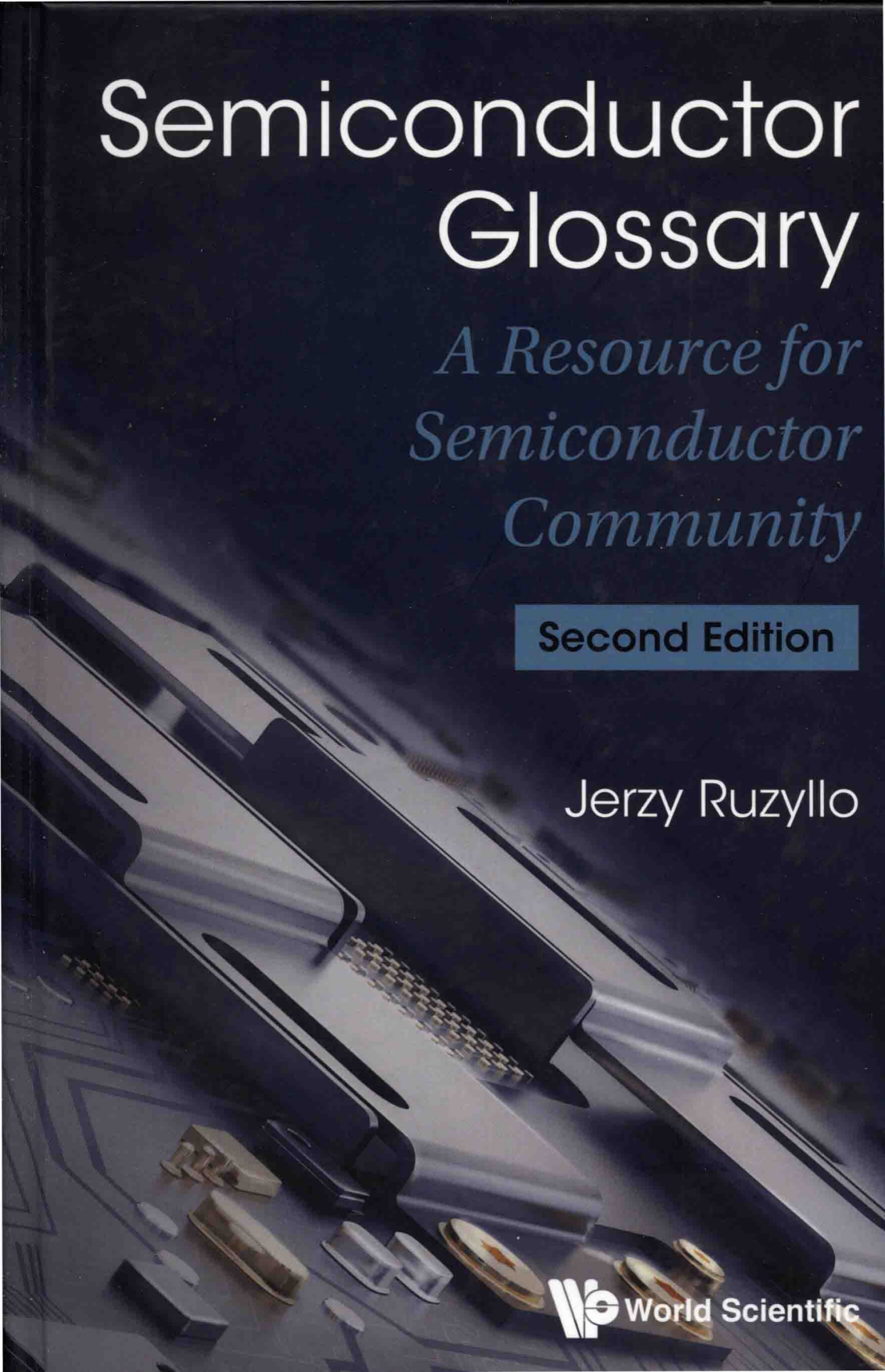
Semiconductor Glossary

A Resource for Semiconductor Community

Second Edition

Jerzy Ruzyllo



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Over the last six decades semiconductor science and engineering has grown into one of the cornerstones of our technical civilization. It continues to grow and expand into new territories at an accelerating pace, which makes keeping up with emerging concepts and terminology increasingly challenging. *Semiconductor Glossary* was conceived in response to an apparent need for reference that would provide brief, straightforward explanations of key terms in the area of semiconductor materials, devices, and processing.

