Microfabrication Introduction

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Schedule of the Lectures and Labs

Lecture 1: Introduction of Microfabrication, Oct. 28

Lecture 2: Soft Lithography I and Lab#9 Intro, Nov. 2

Lab #9: Microfabrication I, Nov. 2-3

Lecture 3: Soft Lithography II and Lab#10 Intro, Nov. 4

Lab #10: Microfabrication II, Nov. 9-10

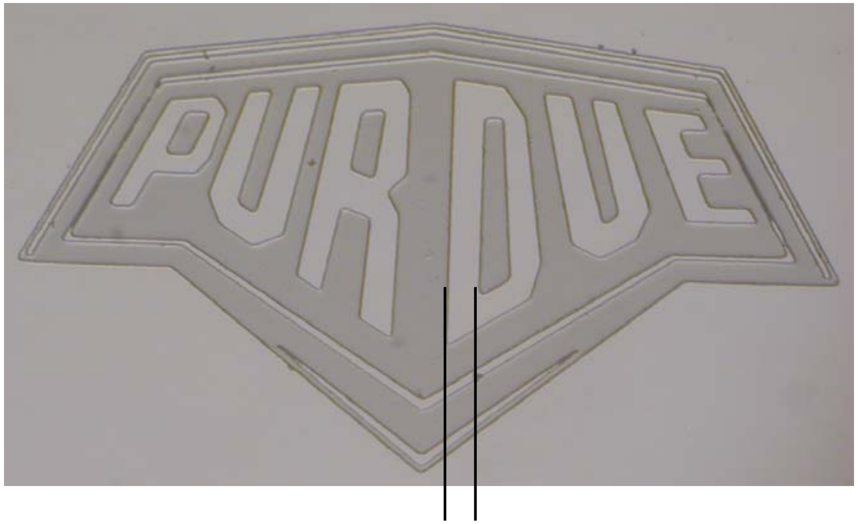
Lectures and lab modules online:

