Micro/Nano Engineering Lab

“MEMS (Micro Electro-Mechanical Systems)”

2.674

Sang-Gook Kim

- Lab sections
- Lab manual (Module #1 and #2)
- Lab safety training certificate, due Feb. 16, 12 PM.
- Reading suggestions
  - Feynman Lecture, “Plenty of Room at the Bottom”
  - Intro MEMS
  - Madou, M. J. (2002). *Fundamentals of Microfabrication.* (2nd ed.). CRC Press
  - C. Liu, Foundations of MEMS, Prentice Hall, 2006

Great Engineering Achievements of the Century,

NAE

http://www.greatachievements.org

Great Engineering Achievements of the Century, NAE

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. Petroleum and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials

No limit in the scale of integration

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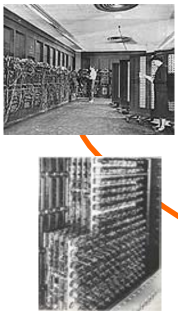
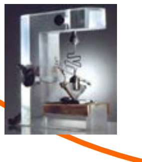
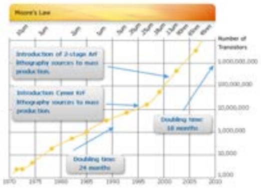


IBM's Early Computers (1950s), MIT Press.

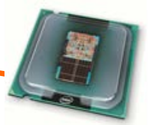


First transistor made in 1947 by Shockley, Bardeen, and Brittain at Bell Labs.

Silicon Valley
A Movie

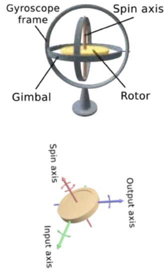


Early integrated circuit from MIT. Edwin Hall, circa 1965.



www.intel.com/pressroom/kits/core2duo/index.htm

- -pitch ✓
- -roll
- -yaw



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Inertial Navigation System

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- -Rate grade, tactical grade, inertial grade
- -Bias drift (°/h)

Coriolis Acceleration

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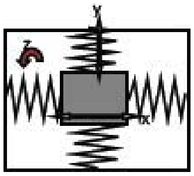
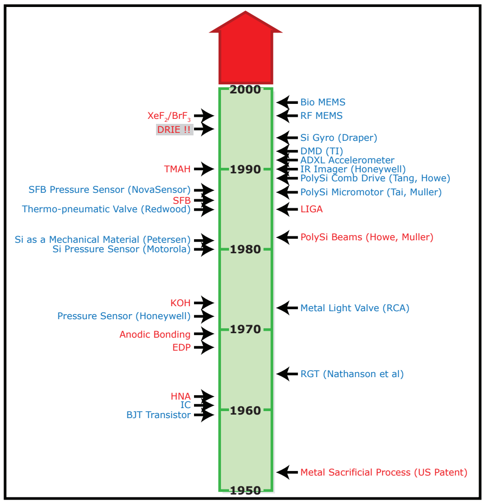


$$F_c = -2m(\omega \times v)$$

History of MEMS



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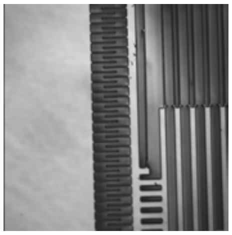
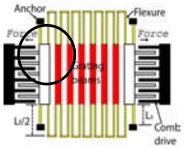
Comb Drive Designs



Linear

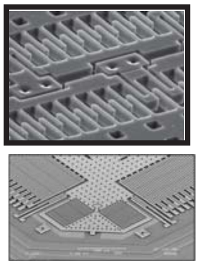


🟥 Grating beams
🟨 Flexures
□ ■ Electrostatic comb-drives

Barbastathis and Kim group, MIT

Airbag Accelerometers

- Airbag accelerometer looks like a silicon circuit, but with moving parts.
- In a crash, your car decelerates very quickly
- A spring, damper and mass can measure the deceleration.



Analog devices

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ADXL-50
Full range: 0-50g
sensitivity: 200 mV/g
resolution: 5 mg at 100 Hz
noise floor: 0.5 mg/(Hz)$^{1/2}$

Micro Technology ...