In agreement with its inherent nature, this glossary is not intended to provide in-depth explanations of complex technical ideas and scientific concepts. Readers searching for this type of knowledge should refer to textbooks and monographs covering all aspects of broadly understood semiconductor science and engineering. The purpose of this glossary is to provide a platform upon which basic concepts and terms in semiconductor science and engineering are identified and explained in an easy to follow fashion.

This volume is a vastly expanded and updated second edition of *Semiconductor Glossary*. An abbreviated version of this material is available on line at *www.semiconductorglossary.com*. The information presented in this volume is based primarily on the knowledge and experiences acquired by the author during over 40 years of research and teaching in the area of semiconductors.

The author would like to acknowledge collaborators and students at Penn State University and the Warsaw University of Technology, as well as numerous colleagues in the industry and academia with whom he has had the privilege of interacting throughout the years. They are the main reason for which immersion in the "world of semiconductors" continues to be such a stimulating and gratifying experience.

Jerzy Ruzyllo
University Park, Pennsylvania

A

a see *lattice constant.*

a-Si see *amorphous silicon.*

AII-BVI, II-VI, semiconductors the II-VI compound semiconductors are synthesized using elements from group II and group VI of the periodic table; e.g., CdSe, ZnS.
elemental semiconductor, CdSe, CdTe, CdHgTe, ZnS, ZnO

AIII-BV, III-V, semiconductors the III-V compound semiconductors are synthesized using elements from group III and group V of the periodic table; e.g. GaAs, InP.
elemental semiconductor, GaAs, GaN, GaP, GaAlAs, InAs, InSb, InP

AIV-BIV, IV-IV semiconductors compound semiconductors with both elements forming a compound originating from group IV of the periodic table; e.g. SiC, SiGe.
elemental semiconductor, SiC, SiGe

AAS Atomic Adsorption Spectroscopy; a surface characterization method.

abrupt heterojunction a junction between two crystalline semiconductors featuring different electron affinities and energy bandgaps; no graded changes in the materials composition in the junction region.
electron affinity, graded heterojunction

abrupt junction a *p-n* junction in which dopant concentration changes from *p*-type to *n*-type over the very short distance, i.e. transition region between *p*-type and *n*-type parts of the junction is very narrow.
linear junction

absorption specie or energy penetrates the surface and is bound or captured in the bulk of the solid where it is releasing its energy.
phonon, photon

absorption coefficient, α, [cm^{-1}] defines depth of penetration of a given medium with the light of a given wavelength; increases as wavelength is getting shorter.
radiation wavelength-energy conversion

acceptor *p*-type dopant; element introduced to semiconductor to generate free holes (by "accepting" electron from semiconductor atom and "releasing" hole at the same time); acceptor atom must have one valence electron less than the host semiconductor; boron (B) is commonly used acceptor in silicon technology; alternatives include indium (In) and gallium (Ga); gallium features high diffusivity in SiO_2, and hence, oxide cannot be used as the mask during Ga diffusion.
donor, doping

access time time needed for the bit of information to go to and return from the memory cell.
memory cell

accumulation condition of semiconductor surface region in MOS devices in which concentration of majority carriers is higher than concentration of dopant atoms.
depletion, inversion

activation energy defines reaction kinetics of the process; the minimum amount of energy required to initiate the reaction; expressed in units of *eV*.

active element (component) a device which displays asymmetric current-voltage characteristics, i.e. dependent upon the direction of the applied bias; is introducing net energy into the circuit; diodes and transistors are active elements.
passive element, diode, transistor

active Si layer a single-crystal Si layer overlaying buried oxide (BOX) in SOI wafers; "active" because transistors are built into it; as opposed to Si substrate (Si underneath BOX) which is a part of the SOI wafer providing mechanical support only; can be as thin as < 10 nm.
Silicon-on-Insulator; *Ultra-Thin Body SOI, BOX, fully-depleted SOI*

ADC Analog to Digital Converter.

