Xinyi Zhang

SYNCHROTRON RADIATION APPLICATIONS

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This is a research-level review volume. It presents both the fundamentals and the advanced research results, covering most part of important aspects of synchrotron radiation applications. Among the broad subjects of synchrotron radiation applications, as the main content of this book we have applications in VUV, soft X-rays, hard X-rays and XFEL (X-ray free electron laser) and important applications by various synchrotron-based techniques and methods, such as ARPES (angle-resolved photoemission spectroscopy), VUV photo-ionization spectroscopy, X-ray absorption/emission spectroscopy and X-ray absorption fine structure, X-ray diffraction, small angle X-ray scattering, X-ray excited optical luminescence, imaging and high pressure techniques.

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SYNCHROTRON RADIATION APPLICATIONS

Preface

This is a review volume. It will tell our readers both the fundamentals and the advanced research results, covering the most important aspects of synchrotron radiation applications. Among the broad subjects of synchrotron radiation applications we choose subjects which cover applications in VUV, soft X-rays, hard X-rays, and XFEL (X-ray free electron laser), and contain important applications by various synchrotron-based techniques and methods, such as ARPES (angle-resolved photoemission spectroscopy), VUV photoionization spectroscopy, X-ray absorption/emission spectroscopy and X-ray absorption fine structure, X-ray diffraction, small angle X-ray scattering, X-ray excited optical luminescence, imaging, and high pressure techniques. Many interesting aspects with latest stirring results will be described, such as recent ARPES study on the iron based superconductors, the charge density wave materials, and the Mott-insulators; crystal structure of macromolecules in structural biology; medical imaging including clinical and pathological applications; study on various advanced functional materials; and the recent encouraging research achievements based on XFELs. One more thing that I would like to stress on is that developing new detectors matters as much as new experimental methods. Simply speaking, you can see nothing without the detectors, and it would be impossible to have top-notch experimental results. In this book, Chapter 5 of Hiroyuki

Oyanagi described the history of segmented X-ray detectors, including the *state-of-the-art* pixel detectors for fluorescence-detected synchrotron radiation X-ray spectroscopy experiments.

I did not expect it would cost me more than four years at the beginning when I accepted the writing job of this book. Tetsuya Ishikawa, director of Riken Harima Institute, once said to me, "The science with XFEL, which I plan to describe, has been expanding very rapidly. Actually, it is extremely difficult for anyone to compile the XFEL science in this rapidly changing time." He is right. In fact, not only XFEL but also various fields of synchrotron radiation applications have developed well and fast, new experimental methods and numerous research results keep on emerging. The team of Tetsuya Ishikawa finally offers our readers the wonderful Chapter 13 reviewing SACLA (Spring-8 Angstrom Compact Free-electron Laser) research achievements.

I kept thinking about collecting the latest research results about synchrotron radiation applications in this book. But it is too hard to do this for reasons that research objects and methods are differentiated in a wide range, experimental techniques are precise but complicated and development is so fast that sometimes it is beyond one's reach. Nevertheless, I tried to ask contributors of each chapter to include the latest synchrotron-based techniques and research results into their work time and time again. Authors were also asked to edit their manuscripts over and over so as to include new research developments. For example, Ando Masami, who wrote Chapter 8 of this book, had at least seven re-edited versions stored in my computer. In truth, many other authors did the similar things. Though this book took a long time, we are fortunate to enclose some new techniques quickly developed in recent years into this book. For example, at the beginning of writing this book, I once listed CDI (coherent diffractive imaging) in, but some others thought it was still under-developed to be described in this book. However, just two years later, CDI has finally succeeded using XFEL; hence we have Chapter 14 contributed by Andrew V. Martin and N. Duane Loh. Also, a short paragraph describing CDI was added in Tiqiao Xiao and Lanhong Xie's

Chapter 9. Many techniques mark great research developments in synchrotron radiation applications over these years, such as time and space resolved technique, especially dynamical research on the relationship between structure and function during operation, namely *operando* techniques; various new imaging techniques, and new X-ray diffractive technique for dynamical structural studies on increasingly complex systems.

This book can be a reference book for researchers and technicians taking up synchrotron radiation application researches and postgraduates majoring in this field. For it is finite in my knowledge, some inadequacies and imperfect points are inevitable; therefore I hope you feel free to enlighten me. Finally, I would like to thank all the authors who made great contributions to this book and also many others, who contributed as well but have not been listed is the chapter authors.

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List of Abbreviations

2D : two-dimensional
3D : three-dimensional
AAV–NT-1 : adeno-associated viral vector–Netrin-1
ABI : analyzer-based imaging
ACA : anterior cerebral artery
ACF : absorption correction factor
AchA : anterior choroidal artery
AC-OSEM : Absorption-corrected ordered subsets expectation maximization
AD : Alzheimer's disease
AFM : atomic force microscopy
AMO : antimicrobial oligomers
ASAXS : anomalous small angle X-ray scattering
BL13W1 : X-ray imaging and biomedical applications beamline
BM : biological macromolecule
BN : boron nitride
BNSLs : binary NPSLs
BSRF : Beijing Synchrotron Radiation Facility
cc : corpus callosum
CCDs : Combustion chamber deposits
CDI : coherent diffraction imaging

