The Supramolecular Chemistry of Organic–Inorganic Hybrid Materials

Edited by

Knut Rurack and Ramón Martínez-Máñez

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Preface

Supramolecular chemistry, which is basically devoted to the study of the interaction between molecules, and materials chemistry, dealing with the development of solids with specific properties, are two powerful disciplines that have traditionally been poorly interrelated. Only the drive to create ever faster, ever more affordable, and ever more convenient technologies with a myriad of new and advanced features has tempted materials scientists to push the boundaries to ever smaller components and chemical researchers to design ever larger supramolecular structures, both entering into the interfacial zone of nanotechnology and nanochemistry. *Function* is the keyword here, especially when the aim is to design “smart” or “intelligent” materials. Inorganic supports are often inert and do not display many functions. In contrast, organic molecules can have a rich functionality, yet an ensemble of them in a disordered state—whether in solution or randomly adsorbed on a surface—often does not perform as desired. Thus, at the dawn of nanotechnology research in the late 1980s, chemists and materials scientists realized that a combination of their skills might be more successful in approaching the aims than to stay on the beaten tracks. Hence, the rapidly growing world of organic–inorganic hybrid materials emerged, producing nanoscopic matter with a plethora of novel properties and functions. Although the basic idea to *combine inorganic materials with functional organic molecules* might sound straightforward, its realization is connected to several challenges. Of course, “smart” hybrid materials cannot be obtained simply by teaching organic molecules to sit on an inorganic support and solve a Sudoku, play tennis, or sing a number-one hit. Organic functions on inorganic supports have to be organized and have to be orchestrated in their action, which often involves sophisticated chemistry and a structuring and patterning of the inorganic partner at molecular dimensions. At this stage, supramolecular concepts and tools from nanotechnology come into play. Only a clever combination of these strategies and techniques allows the creation of tailor-made “hetero-supramolecular” functionalities, showing new synergisms and unprecedented performance. Compared to the vast amounts of macroscopic devices available in society today and molecular biological processes operative in living organisms, naturally, only considerably few active functions have been realized in the young research field covered here. However, this book shows how a plethora of promising ideas has arisen from the combination of supramolecular chemistry, inorganic solids, and nanotechnology and has already accomplished significant advances in many areas such as sensing, controlled motion, or delivery. The objective here is to provide a compendium that gives an overview of the present state and upcoming challenges in this rapidly growing, highly cross- or interdisciplinary research field.

Flanked by three general chapters, the book is divided into five thematic sections. After a brief introduction to basic terms and concepts in the areas of supramolecular chemistry and hybrid (nano)materials in Chapter 1, Ariga et al. sketch general aspects of supramolecular chemistry related to hybrid materials and structures at the mesoscale in Chapter 2. The chapters collected in the first thematic section on Organic–Inorganic Hybrid Nanomaterials provide an in-depth introduction to synthetic strategies, major properties, characterization techniques, key features, and selected applications of today's most important families of hybrid materials: mesoporous organic–inorganic hybrid silica (Chapter 3 by Hoffmann and Fröba), modified gold nanoparticles and surfaces (Chapter 4 by Pengo and Pasquato), and organically functionalized semiconductor nanocrystals (Chapter 5 by Reiss et al.). Chapter 6 by Gu et al. deals with the functionalization of carbon nanotubes and their bioanalytical and biomedical applications and in Chapter 7, Kitagawa and Noro unfurl the world of porous coordination polymers or MOFs.

The second, third, and fourth sections comprise detailed introductions to design strategies, collective properties, signaling aspects, and/or application-oriented features of a broad variety of hybrid materials in the context of major supramolecular concepts such as assembly, sensing, switching, gating, catalysis, and molecular machinery. Part Two, Improvement of Signaling and Sensing by Organization on Surfaces, basically shows how the organization of molecular entities on surfaces can be used to enhance electrochemical or optical signaling and sensing processes for materials such as gold or silica nanoparticles and quantum dots. In Chapter 8, Polsky et al. report on biomolecular–nanoparticle hybrid systems for electrochemical signaling, followed by Guo et al.'s Chapter 9 on the use of modified nanoparticles for electrocatalysis and as amplifying sensors. The use of gold and silica nanoparticles and quantum dots for optical sensing and imaging applications is demonstrated in Chapters 10, 11, and 12 by Wei and Wei, Mancin et al., and Fernández Argüelles et al., respectively.