additive process a process which adds material to the substrate, e.g. in the form of thin-film.
subtractive process

adhesion ability of materials to stick (adhere) to each other.
adhesion promoter

adhesion promoter a compound used to improve adhesion of materials; typically understood as a material improving adhesion of the photoresist to the wafer surface in the lithographic processes.
HMDS

adsorption binding between foreign molecules and the solid occurring only on the solid surface; specie is attached to the solid surface by weak physical forces (Van der Waals force).
desorption, van der Waals force

aerosol cleaning removal of the particulate contaminants from the wafer surface using frozen gas particles.
cleaning, dry cleaning, particles

AFM see *Atomic Force Microscopy.*

afterglow plasma, afterglow plasma generated radiation and ions which remain active downstream from the plasma; a plasma processing mode in semiconductor manufacturing.
downstream plasma, remote plasma

ALD, ALCVD Atomic Layer Deposition; Atomic Layer Chemical Vapor Deposition; see *Atomic Layer Deposition.*

AlGaAs GaAs with Al added in adequate amount to modify width of the energy gap; by gradually (layer-by-layer) varying Al content in GaAlAs continued variation of the energy gap of the material is accomplished.
bandgap engineering, GaAs

aligner a tool used in photolithography which allows desired positioning of the mask (or reticle) relative to a wafer prior to exposure of the photoresist; "aligner" is at the same time an exposure tool.
exposure, photolithography

alignment process of positioning of the mask (or reticle) relative to the wafer prior to exposure of the photoresist in photolithographic processes.
exposure, mask, reticle

alignment mark specially configured mark put on each mask to allow its precise alignment with the pattern on the wafer.
alignment

alloyed junction a junction formed by alloying metal acting as a dopant with semiconductor for the purpose of *p-n* junction formation; e.g. alloy of indium with *n*-type Si forms *p*-type region of the *p-n* junction.
diffused junction, implanted junction

alternative dielectrics dielectrics featuring dielectric constant $k > 3.9$ (3.9 is a dielectric constant of SiO_2) and acting as gate dielectrics in silicon MOS devices instead of SiO_2; referred to as "high-*k* dielectrics"; also dielectrics featuring dielectric constant $k < 3.9$ and used as ILD; referred to as "low-*k* dielectrics".
high-k dielectric, low-k dielectric, ILD

aluminum, Al, conductor common metal in semiconductor processing; used for contacts and interconnects; very low resistivity (2.7 μΩ-cm); melting point 660 °C; easy deposition by evaporation or sputtering; easy etching; shortcomings: electromigration, spiking of silicon, insufficient temperature resistance.
electromigration, spiking

aluminum, Al, contaminant common metallic contaminant in silicon processing; main source: APM cleaning solution and water; slows down thermal oxidation of silicon; affects oxide reliability; detection and measurement on Si surface e.g. by TOF-SIMS.
APM, TOF-SIMS

aluminum nitride, AlN a wide-bandgap semiconductor ($E_g = 6.2$ eV); features direct energy gap, used in UV detection devices.
boron nitride

aluminum oxide, alumina, Al_2O_3 oxide featuring energy gap $E_g \sim 5$ eV and dielectric constant $k \sim 8$; in the form of a single-crystal known as sapphire.
sapphire

ambipolar diffusion coefficient the effective diffusion coefficient of the excess charge carriers (electrons and holes) in semiconductor.
diffusion coefficient

ambipolar mobility the effective mobility of the excess charge carriers (electronics and holes) in semiconductor.
mobility

ambipolar transport the situation where excess electron and hole concentrations in semiconductor are nearly equal is known as quasi-neutrality condition; the charge transport in this case is described by the so-called ambipolar transport in which electrons and holes are diffusing or drifting with the same ambipolar diffusion coefficient and ambipolar mobility.
excess carriers

AMLCD Active Matrix Liquid Crystal Display; higher performance version of an LCD; uses arrays of thin film transistors (TFT) to control individual pixels.
Thin Film Transistor, Liquid Crystal Display

ammonia, NH_3 a gas used in semiconductor processing as a source of atomic nitrogen; atomic nitrogen can be extracted from ammonia at lower temperature than from the molecular nitrogen, N_2; toxic.
nitridation

ammonium hydroxide, NH_4OH a liquid obtained by dissolving ammonia in water; key ingredient of the APM cleaning solution.
APM