- Path 1: Better and better integrated circuits (CPUs, VLSI, Flash etc.)
- Path 2: Micro-Electro-Mechanical Systems (MEMS)
  - Why only make electronics, when you could make little silicon structures that bend, move, and process electrical signals for various purposes?
  - Or make micrometer scale flow channels for rapid DNA analysis?
  - Either way, you need to create empty spaces beneath some of your device elements
  - Vast possibilities enabled by a vast range of manufacturing technologies

Why shrink things? – scaling law

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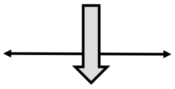

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- Shock and impact
- Scale and form factor
- Load carrying capability
  - Gravity
- Surface/Volume
  - Heat loss/generation
  - Cold blooded

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Image courtesy of NASA.

Frog, Water Strider, Gecko

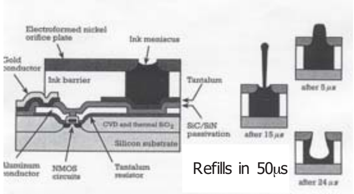
Mass/surface tension

Sangbae Kim

Mass/surface area

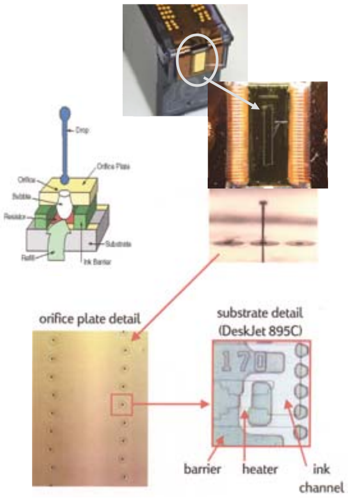
Ink jet printer

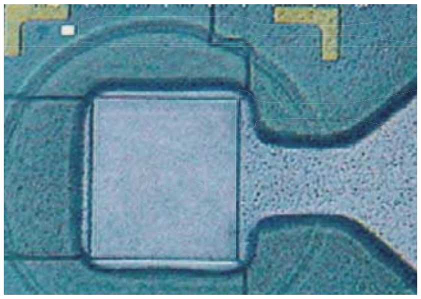
- Thermal jet by HP
- Superheat ink 250°C
- Peak pressure 1.4 MPa



Refills in 50µs

Figure 4.4 Cross-sectional illustration of a Hewlett-Packard thermal inkjet head and the ink firing sequence. Adapted from C. C. Beatty [5].

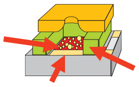




Microscopic view under stroboscopic illumination

- Up to 36 000 vapor bubble cycles per second

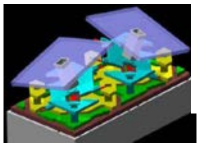
Jeff Nielsen, HP



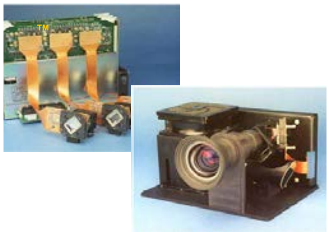
- barrier defines the walls of the chamber where the vapor bubble forms
- refill channel lets fresh ink flow into chamber
- heater generates the vapor bubble in the ink
- nozzle is positioned over resistor to form a drop of ink

Tiny Products

- DLP (Digital Light Processing, TI)



DLP
10^6 *micromirrors, each 16μm², ±10° tilt*
(Hornbeck, Texas Instruments DMD, 1990)



Typical integrated circuit cross-section

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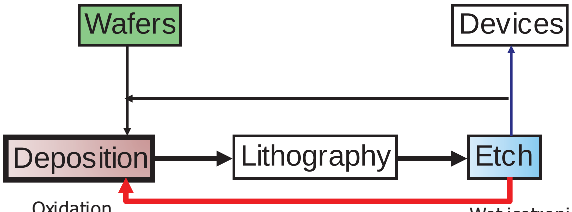
http://www.aero.org/publications/crosslink/summer2003/03.html

- Simplified integrated circuit cross-section (real ones often have more layers of metal interconnects)
- Very complex, small features stacked on top of each other – but only the kinds of features that are needed for integrated circuits

