



# *A sustainable industry-Lab research partnership: advanced semiconductor manufacturing*

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# *Outline*



- Introduction
- Program evolution

# *Semiconductor industry is huge global economic driver*

**\$56 Billion**

Semiconductor  
R&D and Cap Ex  
(2013)



**\$336 Billion**

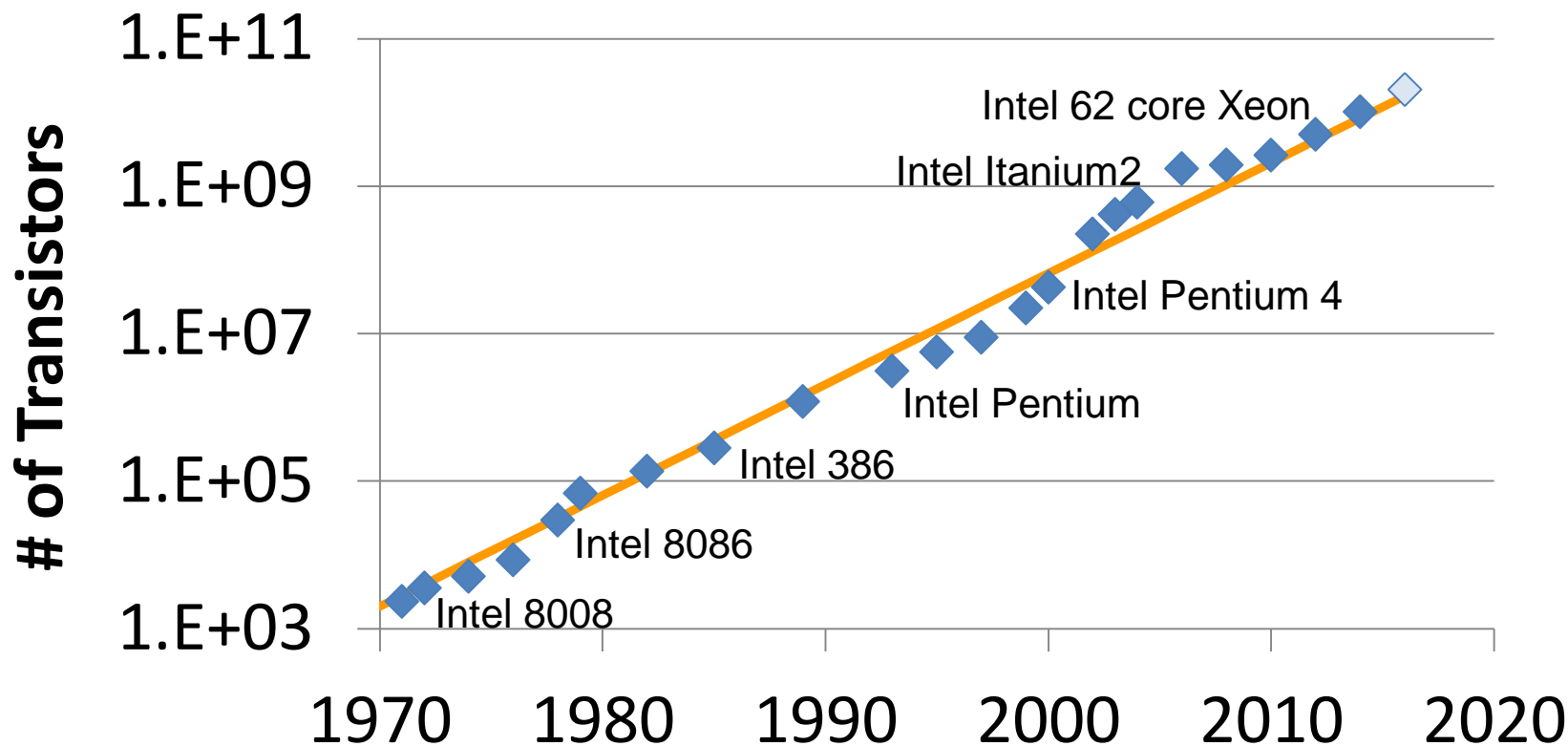
Semiconductor  
device market  
(2014)



