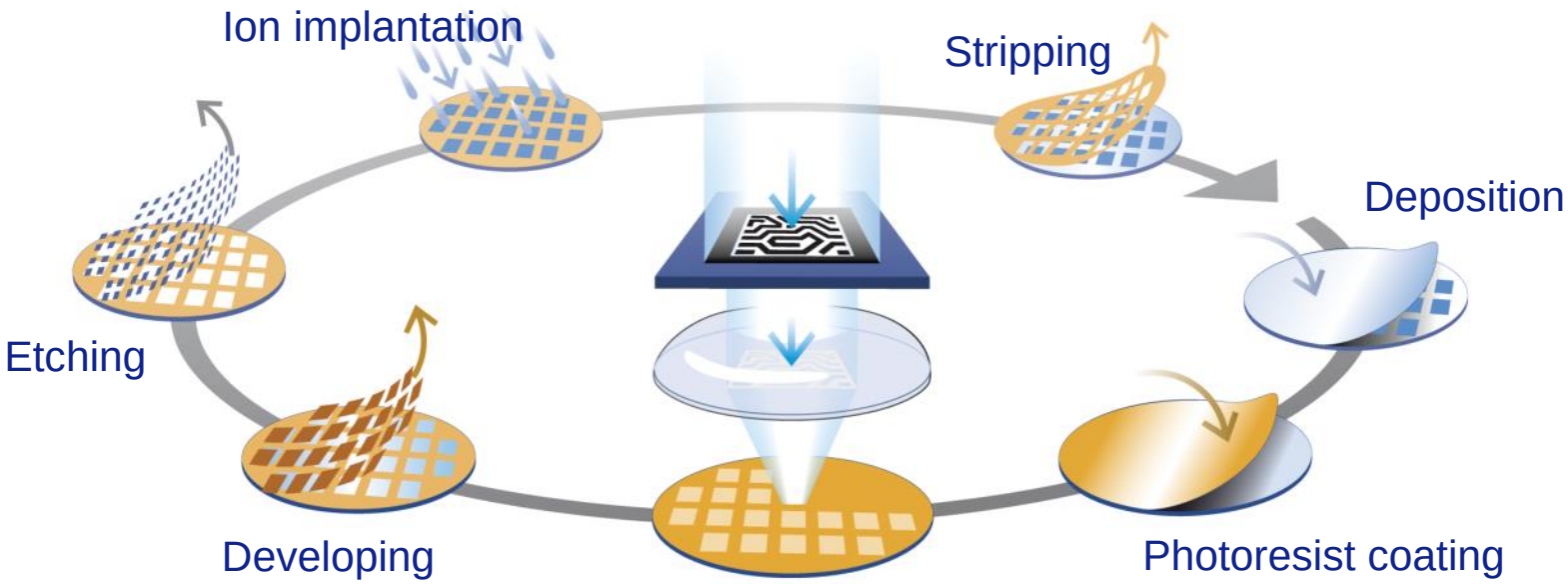


Source: Jonathan Koomey, Lawrence Berkeley National Laboratory and Stanford University, 2009