MEMS Process Flow: overview



Wafers

Devices

Deposition

Lithography

Etch

Oxidation
Sputtering
Evaporation
CVD
Sol-gel
Epitaxy

Photo resist coating
Pattern transfer
Photo resist removal

Wet isotropic
Wet anisotropic
Plasma
RIE
DRIE

Basic Building Block: Wafers

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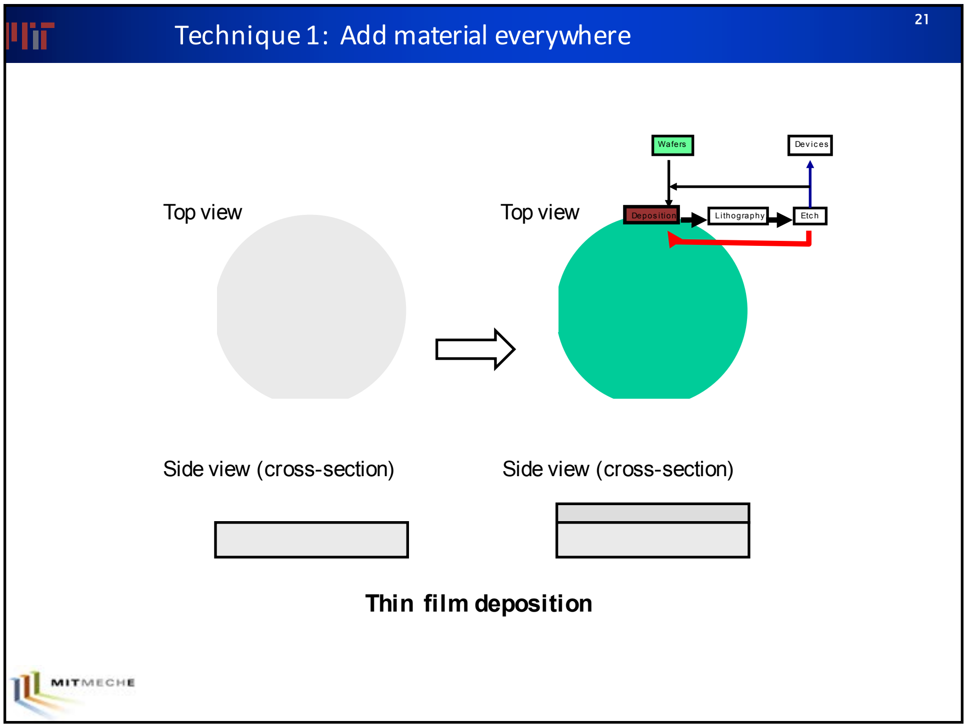
www.addisonengineering.com

engr.calvin.edu

- The most common wafers are silicon wafers, as shown above
- Other wafers (glass, quartz, etc.) are also available
- Silicon wafers come in sizes from a 2" to 12"
- Plain, unpatterned wafers are then patterned into an array of small, repeated structures called dies



