Chemistry of Solid State Materials

Chemical synthesis of advanced ceramic materials

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David Segal
Frontmatter
More information

Chemistry of Solid State Materials

Series Editors
A. R. West, Reader in Chemistry, University of Aberdeen
H. Baxter, formerly at the Laboratory of the Government Chemist, London

Chemical synthesis of advanced ceramic materials

David Segal
Materials Chemistry Department, Harwell Laboratory, Oxfordshire

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Dedicated to my mother and father

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Contents

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More information

Contents

Preface

Advanced ceramic materials have attracted increasing attention throughout the 1980s from many disciplines including chemistry, physics, metallurgy and materials science and this multidisciplinary approach is illustrated by the diverse range of journals and conferences where information is disseminated. In addition the discovery of high-temperature ceramic superconductors in 1986 has raised the profile of advanced ceramics activities not only within the scientific community but also among the general public. Attendance at conferences and surveys of scientific literature show that chemical synthetic methods have played an increasing role, over the past fifteen years, in improving the properties of ceramic materials. Books concerned with fabrication and physical properties of ceramics do not, in my opinion, highlight chemical aspects of ceramic preparations which are not the principal interest of physical, organic and inorganic chemistry textbooks.

My discussions with undergraduate and postgraduate students in chemistry and materials science as well as university lecturers and those in industry concerned with research into and manufacture of advanced ceramics produced two conclusions. Firstly, there did not seem to be a short volume available which acted as a bridge between pure chemistry and conventional ceramic studies such as fabrication. Also, although scientific publications and conference proceedings proliferate it was not obvious how a comprehensive view of the rapid inroads chemistry is making into ceramic synthesis could be obtained. I see this book as that bridge between pure chemical and conventional ceramic studies. I have included a chapter on fabrication for continuity but this is not the main theme. I have not discussed the mechanisms and structures of all reactions and materials described here, or listed 'recipes' for ceramic synthesis. What I have attempted to show is the role chemistry has in the synthesis of advanced ceramic materials but, at all times, synthetic routes are related to the desired ceramic properties for materials in the form of powders, fibre, coatings or monoliths made on the laboratory and industrial scale. All branches of chemistry contribute to advanced ceramic development but three areas occur repeatedly throughout this book, namely colloid chemistry, homogeneous nucleation processes and chemistry at the organic–inorganic interface.

Finally, a paragraph on acknowledgements. I thank authors and copyright owners in Europe, Japan, Australia and The United States of America for giving permission to reproduce their photographs in this book. I am indebted to staff of the Harwell Library who obtained numerous scientific publications for me while line diagrams were drawn in the Tracing Office at Harwell. Anita Harvey typed the manuscript; and lastly an acknowledgement to my employer, The United Kingdom Atomic Energy Authority for permission to publish this book.

Harwell Laboratory David Segal

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Frontmatter
More information

Symbols

N	Avogadro number
h	Planck's constant
k	Boltzmann constant
e	Electronic charge
c	Ionic strength
z	Ion valency
%	Percentage
T	Absolute temperature
T_c	Superconducting transition or critical temperature
E	Young's modulus
S	Tensile fracture strength
$2C$	Crack length
C_1	BET constant
S_A	Surface area
D	Diffusion coefficient
D_c	Crystallite dimension
K	Equilibrium constant
K_{IC}	Fracture toughness
K^*	Constant in Scherrer equation (A.3)
G	Gravitational constant
η	Liquid viscosity
κ	Reciprocal double layer thickness
Q	Scattering vector
Ω	Angular rotational velocity
R, R'	Alkyl chain
R^*	Reflectivity at near normal incidence
R_G	Gas constant
λ	Wavelength
L	Nucleation rate per unit volume
I, I_0	Scattered intensity
$P(\phi)$	Shape factor
ϕ	Angle between incident and scattered radiation
V_L	London energy between two atoms
V_A	van der Waals – London energy for macroscopic bodies
V_R	Electrostatic energy of repulsion
V_S	Free energy due to adsorbed layer overlap
V_T	Total potential energy between particles
θ_B	Bragg angle

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Frontmatter
More information

Symbols

$\theta_{1/2}$	Pure diffraction broadening at half-peak height
θ	Contact angle at solid-air-liquid interface
I_R	Rayleigh scattered intensity
I_{RG}	Rayleigh–Gans scattered intensity
ψ_0	Surface charge
ν_0	Ground-state electron vibrational frequency
α	Static atomic polarizability
λ^*	$=3h\nu_0\alpha^2/4$
A, A_1, A_2, A_{12}	Hamaker constant
a	Sphere radius
H_0	Separation of spheres or flat plates at closest approach
x	$=H_0/2a$
q	Number of molecules per unit volume of material
ε_0	Permittivity of vacuum
ε	Relative permittivity of medium
l	Side length of a cube
l_0	Sample to detector distance
l_1	Sedimentation distance
l_2	Distance between particle and axis of rotation
l_3	Radius of rotation for particles
n_0, n_1, n_2, n_p, n_m	Refractive index
n	Number of molecules in critical cluster
$\Delta G'_n$	Free energy of formation for critical cluster
r	Distance between atoms
r_p	Pore radius
r_d	Radius of liquid droplet
r_g	Radius of gyration
r_n	Critical radius of cluster
b, f, g, j, δ	Number of moles
$t_{1/2}$	Half-life
$t, t_1, t_2, t_3, t_c, \tau$	Time
ρ, ρ_p, ρ_l	Density
γ	Surface tension of liquid
γ'	Surface energy
Δ_p	Capillary pressure
p_F, p_G, p_J	Partial gas pressures
p^0	Saturation vapour pressure
p'	Vapour pressure
p	Gas pressure
M_w	Molecular weight
$\bar{M}_w$	Weight average molecular weight
$\bar{M}_n$	Number average molecular weight
h_c	Coating thickness
C_x, C_0	Concentration of solute or reactant
C_s	Saturated solute concentration

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Frontmatter
More information

Symbols

C_{ss}	Supersaturated solute concentration
N_p	Number of particles
β	Overall growth coefficient for droplets
v	Molar volume of liquid phase
v_l	Volume of molecule in liquid phase
v_a	Adsorbate volume at a specified relative pressure
v_m	Adsorbate volume for monolayer coverage per unit mass of solid
m	Mass of a molecule
m_d	Volume of a diffusing vacancy
M	Metal