ME 517: Micro- and Nanoscale Processes

Lecture 4: Microfabrication - Techniques I

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Outline of Microfabrication Section

- Introduction to Microfabrication
- Lithography
- Dry Etching Techniques
- Additive Techniques
- Bulk Micromachining
- Surface Micromachining
- Novel, quick, advanced techniques

Project 1:

- Choose some topic of interest to you in the ‘small’ world
- Can work in small groups of 1-4 people
- Write a one paragraph abstract describing the topic and the scope of what you will write about.
    - Due next Fri, Jan 24

Supplementary References

MEMS Handbooks

- M. Madou, *Fundamentals of Microfabrication*, CRC Press 2000. ISBN 0-8493-9451-1
- M. Gad-el-Hak, *The MEMS Handbook*, CRC Press, 2002. ISBN 0-8493-0077-0.
- G.T.A. Kovacs, *Micromachined Transducers Sourcebook*, McGraw-Hill Co, 1998. ISBN 0-07-290722-3.

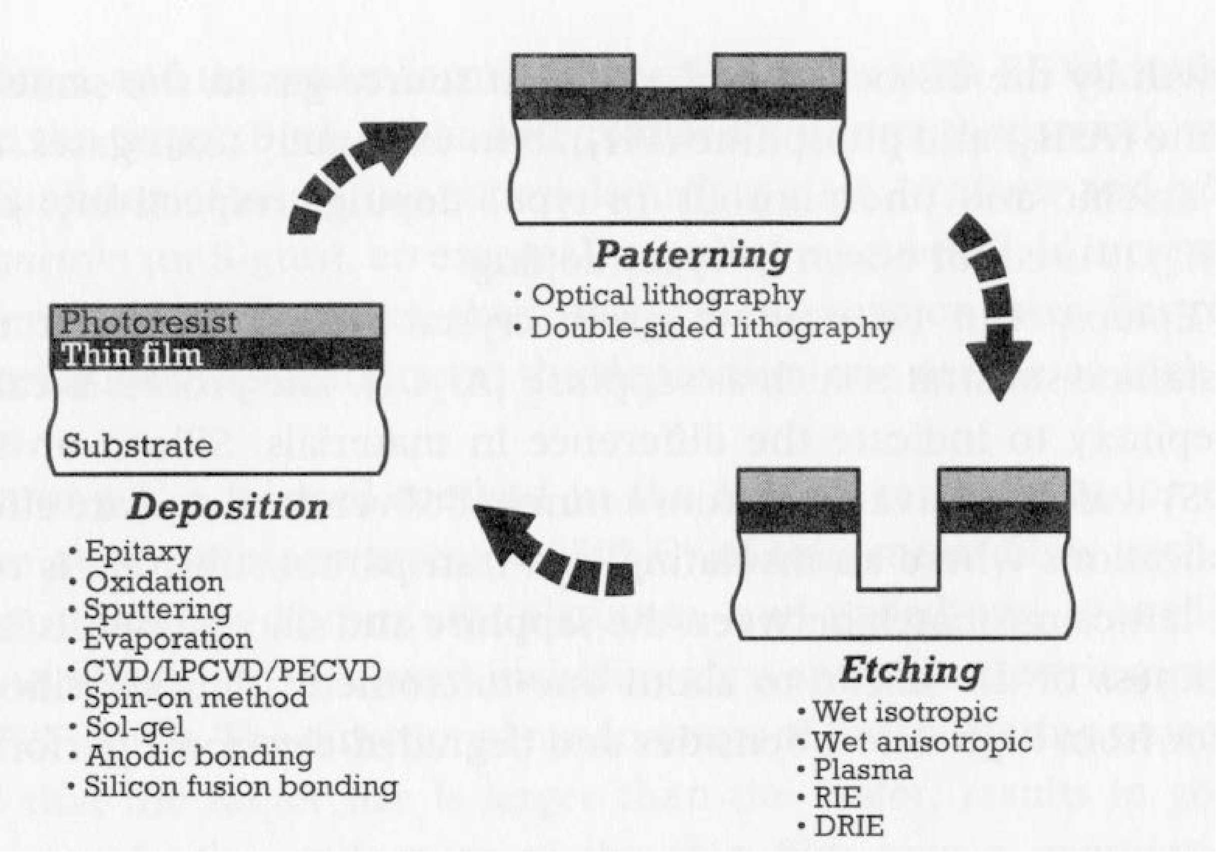
Electrical Engineering and Solid-State Physics texts