http://widget.ecn.purdue.edu/~mmcenter

http://widget.ecn.purdue.edu/~mmcenter/ME363.htm

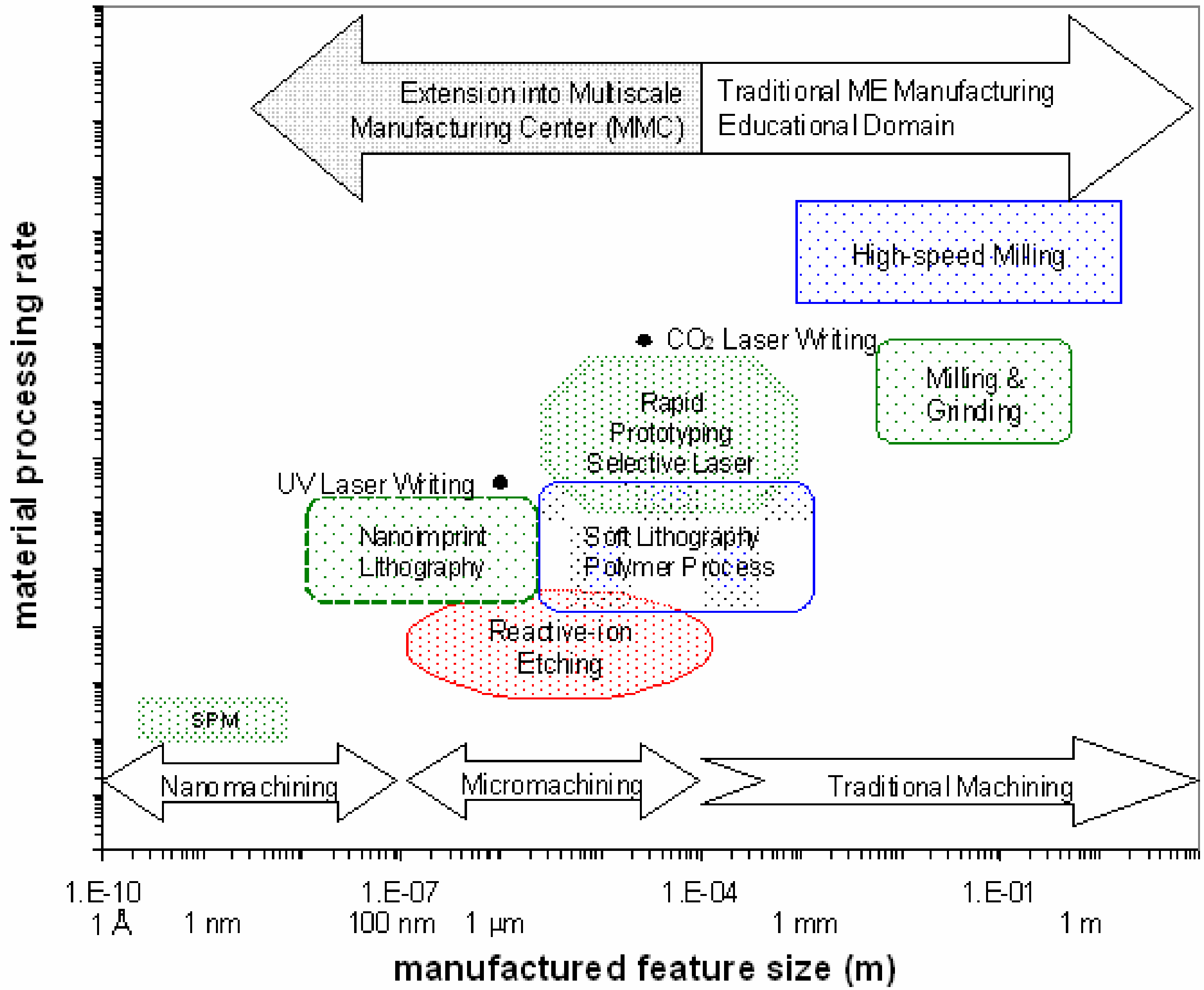
Microfabrication: Overview

Mechanical Engineering is the branch of engineering that serves society through the analysis, design and manufacturing of systems at all size scales that combine energy, materials, and information to produce useful mechanical work.



20 μm

Microfabrication: Overview



Courtesy of Prof. Dan Hirleman, ME, Purdue University

Microfabrication: Introduction

Typical Dimensions

- 100 nm – μm
  - 1 nm – 2 ~10 atoms
  - Average human hair diameter: 50 μm

Advantages

- Less material usage
- Lower power requirement
- More compact and integrated

Microfabrication: Introduction

Microfabrication Applications

- MEMS
- Microfluidics
- Micro-optics
- Nanotechnology

Microfabrication Techniques

- Traditional: Fabrication of microelectronic devices or Integrated Circuits (IC) microfabrication
- Nontraditional: E-beam, Laser beam, ultrasonic, etc.

Microfabrication: Introduction

Fabrication of Microelectronic Devices

- The Invention of the transistor in 1948

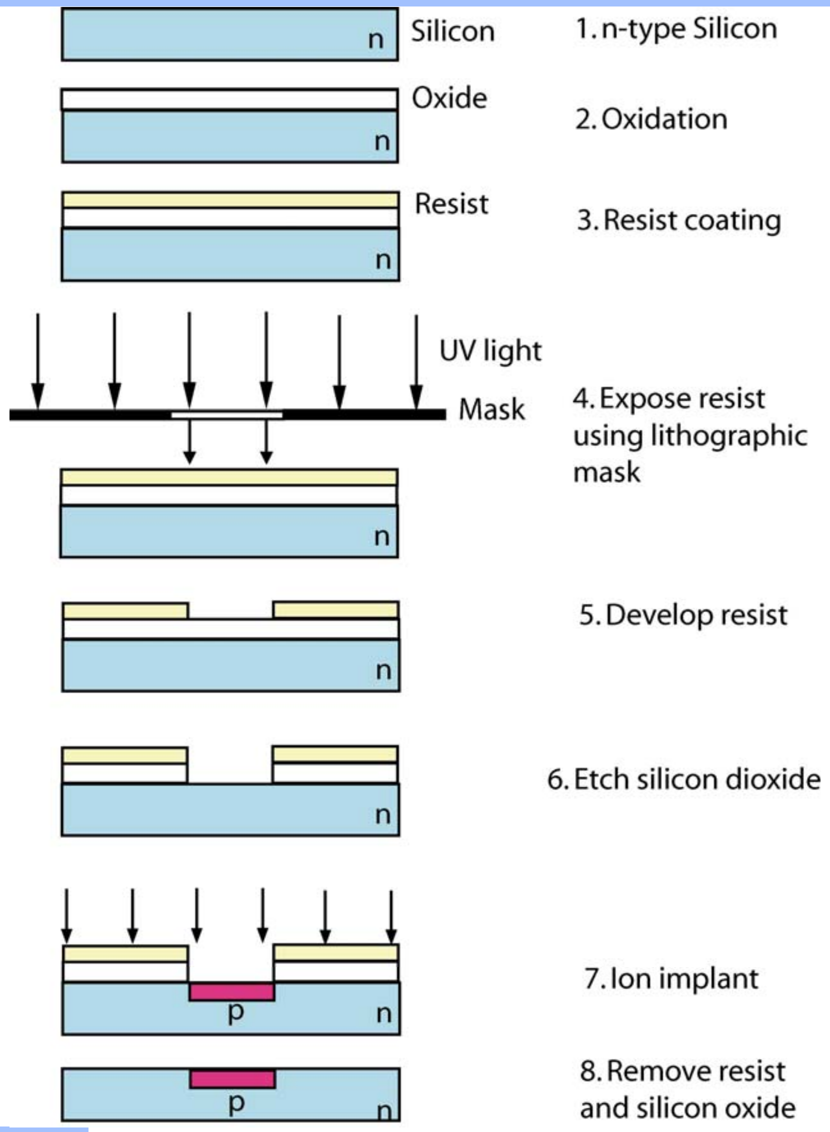
  Developed as a replacement for bulky and inefficient vacuum tubes and mechanical relays, the transistor later revolutionized the entire electronics world. Today, billions of transistors are manufactured weekly.

