Introduction to Microelectronic Fabrication

by

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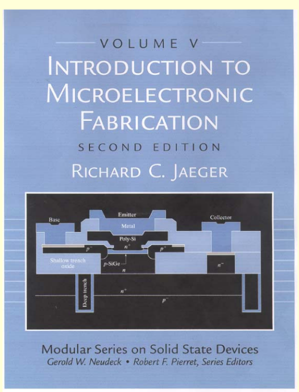
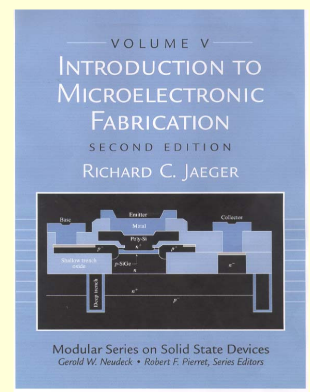


Chapter 7
Interconnections and Contacts



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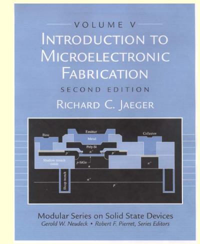

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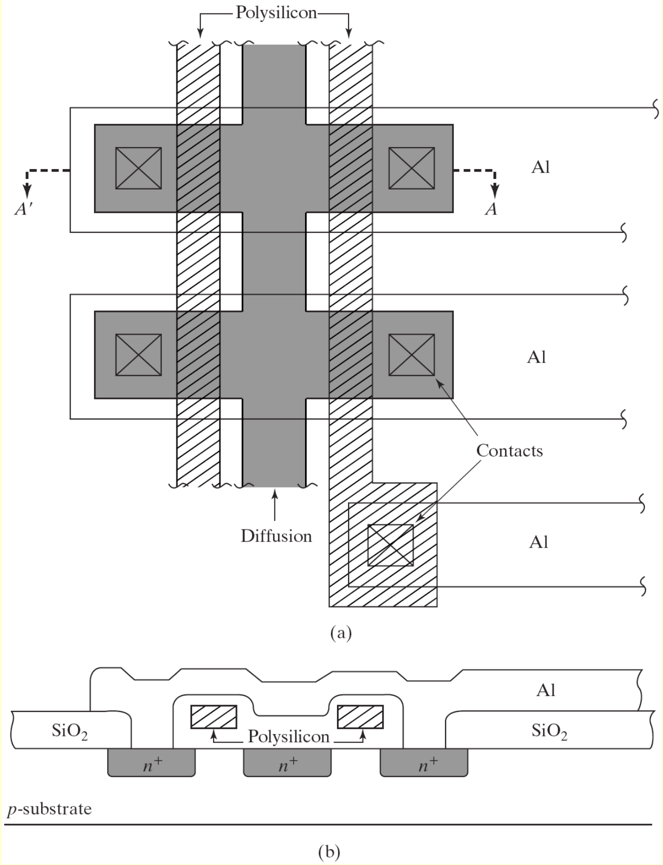
Interconnections and Contacts
MOS Logic Circuit



- 3 Basic Interconnection Levels
  - n^+ diffusion
  - Polysilicon
  - Aluminum Metallization
- Contacts
  - Al-n^+
  - Al-Polysilicon
  - Al-p
    - Substrate Contact Not Shown

Figure 7.1 Portion of MOS integrated circuit
(a) Top view (b) Cross section

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Interconnections
Resistivity of Metals

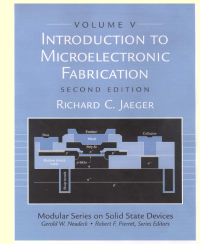


TABLE 7.1 Bulk Resistivity of Metals (μΩ-cm)

Ag: Silver	1.6	$ 438 /lb, Feb 8, 2011
Al: Aluminum	2.65	$ 1.12/lb, Feb 8, 2011
Au: Gold	2.2	$ 19898 /lb, Feb 8, 2011
Co: Cobalt	6	$ 38 /lb, Feb 8, 2011
Cu: Copper	1.7	$ 4.4 /lb, Feb 8, 2011
Mo: Molybdenum	5	
Ni: Nickel	7	$12 /lb, Feb 8, 2011
Pd: Paladium	10	
Pt: Platinum	10.6	
Ti: Titanium	50	
W: Tungsten	5	

Source: WebElements [http://www.webelements.com]

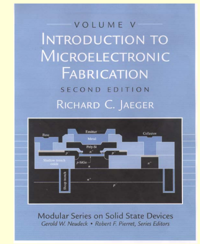
Commonly Used Metals
- Aluminum
- Titanium
- Tungsten
- Copper

Less Frequently Utilized
- Nickel
- Platinum
- Paladium

Hafnium $ 330 /lb, Feb 8, 2011

Silicon $ .71 /lb, Feb 8, 2011

Metal Pricing



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Amalgamet Canada
Amcor Flexibles
American Saw - Lenox
American Wire Group
Ametek Inc

Contact Info

MetalPrices.com
P.O. Box 3050
Basalt, CO 81621, USA
Phone: +1 (970) 927-8595
Fax: +1 (970) 927-8597