AMOLED Active Matrix Organic Light Emitting Diode, active matrix display constructed using organic LEDs in conjunction with thin-film transistors.
organic semiconductor, LED, AMLCD

amorphous material a non-crystalline solid; features no periodicity and long-range order; lower quality than crystalline materials, but cheaper to form; amorphous semiconductors are useful in large-area applications such as solar cells and flat-panel displays; insulators used in semiconductor technology, e.g. SiO_2 and Si_3N_4, are amorphous.
single-crystal, poly-crystalline material

amorphous Si, a-Si a non-crystalline thin-film silicon; features no long-range crystallographic order; inferior electrical characteristics as

compared to single-crystal and polycrystalline-Si (poly-Si), but cheaper and easier to manufacture; used primarily to fabricate solar cells and thin-film transistors.
hydrogenated a-Si, solar cell, TFT

amphoteric dopant an element which can act either as a donor or an acceptor in a given semiconductor; e.g. Si is an amphoteric dopant in GaAs where it acts as a donor on Ga site in GaAs structure or as an acceptor when positioned on As site.
acceptor, donor, dopant

analog device a device designed to realize analog functions such as signal amplification; in analog devices output signal follows continuously input signal.
digital device

analog integrated circuit an integrated circuit realizing analog functions; e.g. operational amplifier; in analog integrated circuits, in contrast to digital integrated circuits, output signal follows continuously input signal.
digital integrated circuit

angstrom, Å unit of length; often used in semiconductor nomenclature; 1Å = 10^{-8} cm = 10^{-4} μm = 0.1 nm; not a standard international (SI) unit; replaced by nm in common usage (1 nm = 10Å).
nanometer

anhydrous HF, AHF a water-free vapor of hydrofluoric acid; used in conjunction with vapor of either water or alcoholic solvents (e.g. methanol) to etch silicon oxides on the wafer surface or sacrificial oxide in MEMS release processes; oxide etch rate depends strongly on wafer temperature and vapor pressure as well as type of oxide; e.g. dry thermal oxide etches much slower than CVD oxide.
hydrofluoric acid, sacrificial oxide, MEMS release

anisotropic etch etching process in which etch rate in the direction normal to the surface is much higher than in directions parallel to the surface; no undercutting, i.e. lateral distortion of the pattern is minimized; needed to define very tight geometrical features.
isotropic etch, etch rate

anneal a heat treatment to which wafer is subjected in order to modify properties of materials/structures processed on its surface or in its bulk.
furnace, RTA

anodic oxidation see *anodization.*

anodization anodic oxidation; process of oxidation in which growth of an oxide on the surface of a conductive solid immersed in the liquid electrolyte or in plasma containing oxygen is stimulated by the flow of electric current.

antimonides groups III-V semiconductor compounds of antimony (Sb), e.g. GaSb. InSb.
arsenides, nitrides, phosphides

antimony, Sb group V element; *n*-type dopant (donor) in silicon; used mainly to dope epitaxial layers; diffusion coefficient in Si is comparable to arsenic and about order of magnitude lower than diffusion coefficient of phosphorous; forms antimonides with group III elements.
donor, antimonides

anti-reflective coating, ARC thin layer of material deposited on the surface of the substrate to minimize reflection and to promote absorption of light in the substrate, e.g. in solar cells; also used to maximize absorption of the UV light in the layer of photoresist.
absorption

antisite defect using GaAs as an example: Ga atom located on As site in GaAs crystal lattice, or As atom located on Ga site in GaAs crystal lattice.
defect

APCVD see *Atmospheric Pressure CVD.*

APD see *Avalanche Photodiode.*

APM **A**mmonia hydroxide-hydrogen **P**eroxide-water **M**ixture; typically 0.25:1:5; same as *SC-1* and *RCA-1*; cleaning solution used primarily to remove particles from the surface; also capable of removing surface organics; strong solutions can etch/roughen silicon surface; forms

chemical oxide (hydrophilic surface) on Si; applied at temperature between 40 °C and 70 °C; typically combined with megasonic agitation.
RCA clean, megasonic agitation, wet cleaning, hydrophilic surface, particles

ARC see *anti-reflective coating.*

ArF excimer laser a chemical laser emitting 193 nm wavelength; used in photolithography; with various resolution enhancement techniques in place suitable for exposing geometries from 150 nm to 10 nm.
photolithography, enhancement techniques

argon, Ar chemically inert gas; nontoxic; due to chemical inactivity and large mass of an ion used in semiconductor technology as an inert gas (more expensive than nitrogen) and in sputtering applications.
nitrogen, sputtering