The section Control of Supramolecular Nanofabrication, Motion, and Morphology is devoted to state-of-the-art applications of certain supramolecular tools and functions on solid supports. In Chapters 13 and 14, Ling et al. and Rożkiewicz et al. discuss different strategies for the directed self-assembly of nanoparticles on surfaces and give an overview of immobilization and patterning techniques for the attachment of biomolecules on surfaces. The other chapters elaborate on the realization of advanced supramolecular functions on solid scaffoldings related to switchable host–guest chemistry (Chapter 15 by Kong et al.), the control of mass transport by gating in mesoporous hybrid silica (Slowing et al. in Chapter 16), the directed motion of molecular machines on surfaces (Chapter 17 by Credi et al.), and controlled changes in morphology of mesostructured hybrid materials (Dunphy et al. in Chapter 18).

The subsequent section Biomimetic Chemistry presents hybrid solids that were developed according to signaling and recognition processes established in nature (Chapters 19 and 20 by Rurack et al. and Collinson) and concludes with Chapter 21 by Kamperman and Wiesner, who show how nature's strategy of combining biomacromolecules and inorganic skeletons can be transferred to block copolymers and inorganic nanomaterials, yielding hybrid materials with unprecedented properties and functions.

The chapters in the last section have a “wildcard” character, each touching a very particular aspect of the area of nanoscopic hybrid materials in a rather short and concise manner yet each having a background of more general importance. In Chapter 22, Shchukin et al. report on the use of hybrid nanocontainer materials as self-healing anticorrosion coatings. The ways in which adaptive or stimuli-responsive “schizophrenic” materials with a dual character might revolutionize chemo- and biosensing systems is discussed by Byrne and Diamond in Chapter 23. After all the chemistry highlighted in the previous chapters, Chapter 24 sheds light on a particular keyword that is often used by scientists in the field themselves as well as by policy makers, interdisciplinarity. Rafols et al. approach an answer to the question of how far hybrid nanomaterials research really is interdisciplinary with scientometric tools, that is, with a bibliometric analysis of the field as presented in the book. Another short chapter written by the editors completes the book by looking ahead on four exemplary research directions that have developed only in the last two to three years, during the making of the book, or that are on the verge of developing in the near future.

Finally, we would like to thank all the authors of this book wholeheartedly for their enthusiastic participation and the effort they made in preparing such interesting and stimulating chapters. To work on this book has been an exciting and pleasurable experience for us, and we are also grateful to Anita Lekhwani and Rebekah Amos of John Wiley & Sons for their belief in the book and for their help in realizing it. Of course, a book like this cannot be complete yet we hope that through this collection of excellent contributions the reader will gain profound insight into this fascinating and emerging research area, will appreciate what has been already achieved by scientists around the globe, will be captivated to keep an eye on the field in the future, and, perhaps, will be inspired to join in and discover future advances in the supramolecular chemistry of organic–inorganic hybrid materials.

Knut Rurack, Berlin, D
Ramón Martínez-Máñez, Valencia, E

Note: Additional color versions of selected figures printed in Chapters 3–13, 15, 16, and 19–25 are available on ftp://ftp.wiley.com/public/sci_tech_med/supramolecular_chemistry.

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Abbreviations

2D	two-dimensional
3D	three-dimensional
3PL	three-photon luminescence
4VP	4-vinylpyridine
AA	alginic acid
AA2024	trade name of an aluminum alloy
Ab	antibody
ac	acetate
adip	5,5′-(9,10-anthracenediyl)di-isophthalate
ADP	adenosine diphosphate
AFM	atomic force microscopy
Aib	α-aminoisobutyric acid
Ala	alanine
AM 1.5	air mass 1.5 conditions
AMP	adenosine monophosphate
AMS	α-methylstyrene
ANA	analcime
AOT	sodium bis(2-ethylhexyl)sulfosuccinate
APC	2,4-bis(4-dialkylaminophenyl)-3-hydroxy-4-alkylsulfanylcyclobut-2-enone
apoB-100	ligand of LDL receptor
Apt	aptamer
APTES	3-aminopropyltriethoxysilane (frequently abbreviated as APTS in the literature)
APTMS	3-aminopropyltrimethoxysilane
Asn	asparagine
ASTM	American Society for Testing and Materials
atp	aminoterephthalate
ATP	adenosine triphosphate
ATR	attenuated total reflection (spectroscopy)
ATRP	atom transfer radical polymerization
AuNP	gold nanoparticle
Az	azurin
azpy	trans-4,4′-azopyridine