Services

Metalprices.com produces current charts for LME Aluminum, Copper, Nickel, Tin, Lead, and Zinc prices, as well as COMEX Copper and Aluminum prices. Click the link below to see

Metal Prices & News on the Internet

16:48:42 GMT | 11:48:42 New York | 16:48:42 London | 22:18:42 Mumbai | 00:48:42 Shanghai

More LME & COMEX Price Tables Below

MetalPrices.com

LB KG MT

USD/LB	Cash	3m	15m
Aluminum	1.1431	1.1526	1.1825
Alum Alloy	1.0546	1.0410	1.0092
NA Alloy	1.1204	1.1317	1.1521
Copper	4.5044	4.5019	4.4067

LME Officials 08 Feb 2011

USD/LB	Cash	3m	15m
Nickel	12.6348	12.6552	12.1495
Lead	1.1648	1.1462	1.1240
Tin	14.1748	14.1748	13.9639
Zinc	1.1177	1.1265	1.1376

COMEX/NYMEX 9 Feb 2011

USD/LB	Month	Open	Settle	USD/Troy Oz	Month	Open	Settle
Copper	Mar 11	4.5920	4.5740y	Gold	Feb 11	1362.80	1363.40y
Copper	May 11	4.6000	4.5825y	Silver	Mar 11	30.285	30.271y
Oil/barrel	Apr 11	90.65	90.24y	Platinum	Mar 11	1849.90	1858.50s
Nat Gas/mmBTU	Apr 11	4.094	4.072y	Palladium	Mar 11	838.05	838.45y

y = yesterday's settle s = today's settle

LME ALUMINUM $/LB — 29 Dec 10 - 09 Feb 11 — Aluminum Page

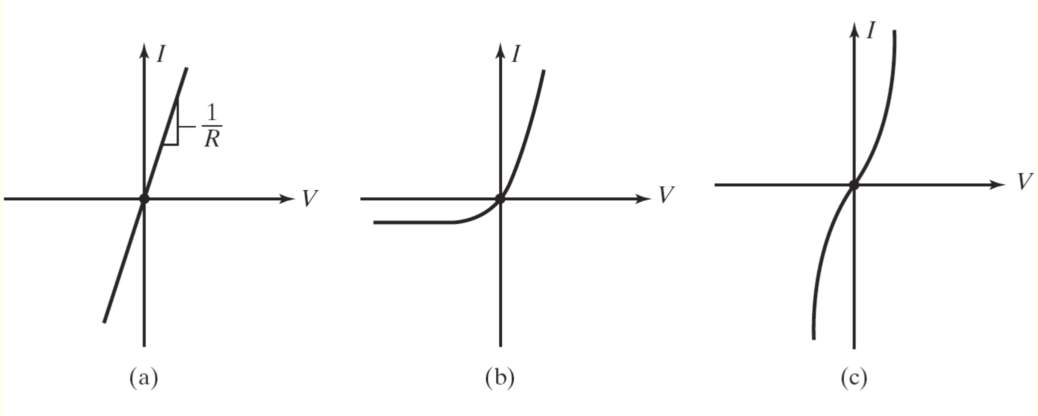
LME COPPER $/LB — 29 Dec 10 - 09 Feb 11 — Copper Page

LME NICKEL $/LB — 29 Dec 10 - 09 Feb 11 — Nickel Page

Public Metal News FREE (GMT)

09 Feb 13:00 Rio Tinto OKs $1.2bn of iron-ore expansions in Canada, Australia (Mining Weekly)

Contacts
Ohmic Contact Formation



(a) Ideal Ohmic Contact
(b) Rectifying Contact (similar to diode)
(c) Practical Nonlinear "Ohmic" Contact

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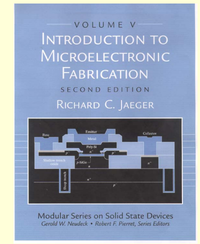
Contacts