Arhenius plot allows determination of activation energy of the process from the slope of reaction rate constant vs. $1/T$ (T- temperature).
activation energy

armchair GNR a type of graphene nanoribbon (GNR) which can display either semiconducting or metallic properties depending on the width of the nanoribbon; the term "armchair" refers to the specific configuration of carbon atoms at the edge of the nanoribbon.
graphene nanoribbon, zigzag GNR

arsenic, As group V element; *n*-type dopant (donor) in silicon; features diffusion coefficient comparable to antimony and about order of magnitude lower than phosphorous; donor of choice in very small geometry devices; forms arsenides with group III elements.
donor, arsenides

arsine, AsH_3 gaseous source of As for *n*-type doping of silicon by diffusion or ion implantation; highly toxic and flammable gas; must be handled with utmost care.
arsenic

arsenides groups III-V semiconductor compounds of arsenic (As), e.g. GaAs, InAs.
antimonides, nitrides, phosphides

ashing removal (by volatilization) of organic materials (e.g. photo-resist) from the wafer surface using strongly oxidizing ambient; e.g. oxygen plasma.
barrel reactor, resist stripping

ASIC Application Specific Integrated Circuit; circuit designed and fabricated for a specific application; custom integrated circuit.

aspect ratio in semiconductor terminology taken as the ratio of the depth of the etched feature to its width on the surface normalized to 1; e.g. aspect ratio 10:1 defines the feature that is 10x deeper than wider.
trench

assembly process during which fully processed semiconductor device/ circuit in the form of a chip is mechanically and electrically connected to the package.
dicing, package, wire bonding

ATE Automated Test Equipment.

Atmospheric Pressure CVD, APCVD process of Chemical Vapor Deposition carried out at atmospheric pressure; typically results in the inferior film quality and conformality of coating as compared to Low Pressure CVD (LPCVD).
CVD, LPCVD, conformal coating

Atomic Force Microscopy, AFM a method used to visualize features of solid surfaces with near-atomic resolution; measurement of roughness of solid surfaces based on electrostatic interactions between surface and measuring tip; tip can be set above the surface, on the surface, or can tap the surface oscillating at high frequency (tapping mode).
surface roughness

Atomic Layer Deposition, ALD deposition method in which deposition of each atomic layer of material is controlled by a pre-deposited layer of precursor; precursors and various components of the film are introduced alternately; method features 100% step coverage and very good conformality; the method is commonly used in deposition of high-*k* dielectrics for MOS gates.
conformal coating, high-k dielectric, step coverage, CVD

Atomic Layer Epitaxy, ALE an atomic layer deposition (ALD) process which forms epitaxial layer.
Atomic Layer Deposition, epitaxy

Atomic Layer Etching, ALE subtractive process allowing selective, anisotropic removal of material (etching) with atomic layer precision; complements ALD processes in semiconductor nano-manufacturing.
Atomic Layer Deposition, selective etching, anisotropic etch

Auger electron an electron ejected from the solid as a result of two-stage ionization of atoms bombarded with high energy ions (Auger process); Auger electron carries energy specific to the atom from which it was ejected.
Auger Electron Spectroscopy

Auger Electron Spectroscopy, AES surface characterization and depth profiling method based on the determination of the energy of Auger electrons ejected from the surface bombarded with high-energy ions; only elements with atomic number above 2 can be detected by means of AES.
depth profiling

Auger recombination a band-to-band recombination process involving three particles interactions; energy released as a result of recombination is transferred to another electron or hole rather than released in the form of photon or phonon.
recombination, band-to-band recombination

autodoping dopant atoms evaporating from semiconductor surface region during high temperature treatments can be reintroduced into semiconductor causing undesired variations in dopant concentration at the surface; highly undesired effect; of particular concern in high-temperature epitaxial deposition processes.
epitaxy, outdiffusion

avalanche breakdown breakdown caused by avalanche multiplication of charge carriers in the space charge region of the *p-n* junction at the very high reverse-bias voltage; results in rapid increase of reverse current across the junction; the most common breakdown mechanism in *p-n* junction (other breakdown mechanism is based on the Zener effect).
breakdown Zener effect, avalanche diode