αCP	affinity contact printing
αG	α-L-guluronic acid (frequently abbreviated as G in the literature)
b	block (in block copolymer nomenclature)
B50-6600	trade name of a block copolymer $EO_{39}BO_{47}EO_{39}$
BaM	barium ferrite nanocrystals
BBDA	*N*,*N*′-bis(4-*tert*-butylphenyl)-*N*,*N*′-bis(4-((*E*)-2-(triethoxysilyl)vinyl)phenyl)biphenyl-4,4′-diamine
bbim	1,3-dibutylimidazolium
bBSA	biotinylated bovine serum albumin
BCAm	benzo[18]crown-6-acrylamide
bdc	benzene dicarboxylate
BDD	boron-doped diamond
BDMS	bis(*tert*-butyldimethylsilyl)
BEA	beta (zeolite beta)
BET	Brunauer–Emmett–Teller
BFc	biferrocene
BHEEEN	1,5-bis[2-(2-(2-hydroxyethoxy)ethoxy)ethoxy]naphthalene
BINAP	2,2′-bis-(diphenylphosphino)-1,1′-binaphthyl (also: binap)
BJH	Barrett–Joyner–Halenda
BO	butyleneoxide
Boc	*tert*-butoxycarbonyl
BP	benzophenone
bpbp	4,4′-bis(4-pyridyl)biphenyl
bpethe	1,2-bis(4-pyridyl)ethene
bpy	bipyridine/yl
Brij 56	trade name of a poly(ethylene glycol hexadecyl ether) detergent and emulsifier
BS^3	bis(sulfosuccinimidyl)suberate
BSA	bovine serum albumin
btapa	1,3,5-benzenetricarboxylic acid tris[*N*-(4-pyridyl)amide]
btb	1,3,5-benzenetribenzoate
btc	benzene tricarboxylate
BTEB	1,4-bis(triethoxysilyl)benzene
BTEBP	4,4′-bis(triethoxysilyl)biphenyl
BTEE	1,2-bis(triethoxysilyl)ethane
BTEMEB	1,4-bis(triethoxysilyl)-2-(1-methoxyethyl)benzene
BTESM	bis-triethoxysilylmethane
BTET	2,5-bis(triethoxysilyl)thiophene
BTEX	benzene, toluene, ethylbenzene, xylenes
BTEY	1,2-bis(triethoxysilyl)ethene
BTME	1,2-bis(trimethoxysilyl)ethane
BTMSEB	1,4-bis(trimethoxysilylethyl)benzene
BTMSPA	bis[3-(trimethoxysilyl)propyl]amine

btt	1,3,5-benzenetristetrazolate
Bu	butyl
bza	benzoate
βM	β-D-mannuronic acid (frequently abbreviated as M in the literature)
CA	cancer antigen
CALNN	Cys-Ala-Leu-Asn-Asn
cAMP	cyclic AMP
CASH	combined assembly by soft and hard (chemistries)
CB	conduction band
CB[6]	cucurbit[6]uril
CBED	convergent beam electron diffraction (patterns)
CBPQT	cyclobis(paraquat-*p*-phenylene)
CCD	charge-coupled device
CCM	Cornell composition of matter (family of materials)
CD	cyclodextrin
CD4	(cluster of differentiation 4) glycoprotein, a co-receptor of the T (thymus) cell receptor
CDA	cell-directed assembly
CE	capillary electrophoresis
CE	cholesterol esterase
CFU	colony forming units
chbt	cyclohexylbutyrate
CHI	chitosan
CHO	Chinese hamster ovary
CMC	critical micelle concentration
CMK-*n*[1]	carbon mesostructured by Korea Advanced Institute of Science and Technology (family of mesoporous carbon materials)
CNT	carbon nanotubes
co	*co*polymer
cod	cyclooctadiene
COx	cholesterol oxidase
CP	conjugated polymer
CP/MAS	cross-polarization MAS (NMR)
CPB	hexadecylpyridinium bromide
CPC	hexadecylpyridinium chloride
CPL	coordination pillared layer
CPO	chloroperoxidase
CPU	central processing unit
CS	core–shell
CT	charge-transfer
CT	computed tomography
CTAB	cetyltrimethylammonium bromide