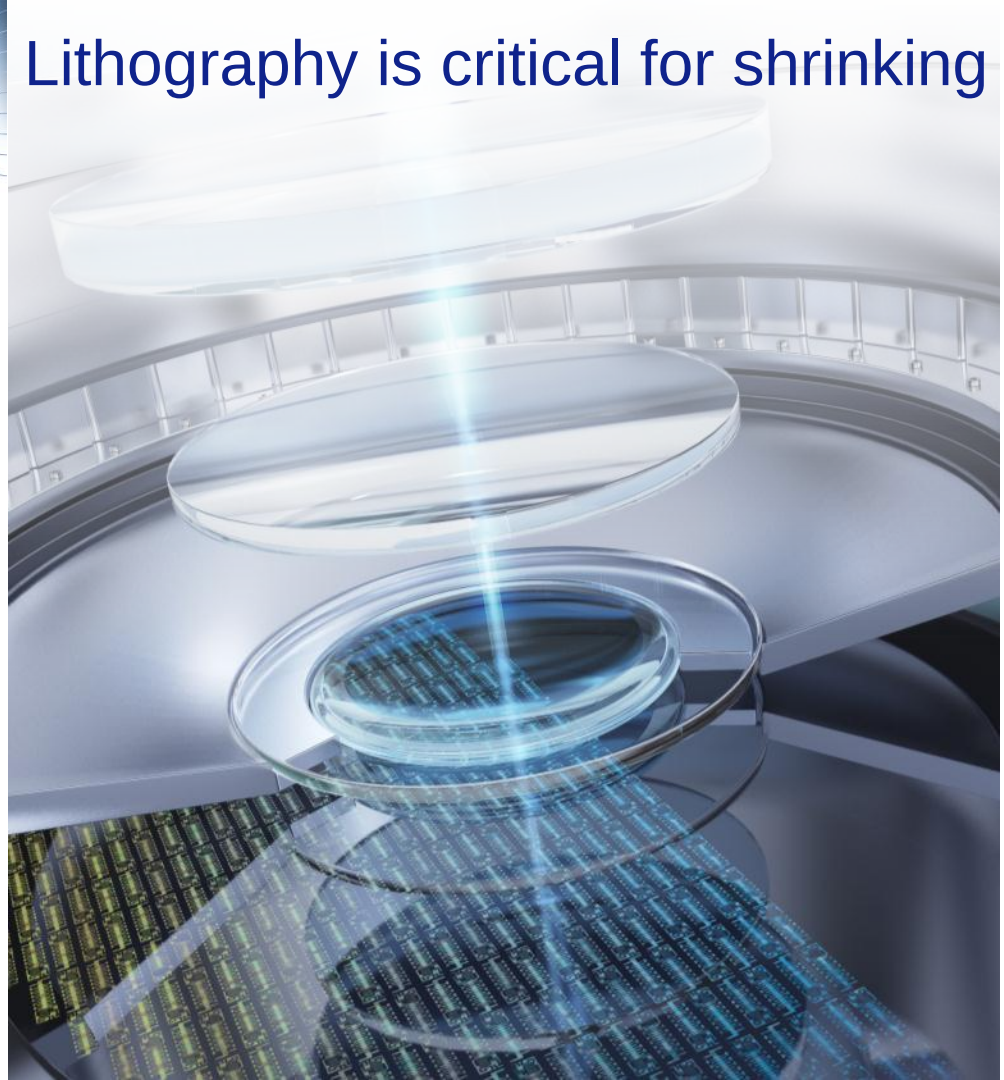
Lithography, the driving force behind Moore’s Law

A chip is made of dozens of layers

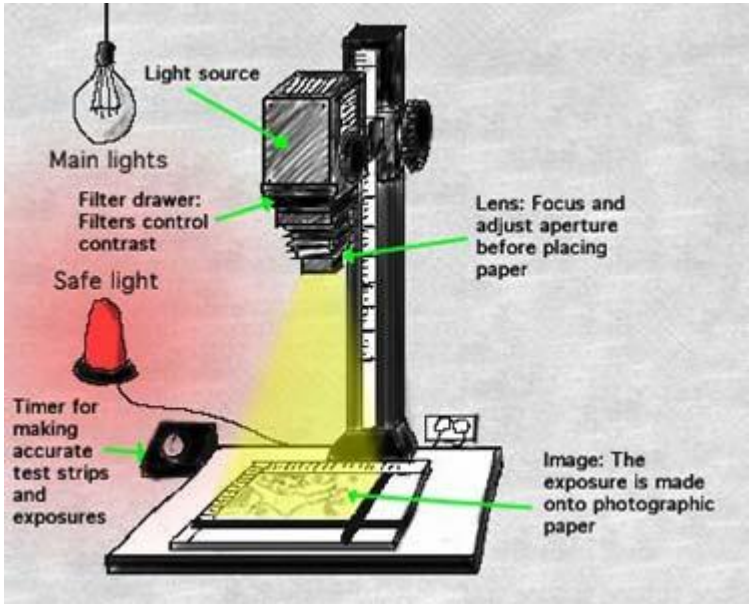
The manufacturing loop



Lithography is critical for shrinking transistors



Like a photo enlarger of old, lithography forms the image of chip patterns on a wafer