- S. A. Campbell, *The Science and Engineering of Microelectronic Fabrication*, Oxford University Press, 2001. ISBN 0-19-513606-5.
- N.W. Ashcroft, N.D. Mermin, *Solid State Physics*, B. Saunders Co, 1976. ISBN 0-03-083993-9.
- C. Kittel, *Introduction to Solid State Physics*, J. Wiley & Sons, 1986. ISBN 0-471-87474-4.

Outline of Introduction to Microfabrication and Lithography

- Basic Microfabrication Processes
- MEMS Materials
  - Silicon: Chemistry and Materials Properties
  - Metals
- Solid State Properties
  - Piezoresistivity
  - Piezoelectricity
- Photolithography
  - Photoresists
  - Resolution
  - Other Forms of Lithography

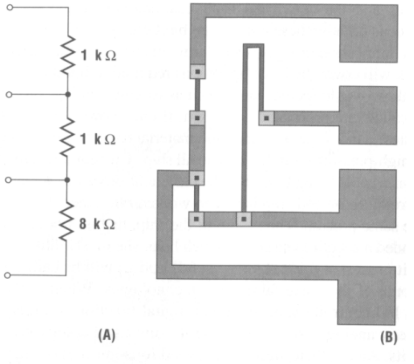
Basic Processes in Microfabrication



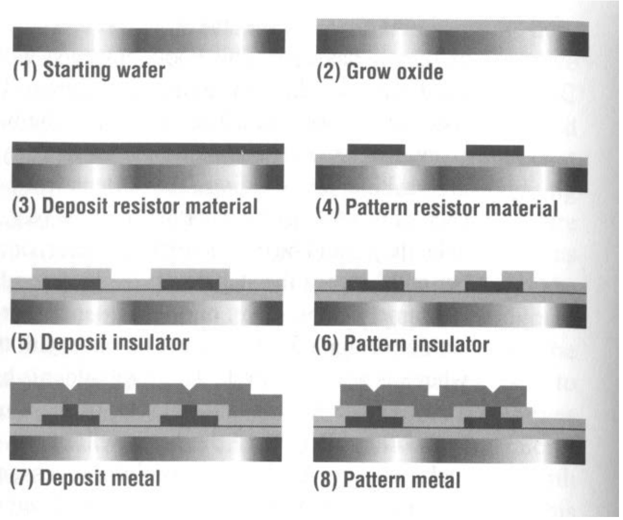
An Introduction to Microelectromechanical
Systems Engineering, N. Maluf, Artech House, 2000.