Technique 1: Add material everywhere

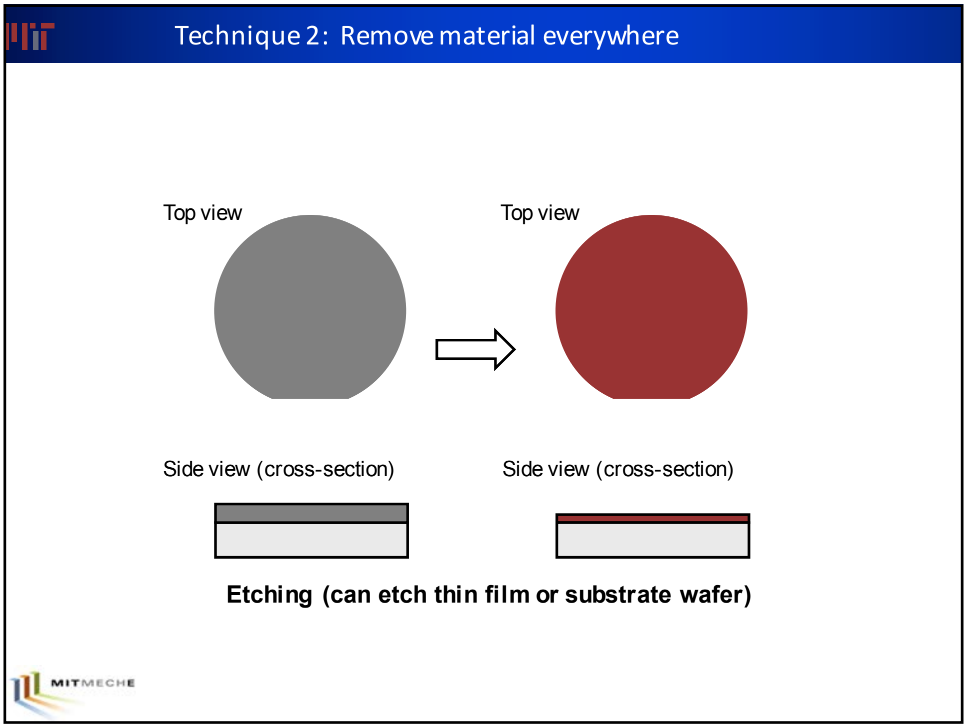
Top view

Top view

Side view (cross-section)

Side view (cross-section)

Thin film deposition



Technique 2: Remove material everywhere

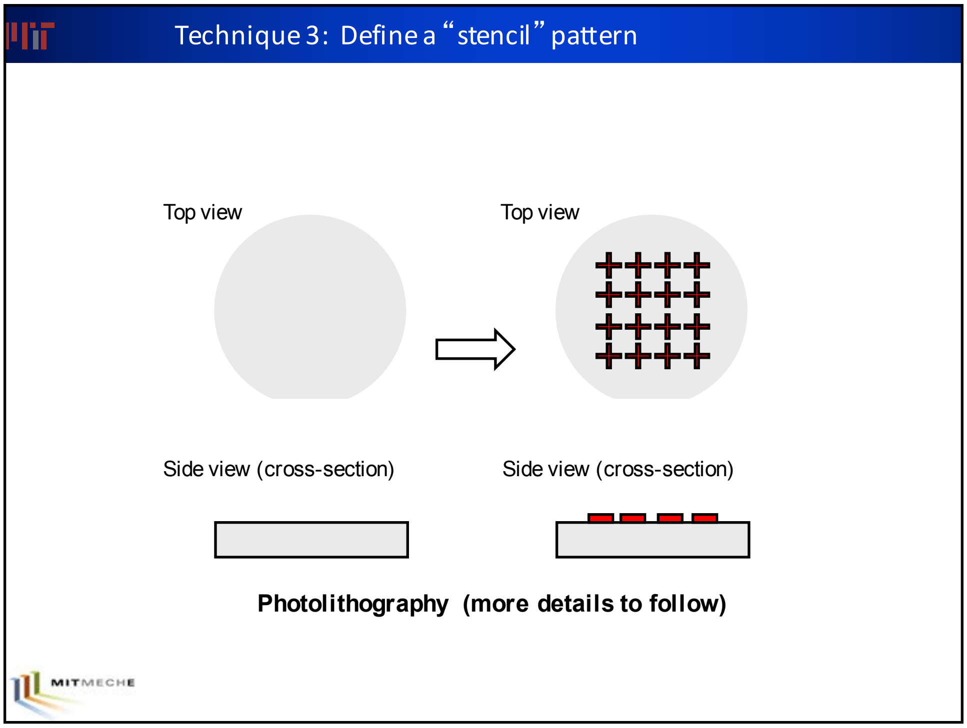
Top view

Top view

Side view (cross-section)

Side view (cross-section)

Etching (can etch thin film or substrate wafer)