CTAC	cetyltrimethylammonium chloride
CTES	carboxyethylsilanetriol, sodium salt
CV	cyclic voltammetry
CVD	chemical vapor deposition
CW	continuous wave
CXCR4	CXC chemokine receptor; CXC stands for a C-X-C motif with C = cysteine and X = arbitrary amino acid
Cy3	carbocyanin 3
Cy3.5	carbocyanin 3.5
Cys	cysteine
DA	dodecylamine (frequently abbreviated as DDA in the literature)
dabco	diazabicyclo[2.2.2]octane
DAP	diaminopyrimidine
DAR	diazo resin
DART	direct analysis in real time (ionization technique in MS)
DAT	diaminotriazine
DB24C8	dibenzo[24]crown-8
DBM	dibenzoylmethane
DBS	dibutyl sebacate
DDA	discrete dipole approximation
DDAB	dilauryldimethylammonium bromide
DFT	density functional theory
dhbc	2,5-dihydroxybenzoate
DHLA	dihydrolipoic acid
DIEA	diisopropylethylamine
diglyme	diethylene glycol dimethyl ether
dipn	*N*,*N*-di(3-aminopropyl)amine
diPyNI	*N*,*N*′-di-(4-pyridyl)-1,4,5,8-naphthalenetetracarboxydiimide
DMAP	4-dimethylaminopyridine
DMB	(1*R*,2*S*)-(-)-*N*-dodecyl-*N*-methylephedrinium bromide
DMF	*N*,*N*-dimethylformamide
DMPA	dimyristoylphosphatidyl
DMSO	dimethyl sulfoxide
DNA	deoxyribonucleic acid
DOE	U.S. Department of Energy
DON	1,5-dioxynaphthalene
DOPA	D-/L-3,4-dihydroxyphenylalanine
DOPO-Br	*p*-bromobenzyl-di-*n*-octylphosphine oxide
DOX	doxorubicin
DPAR	4-*n*-dodecyl-6-(2-pyridylazo)phenol
DPC	diphenylcarbazide
DPN	dip-pen nanolithography
dpp	4,4′-diphenylphenanthroline
DPV	differential pulse voltammetry

dpyg	1,2-di(4-pyridyl)glycol
dsDNA	double-stranded DNA
DSG	disuccinimidylglutarate
DsRed	mutant of red fluorescent protein
DT	dodecanethiol
DTA	differential thermal analysis
DTAR	4-*n*-dodecyl-6-(2-thiazolylazo)resorcinol
DTC	dithiocarbamate
dtoa	dithiooxamide
DTPA	diethylenetriaminepentaacetic acid
DTT	dithiothreitol
DVB	divinylbenzene
dx	decylxanthate
DZ	diphenylthiocarbazone
E	energy
e^-	electron
eAuNP	enlarged AuNP
ECL	electrochemiluminescence
EDAC	see EDC
EDC	1-ethyl-3-[(3-dimethylamino)propyl]carbodiimide hydrochloride
EDOT	3,4-ethylenedioxythiophene
EDS	energy-dispersive spectroscopy
EDTA	ethylenediaminetetraacetic acid
EELS	electron energy loss spectroscopy
EFTEM	energy-filtered TEM
EG4	tetra(ethylene glycol)
EG6	hexa(ethylene glycol)
EGDMA	ethylene glycol dimethacrylate
EGFP	enhanced green fluorescent protein
EGFR	epidermal growth factor receptor
EHTES	5,6-epoxyhexyltriethoxysilane
eim	2-ethylimidazolate
EISA	evaporation-induced self-assembly
ELISA	enzyme linked immunosorbent assay
EO	ethyleneoxide
EPR	enhanced permeability and retention
ER	electrorheological
ESR	electron spin resonance
Et	ethyl
EU	European Union
ex	ethylxanthate
F88	trade name for a Pluronic surfactant
F127	trade name for a Pluronic surfactant