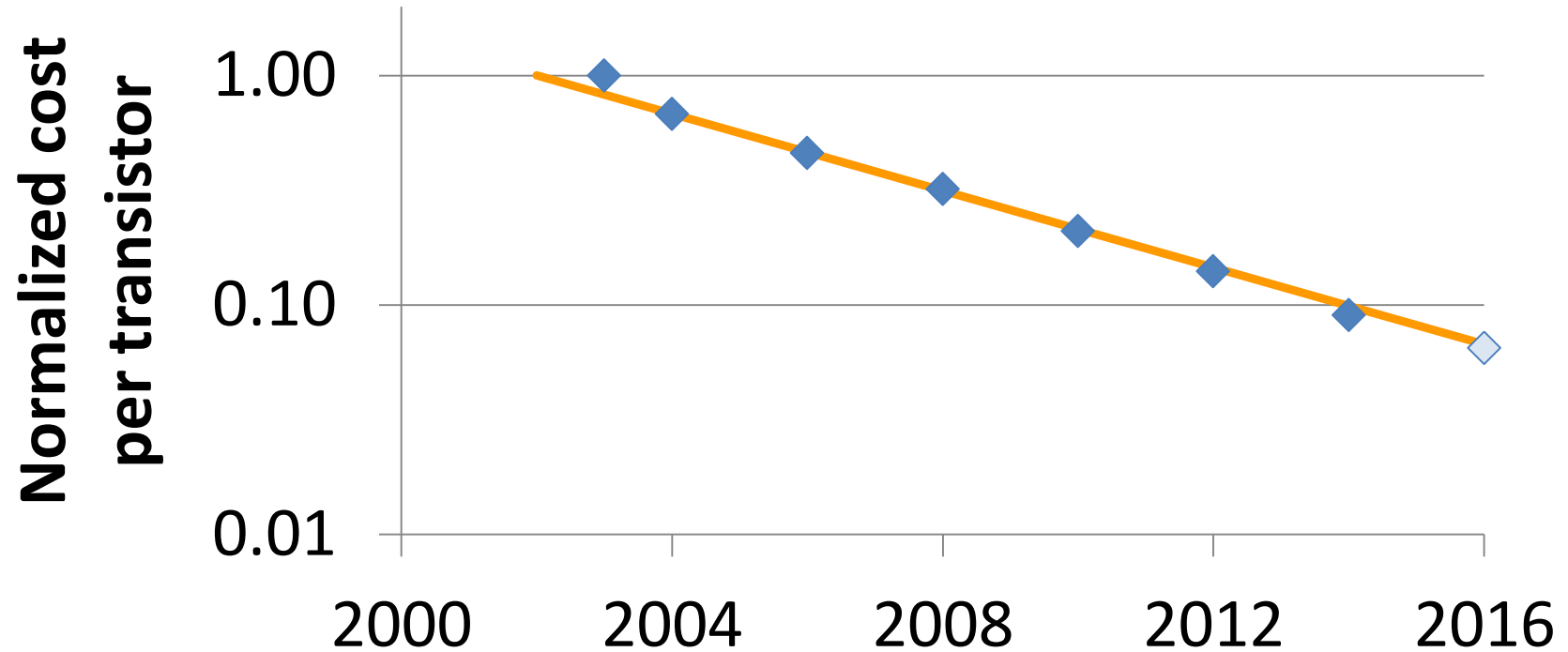
**\$2.3 Trillion**

Global electronics  
market (2014)

# Industry growth enabled by Moore's Law: transistors double every two years



# The other half of Moore's Law: *density increase at shrinking cost*



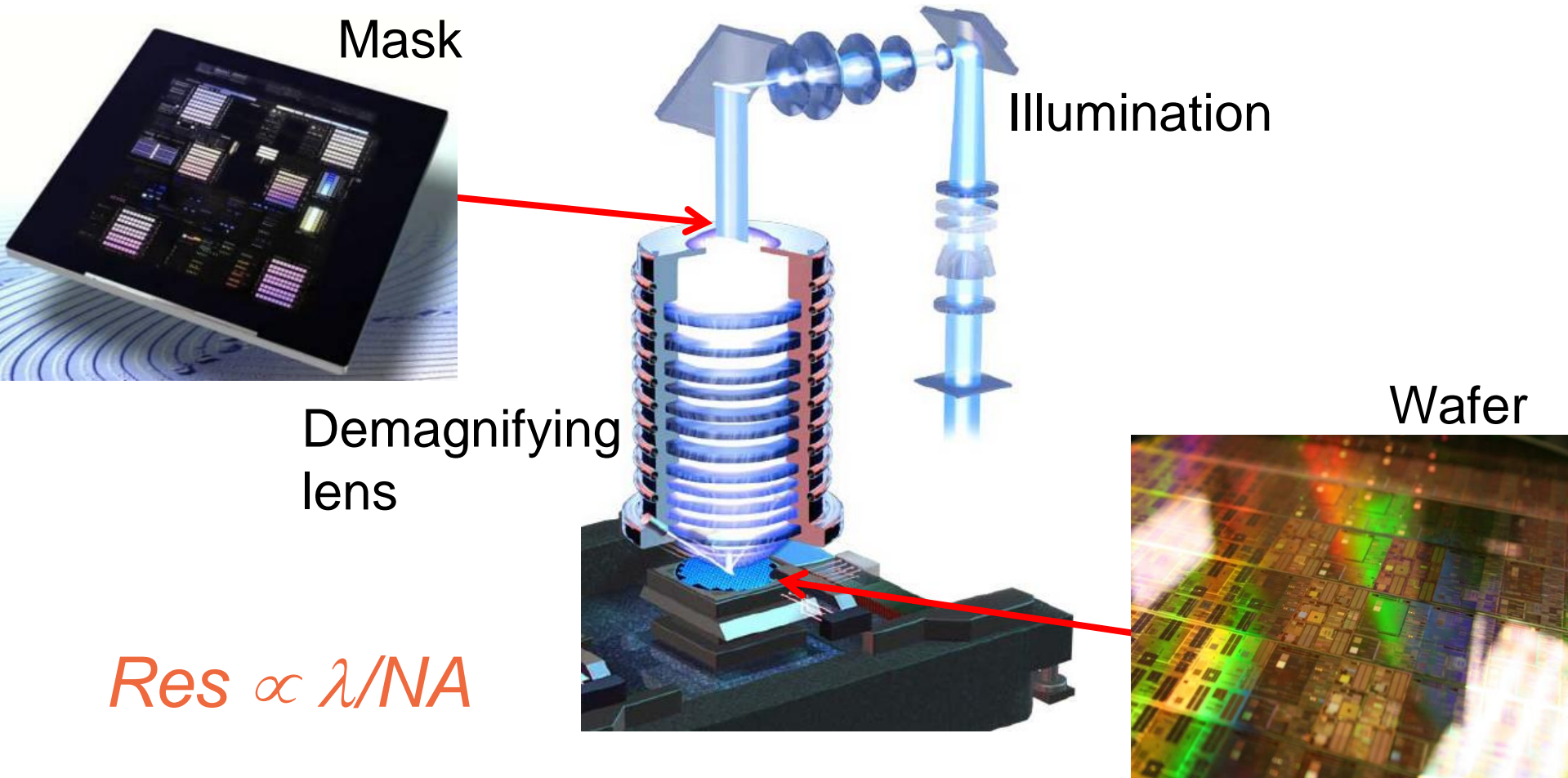
Data from Intel (<http://www.pcworld.com/article/2887275/intel-moores-law-will-continue-through-7nm-chips.html>)