Technique 3: Define a “stencil” pattern

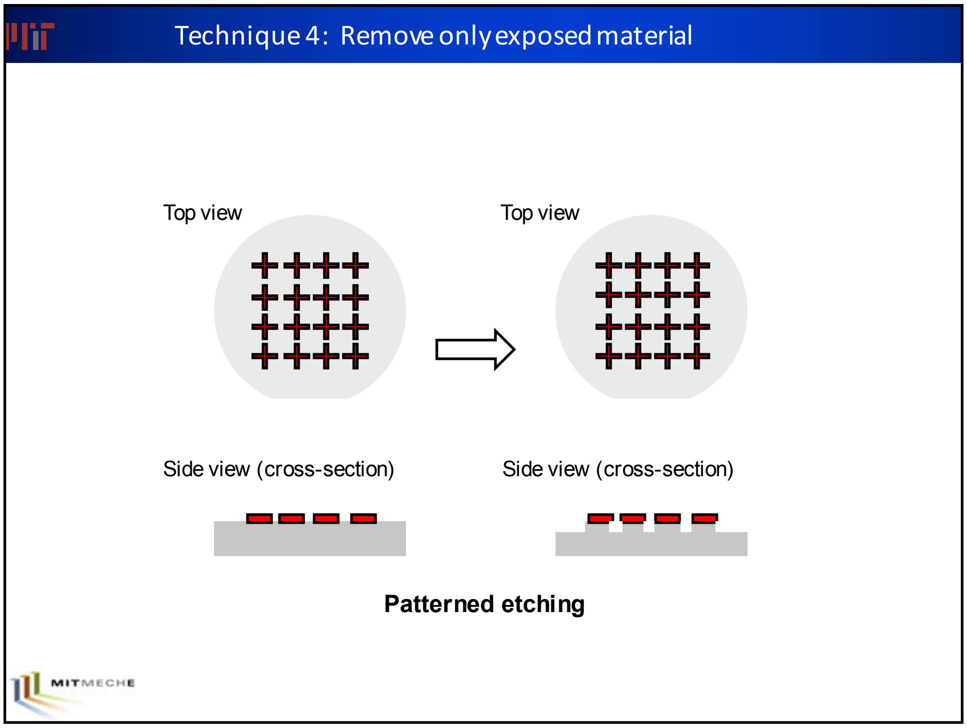
Top view

Top view

Side view (cross-section)

Side view (cross-section)

Photolithography (more details to follow)



Technique 4: Remove only exposed material

Top view

Top view

Side view (cross-section)

Side view (cross-section)

Patterned etching

Technique 5: Add material in exposed areas

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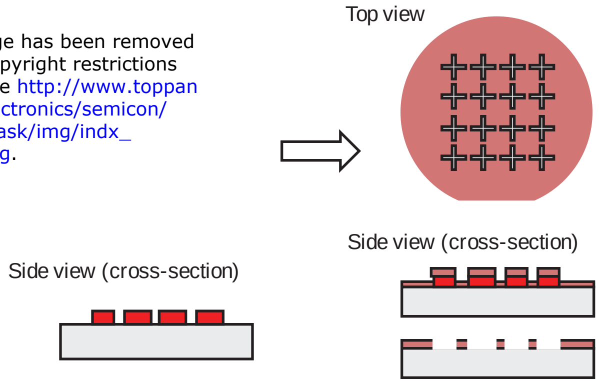

Thin film lift-off

Masks

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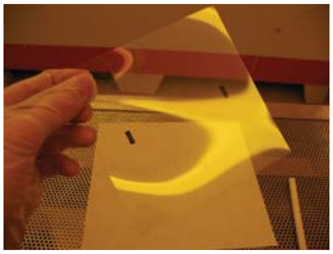
Please see http://www.toppan.co.jp/electronics/semicon/photo_mask/img/indx_pic_01.jpg.

www.toppan.co.jp

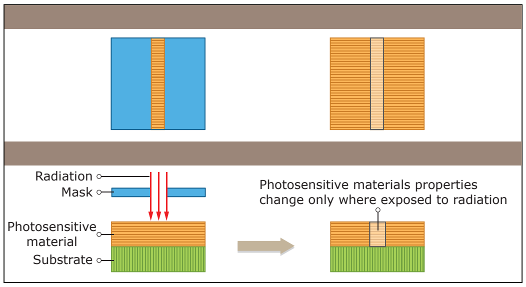
"Real" masks: patterned chrome on quartz or glass (expensive but high resolution)



Transparency masks: patterns printed from a high resolution printer onto transparency film (cheap, fast, lower resolution)

Lithography (Greek, “stone-writing”)

- Pattern Transfer
  - Application of photosensitive PR
  - Optical exposure to transfer image from mask to PR
  - Remove PR --> binary pattern transfer

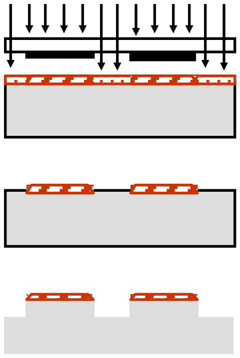


Photosensitive materials properties change only where exposed to radiation

Image by MIT OpenCourseWare.