FA	folic acid
FAD	flavin adenine dinucleotide
Fc	ferrocene or ferrocenyl
Fc	fragment, crystallizable (of an antibody)
Fc-D	ferrocenyl-tethered dendrimer
FCC	fluid catalytic cracking
FcN	(*R*)-/(*S*)-*N*,*N'*-dimethylferrocenylethylamine
FDA	U.S. Food and Drug Administration
FDM	ferrocene dimethanol
FDMDG	ferrocene dimethanol diethylene glycol
FDTD	finite difference time domain (method)
FDU-*n*	Fudan University (family of mesoporous silicas)
FET	field effect transistor
FGD	flue gas desulfurization
FIA	fluoroimmunoassay
FITC	fluorescein isothiocyanate
Fmoc	fluorenylmethoxycarbonyl
FND	fluorescent ND
FNP	fluorescently doped nanoparticles
FR^+	receptors for FA ligands
FRET	Förster resonance energy transfer (frequently yet inappropriately referred to as fluorescence resonance energy transfer, see IUPAC recommendations)[2]
FSM-*n*	(family of) folded sheet mesoporous (materials)
FTIR	Fourier transform IR
FUM	fumaramide
Fur	ferric uptake regulator
FWHM	full width at half maximum
G	generation (of dendrimer)
GAG	glycosaminoglycan
Gal	galactose
GBP	gold binding polypeptide
GCE	glassy carbon electrode
GCNF	graphitic carbon nanofiber
GEPI	genetically engineered peptides for inorganics
gFND	green FND
GFP	green fluorescent protein
Glu	glutamine
GLYMO	3-glycidyloxypropyltrimethoxysilane
GMP	guanosine monophosphate
GOx	glucose oxidase
GSH	reduced form of glutathione
GSSG	oxidized form of glutathione

h^+	hole
h-h	head-to-head coupling
HDA	hexadecylamine
hdx	hexadecylxanthate
HeLa	Henrietta Lacks (HeLa cells: immortal cell line derived from H.L.'s cervical cancer cells)
HETCOR	heteronuclear correlation (NMR)
HFBI	hydrophobin
HFE	gene responsible for hereditary hemochromatosis
HH	hexadecyl hexadecanoate
HHCC	horse heart cytochrome c
HI	hot-injection method
His	histidine
HIV	human immunodeficiency virus
HMDS	hexamethyldisilazane
HOMO	highest occupied molecular orbital
HOPG	highly ordered pyrolytic graphite
HPLC	high pressure liquid chromatography
HREELS	high-resolution EELS
HRP	horseradish peroxidase
HRS	hyper-Rayleigh scattering
HRTEM	high resolution TEM
HSMA	hydrolyzed poly(styrene-*alt*-maleic anhydride)
HU	heating up method

I	inorganic species
IC_{50}	half-maximum inhibitory concentration
iCCD	intensified charge-coupled device
ICS	ion channel sensor
ICS	isocyanurate
ICTES	(3-isocyanatopropyl)triethoxysilane (frequently abbreviated as ICPES in the literature)
IgE	immunoglobulin E
IgG	immunoglobulin G
IL	ionic liquid
im	imidazolate
IMAC	immobilized metal ion affinity chromatography
IR	infrared
IRMOF-*n*[3]	isoreticular metal–organic framework
ISE	ion-selective electrode
ISI	ISI Web of Knowledge℠ (database by Thomson Reuters)
ITO	indium tin oxide
IUPAC	International Union of Pure and Applied Chemistry

KIT-*n*[4]	(family of) large mesopore *Fm3 m* silica(s)
LA	lauric acid
LB	Langmuir–Blodgett
LbL	layer-by-layer
LC	liquid chromatography
LC	liquid crystal/crystalline
LCST	lower critical solution temperature
LD	lethal dose
LDL	low density lipoprotein
LD-SAM	low density SAM
LED	light emitting diode
Leu	leucine
LOD	limit of detection
LPEI	linear poly(ethylene imine)
LSPR	localized surface plasmon resonance
LTA	Linde type A (zeolite A)
LUMO	lowest unoccupied molecular orbital
M41S[5,6]	family of mesoporous molecular sieves
MA	myristic acid
MAA	methacrylic acid
mAb	monoclonal Ab
MagMOON	magnetically-modulated optical nanoprobes
MAL	maleamide
MALDI-TOF	matrix assisted laser desorption/ionization time-of-flight (MS)
MAS	magic angle spinning NMR
MAXSORB	trade name of an activated carbon adsorbent
MBP	maltose binding protein
MBP-zb	maltose binding protein with a positive leucine zipper domain
MC	merocyanine
MCF-7	human breast cancer cells
MCM-*n*	Mobil Composition of Matter (family of mesoporous silicas)
MDMO-PPV	poly[2-methoxy-5-(3′,7′-dimethyloctyloxy)-1,4-phenylenevinylene]
Me	methyl
MEH-PPV	poly(2-methoxy-5-(2′-ethyl-hexyloxy)-1,4-phenylene-vinylene)
MeOTAD	2,2′,7,7′-tetrakis(*N*,*N*-di-*p*-methoxyphenylamine)9,9′-spirobifluorene
MFI	Mobil five (ZSM-5; zeolite)
MHDA	16-mercaptohexadecanoic acid (frequently abbreviated as MHA in the literature)
MHT	1-(6-mercaptohexyl)thymine
MHV68	murine gammaherpesvirus 68