CF : cystic fibrosis
CI : crystal interferometry
CMC : carboxymethyl cellulose
CMFs : cellulose microfibrils
CMMS : Calcium/magnesium-doped silica-based hierarchically mesoporous scaffolds
CNCD : computerized numerical control drilling
CPu : caudate putamen
CS : compressed sensing
CT : computed tomography
CTAC : cetyl trimethylammonium chloride
CT-DE : computed tomography-Diffraction enhancement
DA : decoupling approximation
DCM : data-constrained modeling
DEI : diffraction enhancement imaging
DLS : dynamic light scattering
DNA : deoxyribonucleic acid
DOSs : densities of states
DWBA : Distorted Wave Born Approximation
ECM : extracellular matrix
EDM : electrical discharge machining
EGFR : Epidermal Growth Factor Receptor
EM : electron microscopy
EPR : electron paramagnetic resonance
ERK2 : extracellular signal-regulated kinase 2
EROS : ensemble refinement of SAXS
EST : equally sloped tomography
FBP : filtered back projection
FEL : free electron laser
FOV : field of view
FT : Fourier transform
FWHM : Full width at half maximum
GAG : glycosaminoglycan
GDPC : Grating-based differential phase contrast imaging
GI : grating interferometry

GIFT : generalized indirect Fourier transformation
GISAXS : grazing incidence small angle X-ray scattering
GUI : graphical user interface
HePTP : hematopoietic tyrosine phosphatase
HNC : hypernetted chain
HTA : hypothalamic artery
ICH : intracranial hemorrhage
ICP-MS : Inductively coupled plasma mass spectroscopy
IFs : intermediate filaments
IL-PCI : in-line X-ray phase-contrast imaging
IL-XPμCT : in-line X-ray phase contrast micro-computed tomography
IL-XPCT : in-line X-ray phase-contrast CT
IMC : intermetallic compound
LMA : local monodisperse approximation
LV : lateral ventricle
MAP : mitogen-activated protein
MB : Methylene Blue
MBA : Modified Bronnikov algorithm
MCA : middle cerebral artery
MCAO : middle cerebral artery occlusion
MD : molecule dynamics
Micro-CT : X-ray microscopic computerized-tomography
MRI : magnetic resonance imaging
NAC : nascent polypeptide associated complex
NFTs : neurofibrillary tangles
NMR : nuclear magnetic resonance
NPs : nanoparticles
NPSL : nanoparticle superlattice
OA : osteoarthritis
ODDS : Osmotic drug delivery systems
OSEM : ordered subsets expectation maximization
OZ : Ornstein-Zernike
PAD : phase-attenuation duality
PBI : propagation-based phase-contrast imaging
PC : phosphatidylcholine

PCA : posterior cerebral artery
PC-CT : phase-contrast enhanced computed tomography
PCI : phase-contrast imaging
PCL : poly(ε-caprolactone)
PcomA : posterior communication arteries
PCXI : phase contrast X-ray imaging
PDB : protein data bank
PDDF : pair distance distribution function
*PeaT*1 : protein elicitor from Alternaria tenuissima
PEG–PE : Poly(ethylene glycol)–phosphatidylethanolamine
PEO : poly-(ethylene oxide)
PET : positron emission tomography
PG : proteoglycan
PITRE : Phase-sensitive X-ray Image processing and Tomography Reconstruction
PLLA : Poly(L-lactide)
PPCI : X-ray propagation-based phase-contrast imaging
PPCT : X-ray propagation-based phase-contrast CT
PPI : phase propagation X-ray imaging
PPO : poly(propylene oxide)
PS-PVP : poly(styrene-b-2-vinylpyridine)
PVME : poly(vinyl methyl ether)
RC : rocking curve
rhBMP-2 : recombinant human bone morphogenetic protein-2
RNA : Ribonucleic acid
ROI : region of interesting
SAH : subarachnoid hemorrhage
SANS : small-angle neutron scattering
SAXS : small angle X-ray scattering
SCF/EP : short carbon fiber/epoxy
SD : Sprague-Dawley
SDD : sample-to-detector distance
SDF : size distribution function
SEM : scanning electron microscopy
SL : superlattice

SLS : static light scattering
SNSLs : single NPSLs
SPECT : single-photon emission computed tomography
SR-μCT : synchrotron based X-ray micro-CT
SR : synchrotron radiation
SR-CT : synchrotron radiation absorption-based CT
SSCA : size-spacing correlation approximation
SSRF : Shanghai Synchrotron Radiation Facility
SSRL : Stanford Synchrotron Radiation Lightsource
TBC : tetrabromocathecol
TBT : tangent by tangent
TCMs : traditional Chinese medicines
TE : tissue engineering
TEM : transmission electron microscopy
TIE : differential transport-of-intensity equation
TIEG1 : TGFβ inducible early gene 1
TMV : tobacco mosaic virus
t-SAXS : time-resolved small angle X-ray scattering
UBA : ubiquitin-associated
US : ultrasound
USAXS : ultra-small-angle X-ray scattering
UV : ultraviolet-visible
WAXS : wide-angle X-ray scattering
WHO : World Health Organization
XAFS : X-ray absorption fine structure
XANES : X-ray absorption near-edge structure
XDFI : X-ray dark field image
XFCT : X-ray fluorescence computed tomography
XPμCT : X-ray phase contrast micro-computed tomography
XPCI : X-ray phase-contrast imaging
XPCMT : X-ray phase contrast micro-tomography
XRD : X-ray diffraction
XRF : X-ray fluorescence

Program Names

ATSAS
PCG
DECON
GIFT
IsGISAXS
PRIMUS
GNOM
DAMMIN
DAMAVER