Ohmic Contact Formation



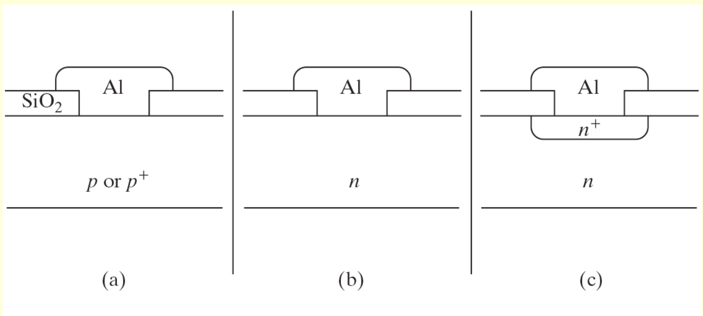


Figure 7.3

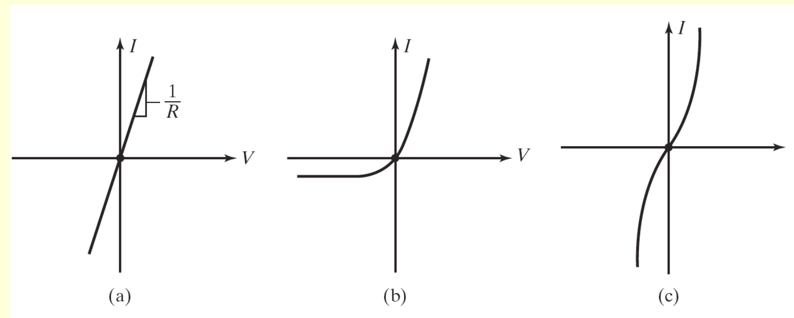


Figure 7.2

- Aluminum to p-type silicon forms an ohmic contact similar to Fig. 7.2(a) [Remember Al is p-type dopant]
- Aluminum to n-type silicon can form a rectifying contact (Schottky barrier diode) similar to Fig. 7.3(b)
- Aluminum to n+ silicon yields a contact similar to Fig. 7.3c

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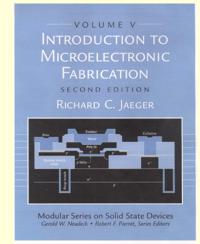
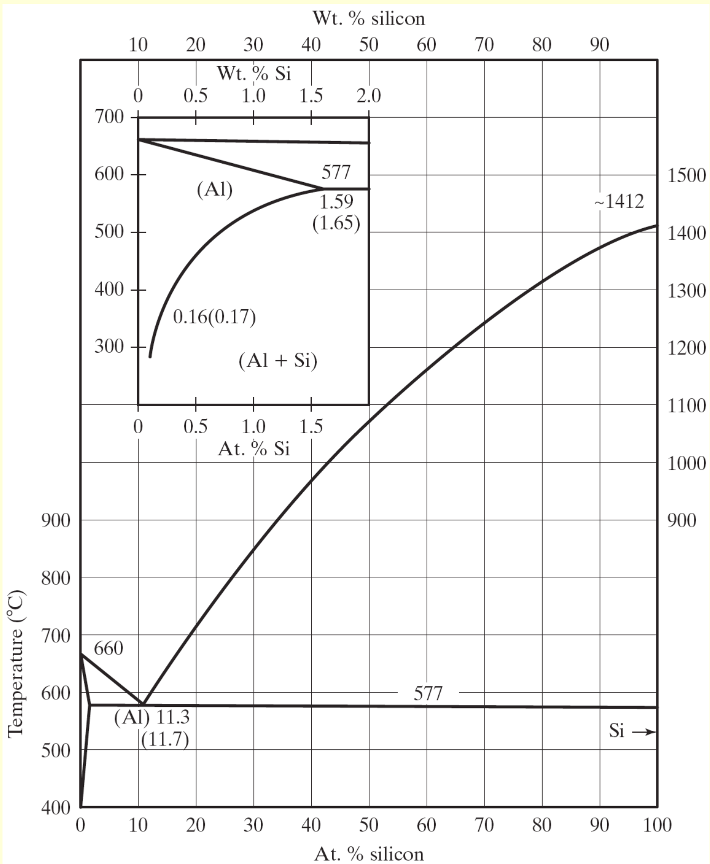
Contacts
Aluminum-Silicon Phase Diagram



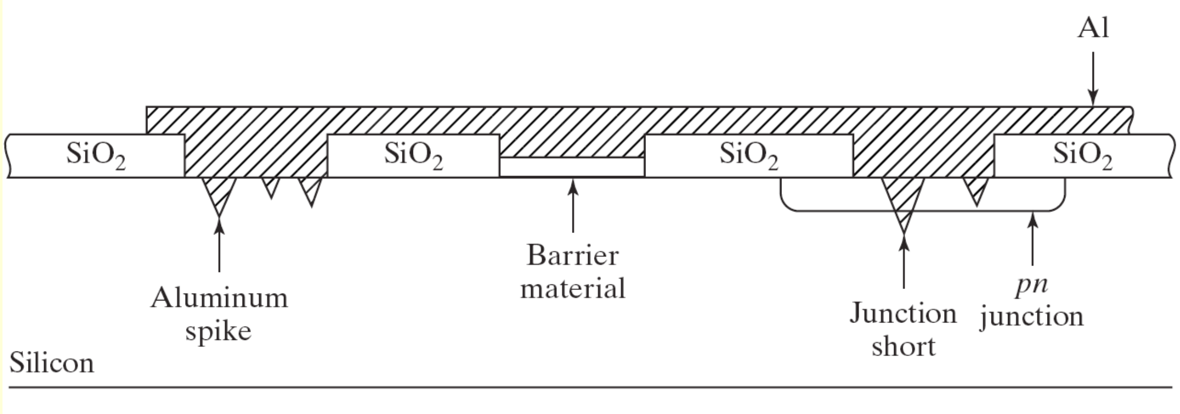


Aluminum-Silicon Eutectic Point 577^{o} C

FIGURE 7.4

Phase diagram of the aluminum-silicon system. The silicon-aluminum eutectic point occurs at a temperature of 577 °C. At contact-alloying temperatures between 450 and 500 °C, aluminum will absorb from 0.5 to 1% silicon. Copyright 1958 McGraw-Hill Book Company, with permission from Ref. [1].