iPod nano 16 GB  
\$139.99



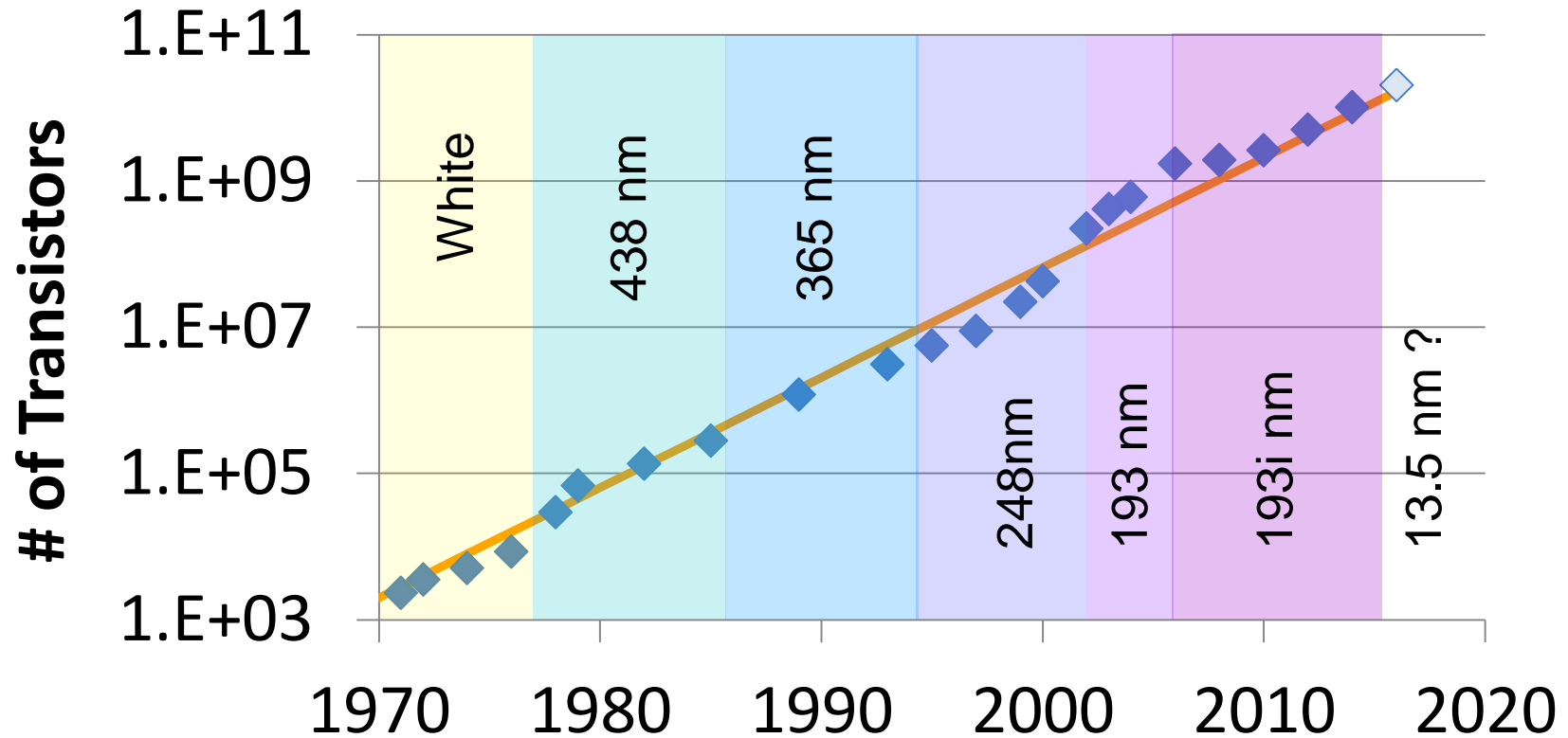
Would have cost  
**\$32 billion** in 1970