- Microelectronics have played an ever-increasing role in our lives:
  - Computers
  - Cell phones
  - Calculators
  - CD/MP3 players
  - Cars

Collection of printed circuit boards

Fabrication of Microelectronic Devices

Example: processing of a *p-n* Junction diode



Fabrication of Microelectronic Devices

Microfabrication Processes

- Wafer preparation
- Oxidation
- Resist coating
- Pattern generation
- Etching
- Diffusion and ion implantation
- Bonding and packaging

Fabrication of Microelectronic Devices

Substrate Materials

- Germanium
  - Earliest electronic devices were fabricated on Ge
- Silicon
  - The second abundant element only to oxygen
  - Larger bandgap (1.12 eV), better suited to higher operating temperatures
  - Stable and water insoluble oxides (SiO_2)
- Gallium Arsenide
  - Compound semiconductors
  - Ability to emit light, laser diode, LEDs
  - Higher operating temperatures

Fabrication of Microelectronic Devices

Making Silicon Wafer

- Silicon purification

Step 1: $SiO_2 + 2C \rightarrow Si + 2CO$

MGS (Metallurgical grade silicon): 95% -98%

Step 2: $Si + 3HCL \rightarrow SiHCL_3\ (g) + H_2$

$SiHCL_3$ gas is purified by distillation

Step 3: $2SiHCL_3 + 2H_2 \rightarrow 2Si + 6HCL$

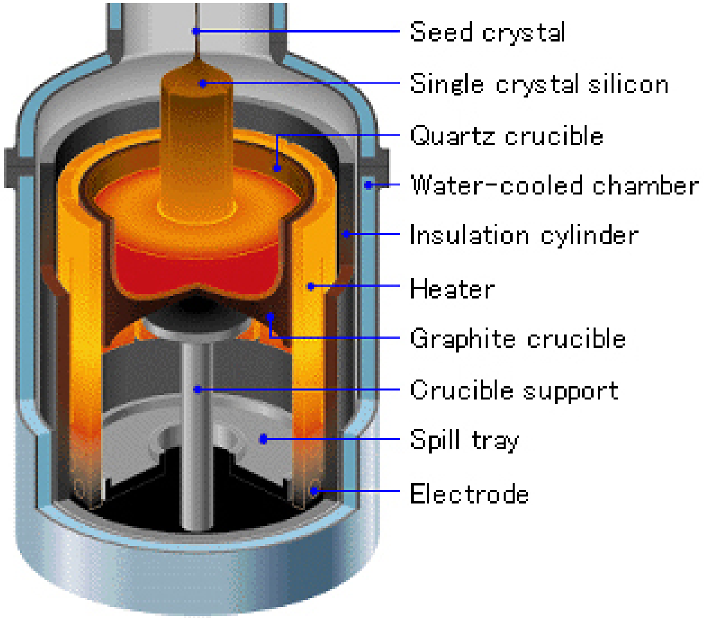
EGS (electronic grade silicon): >99% purity

Both MGS and EGS are polycrystalline material, which is used as a source in single-crystal growth.

Fabrication of Microelectronic Devices

Making Silicon Wafer

- Czochralski silicon crystal growth
  - A seed crystal is dipped into a silicon melt crucible and then slowly pulled out while being rotated.
  - A single-crystal silicon ingot over 40 inches in length.



- Ground and slice
  - A precise diameter is obtained by grounding
  - Silicon ingot is sliced into wafers
  - Typical wafer thickness: 300 μm, 500 μm, diameter: 2”, 4”

Fabrication of Microelectronic Devices

Oxidation

- Silicon dioxide can be used for dopant masking and device isolation
- Silicon dioxide is the most widely used oxide in IC industries
- Silicon dioxide is non-conductive, transparent, etchable
- Thickness of silicon dioxide: the tens to the thousands of angstroms
- Dry oxidation: elevating the substrate temperature typically to 750 ºC -1100 ºC in an oxygen-rich environment

Fabrication of Microelectronic Devices

Oxidation

• Wet oxidation: oxidizing agent in water-vapor atmosphere. Higher oxidation rate but lower oxide density

• Selective oxidation: use silicon nitride to inhibit the passage of oxygen and water vapor. Through the masking of certain areas with silicon nitride, the silicon under these areas remains unaffected but the uncovered areas are oxidized.