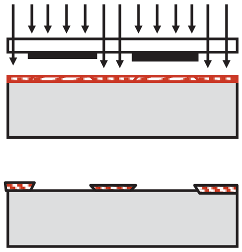
Photolithography with Positive Resist

- Spin a photosensitive resist layer onto the wafer surface
- Photoresist is a few micrometers thick
- Expose resist with UV light through a photolithographic mask; wherever the light hits it, the resist molecules get chopped up
- Developer removes exposed resist
- Forms a stencil that determines which parts of the surface are affected by the next process



Photolithography with Negative Resist

- Spin a photosensitive resist layer onto the surface
- Thickness of order 1 micron
- Expose resist with UV light through a mask
- This time, light links the molecules together to make them tougher
- Developer removes unexposed resist



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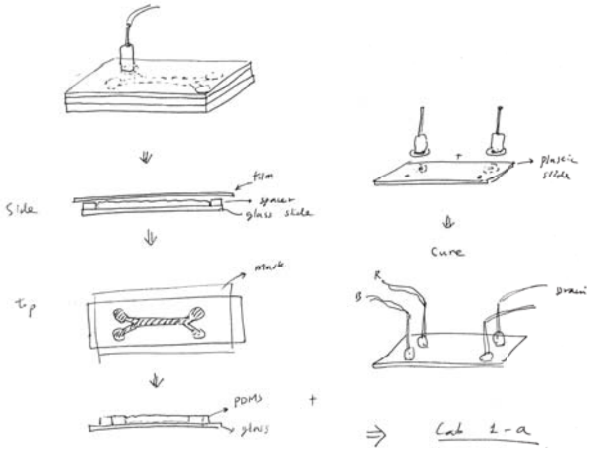
Lab module 1-a: Milifluidics



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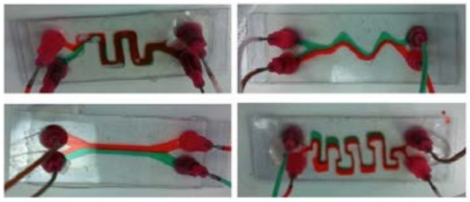
Lab #1

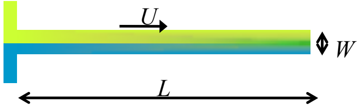


Mixing in flowing systems- Péclet number

- Péclet number: Compares transport due to advection to transport due to diffusion

$$t_{adv} \sim \frac{L}{U}$$

$$t_{diff} \sim \frac{W^2}{D}$$



D: difision Coeff.

$$\frac{\textit{timescale for diffusion across channel width}}{\textit{timescale for advection along channel length}} \sim \frac{W^2/D}{L/U} = \frac{LU}{D}\left(\frac{W}{L}\right)^2 = Pe\left(\frac{W}{L}\right)^2$$

- *W = k λ / NA* (Rayleigh Eqn.)
- In 1975, 405 nm (Hg H-line) at an NA of 0.32, a line width of 10 μm, mercury lamps
- deep-UV (248-nm) KrF Excimer laser, 193 nm ArF laser, 157nm

Table 1: ***Wavelength "Generations"***
Intel Road Map

Year	Node	Lithography
1981	2000nm	i/g-line Steppers
1984	1500nm	i/g-line Steppers
1987	1000nm	i/g-line Steppers
1990	800nm	i/g-line Steppers
1993	500nm	i/g-line Steppers
1995	350nm	i-line -> DUV
1997	250nm	DUV
1999	180nm	DUV
2001	130nm	DUV
2003	90nm	193nm
~~2005~~	~~65nm~~	~~193nm -> 157nm~~
~~2007~~	~~45nm~~	~~157nm -> EUV~~
2009	32nm and below	EUV, X-ray

Nanoimprinting
- Soft Lithography
- Dip Pen Lithography
- SPM-based patterning

193 nm immersion lithography

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- Area 7 in DME
- Fluidics, heat transfer and energy conversion at the micro- and nanoscale
- Bio-micro-electromechanical systems (bio-MEMS)
- Optical-micro-electromechanical systems (optical-MEMS)
- Engineered nanomaterials
- Energy and Nano-Manufacturing
- Course 2A (Nano Track)
- Micro/Nano Area in ME

http://web.mit.edu/nanomicro

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