



Nanoparticle decoration with surfactants: Molecular interactions, assembly, and applications



Hendrik Heinz^{a,*}, Chandrani Pramanik^a, Ozge Heinz^b, Yifu Ding^b, Ratan K. Mishra^c,
Delphine Marchon^c, Robert J. Flatt^c, Irina Estrela-Lopis^e, Jordi Llop^f, Sergio Moya^f,
Ronald F. Ziolo^{a,d}

^a Department of Chemical and Biological Engineering, University of Colorado at Boulder, Boulder, CO 80309, USA

^b Department of Mechanical Engineering, University of Colorado at Boulder, Boulder, CO 80309, USA

^c Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, CH-8093 Zürich, Switzerland

^d Centro de Investigación en Química Aplicada (CIQA), Department of Advanced Materials, 25294 Saltillo, Coahuila, Mexico

^e Institute for Physics and Biophysics, University of Leipzig, D-04107 Leipzig, Germany

^f Centro de Investigación Cooperativa en Biomateriales (CIC BiomaGUNE), 20009 Donostia-San Sebastián, Guipúzcoa, Spain

ARTICLE INFO

Article history:

Received 27 September 2016

Received in revised form

2 January 2017

Accepted 11 January 2017

Available online 15 February 2017

Keywords:

Nanoparticles

Surfactants

Biological ligands

Self-assembled monolayers

Polymers

Oxides

Layered materials

Cement

ABSTRACT

Nanostructures of diverse chemical nature are used as biomarkers, therapeutics, catalysts, and structural reinforcements. The decoration with surfactants has a long history and is essential to introduce specific functions. The definition of surfactants in this review is very broad, following its lexical meaning “surface active agents”, and therefore includes traditional alkyl modifiers, biological ligands, polymers, and other surface active molecules. The review systematically covers covalent and non-covalent interactions of such surfactants with various types of nanomaterials, including metals, oxides, layered materials, and polymers as well as their applications. The major themes are (i) molecular recognition and noncovalent assembly mechanisms of surfactants on the nanoparticle and nanocrystal surfaces, (ii) covalent grafting techniques and multi-step surface modification, (iii) dispersion properties and surface reactions, (iv) the use of surfactants to influence crystal growth, as well as (v) the incorporation of biorecognition and other material-targeting functionality. For the diverse materials classes, similarities and differences in surfactant assembly, function, as well as materials performance in specific applications are described in a comparative way. Major factors that lead to differentiation are the surface energy, surface chemistry and pH sensitivity, as well as the degree of surface regularity and defects in the nanoparticle cores and in the surfactant shell. The review covers a broad range of surface modifications and applications in biological recognition and therapeutics, sensors, nanomaterials for catalysis, energy conversion and storage, the dispersion properties of nanoparticles in structural composites and cement, as well as purification systems and classical detergents. Design principles for surfactants to optimize the performance of specific nanostructures are discussed. The review concludes with challenges and opportunities.

© 2017 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

Contents

1. Introduction	2
1.1. Definitions	3
1.2. Historical perspective	3
1.2.1. Detergents	3
1.2.2. Water purification and chromatography	3
1.2.3. Soil and the surface modification of clay minerals	4
1.2.4. Self-assembled monolayers and functionalized nanoparticles	4

* Corresponding author.

E-mail address: hendrik.heinz@colorado.edu (H. Heinz).