# Lithography drives shrink



$$Res \propto \lambda/NA$$

# Moore's Law driven by wavelength shrink



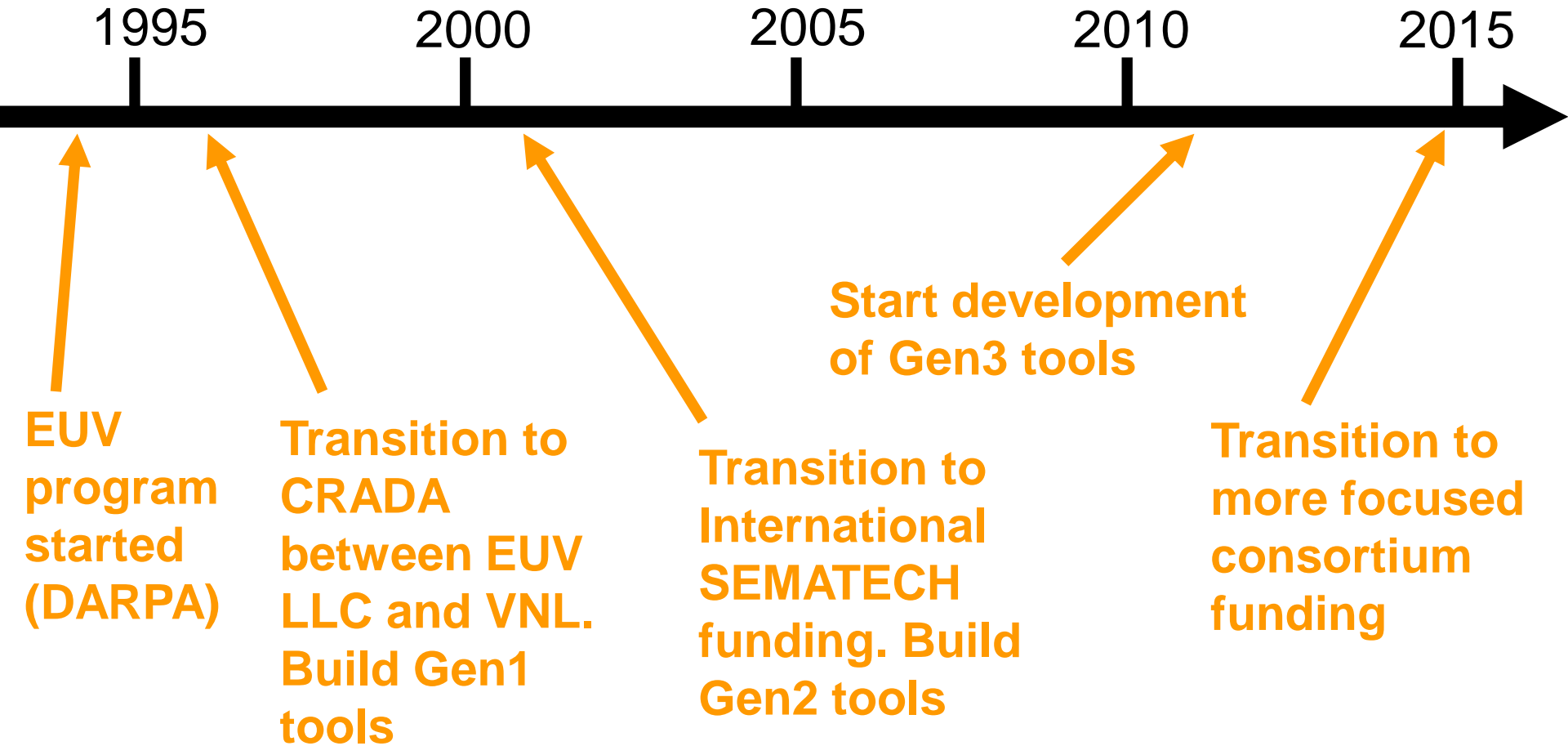


# Outline



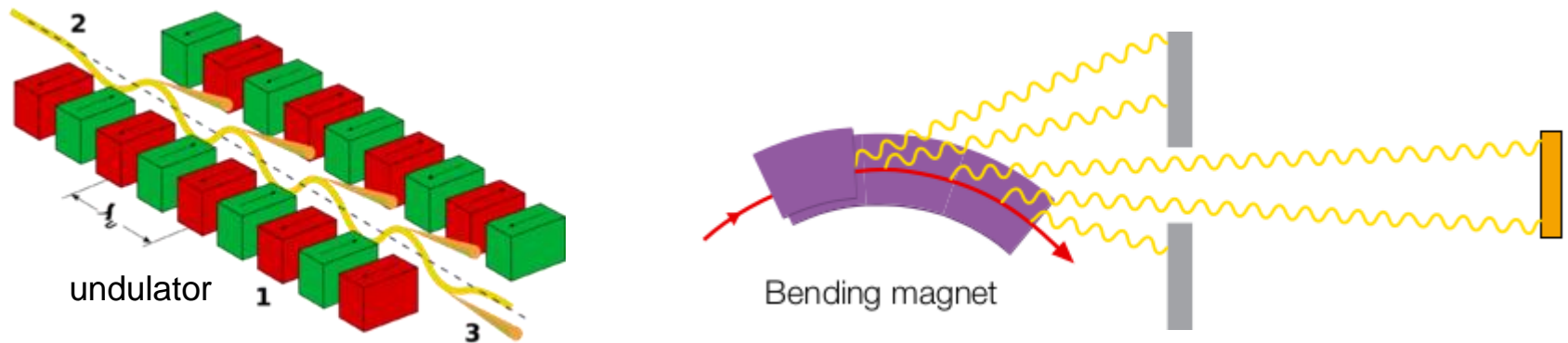
- Introduction
- Program evolution

# ***LBNL EUV program history***



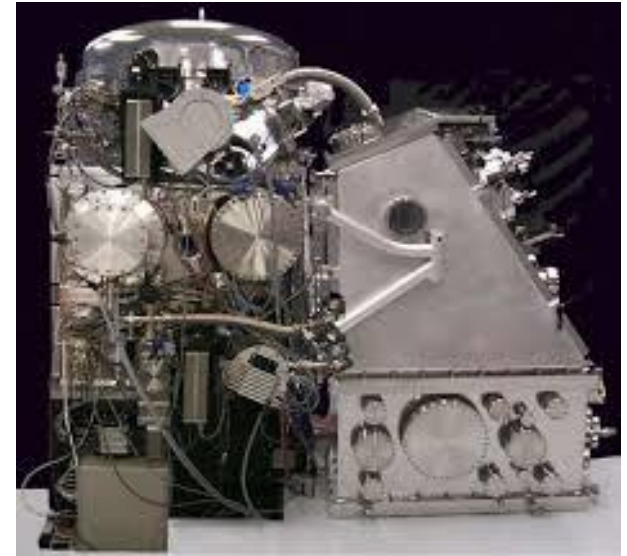