The ASML ecosystem makes this happen

Open Innovation from design to manufacturing

Customers
Semiconductor producers

Co-solution network
Mask, Resist, Wafer track
Wafer processing

Supplier and
partner network
Optics, measurement
systems, parts, subsystems

Virtual innovation network
Academia, technology providers, research institutes

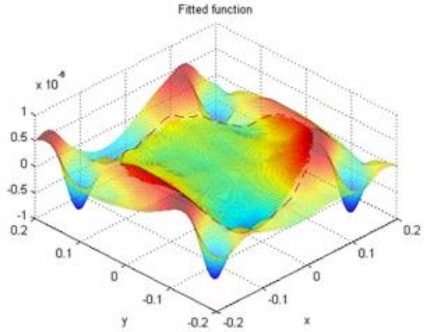
Open Innovation from design to manufacturing

Increasing complexity, increasing challenges

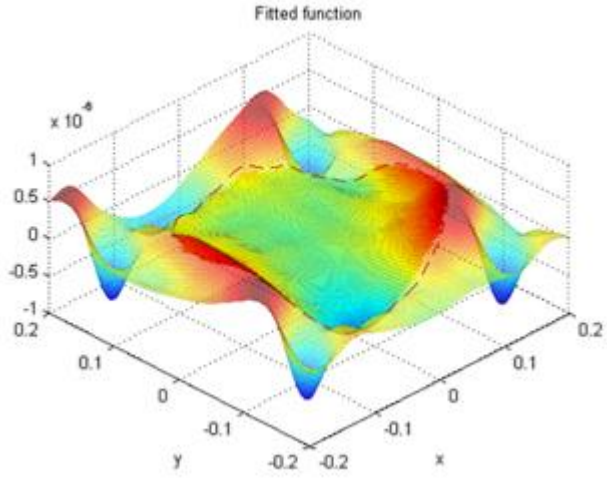
Scanner functionality and hardware become increasingly more complex

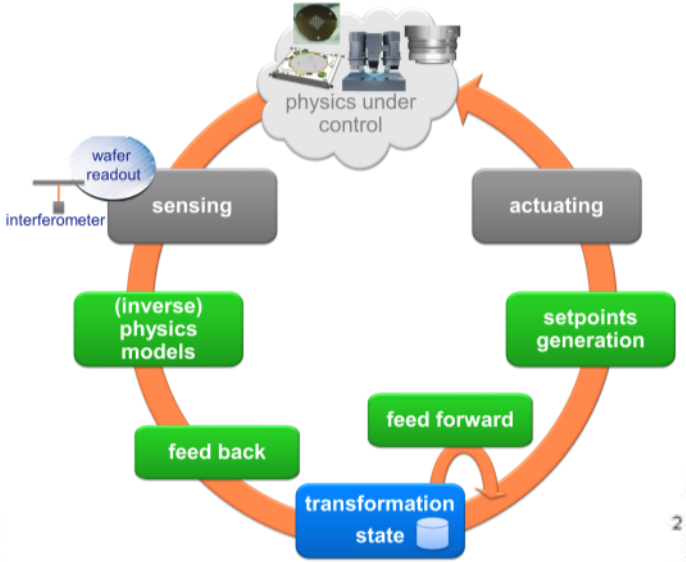
The world is far from perfect at (sub-)nanometer level

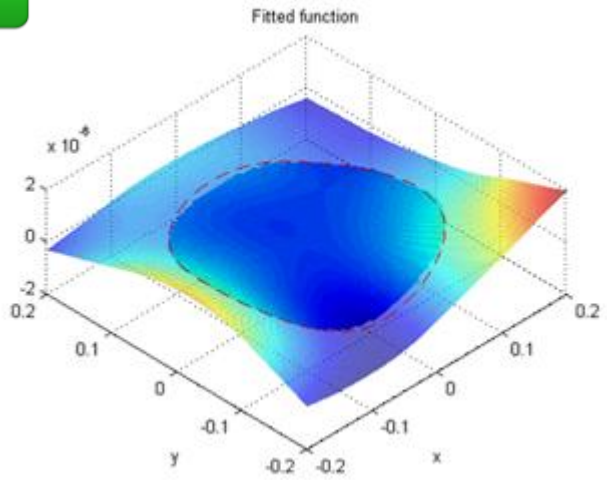
- Flat is no longer flat, straight is no longer straight
- Variations due to flow, temperature and humidity variations
- Sensitivity to dynamics, magnetics, and pressure differences



