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Edited by Katsumi Suzuki, Shinji Matsui and Yukinori Ochiai
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Sub-Half-Micron Lithography for ULSIs

In semiconductor-device fabrication processes, lithography technology is used to print circuit patterns on semiconductor wafers. The remarkable miniaturization of semiconductor devices has been made possible only because of the continuous progress in lithography technology. However, for the trend of ever-increasing miniaturization to continue a breakthrough in lithography technology is now needed. This book describes advanced techniques under development in Japan and elsewhere that represent the key to future semiconductor-device fabrication.

The background to developments in lithography technology, trends in ULSI technology and future prospects are reviewed, and the requirements that future lithography technology must meet are described. Several important lithography methods, such as deep-UV lithography, X-ray lithography, electron-beam lithography, and focused-ion-beam lithography are described in detail by experts in each area. The principles underlying each of these methods are illustrated at the beginnings of each chapter to help the reader understand the basis of the different approaches. Other relevant technologies, such as those that concern resist materials, metrology, and defect inspection and repair are also described. Original figures and tables are presented to highlight the key issues and recent developments.

This book will be of value to graduate students studying semiconductor-device fabrication, to engineers engaged in such fabrication and to designers of ULSI devices.

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Preface

LSI (large-scale integration) is an invention that has greatly influenced our life in the latter half of the 20th century by bringing us new forms of convenience, comfort, and entertainment. It will continue to play an important role in the 21st century. Today's multimedia systems require ultra-high-density, high-speed, and low-power-consumption devices. Within a few years, practical Gb-scale dynamic random access memories (DRAMs) and GHz-scale processors will be developed, and battery-operated multimedia processors with high-density memories and analog circuits will be among the main targets of ultra-large-scale integration (ULSI). To achieve such devices, breakthroughs in materials, fabrication processes, circuits, and systems will be needed. The development of next-generation lithography technologies is especially urgent.

The purpose of this book is to describe the present status of the principal lithography technologies and the expected future developments. To cover all of the important lithography technologies, including resist materials, metrology, inspection, and repair technologies, each item has been described by experienced engineers currently active in each field in Japan.

Chapter 1 reviews ULSI technology trends, and clarifies the requirements that lithography techniques must satisfy. Chapter 2 examines optical lithography technology, which is currently the most widely used form of lithography. Chapters 3 to 5 explain advanced lithography technologies such as X-ray lithography (XRL), electron-beam lithography (EBL), and ion-beam lithography (IBL) in that order. Resist materials and technologies, metrology, and defect inspection and repair techniques, which play an essential role in practical ULSI production, are described in detail in Chapters 6 and 7. Throughout this book, recent experimental data are cited, which will help readers appreciate the current state-of-the-art for each technology.

We have written this book mainly for researchers and engineers who are engaged in electronic device fabrication, and for university students who are interested in this field.

Katsumi Suzuki

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Principal abbreviations

AdMA–tBuMA	adamantylmethacrylate and t-butylmethacrylate
AFM	atomic force microscopy
ALTA-3000	name of electron-beam exposure system manufactured by ETEC Co.
ALU	arithmetic logic unit
AMIS	automated mask inspection system
ARC	anti-reflective coating
ASIC	application-specific integrated circuit
AURORA	the name of synchrotron developed by Sumito Heavy Industries Ltd.
BAA	blanking aperture array
B(DMA)DS	bis(dimethylamino)dimethylsilane
B(DMA)MS	bis(dimethylamino)methylsilane
B(DMA)TMDS	bis(dimethylamino)tetramethyldisilane
BST	barium strontium titanate $(Ba,Sr)TiO_3$
CA	chemical amplification (or chemically amplified)
CAD	computer-aided design
CCD	charge-coupled device
CD	critical dimension
CF	compression filter
CMOS	complementary metal oxide semiconductor
CMP	chemical–mechanical polishing
COP	polyglycidylmethacrylate copolymer
CP	cell projection (or character projection)
CRT	cathode-ray tube
CVD	chemical vapor deposition
DAADMDS	dialkylaminodimethyldisilanes
DDD	double diffused drain
DESIRE	diffusion-enhanced-silylation resist
DF	decompression filter
DMAPMDS	dimethylaminopentamethyldisilane
DMSDMA	dimethylsilyldimethylamine
DNQ	diazonaphthoquinone
DOF	depth of focus