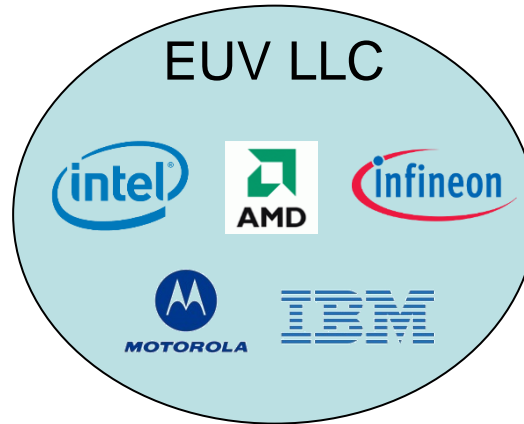
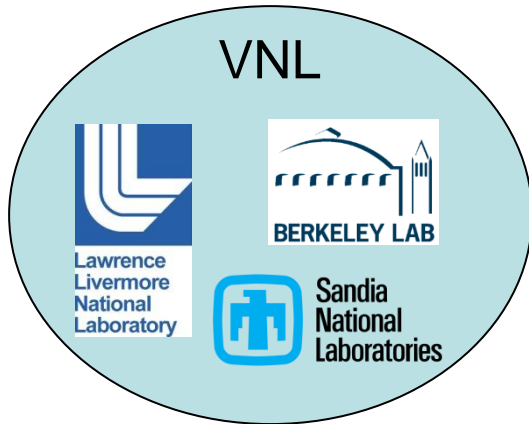
# ***DARPA program (1994-1996)***

- Develop key EUV facilities at the ALS to enable research and development
  - Coherent undulator beamline
  - Incoherent bending magnet beamline