Physics, mathematics and software correct hardware imperfections at (sub-)nanometer level

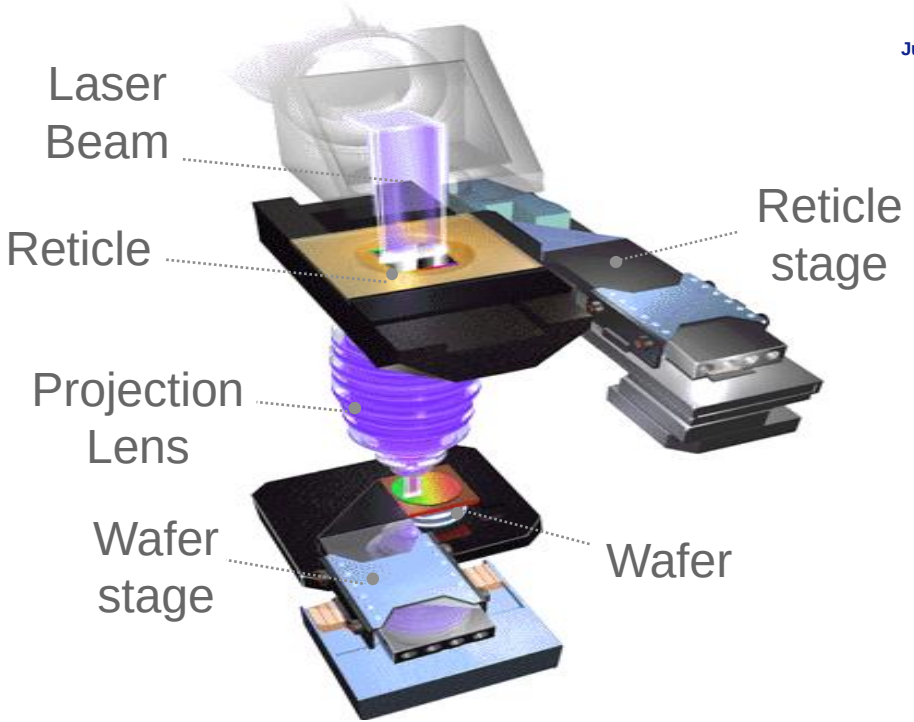






Example: Lens Model

- Laser beam heats up lens
- A sensor measures the lens aberrations
- The lens model calculates how to adjust the lens (within 12 ms)
- Lens is adjusted and wafer is exposed in optimum state