Fabrication of Microelectronic Devices

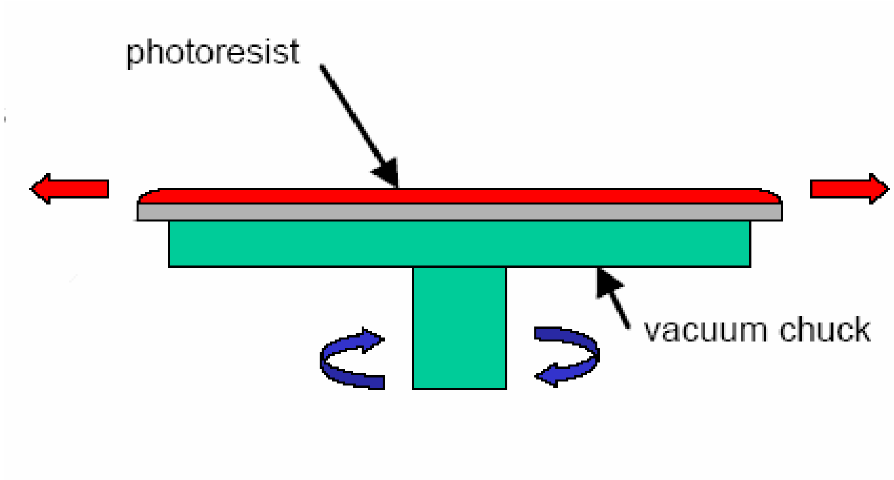
Resist Coating

- Resist chemistry
  - Photoactive compound
  - Base resin
  - Solvent
  - Negative (SU-8) and positive resist
- Coating methods
  - Spin coating: standard
  - Electrochemical coating: for special resist
  - Spray coating: thin resist only
  - Casting: thick resist only

Fabrication of Microelectronic Devices

Spin coating

- Wafer is held on a spinner chuck by vacuum and resist is coated to uniform thickness by spin coating.
- Typically 3000-6000 rpm for 15-30 seconds.
- Most resist thicknesses are 1-2 μm for commercial Si processes



Fabrication of Microelectronic Devices

Pattern Generation

- To transfer the circuit design data into a physical structure.
- Must be able to expose single pixels and expose them very fast.
- Earliest pattern generator: optomechanical shutter systems with a flash bulb. Wafer is mounted on a scan stage. Line width > 10 μm, scan rate >1 Hz

Fabrication of Microelectronic Devices

Pattern Generation

•Electron beam writing: drawing a single feature with a focused beam of electrons or ions.

Pros:

– Ultimate resolution beam spot size can be as small as 5 nm, line width ~10 nm.

– Faster than the mechanical aperture method

Cons:

– Small writing area

– Not as fast as optical lithography

E-beam writers is used to write photomasks for optical lithography

Fabrication of Microelectronic Devices

Pattern Generation

•Optical lithography with photomasks is the dominant patterning technology.

– Instead of direct writing millions of pixels by scanning, optical lithography uses a photomask to transfer the pattern to the substrate by one exposure.

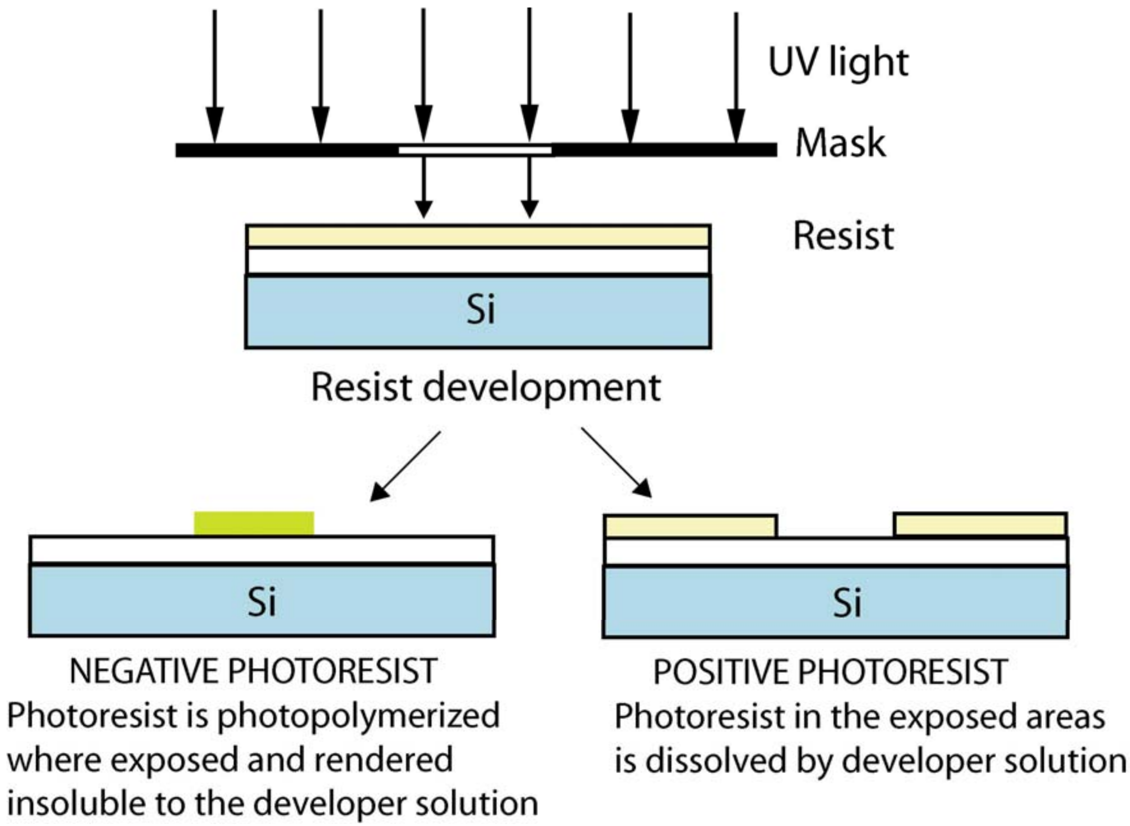
– Fastest speed: 10^{10} pixels in a one second exposure.

