Coordination Chemistry Reviews 370 (2018) 1–21

Contents lists available at ScienceDirect

Coordination Chemistry Reviews

journal homepage: www.elsevier.com/locate/ccr

Review

Recent advances in gold nanostructures based biosensing and bioimaging

Yang Zhang [a], Ge Wang [b], Lu Yang [b], Fei Wang [d], Aihua Liu [a,b,c,*]

[a] Institute for Biosensing, and College of Life Sciences, Qingdao University, 308 Ningxia Road, Qingdao 266071, China
[b] College of Chemistry and Chemical Engineering, Qingdao University, 308 Ningxia Road, Qingdao 266071, China
[c] College of Medicine, Qingdao University, Qingdao 266021, China
[d] Jecho Biopharmaceuticals Co. Ltd., Eco-Business Park, 1620 Zhongtian Road, Sino-Singapore Tianjin Eco-City, Tianjin 300467, China

ARTICLE INFO

Article history:
Received 22 March 2018
Accepted 4 May 2018

Keywords:
Gold nanostructures
Biosensing
Bioimaging
Plasmonic sensing
Peroxidase-like activity
Electrochemical sensing

ABSTRACT

Gold nanostructures have been arousing great interest due to their superb optical, catalytic, and chemical properties, which enable a broad of applications. In this review, on one hand, optical biosensing on basis of various gold nanostructures are summarized dependent mainly on how nanostructures signify the recognition and targeting events for specific molecules. On the other hand, sensors based on the peroxidase-like activity and electrocatalytic properties of gold nanostructures are highlighted. In addition to dark field and SERS imaging, the gold nanostructures based imaging session is devoted to the discussion of photoacoustic and computer tomography imaging. Finally, current challenges and perspectives on the gold nanostructures based biosensing and biomedical imaging are envisioned.

Contents

1. Introduction . . . 2
2. Gold nanostructures for biosensor . . . 2
2.1. Plasmonic biosensor . . . 2
2.2. Fluorescent biosensor . . . 5
2.3. SERS . . . 6
2.4. Gold nanostructures exhibiting peroxidase-like activity for colorimetric assay . . . 7
2.5. Gold nanostructures-based electrochemical biosensor . . . 8

Abbreviations: AA, ascorbic acid; ABTS, 2,2′-azino-bis(3-ethylbenzthiazoline-6-sulfonicacid) diammonium salt; AEF, analytical enhancement factor; AFP, alpha fetoprotein; Anti-CEA, anticarcinoembryonic antibody; Au NBPs, gold nanobipyramids; AuNCs, gold nanoclusters; AuNCs@GSH, gold nanoclusters capped glutathione; Au@M, gold@metal; AuNPs, gold nanoparticles; AuNP–Fe_2O_3NC, gold-loaded nanoporous ferric oxide nanocubes; AuNRs, gold nanorods; AuNSts, gold nanostars; BDD, boron-doped diamond; BOD, biochemical oxygen demand; BRCA1, breast cancer susceptibility gene; BSA, bovine serum albumin; CAP, chloramphenicol; cDNAs, complementary DNAs; CDs, carbon dots; CS, chitosan; CTCs, circulating tumor cells; CF-AuNPs, cauliflower-like AuNPs; CuNCs, copper nanoclusters; CS-AuNCs, chondroitin sulfate-stabilized gold nanoclusters; CT, computed tomography; DA, dopamine; DTTC, diethylthiatricarbocyanine iodide; FAD, flavine-adenine dinucleotide; FITC, fluoresceinisothiocyanate; FRET, förster resonance energy transfer; FTO, fluorine-doped tin oxide conducting glass; GCE, glassy carbon electrode; GN-COOH, carboxyl graphene; GO, graphene oxide; GOx, glucose oxidase; GSH, glutathione; GST, glutathione S-transferase; HBV, hepatitis B virus; HCV, hepatitis C virus; HIV, human immunodeficiency virus-1; HPANs, hierarchical porous Au networks; HRP, horseradish peroxidase; LSPRs, localized surface plasmon resonances; MC-LR, microcystin-LR; MCF-7, Michigan Cancer Foundation-7 breast cancer cell line; MGITC, malachite green isothiocyanate; MIPs-AuNCs, molecularly imprinted polymers coated gold nanoclusters; miRNA, microRNA; MMPs, matrix metalloproteinases; MNPs, gold-coated iron oxide nanoparticles; MoS_2-MS, MoS_2-microspheres; MRI, magnetic resonance imaging; NCPs, nanocomposite particles; NERS, nanogap-enhanced Raman scattering; NIR, near infrared reflection; NPG, nanoporous gold; NSET, nanomaterial surface energy transfer; PA, photoacoustic; PDDA, poly (diallyldimethylammonium) chloride; PET, positron emission tomography; PLH, poly-L-histidine; PSA, prostate-specific antigen; PNA, peptide nucleic acid; PNRs, plasmonic nanorods; PEG, polyethylene glycol; PSA, prostate specific antigen; RBITC, rhodamine B isothiocyanate; r-GO, reduced graphene oxide; RGD, arginine-glycine-aspartic acid; RhBAM, RhB based thermosensitive polymer; R6G, rhodamine 6G; SPR, surface plasmon resonance; SERS, surface enhanced Raman scattering; TPL, two-photon luminescence; UA, uric acid; VA-AuNRs, vertically aligned AuNRs; 4-NTP, 4-nitrothiophenol.