MIL-*n*[7]	Materials of Institut Lavoisier (family of metal–organic frameworks)
mim	2-methylimidazolate
MIMIC	micromolding in capillaries
MIP	molecularly imprinted polymer
MM	methyl myristate
MNP	magnetic nanoparticles
MO	molecular orbital
MOF	metal–organic framework
MOR	methanol oxidation reaction
MPA	mercaptopropionic acid
MPC	monolayer protected cluster
MPL	multiphoton luminescence
MPMD	(mercaptopropyl)methyldimethoxysilane
MPTES	3-mercaptopropyltriethoxysilane
MPTMS	3-mercaptopropyltrimethoxysilane (frequently abbreviated as MPMS in the literature)
MRI	magnetic resonance imaging
MS	mass spectrometry
MSH	α-melanocyte stimulating hormone
MSN	mesoporous silica nanoparticles
MSU-*x*	Michigan State University (family of mesoporous silicas)
mTERT	murine telomerase reverse transcriptase
MTG	methanol-to-gasoline
MTMOS	methyltrimethoxysilane
MTX	methotrexate
MUA	11-mercaptoundecanonic acid
MWNT	multiwalled carbon nanotube
my	myristate
μCP	microcontact printing
μFN	microfluidic network
μTM	microtransfer molding
n	wildcard character for numbers
NBIC	nanotechnology, biotechnology, information technology, and cognitive science
NBTC	Nanobiotechnology Center (Cornell University)
NC	nanocrystal
ND	nanodiamond
Nd:YAG	neodymium-doped yttrium aluminium garnet (laser)
ndc	2,6-naphthalenedicarboxylate
NDR	2-nitro-*N*-methyl-4-diazonium-formaldehyde resin
NEST	New and Emerging Science and Technology
NEXAFS	near-edge x-ray absorption fine structure (spectroscopy)

NHA	carbon nanohorn aggregate
NHS	*N*-hydroxysuccinimide/yl
$NHSC_{11}SH$	11-mercaptoundecanoyl-*N*-hydroxysuccinimide ester
NIL	nanoimprint lithography
NIR	near infrared
NLO	nonlinear optics
NLS	nuclear localization sequence (peptide sequence for nuclear targeting)
NMR	nuclear magnetic resonance
NN	next-neighbor (interactions)
NOM	nano-on-micro
NP	nanoparticle
NR	nanorod
NTA	nitrilotriacetic acid
NTS	nonadecenyltrichlorosilane
NV	nitrogen vacancy (defect sites)
NVOC	nitroveratryloxycarbonyl
NVP	naphthalenylvinylpyridine
OA	oleic acid
OAm	oleylamine
OCT	optical coherence tomography
ODA	octadecylamine
ODE	1-octadecene
ODPA	octadecylphosphonic acid
ODT	octadecanethiol
OFMS	organic-functionalized molecular sieve
ON	oxynaphthalene
OPTA	*o*-phthalic hemithioacetal
OR	alkoxy group
ORMOSIL	organically modified silicate
ORR	oxygen reduction reaction
ORTEP	Oak Ridge thermal ellipsoid plot
OT	octanethiol
OTAB	octadecyltrimethylammonium bromide
OTAC	octadecyltrimethylammonium chloride
OTf	trifluoromethanesulfonate
OTS	octadecyltrichlorosilane
ox	oxalate
P123	trade name for a Pluronic block copolymer
P3HT	poly(3-hexylthiophene)
P3(ODAP)HT	poly(3-(6-oxy-2,4-diaminopyrimidine)hexylthiophene)
P3TOPA	poly(3-(3′-thienyloxy)propyltrimethylammonium)