# VNL/EUV LLC CRADA (1997-2002)

- Engineering prototype development
- \$50M/yr

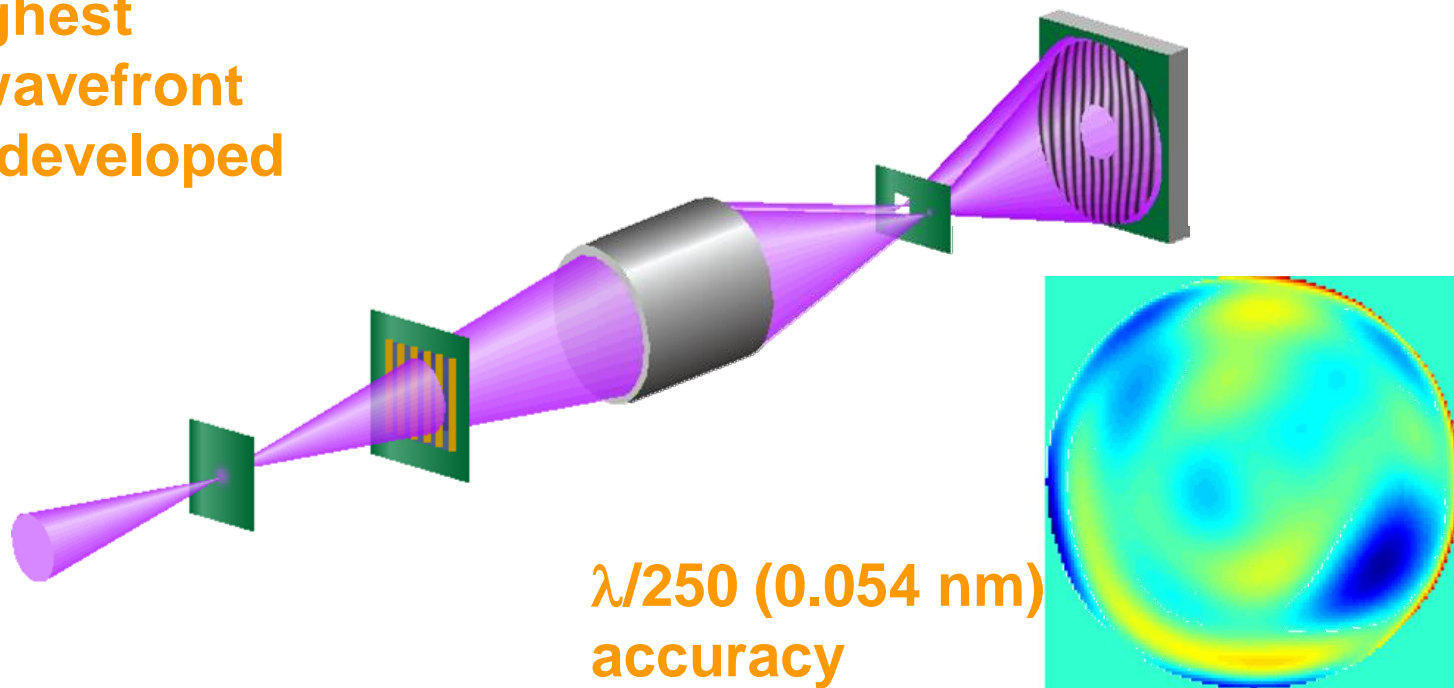


# ***VNL/EUV LLC CRADA (1997-2002)***

- Engineering prototype development
  - LBNL: EUV metrology and testing and coating development
  - LLNL: EUV optic and mask development
  - SNL: Lithography system development, stages, source ...

# Key LBNL contributions in VNL period

World's highest  
accuracy wavefront  
metrology developed

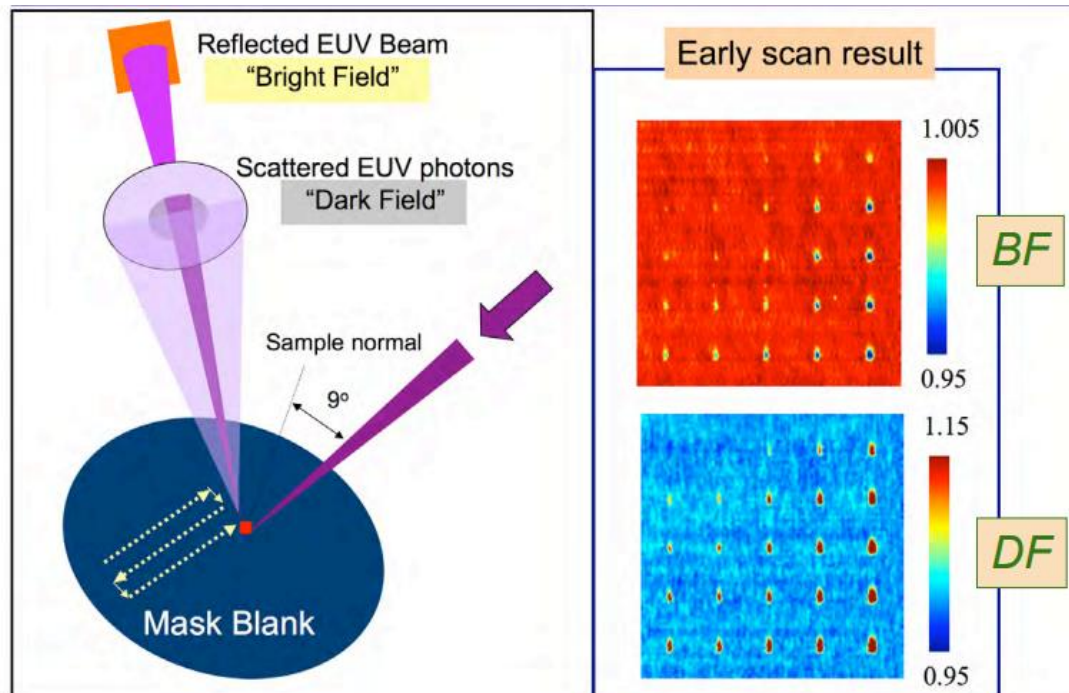


# Key LBNL contributions in VNL period

World's first EUV defect scanner

Discovery of EUV "haze"