Example of Voltage Divider Fabrication

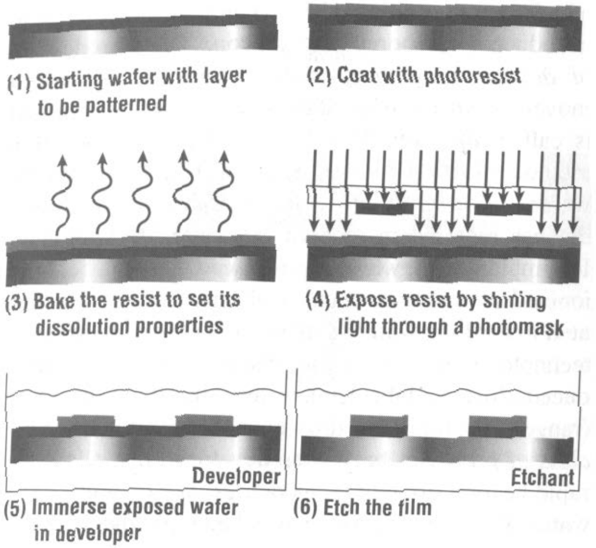
Physical layout of a voltage divider



Flow diagram for Fabrication of IC



Pattern transfer using optical lithography



S. A. Campbell, *The Science and Engineering of Microelectronic Fabrication*, Oxford University Press, 2001.

MEMS Materials

Materials

- Silicon
- Glass (quartz or Pyrex)
- Ceramics (e.g., Al2O3)
- Polymers
- Group III-V semiconductors (e.g., GaAs)
- Titanium
- Tungsten

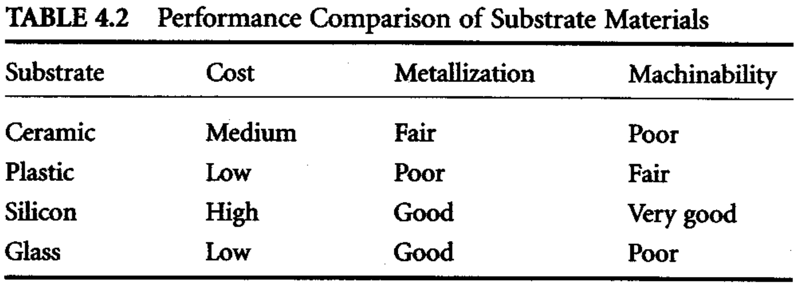


TABLE 4.2 Performance Comparison of Substrate Materials

Substrate	Cost	Metallization	Machinability
Ceramic	Medium	Fair	Poor
Plastic	Low	Poor	Fair
Silicon	High	Good	Very good
Glass	Low	Good	Poor

M. Madou, *Fundamentals of Microfabrication*,
CRC Press 2000

Why Silicon?

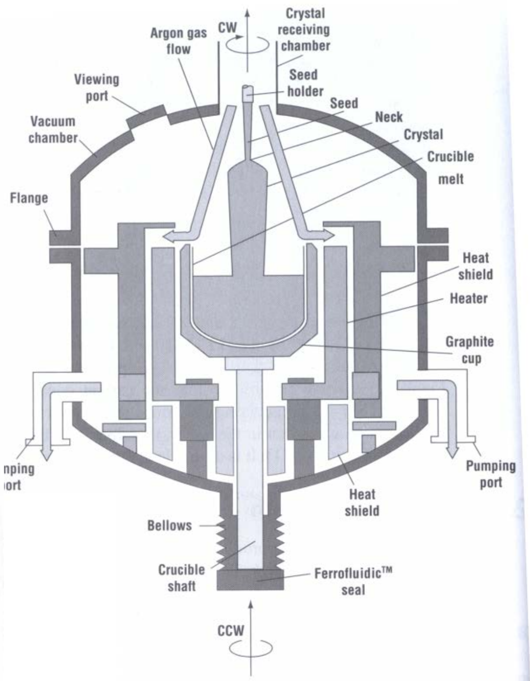
- Bulk single crystals are available for ~ $10 wafer.
- Favorable electrical, mechanical, thermal, and optical properties.
- Precise control of electrical properties.
- Wealth of information on handling and machining.