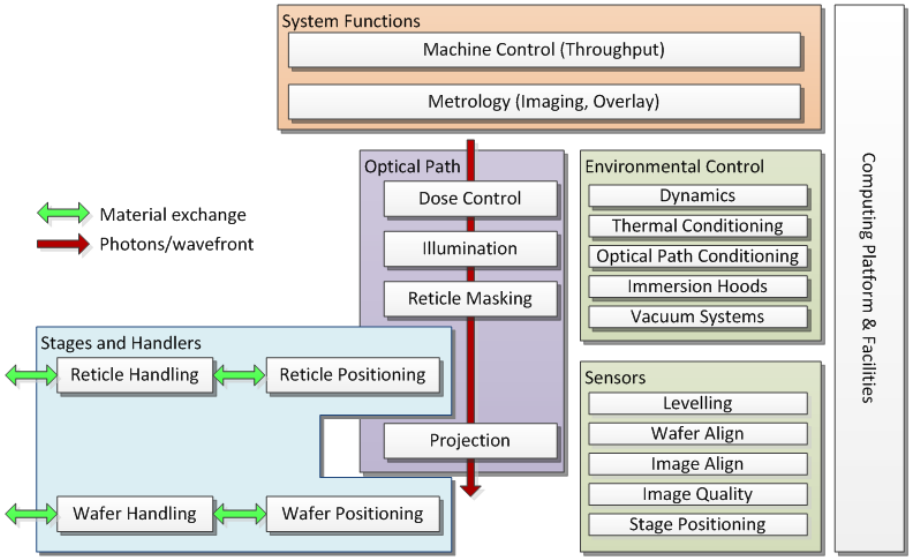


- Lens model implemented in MATLAB
- Timing constraints met by code optimization together with MathWorks: 39% speed gain

Function	Original MATLAB Code	Best solution in MATLAB	Speedup Gain
qpGTikh	1.331 s	0.613 s	54 %
analytic_center	3.206 s	2.549 s	21 %
Total	**4.403 s**	**2.693 s**	**39 %**

ASML software development reflects increasing complexity

- TWINSCAN software consists of 40 million lines of code
- More than 500,000 lines of MATLAB code in TwinScan archive
- 20+ computing nodes running more than 200 processes



- Our software supports old as well as new systems
  - SW archive embeds > 10 years of development history, thousands of man years of work

How to continue driving Moore’s law?

The other side of Moore's medal…

Development & engineering costs rapidly growing

1980s:

PAS 2000/5000

R&D: 50 mln €

1990s:

PAS 5500

R&D: 400 mln €

2000s:

TWINSCAN

R&D: 1500 mln €

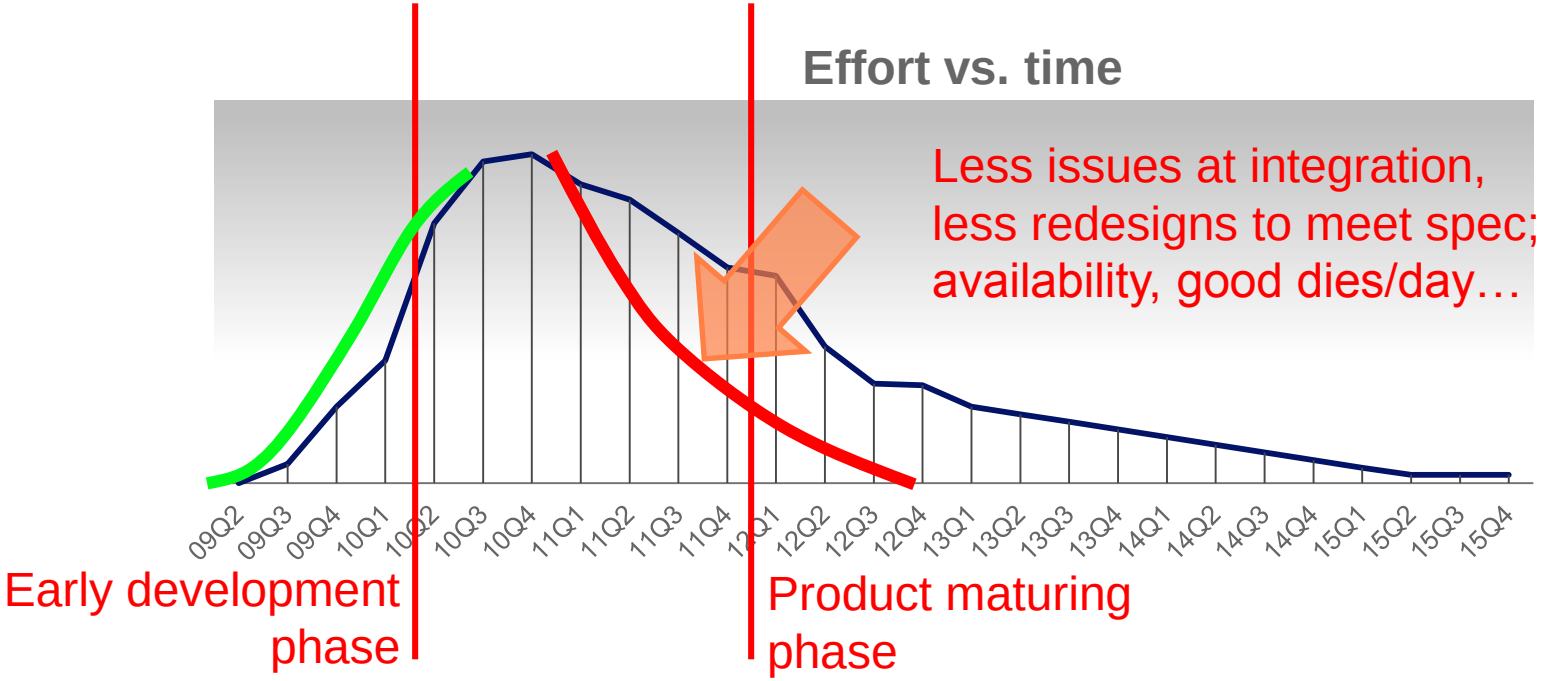
2010s:

NXE EUV

R&D: > 2000 mln €

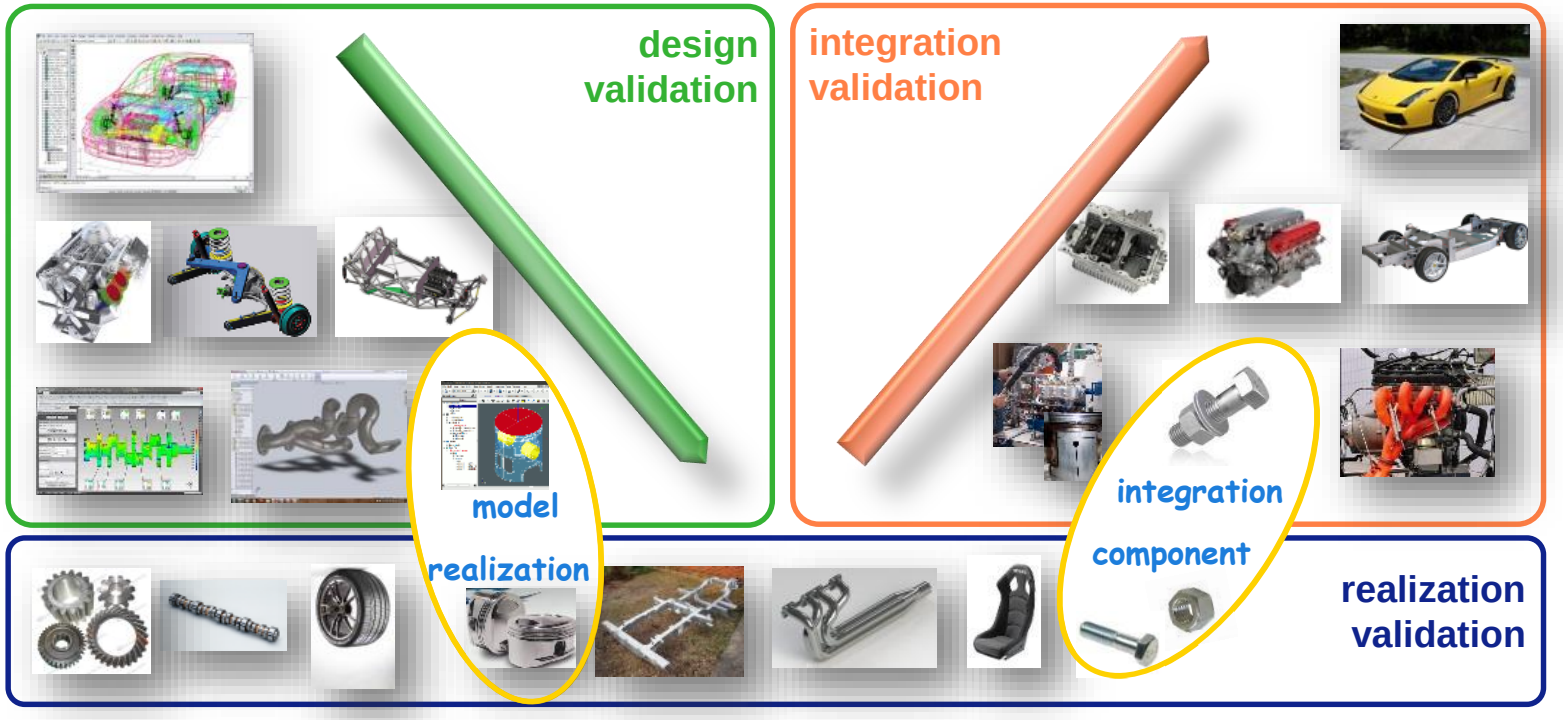
How to continue driving Moore's law and ensure customer profitability, while keeping R&D cost under control?