Discovery of EUV specific defects

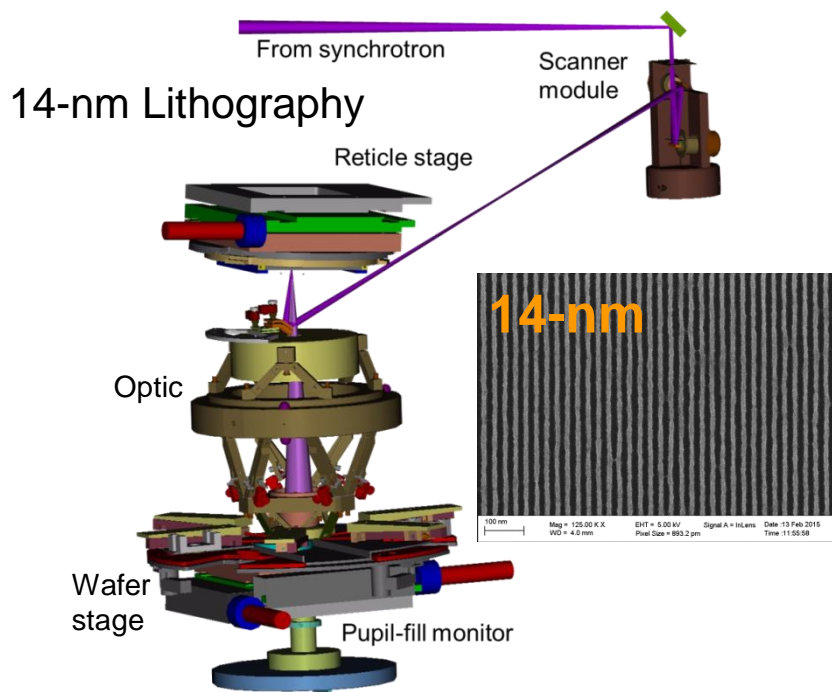


VNL  
National  
Laboratory

EUVL

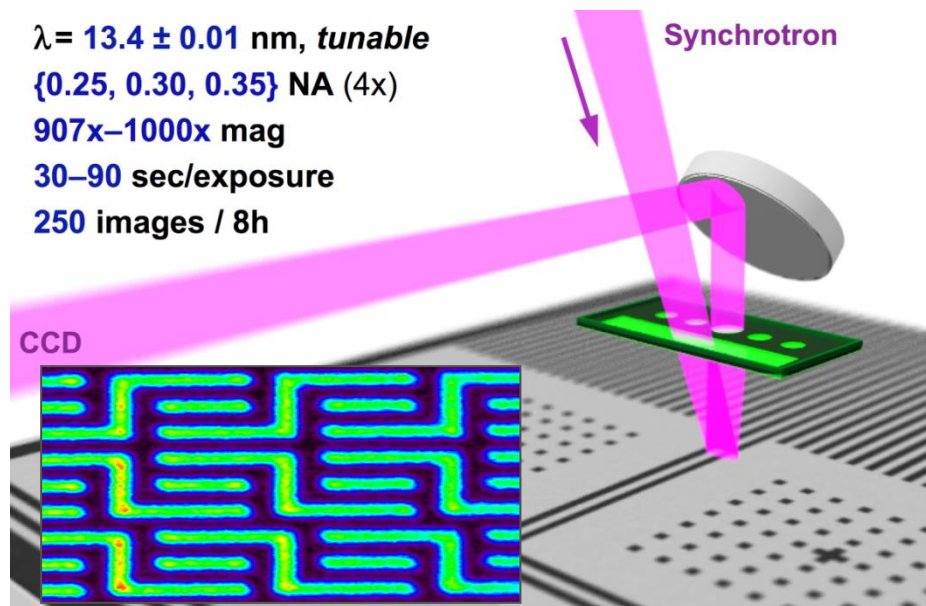
# LBLN/SEMATECH program (2003-2014)

- Transition to materials (resist and mask) characterization (\$5M/yr)



## EUV Microscopy

$\lambda = 13.4 \pm 0.01$  nm, *tunable*  
{0.25, 0.30, 0.35} NA (4x)  
907x–1000x mag  
30–90 sec/exposure  
250 images / 8h

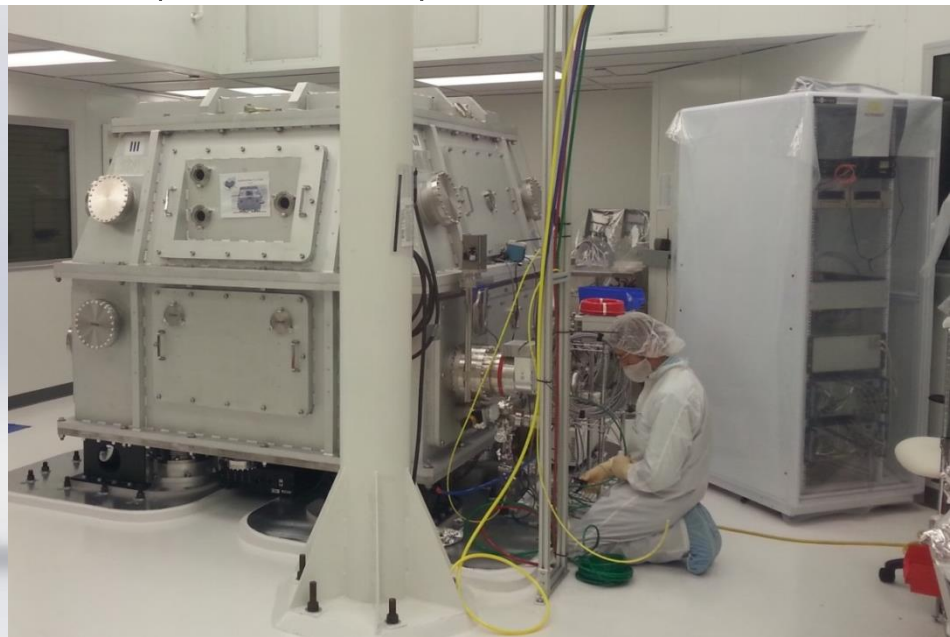
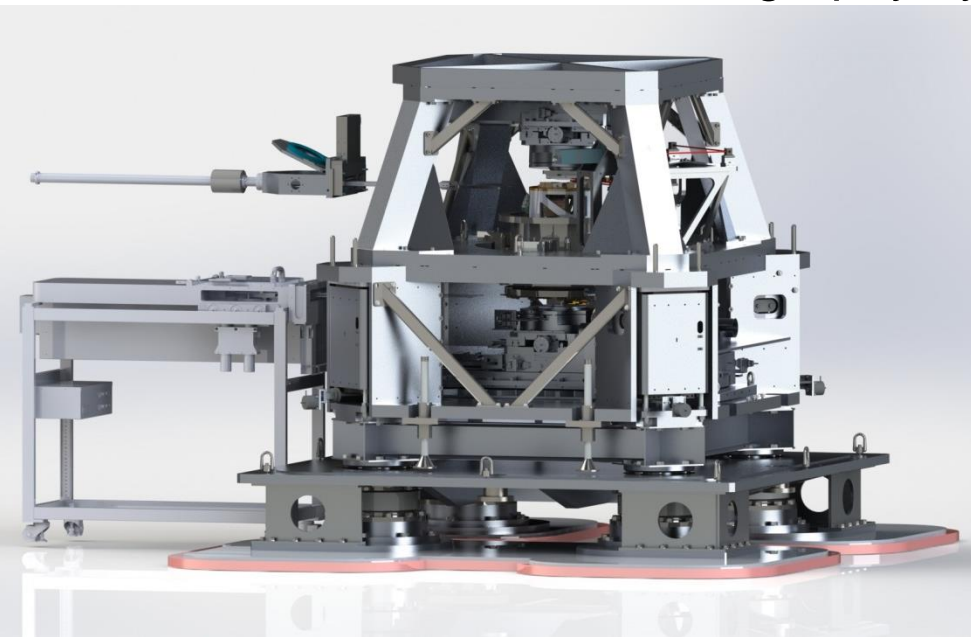