Crystalline Silicon

Production

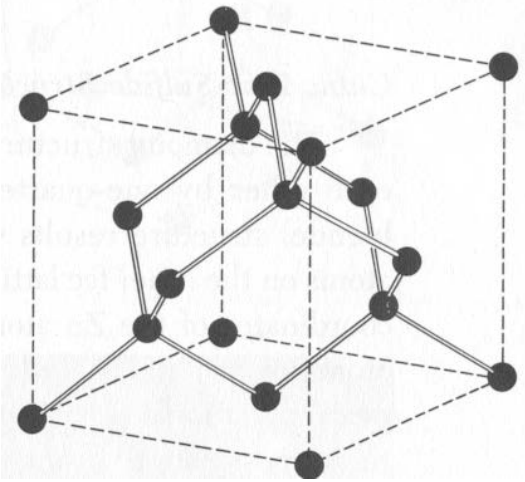
- Grow a SCS boule from a 2 mm diameter seed crystal. Diameter 100 mm (4”), 150 mm (6”), ...
- Zone refine (remove defects and impurities).
- Dice the boule into 525 to 650 μm thick wafer.
- Polish to 0.2 nm rms roughness (1 or 2 sides).

Czochralski growth system



Structure

- Diamond lattice structure (fcc space lattice with two identical atoms at (000) and (1/4 1/4 1/4)
- 0.54 nm lattice spacing