Contacts
Aluminum Spiking and Junction Penetration



- Silicon absorption into the aluminum results in aluminum spikes
- Spikes can short junctions or cause excess leakage
- Barrier metal deposited prior to metallization
- Sputter deposition of Al - 1% Si

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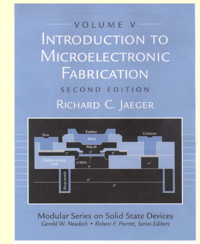
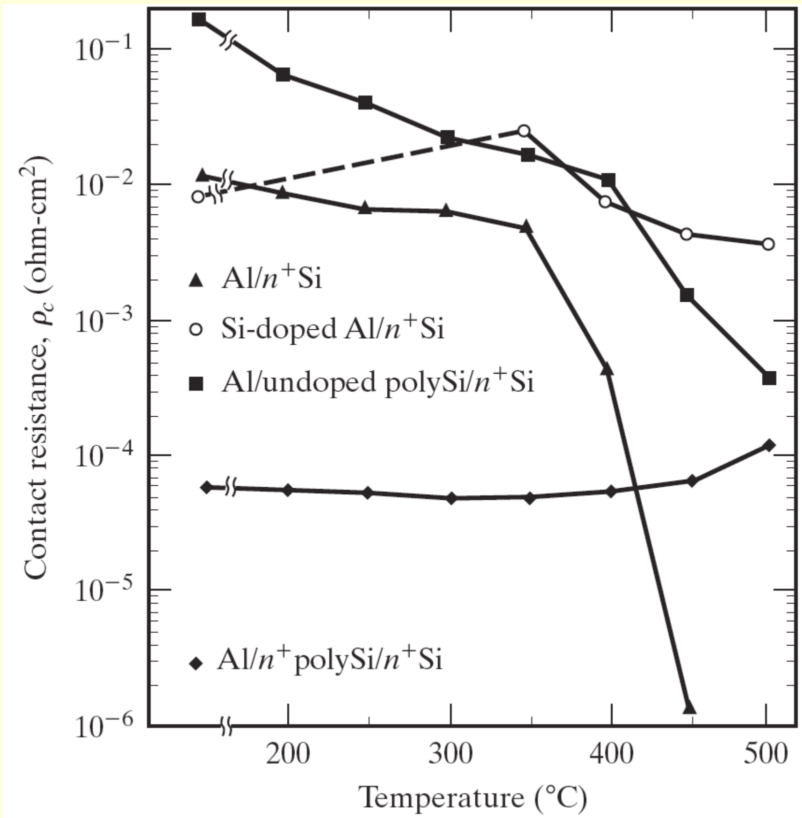
Contacts
Alloying of Contacts





Alloy to Obtain Very Low Contact Resistivity

Specific Contact Resistivity

$$\rho_c = 1.2x10^{-6}\Omega - cm^2$$

Contact Resistance R_C

$$R_C = \frac{\rho_c}{A} \qquad \text{A = contact area}$$

FIGURE 7.6

Contact resistivity of a variety of aluminum-silicon systems. An alloying temperature of 450 °C is typically used to obtain low-contact resistance for Al-Si contacts. Reprinted with permission from *Solid-State Electronics*, Vol. 23, p. 255-262, M. Finetti et al., "Aluminum-Silicon Ohmic Contact on Shallow n^+/p Junctions" [2]. Copyright 1980, Pergamon Press, Ltd.

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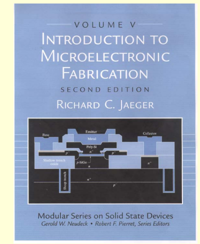
Contacts