# ***LBLN/EUREKA program (2015-present)***

- Renew research infrastructure to maintain >5 year time horizon (\$6M/yr)

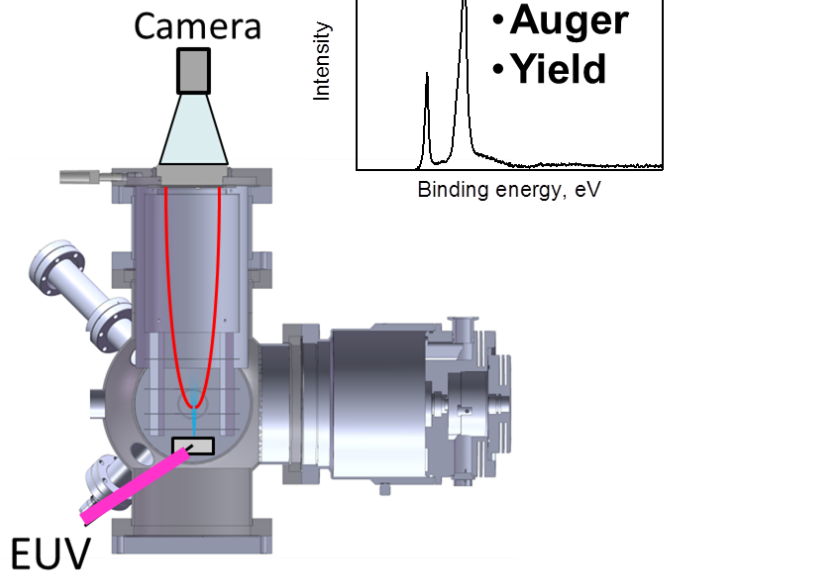
8-nm lithography system (2-nm node)



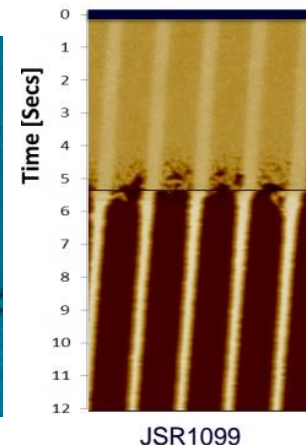
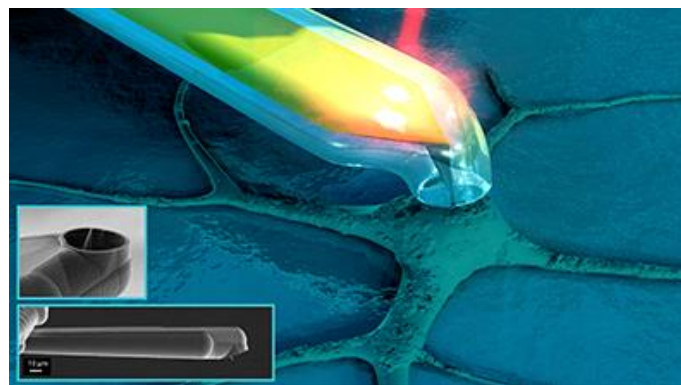
# ***LBLN/EUREKA program (2015-present)***

- Expand materials characterization to fundamental properties

## **Photoelectron Spectrometer**



## **Encased cantilever for fast response in liquid**



# Summary

- LBNL/Industry partnership in EUV development is 20 years old and going strong
- Keys to success
  - Time horizon not too long and not too short
    - Keep industry directly engaged in true co-work
  - Adapt to changing needs
    - Welcome timely transitions to industry
    - Anticipate future needs