Crystallography

Directions

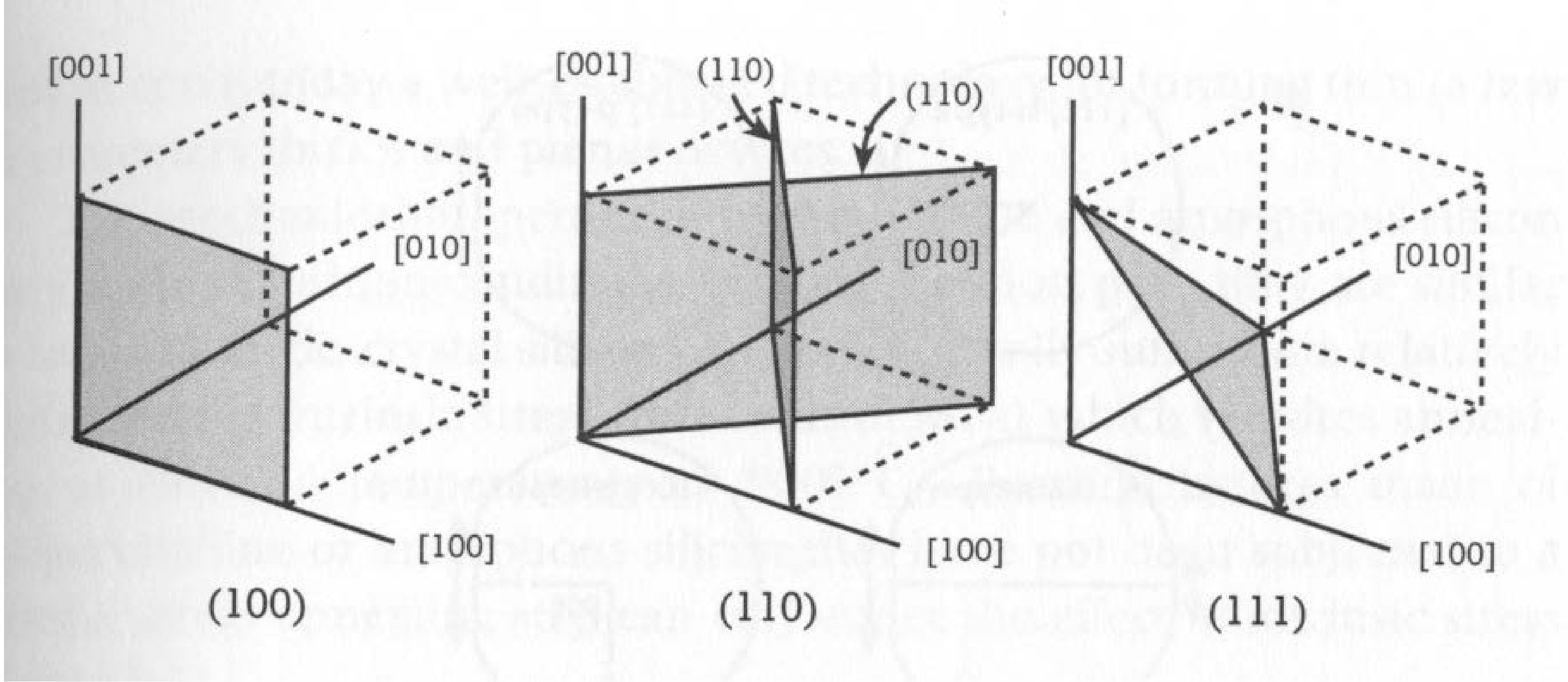
[100] +x direction vector

<100> the six equivalent directions

Planes

(111) Plane perpendicular to [111]

{111} Eight equivalent planes



M. Madou, CRC Press 2000

Other Forms of Silicon

Polycrystalline or amorphous silicon

- Chemical vapor deposition (CVD) deposition to ~ 5 μm
- Mechanical properties similar to crystalline silicon except it has high intrinsic stress as deposited.