Contact Resistance



Example for $\rho_C = 1\ \mu\Omega - cm^2$

$$A = 10\ \mu m \text{ x } 10\ \mu m = 10^{-6} cm^2$$

$$R_C = \frac{\rho_C}{A} = 1\ \Omega$$

$$A = 1\ \mu m \text{ x } 1\ \mu m = 10^{-8} cm^2$$

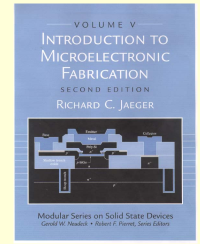
$$R_C = 100\ \Omega$$

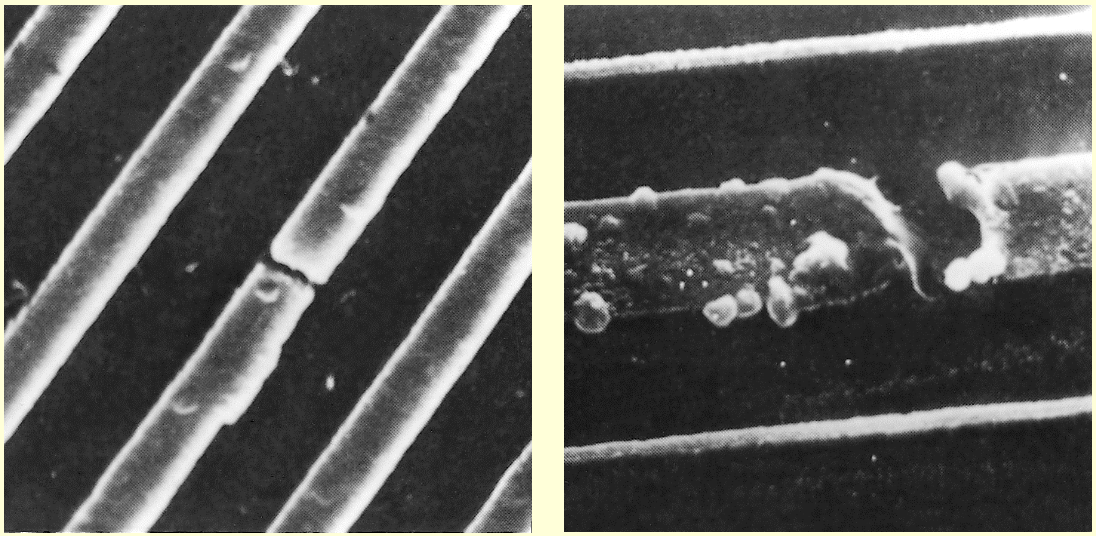
$$A = 0.1\ \mu m \text{ x } 0.1\ \mu m = 10^{-10} cm^2$$

$R_C = 10\ k\Omega$ Unacceptable!

Interconnections

Electromigration





(a) (b)

FIGURE 7.7

Scanning electron micrographs of aluminum interconnection failure caused by electro-migration. (a) Sputtered aluminum with 0.5% copper; (b) evaporated aluminum with 0.5% copper. Copyright 1980, IEEE. Reprinted with permission from Ref. [3].

High current density causes voids to form in interconnections

"Electron wind" causes movement of metal atoms

$$J = \frac{1A}{(1\mu m)^2} = \frac{10mA}{(10^{-4}\,cm)^2} = 1\ MA/cm^2$$

High Current Densities

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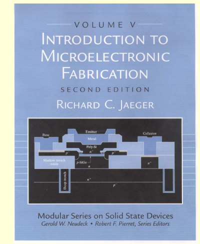
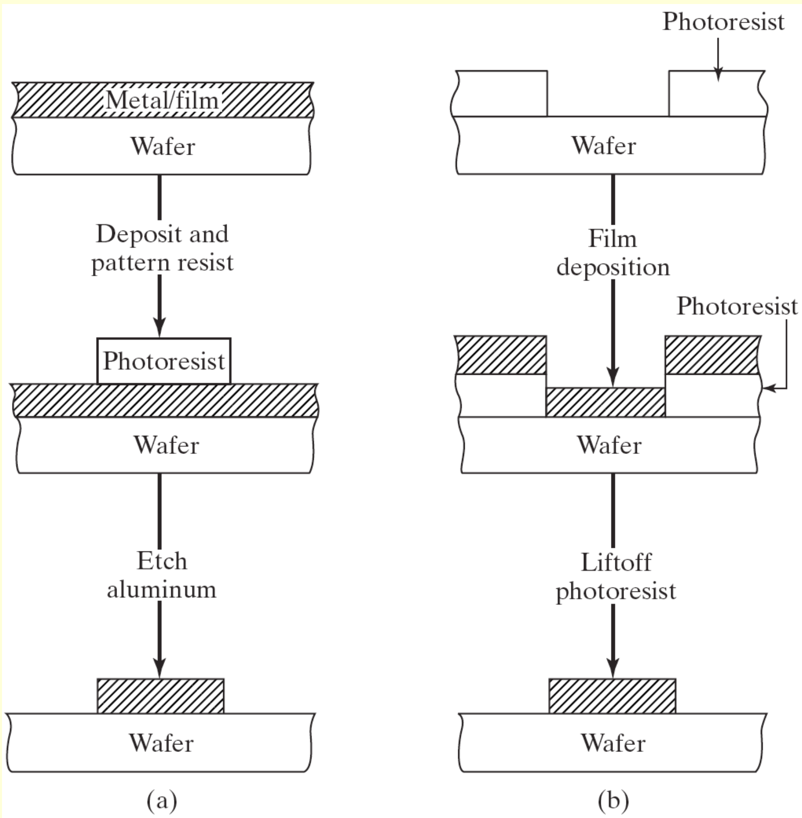
Interconnections
Liftoff Process





(a) Subtractive etching process

(b) Additive metal liftoff process

Figure 7.15

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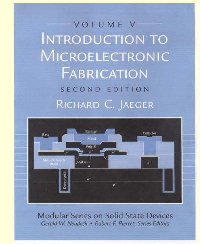
Interconnections