– Line width: submicron - micron

Fabrication of Microelectronic Devices

Pattern Generation

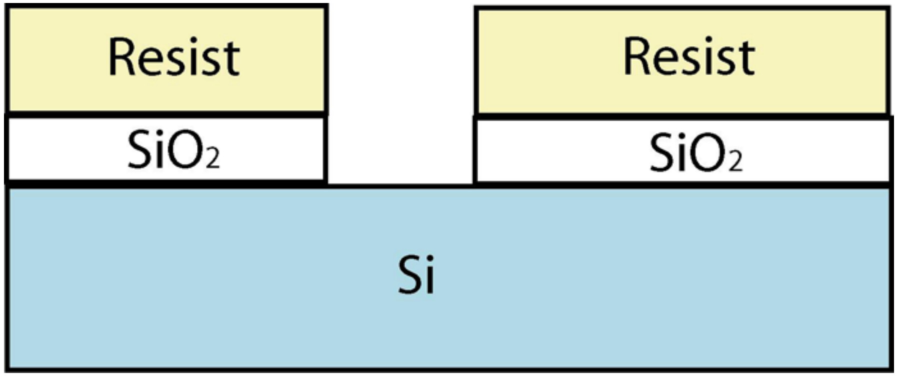
- Optical lithography



Fabrication of Microelectronic Devices

Etching

- Etching is the process by which entire films or particular sections of films are removed.
- It is important to etch one material without etching another – selectively etching.
- Etching methods:
  - wet etching
  - dry etching
  - sputter etching
  - plasma etching



Fabrication of Microelectronic Devices

Ion Implantation

• Semiconductor's electrical properties can be altered when controlled amount of dopant are added to their crystal structures.

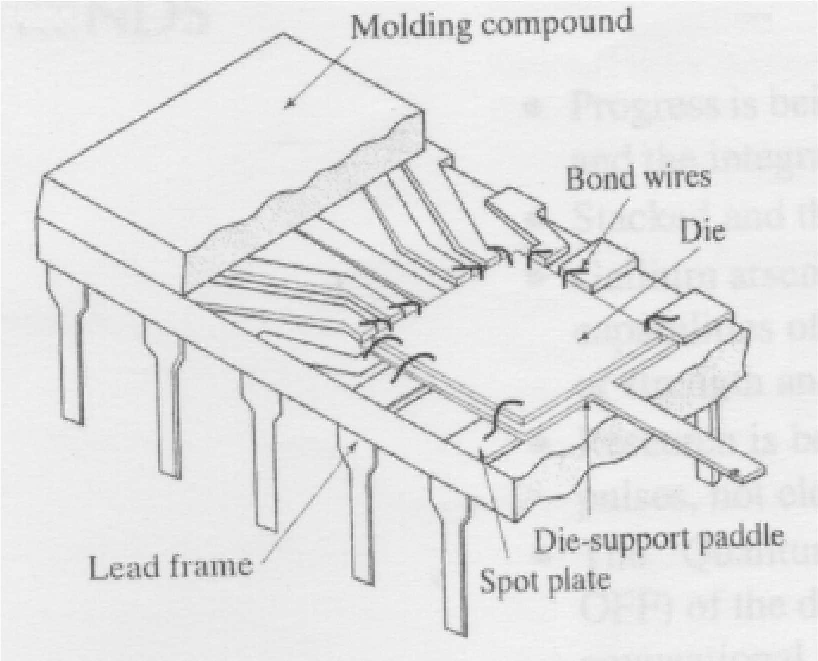
• Dopant types: Boron (p-type), Phosphorus (n-type)

• Ion implantation is a process in which accelerated ions hit the silicon wafer, penetrate into the silicon, and introduce dopants.

