

TABLE 3.8 Comparison of Evaporation and Sputtering Technology

	Evaporation	Sputtering
Rate	Thousand atomic layers per second (e.g., 0.5 $\mu\text{m}/\text{min}$ for Al)	One atomic layer per second
Choice of materials	Limited	Almost unlimited
Purity	Better (no gas inclusions, very high vacuum)	Possibility of incorporating impurities (low-medium vacuum range)
Substrate heating	Very low	Unless magnetron is used substrate heating can be substantial
Surface damage	Very low, with e-beam x-ray damage is possible	Ionic bombardment damage
<i>In situ</i> cleaning	Not an option	Easily done with a sputter etch
Alloy compositions, stoichiometry	Little or no control	Alloy composition can be tightly controlled
X-ray damage	Only with e-beam evaporation	Radiation and particle damage is possible
Changes in source material	Easy	Expensive
Decomposition of material	High	Low
Scaling-up	Difficult	Good
Uniformity	Difficult	Easy over large areas
Capital equipment	Low cost	More expensive
Number of depositions	Only one deposition per charge	Many depositions can be carried out per target
Thickness control	Not easy to control	Several controls possible
Adhesion	Often poor	Excellent
Shadowing effect	Large	Small
Film properties (e.g., grain size and step coverage)	Difficult to control	Control by bias, pressure, substrate heat

TABLE 3.10 Review of CVD Processes

Process	Advantages	Disadvantages	Applications	Remark	Pressure/temp.
APCVD	Simple, high deposition rate, low temperature	Poor step coverage, particle contamination	Doped and undoped low-temperature oxides	Mass-transport controlled	100–10 kPa 350–400°C
LPCVD	Excellent purity and uniformity, conformable step coverage, large wafer capacity	High temperature and low deposition rate	Doped and undoped high temperature oxides, silicon nitride, poly-Si, W, WSi_2	Surface-reaction controlled	100 Pa 550–600°C
VLPCVD			Single-crystalline Si and compound semiconductor superlattices	Surface-reaction controlled	1.3 Pa
MOCVD	Excellent for epi on large surface areas	Safety concerns	Compound semiconductors for solar cells, laser, photocathodes, LEDs, HEMTs, and quantum wells	High volume, large surface area production	
PECVD	Lower substrate temperatures, fast, good adhesion, good step coverage, low pinhole density	Chemical (e.g., hydrogen) and particulate contamination	Low-temperature insulators over metals, passivation (nitride)	Tends to have more pinholes than LPCVD	2–5 Torr 300–400°C
Spray pyrolysis	Inexpensive	Difficult to control, not compatible with IC	Gas sensors, solar cells, ITO, large area		Atmospheric 100–180°C

Source: Adapted from K. F. Jensen, in *Microelectronics Processing*, D. W. Hess and K. F. Jensen, Eds., American Chemical Society, Washington, D.C., 1989;⁹ and A. C. Adams, in *VLSI Technology*, S. M. Sze, Ed., McGraw-Hill, New York, 1988.²

TABLE 1.1 Comparison of Traditional Negative and Positive Photoresists*

Characteristic	Resist type	
	Positive	Negative
Adhesion to Si	Fair	Excellent
Available compositions	Many	Vast
Contrast γ	Higher, e.g., 2.2	Lower, e.g., 1.5
Cost	More expensive	Less expensive
Developer	Aqueous based (ecologically sound)	Organic solvent
Developer process window	Small	Very wide, insensitive to overdeveloping
Influence of oxygen	No	Yes
Lift-off	Yes [usually with multiple-layer resist (MLR)]	Yes, with new types of negative resists [single-layer resist (SLR)]
Minimum feature	0.5 μm and below	$\pm 2 \mu\text{m}$
Opaque dirt on clear portion of mask	Not very sensitive to it	Causes printing of pinholes
Photospeed	Slower	Faster
Pinhole count	Higher	Lower
Pinholes in mask	Prints mask pinholes	Not so sensitive to mask pinholes
Plasma etch resistance	Very good	Not very good
Proximity effect	Prints isolated holes or trenches better	Prints isolated lines better
Residue after development	Mostly at $<1 \mu\text{m}$ and high aspect ratio	Often a problem
Sensitizer quantum yield Φ	0.2 to 0.3	0.5 to 1
Step coverage	Better	Lower
Strippers of resist over		
Oxide steps	Acid	Acid
Metal steps	Simple solvents	Chlorinated solvent compounds
Swelling in developer	No	Yes
Thermal stability	Good	Fair
Wet chemical resistance	Fair	Excellent

*Newer resist systems are discussed under *Photolithography Resolution Enhancement Technology*, page 32.

about 2 to 3 μm , and because the industry has moved away from organic-solvent-based systems in favor of less toxic, water-based developers, positive resists have gained in popularity. However, traditional negative resists continue to be used in the production of PWBs and low-cost, high-volume chips, as they require only small amounts of sensitizers and therefore are substantially less expensive than positive resists. Moreover, great progress has been made in improving the resolution of new types of water-soluble negative resists. These are used in new generations of ICs and in high-aspect-ratio miniaturized systems.^{13,14} In working with different resists, it is also important to be aware of such properties as shelf life, flash point, and threshold limit value (TLV) rating. The flash point is the temperature at which the resist vapors ignite in the presence of an open flame. The TLV is the toxicity rating that specifies the maximum ambient concentration (in ppm, i.e., parts per million) to which a worker can be safely exposed during a normal workday.

Table 1.2 lists some common positive and negative resists employed in various lithography strategies along with their

lithographic sensitivities. For charged particles (e-beam lithography and ion-beam lithography), sensitivity is expressed in coulombs per centimeter square (C/cm^2); for photons (optical and x-ray), joules per centimeter square (J/cm^2) is used. Ideally, in charged-particle lithography, one should select a resist with sensitivity in the range of 10^{-5} to 10^{-7} C/cm^2 , and in photon lithography, 10 to 100 mJ/cm^2 , to minimize the exposure duration.

Permanent Resists

Resists typically are removed (stripped) once they have served their function as temporary stencils. Some negative resists, hardened through UV exposure, are used as permanent parts of miniature devices. In this book, we will cover two examples in this category: dry film resists and polyimides. Dry film resists have been used for a long time in PWBs but less so in ICs and miniaturization science. Polyimides are used, for example, in multichip modules as low-dielectric insulation layers¹⁵ and as flexible hinges in mechanical miniaturized structures.¹⁶ Recently, the benefits of using dry resist films in the fabrication