Multilevel Metallization



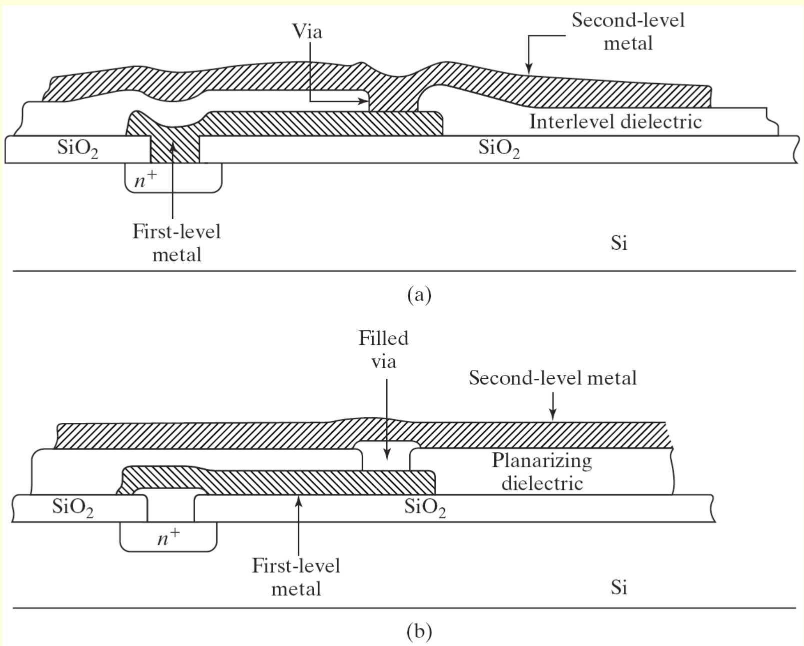


Figure 7.16

- Two level metal processes
- Silicon dioxide, polyimide or silicon nitride dielectrics
- Vias formed to connect between metal levels
- Vias can be filled (b)to improve planarization

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Interconnections

Multilevel Metallization

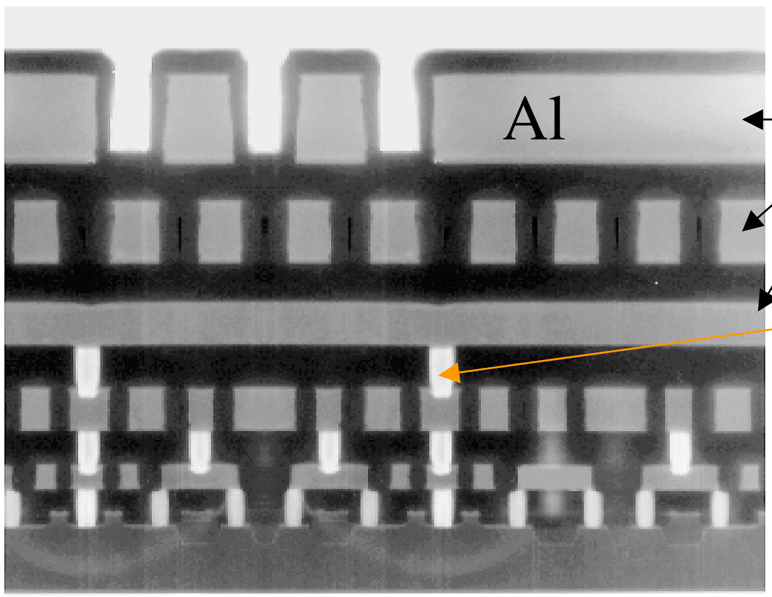

Figure 7.17
Multilevel aluminum metallization with tungsten plugs. Copyright 1998 IEEE. Reprinted with permission from Ref. [7].

- Example of multilevel aluminum metallization with tungsten via plugs
- Planarity achieved through Chemical Mechanical Polishing (CMP)

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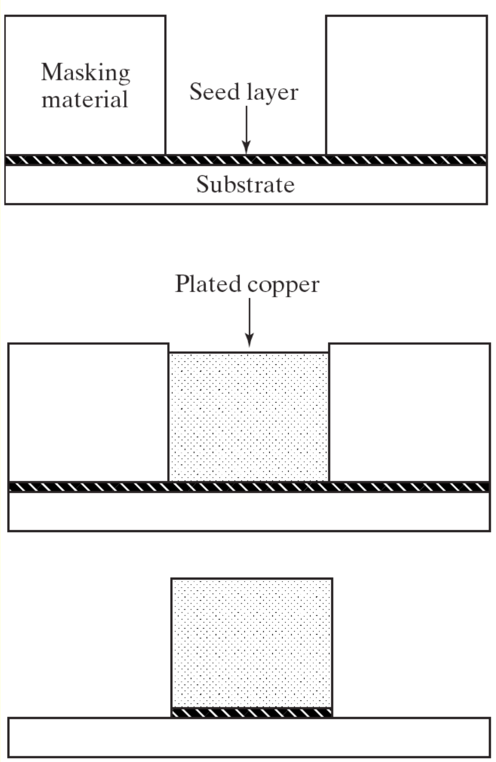
Interconnections