Fabrication of Microelectronic Devices

Other processes (not covered in this lecture)

- Diffusion
- Metallization
- Bonding
- Packaging



Courtesy of R. C. Jaeger and A. B. Glaser

Microfabrication: Other Technologies

Other Microfabrication Technologies

- High-precision machining tools
  - Micro-mills, drills 10 ~ 100 μm
  - Single-crystal diamond fly-cutter <1μm

- Laser-assisted micromachining
  - Laser used as a heating and softening tool
  - Laser directly machining

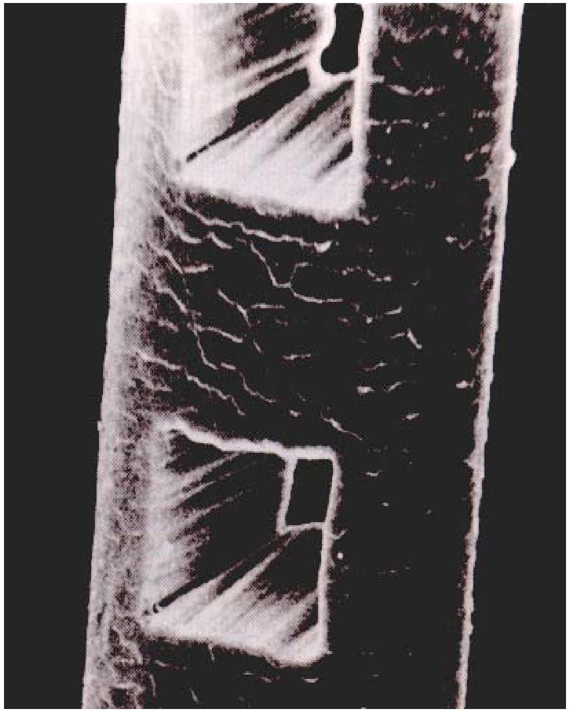
Microfabrication: Other Technologies

Advantages of Laser Micromachining

– Extremely powerful: a 100 W CO_2 laser can be focused into a spot of 0.01 cm in diameter. That gives approximately the irradiance of 1,000,000 W/cm^2

– Focusable: laser beam can be focused down to 1 μm by lens

– Controllable: laser power, diameter, wavelength, repetition frequency, pulse width

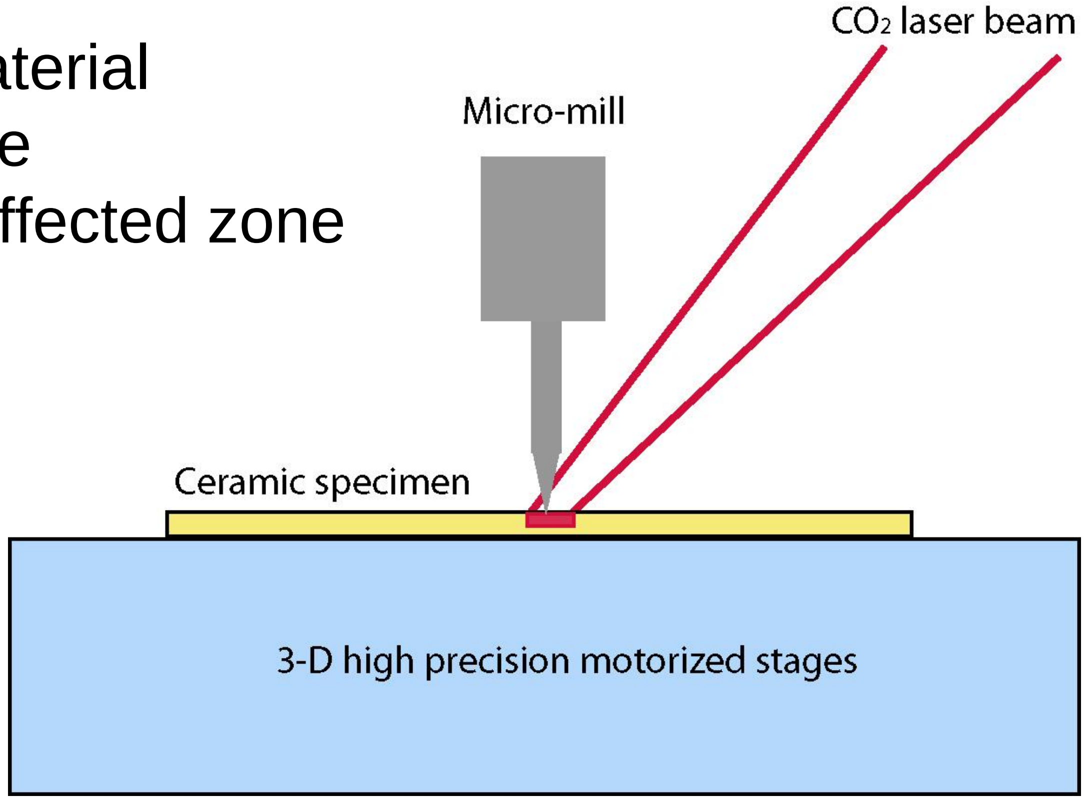


40 μm square holes drilled in human hair with an excimer laser. (R. C. Crafer and P. J. Oakley, 1993)