Investing in early development phase leads to gain in product maturing phase and earlier customer profitability

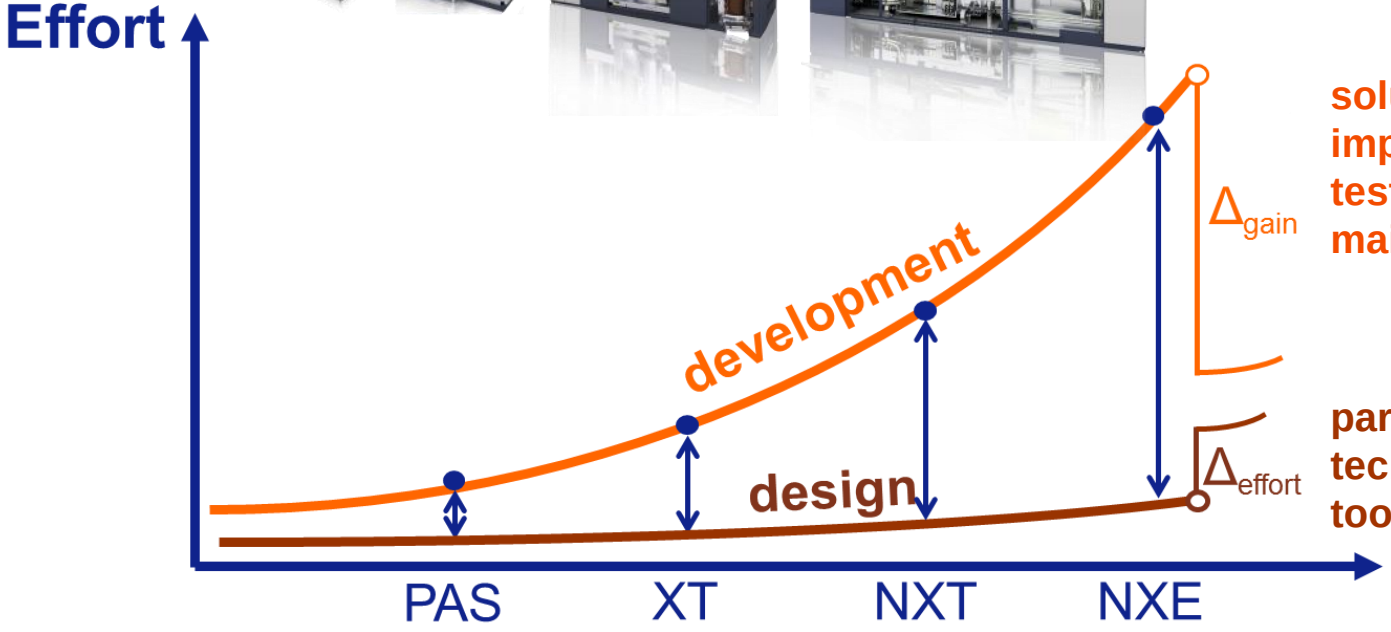


But how to invest more in the early development phase?