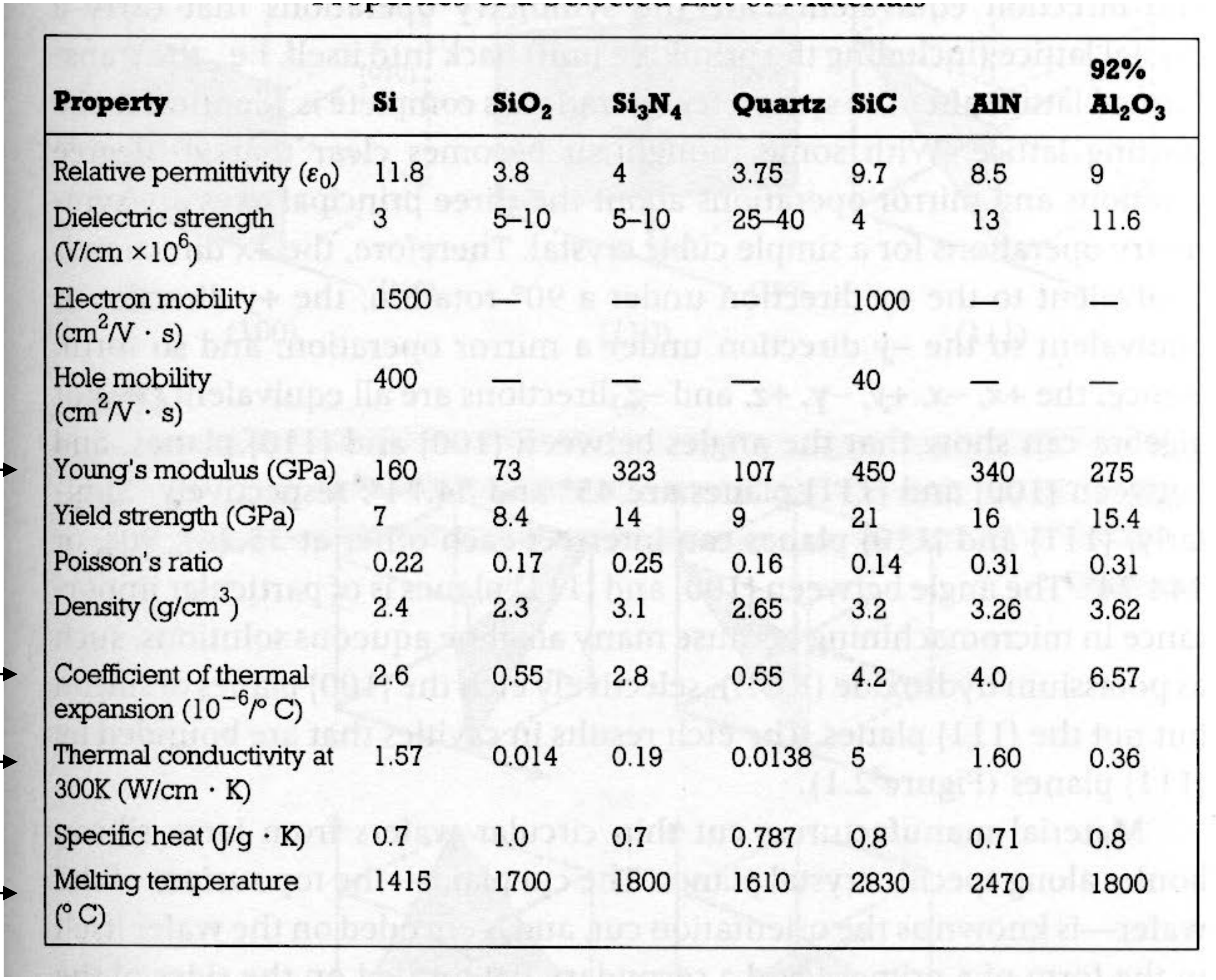
Silicon oxide

- SiO_2 is thermally grown by oxidation at T > 800 C.
- SiO_x or silicate glass are grown via CVD, sputtering or spin coating.
- Excellent electrical and thermal insulator.
- Used as sacrificial layers in processing because of preferential etching by HF.

Silicon nitride

- Nominal Si_3N_4 films are grown by CVD deposition.
- Insulating films and barrier to ion diffusion.
- Young's modulus larger than Si and controlled intrinsic stress.
- Mask for alkaline etch solutions.