Microfabrication: Examples

Laser-Assisted Micromachining of Ceramic

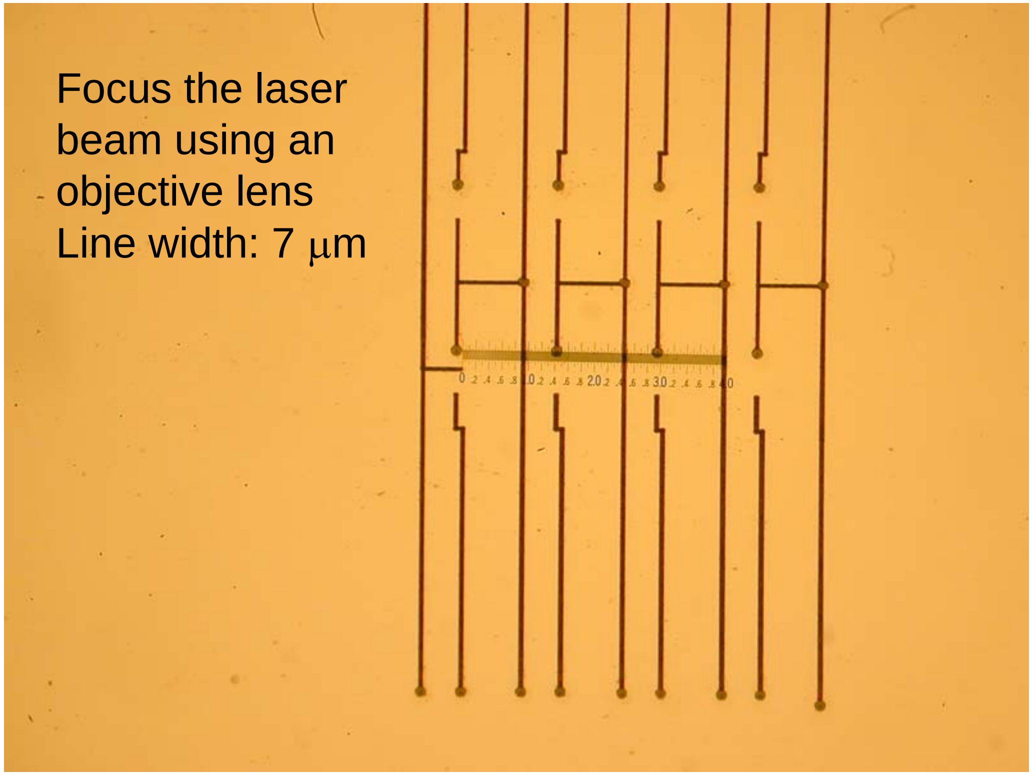
- Higher material removal rate
- No heat-affected zone



Prof. Young C. Shin, Laser Materials Processing Laboratory , ME, Purdue University