Plated Copper

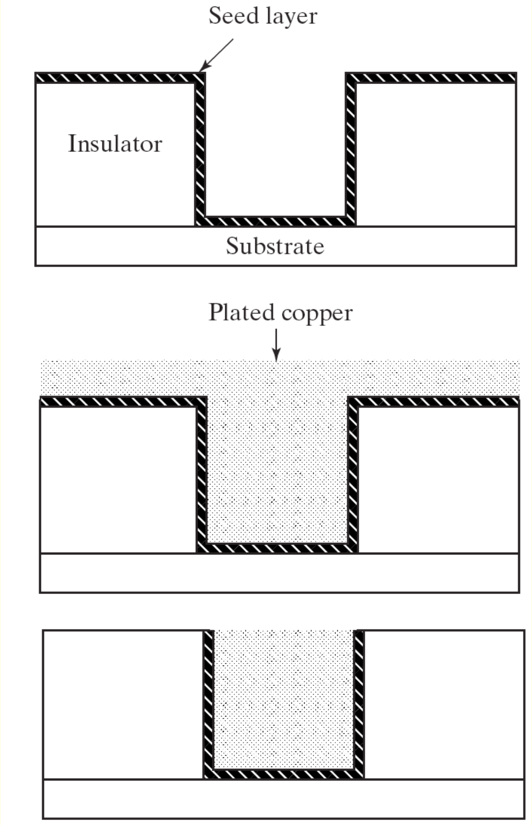


(a) Plated copper

- Copper deposited using "standard" plating processes adapted to microelectronics
- Seed layer deposited
- Mask layer deposited and patterned
- Copper plated up
- Mask layer removed
- Seed layer etched away

Interconnections

Copper Damascene Process



(b) Copper Damascene process

- Damascene process used to obtain highly planar surfaces
- Dielectric layer (insulator) deposited and patterned
- Seed layer deposited
- Copper plated
- Surface polished mechanical & chemical

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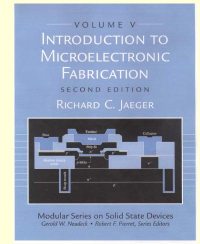
Interconnections

Dual Damascene Process



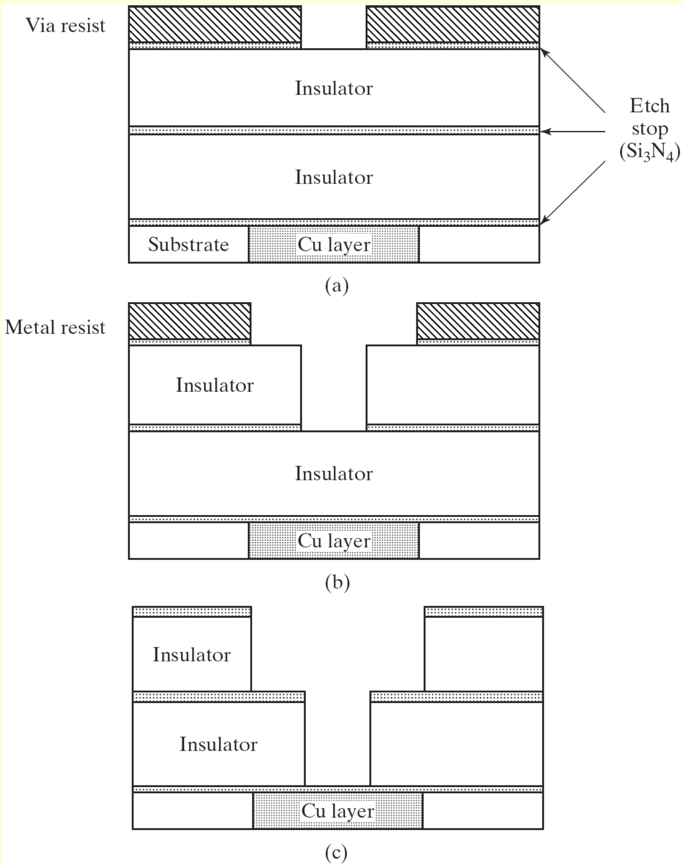


FIGURE 7.19

Dual damescene process flow. (a) An insulator sandwich is first deposited and the upper nitride layer is patterned. The insulator layer is etched. The etch terminates on the silicon nitride etch stop. (b) The nitride layer is patterned and etched. (c) Following the next oxide etch step, two different width openings exist in the two oxide layers. (d) Barrier and seed layers are deposited and plated with copper (e) Final structure following removal of excess copper.

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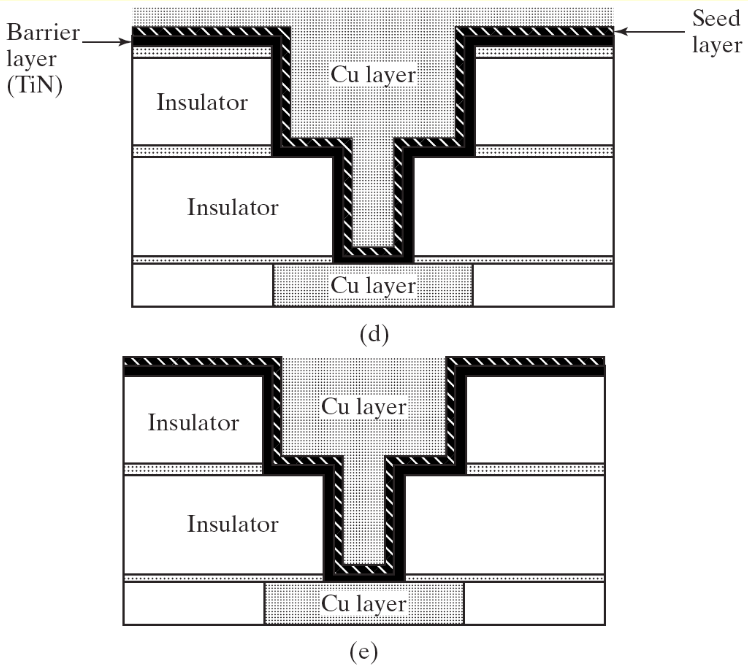
Interconnections

Dual Damascene Process (cont.)