Let us look at a Development and Engineering work flow



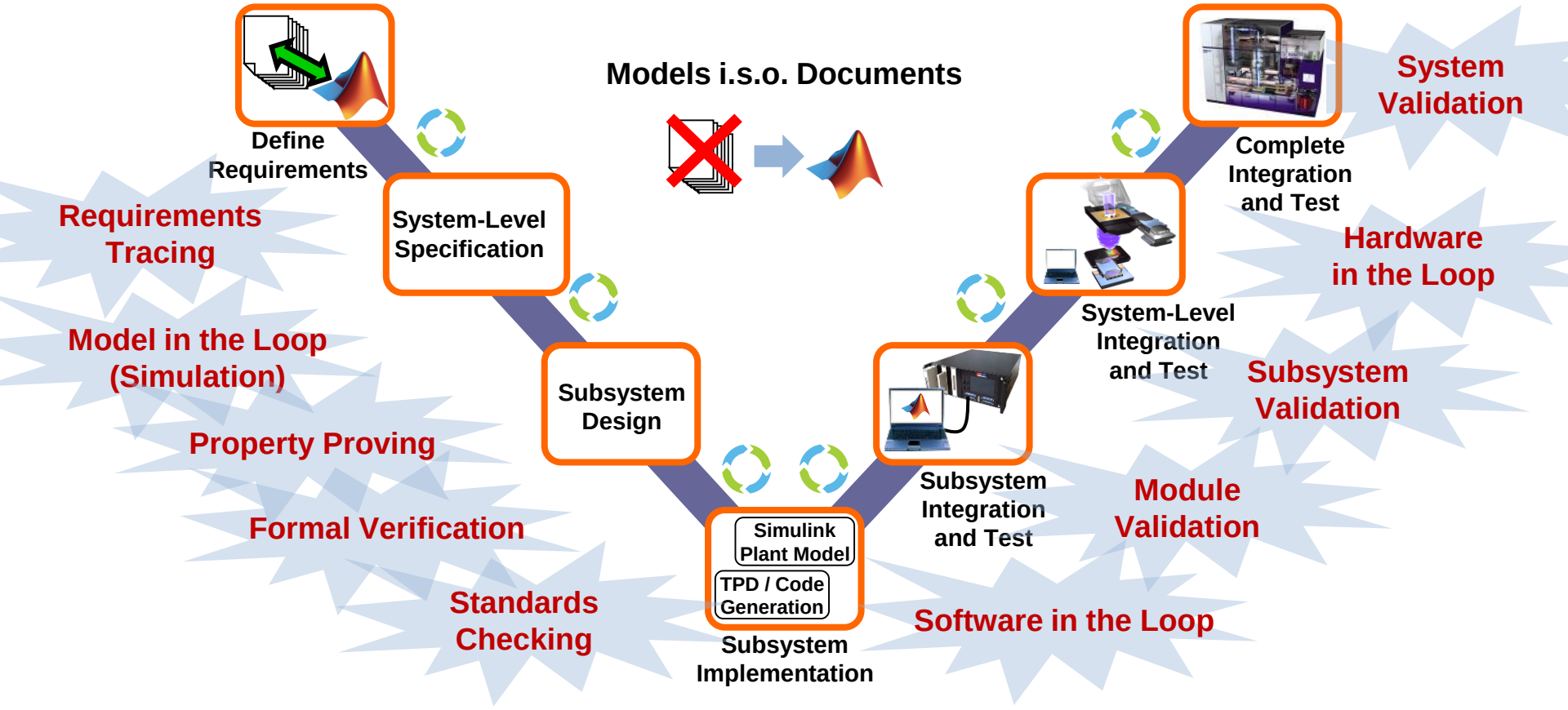
Different approach needed to reduce development effort



solution implementation, testing and maintenance

paradigms, models, technology and tools

Model Driven Engineering vision



Summary and conclusions

Summary and Conclusions

- Moore's Law has shaped the world as we know it
- Lithography has enabled and driven Moore's Law

- "Moore's law for product development" is not sustainable
- To continue driving Moore's law, the R&D way of working needs to evolve towards a system-wide model driven engineering approach
- Directions pursued are: higher abstraction levels, executable specifications (models instead of documents), formal model verification and design time validation, automatic code generation

- Further elaboration of industry standards is desirable to easily connect solutions across the development chain
- Strategic partnerships, such as between ASML and MathWorks, are instrumental to achieve this


ASML