1.2.5.	In-vivo interaction of nanostructures with surfactants and cells	4
1.3.	Outline of this review	4
1.3.1.	Systems and aims	4
1.3.2.	Organization	5
2.	General concepts of nanoparticle decoration with surfactants	5
2.1.	Early studies	5
2.2.	Structure, tilt angle, and thermal properties of surfactant layers	5
2.3.	Influence of nanoparticle curvature	6
2.4.	Rigid surfactants for particle ordering	7
2.5.	Grafting mechanisms	8
2.6.	Colloidal stability and dispersion	9
2.7.	Imaging, tracking, and dosimetry of nanoparticles	10
2.8.	Enthalpy versus entropy of surfactant adsorption	11
3.	Modification of metallic nanostructures with surfactants	13
3.1.	Noncovalent binding of ligands via soft epitaxy	13
3.2.	Relationship between facet-specific ligand binding and nanocrystal growth	15
3.3.	Nanoparticle superlattices from densely grafted rigid thiol surfactants	16
3.4.	Applications in catalysis	16
3.5.	Applications in diagnostics and therapeutics	19
4.	Modification of oxide and chalcogenide nanostructures with surfactants	19
4.1.	Surface chemistry and noncovalent binding mechanisms of surfactants	19
4.1.1.	Surface chemistry	19
4.1.2.	Noncovalent binding mechanisms of surfactants	21
4.2.	pH-specific contributions to ligand adsorption	22
4.3.	Covalent modification of oxide surfaces	23
4.4.	Surfactant-directed growth of oxide nanoparticles, nanowires, and porous nanostructures	26
4.5.	Optical and electronic properties of surfactant-modified oxide nanoparticles, quantum dots, and applications	27
4.6.	Applications as therapeutics and diagnostics	29
5.	Surface modification of 2D layered nanostructures	31
5.1.	Graphene-based nanomaterials	31
5.2.	Transition metal chalcogenides	33
5.3.	Layered transition metal oxides	34
5.4.	Clay minerals	35
5.4.1.	Ion exchange, structure and dynamics of alkyl-modified clay minerals	35
5.4.2.	Cohesion between layers	38
5.4.3.	Dispersion in a host matrix	39
5.5.	Layered double hydroxides and applications	39
6.	Surface modification of cement minerals and other inorganic nanostructures	41
6.1.	Nanoparticle-organic interfaces in cementitious materials	41
6.1.1.	Polymer effects on the nanostructure of calcium silicate hydrates	42
6.1.2.	Modification of the formation of calcium sulfo-aluminates	42
6.1.3.	Polymeric dispersants at the cement-water interface	43
6.1.4.	Molecular modelling of interfacial properties	43
6.2.	Other inorganic nanostructures	44
7.	Modification of polymer nanoparticles with surfactants	46
7.1.	Surface modification of polymer nanoparticles for drug delivery	46
7.1.1.	Types of polymers, particle size, shape, and cell targeting properties	46
7.1.2.	Tuning surface properties by surfactants	49
7.1.3.	Release mechanism of drugs	49
7.1.4.	Synthesis and assembly for specific surface properties	50
7.1.5.	Surfactant modification and blood brain barrier	51
7.2.	Polymeric nanoparticles in protective coatings	52
8.	Summary, challenges, and opportunities	53
	Acknowledgements	53
	References	53

1. Introduction

Nanomaterials with specific surface functionality are ubiquitous in nature. Soils, seashells, bone, and teeth contain inorganic/organic nanostructures [1–3]. Small cells like mycoplasma (~200 nm) and cell organelles can be regarded, according to size, as living polymeric nanoparticles [4]. The term surfactant-decorated nanoparticles, as used in the chemical sciences and in this review, is typically associated with manmade nanostructures for applications in imaging, drug delivery, composites, catalysis, energy conversion devices, purification systems, and other technologies

(Fig. 1) [5,6]. The terminology “surfactant” is used here for a broad array of surface active agents, according to its true definition (see Section 1.1), and includes classic alkyl-based surfactants, peptides, lipids, DNA, molecular ligands, bioconjugates, and polymers covalently grafted to or non-covalently assembled on nanomaterial surfaces, thereby changing their properties. The term nanoparticles encompasses a broad range of nanostructures of different chemical composition, shape, and size in the 1–1000 nm range. Details of the definitions, a historical perspective, and a full outline of this review follow in the subsections below. The main part of the review consists of general concepts in Section 2, the discussion

Download English Version:

<https://daneshyari.com/en/article/7845019>

Download Persian Version:

<https://daneshyari.com/article/7845019>

[Daneshyari.com](https://daneshyari.com)