

Field Guide to

# Optical Lithography

Chris A. Mack

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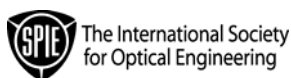
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John E. Greivenkamp, *Series Editor*  
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## Field Guide to Optical Lithography

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The material in this *Field Guide to Optical Lithography* is a distillation of material I have been putting together for the last 20 years or so. I have been subjecting students in my graduate-level lithography course at the University of Texas at Austin to my disorganized notes for 14 years, and have published some similar material in my first book *Inside PROLITH* and my column in *Microlithography World* called “The Lithography Expert.” However, the challenge here was not in creating the material for the book but rather deciding what material to leave out and how to make what remained as condensed as possible. As people who know me can attest, I am rarely lacking for words and brevity is not my strong suit (I am a lousy poet). I hope, however, that the kind reader will forgive me when one page on a topic of interest does not satisfy—it is an unavoidable consequence of the Field Guide format, and my own limitations as an overly verbose writer.

I thank Jeff Byers, William Howard, and Rob Jones for their help in reviewing the draft manuscript of this Field Guide. My many mistakes kept them quite busy.

This Field Guide is dedicated to my wife Susan and our daughter Sarah, who have taught me that there is indeed something more fun in this world than lithography.

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## Symbol Glossary

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$a$	Dose-dependent curvature of the $CD$ -through-focus curve; molar absorption coefficient; constant in the Mack 4-parameter dissolution rate model
$A$	Electric field amplitude; bleachable absorption coefficient
$A_r$	Arrhenius coefficient
$B$	Magnetic induction, non-bleachable absorption coefficient
$c$	Speed of light; concentration
$C$	Photoresist exposure rate constant
$CD$	Critical dimension
$d$	Shifter thickness for a phase-shift mask
$D$	Electric displacement, photoresist thickness; ARC thickness
$D_H$	Diffusivity of acid in photoresist
$DOF$	Depth of focus
$E$	Electric field, incident exposure dose
$E_a$	Activation energy
$E_0$	Dose to clear
$E_z$	Exposure dose at depth $z$ in the resist
$f_x$	Spatial frequency
$G_0$	Initial PAG concentration
$h$	Planck's constant; normalized acid concentration in a chemically amplified resist
$H$	Magnetic field; acid concentration in a chemically amplified resist
$I$	Intensity of light, aerial image
$J$	Electric current density
$k$	Propagation constant, wavenumber; chemical reaction rate constant
$k_1$	Normalized Rayleigh resolution
$k_2$	Normalized Rayleigh depth of focus
$L_{eff}$	Effective gate length
$m$	Magnification; normalized unreacted site concentration in conventional or chemically amplified resists
$m_{TH}$	Threshold inhibitor concentration
$M$	Photoactive compound concentration, unreacted site concentration

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## Symbol Glossary (cont'd)

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$M_0$	Initial PAC concentration
$n$	Index of refraction; dissolution selectivity parameter; diffraction order number
$n_j$	Complex index of refraction of layer $j$
$N_A$	Avogadro's number
$NA$	Numerical aperture
$NILS$	Normalized image log-slope
$OPD$	Optical path difference
$p$	Pitch
$P$	Pupil function; photoresist exposure products; a point in $x$ - $y$ - $z$ space
$r$	Photoresist dissolution rate
$r_{\max}$	Dissolution rate of fully exposed positive resist
$r_{\min}$	Dissolution rate of unexposed positive resist
$R$	Resin concentration; resolution; relative pupil radius position; intensity reflectivity; universal gas constant; photoresist dissolution rate
$S$	Solvent concentration
$t$	Time, exposure time
$t'$	Bake time
$t_m$	Mask transmittance function
$T$	Transmittance; absolute temperature
$T_m$	Fourier transform of the mask transmittance function (diffraction pattern amplitude)
$U$	Phasor representation of the sinusoidal e-field
$v$	Process variable
$w$	Slit width, mask feature width, nominal linewidth
$x$	Normalized concentration of reacted sites in a chemically amplified resist; horizontal position
$X$	Concentration of reacted sites in a chemically amplified resist
$Z$	Zernike polynomial coefficient
$\alpha$	Maximum angle of diffraction captured by a lens; absorption coefficient
$\delta$	Dirac delta function; defocus distance
$\epsilon$	Dielectric constant
$\theta$	Angle; polar angle of pupil position; photoresist sidewall angle

## Symbol Glossary (cont'd)

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$\gamma$	Photoresist contrast
$\kappa_j$	Imaginary portion of complex refractive index
$\lambda$	Wavelength (in vacuum)
$\mu$	Magnetic permeability
$\rho$	Electric charge density
$\rho_{ij}$	Reflection coefficient between films $i$ and $j$
$\sigma$	Conductivity; partial coherence factor; diffusion length
$\tau_{ij}$	Transmission coefficient between films $i$ and $j$
$\Phi$	Phase of an electric field; fraction of absorbed photons producing a chemical change (quantum yield)
$\omega$	Frequency of monochromatic light; photoresist spin coat speed