Microfabrication: Examples

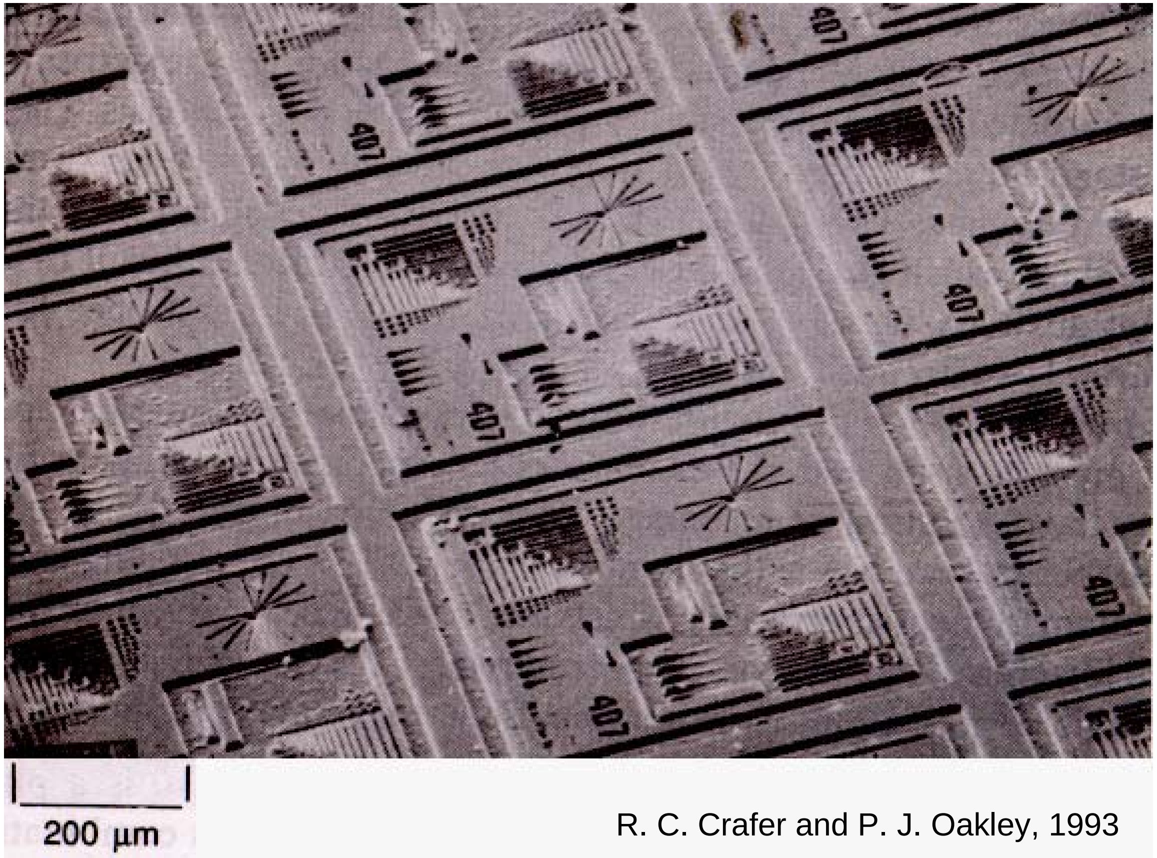
Nd:YAG Laser Direct Writing of Microcircuit



Prof. Xianfan Xu, Center for Laser Microfabrication, ME, Purdue University

Microfabrication: Examples

Polycarbonate Etched with KrF Laser

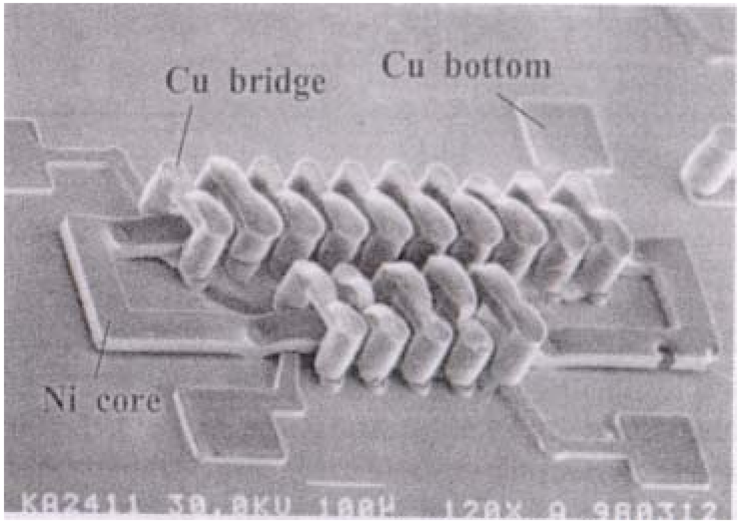


R. C. Crafer and P. J. Oakley, 1993

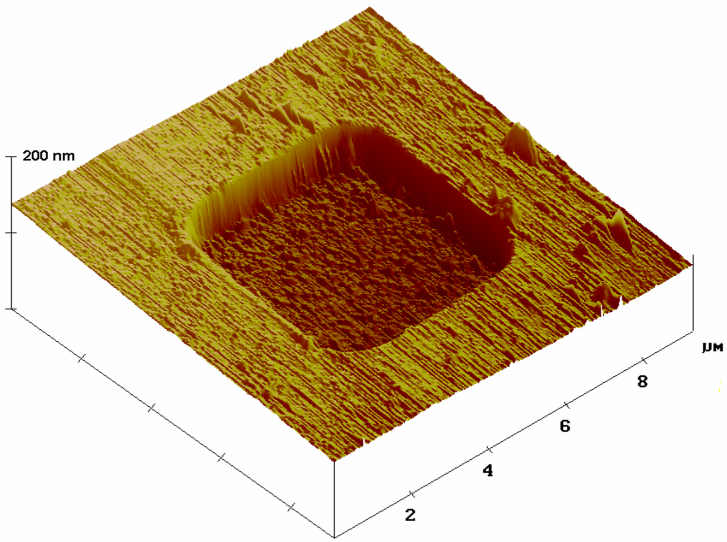
Microfabrication: Characterization

Structure Characterizing Techniques

- Optical microscopy
- Scanning Electron Microscope (SEM)
- Atomic Force Microscope (AFM)



SEM image of a 3D Micro-transformer (Yoon J.B., 1998)



AFM image of a 5x5 μm hole etched in silicon