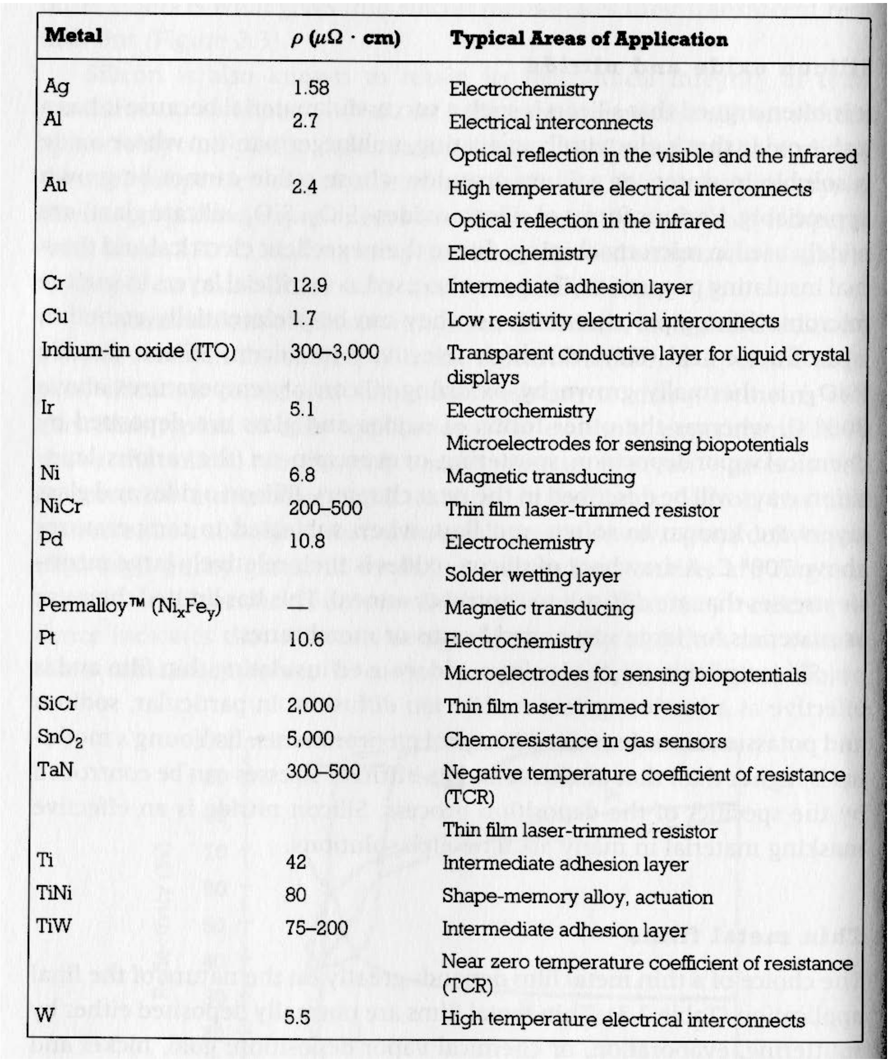
Physical Properties of Silicon



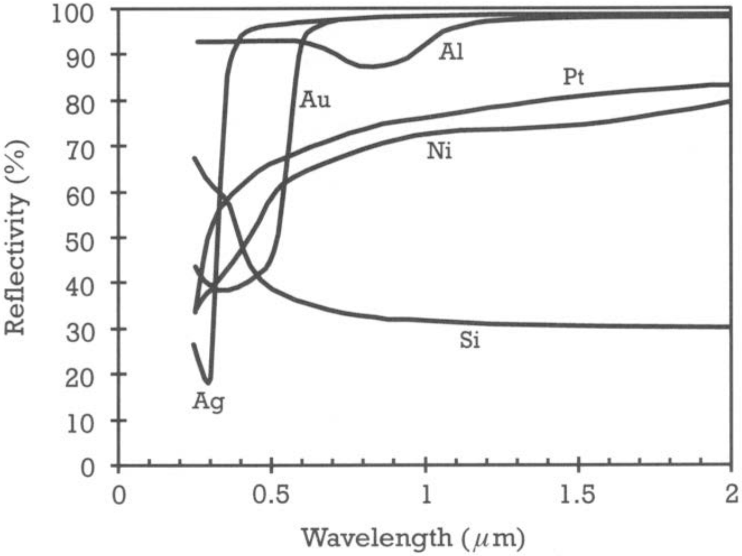
Property	Si	SiO_2	Si_3N_4	Quartz	SiC	AlN	92% Al_2O_3
Relative permittivity (ε_0)	11.8	3.8	4	3.75	9.7	8.5	9
Dielectric strength (V/cm $\times 10^6$)	3	5–10	5–10	25–40	4	13	11.6
Electron mobility ($cm^2/V \cdot s$)	1500	—	—	—	1000	—	—
Hole mobility ($cm^2/V \cdot s$)	400	—	—	—	40	—	—
Young's modulus (GPa)	160	73	323	107	450	340	275
Yield strength (GPa)	7	8.4	14	9	21	16	15.4
Poisson's ratio	0.22	0.17	0.25	0.16	0.14	0.31	0.31
Density (g/cm^3)	2.4	2.3	3.1	2.65	3.2	3.26	3.62
Coefficient of thermal expansion ($10^{-6}/°C$)	2.6	0.55	2.8	0.55	4.2	4.0	6.57
Thermal conductivity at 300K ($W/cm \cdot K$)	1.57	0.014	0.19	0.0138	5	1.60	0.36
Specific heat ($J/g \cdot K$)	0.7	1.0	0.7	0.787	0.8	0.71	0.8
Melting temperature (°C)	1415	1700	1800	1610	2830	2470	1800