* Corresponding author at: Institute for Biosensing, and College of Life Sciences, Qingdao University, 308 Ningxia Road, Qingdao 266071, China.
E-mail address: liuah@qdu.edu.cn (A. Liu).

https://doi.org/10.1016/j.ccr.2018.05.005
0010-8545/

3. Biomedical imaging modes based on gold nanostructures . . . 10
3.1. Dark field imaging. . . . 11
3.2. Photoacoustic imaging . . . 13
3.3. SERS-based imaging . . . 15
3.4. CT imaging. . . . 17
4. Conclusions and perspectives . . . 18
Notes. . . . 18
Acknowledgements . . . 18
References . . . 18

1. Introduction

Gold nanoparticles (AuNPs), especially the anisotropic AuNPs have been arousing great interest due to their superb optical, catalytic, electronic, magnetic and chemical properties properties, which are not met for spherical (nonhollow) AuNPs (isotropic). Compared to isotropic AuNPs, the main attractive feature of most anisotropic and hollow AuNPs is probably the appearance of a plasmon band in the near-infrared (NIR) region [1,2]. Strictly speaking, almost all nanostructures are anisotropic. A well-known example for the use of AuNPs is the fabrication of nanoplasmonic Lycurgus cup dated back to the fourth century [3], showing amazing color change that depends on light passing through it or not. Actually, surface plasmon resonance (SPR) properties have been attracted more attention in many applications such as sensors. Since anisotropic nanoparticles are powerful building blocks that possess unusual properties and have capabilities for many emerging applications, the scientists from academia show a great interest on the development of plasmonic AuNPs in recent years [1,4,5]. Astruc and coworkers summarized the synthesis and applications of anisotropic AuNPs which showed different SPR properties corresponding to their sizes and shapes [2]. Recently, we comprehensively surveyed on the preparation and functionalization approaches for a wide range of gold nanostructures that exhibit SPR in the NIR region, including gold nanorods (AuNRs), gold nanoclusters (AuNCs), gold nanoshells, gold nanocages, gold nanostars (AuNSts), branched gold nanostructures and Au@metal (Au@M) bimetallic nanocomposite [6]. On the other hand, the last few decades have also witnessed a surge in application of gold nanostructures for catalysis [7] and biomedical applications such as in vitro diagnostics, biomedicine and biotherapy [8–15].

The rapid progress in nanotechnology facilitates to provide good strategies and approaches to meet the increasing demands of chemical and biological analysis [16–21]. Nanosensor is an emerging technique that utilizes the novel properties of nanomaterials for signal generation and transduction in recognition events. To date, many nano-biosensors have been constructed based on the properties of gold nanostructures. Most recent review papers summarized gold nanostructures based biosensing [22] and bioimaging [23], mainly focusing on one or several kinds of approaches [24–27]. However, there are few review articles systematically investigating on biosensing and biomedical imaging, especially on biosensors on basis of peroxidase-like activity and catalytic properties of gold nanostructures.

Herein we present the recent advances on gold nanostructures based biosensing and bioimaging. We first overview various gold nanostructures for optical biosensing on basis of SPR, fluorescence and surface enhanced Raman scattering (SERS). Followed by, sensors based on the peroxidase-like activity and electrocatalytic properties of gold nanostructures are highlighted. Then we summarize recent advancements in biomedical imaging based on gold nanostructures. Finally, the perspectives and future directions are anticipated.

2. Gold nanostructures for biosensor

Depending on the transducers, gold nanostructures based biosensing is generally categorized into plasmonic, fluorescent, colorimetric, SERS and electrochemical biosensors. The performances of some gold nanostructure based biosensors are summarized in Table 1, some of which are detailed in the following sub-Sections 2.1–2.5.

2.1. Plasmonic biosensor

The unique optical properties of plasmon resonant nanostructures have attracted great attention of the biosensing community. So far, the plasmonic biosensors have two types of sensing platforms based on either the thin metallic films [104,105] or the individual inorganic plasmon resonant nanostructures [106–108]. Gold is the most common noble metal film attributing to its SPR property, which can be interrogated using wavelengths of visible light. Besides that, gold exhibits relative inertness, easy functionalization, etc [105]. The other main category of plasmonic sensing is the use of localized surface plasmon resonances (LSPRs) of metal nanostructure. Under resonant excitation, noble metal nanostructures concentrate free-space electromagnetic waves within the near-field regions (<100 nm) close to their surfaces. This unique property endows noble metal nanostructures with multiple outstanding performances, such as huge light scattering and absorption, striking photothermal conversion capabilities, etc. Typically, the light scattering of gold nanostructures can be used in optical sensing and biological imaging, while the light absorption can be used in phototherapies of tumor by converting the plasmon resonance to heat [25]. As the tissue and water have lowest absorption in the wavelength range of 650–900 nm [109], gold nanostructures with the longitudinal SPR peak in the NIR region are promising in plasmonic biosensing.

The shift of plasmonic nanostructures in SPR property is often related to the change in their surrounding dielectric environment. It can be readily quantified by measuring absorption and even seeing color change by the naked eyes [26]. Recently, our group developed colorimetric immunosensor for pathogenic bacteria using AuNPs modified with specific phage peptides, in which the SPR spectra of AuNPs were used as an optical signal [44]. The plasmonic nanostructures for colorimetric biosensing possesses advantages of high sensitivity, low cost and easy readout [110]. The linkage of AuNPs will induce the shift of SPR peaks and change the color of solution. Moreover, the SPR bands of gold nanostructures exhibit drastic shift when the coupling distance was smaller than 10 nm [27]. Consequently, by precisely designing the dimensions, shapes and the coupling distance of nanoparticles, optical biosensor based on gold nanostructures can be used to detect biological species with tunable detection limit and dynamic range. For the first time, Mirkin and coworkers took advantage of this SPR sensitivity to construct plasmonic biosensor for DNA by attaching thiolated DNA onto the AuNPs [111]. By introducing a target sequence to