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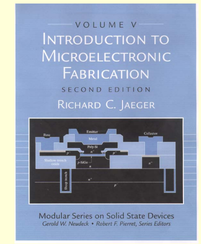
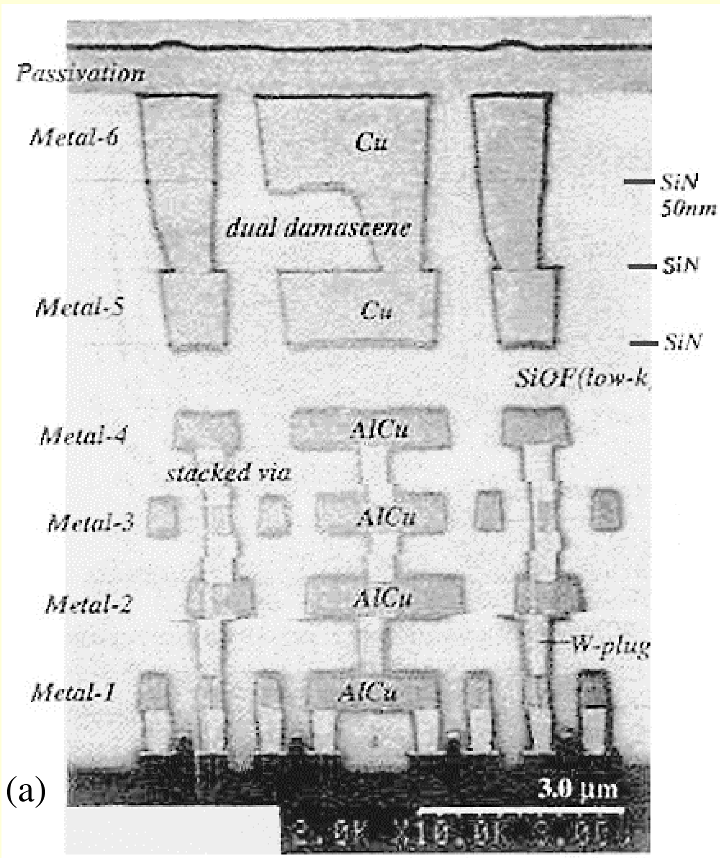
Multilevel Metallization

Examples





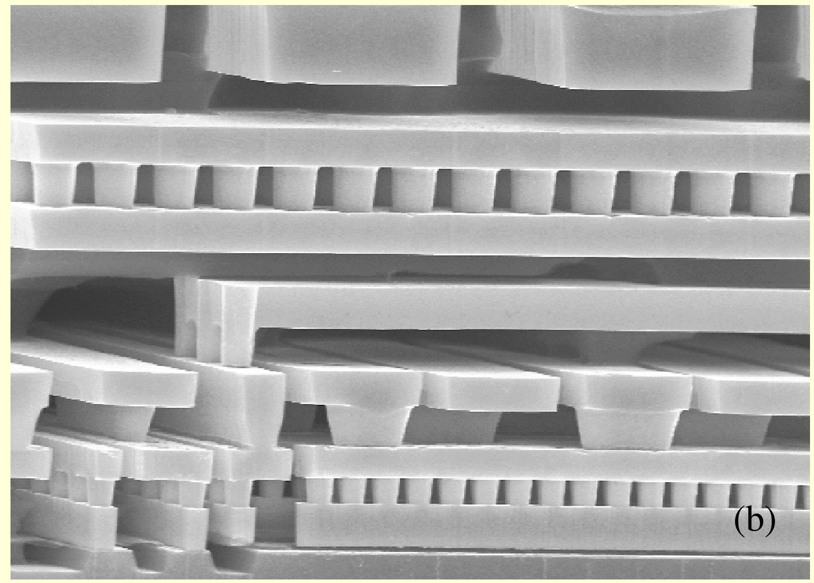


Figure 7.20
(a) Dual Damascene copper combined with aluminum-copper and tungsten plugs on the lower levels. Copyright 1997 IEEE. Reprinted with permission from Ref. [6]. (b) Dual Damsascene Copper. Courtesy of Motorola Inc. Note planarity of both structures.

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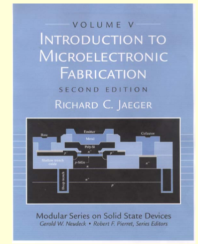
Interconnections and Contacts References



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End of Chapter 7

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