N. Maluf, Artech House, 2000.

Metal Films



Metal	**ρ ($\mu\Omega \cdot$ cm)**	**Typical Areas of Application**
Ag	1.58	Electrochemistry
Al	2.7	Electrical interconnects Optical reflection in the visible and the infrared
Au	2.4	High temperature electrical interconnects Optical reflection in the infrared Electrochemistry
Cr	12.9	Intermediate adhesion layer
Cu	1.7	Low resistivity electrical interconnects
Indium-tin oxide (ITO)	300–3,000	Transparent conductive layer for liquid crystal displays
Ir	5.1	Electrochemistry Microelectrodes for sensing biopotentials
Ni	6.8	Magnetic transducing
NiCr	200–500	Thin film laser-trimmed resistor
Pd	10.8	Electrochemistry Solder wetting layer
Permalloy™ (Ni_xFe_y)	—	Magnetic transducing
Pt	10.6	Electrochemistry Microelectrodes for sensing biopotentials
SiCr	2,000	Thin film laser-trimmed resistor
SnO_2	5,000	Chemoresistance in gas sensors
TaN	300–500	Negative temperature coefficient of resistance (TCR) Thin film laser-trimmed resistor
Ti	42	Intermediate adhesion layer
TiNi	80	Shape-memory alloy, actuation
TiW	75–200	Intermediate adhesion layer Near zero temperature coefficient of resistance (TCR)
W	5.5	High temperature electrical interconnects



N. Maluf, Artech House, 2000.

Piezoresistivity

Piezoresistivity

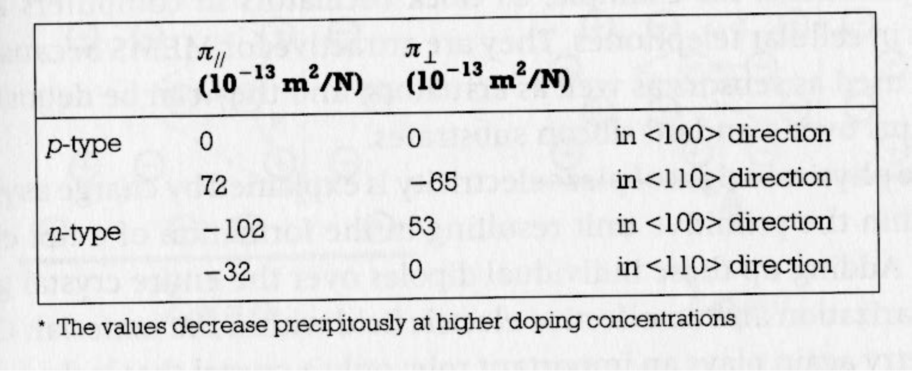
$$\frac{\Delta\rho}{\rho} = \pi_{ll}\sigma_{ll} + \pi_{\perp}\sigma_{\perp}$$

ρ Resistance

σ_{ll} Stress parallel to direction of the resistor

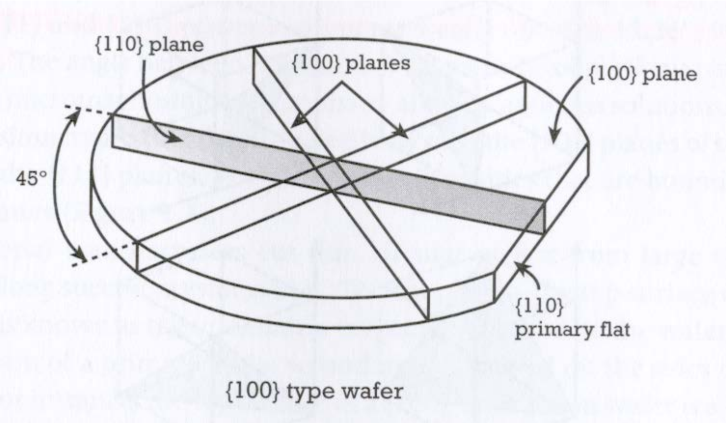
$\sigma_{\perp}$ Stress perpendicular to resistor

Single Crystal {100} Wafer



	$\pi_{//}$ (10^{-13} m^2/N)	$\pi_{\perp}$ (10^{-13} m^2/N)	
p-type	0	0	in <100> direction
	72	−65	in <110> direction
n-type	−102	53	in <100> direction
	−32	0	in <110> direction

* The values decrease precipitously at higher doping concentrations



N. Maluf, Artech House, 2000.

Polysilicon

Piezoresistance coefficients are smaller for polysilicon, but are not direction dependent and do not depend on temperature as strongly.