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# Preface

Research and development for new, improved materials and their manufacturing processes have been rapidly accelerating during the last decades. This multi- and interdisciplinary effort encompasses many fields of science and technology such as physics, chemistry, and materials and chemical engineering. One of these fast-growing areas is processing by plasma assisted methods. A search of the published literature in the last 15 years shows an enormous growth in plasma assisted research and development activities, which reflects the significant task undertaken to understand these processes and use them in novel applications or as a useful substitute to established techniques.

Processing by plasma assisted techniques is being increasingly used in various areas of production and manufacturing as diverse as the automotive, aerospace, and biomedical industries and in the fabrication of microelectronic components. The current predominant trend in the microelectronics industry is to switch increasingly from wet to dry processing of materials by plasma assisted methods. The use of plasma techniques for deposition of films is expanding in response to requirements for processing at lower temperatures than those possible using chemical vapor deposition. As a result, a growing number of engineers and scientists from a wide range of disciplines are involved in plasma assisted processing, either in manufacturing or in research and development. To provide these engineers and scientists with an appropriate working background, a special course on plasma processing of materials must become part of their preparatory curriculum.

Although a number of books deal with cold, low-pressure plasmas and their applications, a textbook for a basic course appears to be needed, and this book is



intended to fill that gap. The book will serve college seniors and graduate students in science (physics and chemistry) and engineering (materials, chemical, and electrical). It assumes the reader already has suitable knowledge of physics and chemistry. Two years of physics courses in a science or engineering program and a basic course in chemistry should provide the necessary basis for the comprehension of the material discussed in the book. The book is also designed to serve as an introductory and refreshment reference tool for the manufacturing engineer actively involved with plasma assisted techniques but also in need of detailed, in-depth knowledge of the field.

This book aims to present the fundamentals of physics and chemistry of cold plasmas, methods of generation, diagnostics, and state-of-the-art applications for processing of materials. The book is organized in eight chapters. The first chapter defines plasma in general as well as its main parameters and classifies the types of plasmas. All the chapters following focus on cold plasma only. The principles of the various methods to create and sustain a plasma are treated in the second chapter. The third chapter describes the reactions that can occur in cold plasmas and the interactions taking place between a plasma and a solid surface in contact with it. Reactors types, their design, and particular features are discussed in Chapter 4. Chapter 5 deals with plasma diagnostic methods, emphasizing quadrupole mass spectrometry, electrostatic Langmuir probes, and optical methods. Chapters 6–8 present a selection of applications of cold plasmas for processing solid surfaces: Chapter 6, devoted to surface modifications, covers surface activation, cleaning, ashing, oxidation, and hardening; Chapter 7 describes the deposition of coatings of inorganic films and polymerization; Chapter 8 centers on the use of plasma for dry etching. For the ease of the reader, a bibliographic list of relevant publications follows each chapter.

I wish to thank my wife Any for the critical reading of the manuscript and her constructive suggestions for improving its clarity.

Alfred Grill

# List of Symbols

## Fundamentals of Plasma

$A$	area	$p$	pressure
$B$	magnetic field	$P$	electrical power
$c$	velocity of light	$q$	electrical charge
$d$	distance	$Q$	flow rate
$d_s$	thickness of plasma sheath	$r$	radius
$D$	diffusion coefficient	$R$	reaction rate
$e$	electron charge	$T$	temperature
$E$	electric field	$U, V$	electrical potential, voltage
$f(W)$	energy distribution function	$v$	velocity
$f(v)$	velocity distribution function	$Vol$	volume
$f_{ce}$	critical electron frequency	$W$	energy
$f_{ci}$	critical ion frequency	$\alpha$	degree of ionization
$h$	Planck's constant	$\epsilon_0$	permittivity of free space
$I$	current	$\Gamma$	particle flux
$I_n$	light intensity	$\lambda_D$	Debye length
$J$	current density	$\lambda$	mean free path
$k$	Boltzman's constant	$\mu$	mobility
$L$	characteristic reactor dimension	$\nu$	collision frequency
$m, M$	mass of particle	$\omega$	frequency
$n$	particle density, plasma density	$\sigma$	cross section
$N_D$	number of particles in a Debye sphere	$\tau_r$	residence time