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DRAM	dynamic random access memory
DRM	development-rate monitor
DSP	digital signal processor
DUV	deep ultraviolet
EB	electron beam
EBES™	name of electron-beam exposure system developed by AT&T
EBL	electron-beam lithography
EBM-130/40	name of electron-beam exposure system manufactured by Toshiba Machine Co.
ECR	electron cyclotron resonance
EEPROM	electrically erasable programmable read-only memory
ESCAP	environmentally stable chemical amplification positive-tone resist
ESD	electrostatic discharge
EX-8	name of electron-beam exposure system developed by Toshiba Machine Co.
FeRAM	ferroelectric random access memory
FET	field effect transistor
FIB	focused ion beam
FIR	finite impulse response
FZP	Fresnel zone plate
GHOST	name of proximity effect correction in electron-beam exposure
HELIOS	name of synchrotron developed by Oxford Instruments Ltd.
HEMT	high-electron-mobility transistor
HMCTS	hexamethylcyclotrisilazane
HMDS	hexamethyldisilazane
HSG	hemispherical grain
HS-tBuA	hydroxystyrene with t-butyl acrylate
HT	half-tone
IBL	ion-beam lithography
IC	integrated circuit
ICA	indenecarboxylic acid
I/F	interface
I/I	ion implantation
I/O	input/output
IPA	isopropyl alcohol
KLA	KLA Instruments Co.
KrF	krypton fluoride
L&S	line-and-space (*also* **L/S**)
LaB_6	lanthanum hexaboride
L_g	gate length (= width of gate electrode) (also L_G)
LDD	lightly doped drain
LIGA	Lithographie Galvanoformung Abform Technik
LMIS	liquid-metal ion source
LOCOS	local oxidation of silicon
LPCVD	low-pressure chemical vapor deposition

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LSI	large-scale integration
LUNA	name of synchrotron developed by Ishikawajima-harima Corp.
MCP	multi-channel plate
MEBES™	production name of EBES manufactured by ETEC Co.
MELCO	name of synchrotron developed by Mitsubishi Electric Corp.
MIB	masked ion beam
MIBK	methylisobutyl ketone
MIPS	millions of instructions per second
MOS	metal oxide semiconductor
NA	numerical aperture
NAND	one of logical circuits, which means an inverse of AND (product of propositions)
Nd:YAG	neodymium-doped yttrium aluminum garnet
NIJI-III	name of synchrotron developed by Sumito Electric Industries Ltd
NMP	*N*-methylpyrrolidine
OAI	off-axis illumination
OPC	optical proximity correction
OPE	optical proximity effect
PαMSt	poly-α methylstyrene
PAC	photoactive compound
PAG	photoacid generator
PAT	previous analysis of distortion and transformation of coordinates (a method of distortion correction for electron-beam delineation)
PB	pre-bake
PBOCST	poly-(t-butoxycarbonyloxy) styrene
PBS	polybutenesulfone
PC	personal computer
PEB	post-exposure baking
PED	post-exposure delay
PHS	polyhydroxystyrene
PID	Proportional Integral Differential
PLL	phase-locked loop
PMGI	polydimethylglutarimide
PMMA	polymethylmetacrylate
PMSt	polymethylstyrene
PSM	phase-shift mask
PZT	lead zirconium titanate
QTAT	quick turn-around time
Qz	quartz
RET	resolution-enhancement technology
RIE	reactive ion etching
ROM	read-only memory
S&R	step-and-repeat
SABRE	silicon-added bi-layer resist

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Salicide	self-aligned silicide
SBT	strontium bismuth titanate ($SrBi_2Ti_2O_9$)
SCALPEL	scattering angular limitation in projection electron-beam lithography system
SD	source drain
S/D contact	source/drain contact
SE	secondary electron
SEM	scanning electron microscope
SEMI	Semiconductor Equipment and Materials International
SEQ	sequencer
SIM	scanning ion microscope
SIMOX	separation by implanted oxygen
SN	signal-to-noise ratio (*also* **SNR**)
SNR™	product name of resist
SOG	spin-on glass
SOI	silicon on insulator
SPD	solid-phase diffusion
SPM	scanning probe microscope
SR	synchrotron radiation
SRAM	static random access memory
STAR	simultaneous transmitted and reflected
STC	stacked capacitor
STM	scanning tunneling microscope
STO	strontium titanate
Super-ALIS	name of synchrotron developed by NTT Corp.
TAR	top anti-reflector
tBOC	t-butoxycarbonyl
tBOCM	t-butoxycarbonylmethyl
TBPB	tetrabromophenol blue sodium salt
T_g	glass-transition temperature
TIS	tool-induced shift
TMAH	tetramethylammonium hydroxide
Tri-MDS	trimethyldisilazane
TPS-OTf	triphenylsulfonium triflate
TSI	top-surface imaging
TTL	through the lens
TTR	through the reticle
TV	television
ULSI	ultra-large-scale integration
VSB	variably shaped beam
WIS	wafer-induced shift
XRL	X-ray lithography

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