Nanotechnology in the Life Sciences

Abdul Majid
Humaira Arshad
Muhammad Azmat Ullah Khan

Quantum Dots for Plant Systems

Springer

Nanotechnology in the Life Sciences

Series Editor
Ram Prasad, Department of Botany
Mahatma Gandhi Central University
Motihari, Bihar, India

Nano and biotechnology are two of the 21st century's most promising technologies. Nanotechnology is demarcated as the design, development, and application of materials and devices whose least functional make up is on a nanometer scale (1 to 100 nm). Meanwhile, biotechnology deals with metabolic and other physiological developments of biological subjects including microorganisms. These microbial processes have opened up new opportunities to explore novel applications, for example, the biosynthesis of metal nanomaterials, with the implication that these two technologies (i.e., thus nanobiotechnology) can play a vital role in developing and executing many valuable tools in the study of life. Nanotechnology is very diverse, ranging from extensions of conventional device physics to completely new approaches based upon molecular self-assembly, from developing new materials with dimensions on the nanoscale, to investigating whether we can directly control matters on/in the atomic scale level. This idea entails its application to diverse fields of science such as plant biology, organic chemistry, agriculture, the food industry, and more.

Nanobiotechnology offers a wide range of uses in medicine, agriculture, and the environment. Many diseases that do not have cures today may be cured by nanotechnology in the future. Use of nanotechnology in medical therapeutics needs adequate evaluation of its risk and safety factors. Scientists who are against the use of nanotechnology also agree that advancement in nanotechnology should continue because this field promises great benefits, but testing should be carried out to ensure its safety in people. It is possible that nanomedicine in the future will play a crucial role in the treatment of human and plant diseases, and also in the enhancement of normal human physiology and plant systems, respectively. If everything proceeds as expected, nanobiotechnology will, one day, become an inevitable part of our everyday life and will help save many lives.

Abdul Majid • Humaira Arshad
Muhammad Azmat Ullah Khan

Quantum Dots for Plant Systems

Springer

Abdul Majid
Department of Physics
University of Gujrat
Gujrat, Pakistan

Humaira Arshad
Department of Physics
University of Gujrat
Gujrat, Pakistan

Muhammad Azmat Ullah Khan
Deptartment of Biochemistry
and Biotechnology
University of Gujrat
Gujrat, Pakistan

ISSN 2523-8027 ISSN 2523-8035 (electronic)
Nanotechnology in the Life Sciences
ISBN 978-3-031-10215-8 ISBN 978-3-031-10216-5 (eBook)
https://doi.org/10.1007/978-3-031-10216-5

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2022
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Abbreviations

A

TBAP	Acetonitrile tetrabutylammonium perchlorate
ATP	Adenosine triphosphate
ApCP	Albizia procera
NH_3	Ammonia
ASPV	Apple stem pitting virus
AM	Armchair
AO	Atomic orbitals
AM	Atrazine-mercapturate

B

BSMV	Barley stripe mosaic virus
Bi_2WO_6	Bismuth tungstate
B	Boron
k	Boltzmann’s constant
BSA	Bovine serum albumin
BTCs	Breakthrough curves

C

C_3N_4	Carbon nitride
Cd^{2+}	Cadmium ions
CdO	Cadmium oxide
CdSe	Cadmium selenide

CdS	Cadmium sulphide
CdTe	Cadmium telluride
CF	Carbofuran
C	Carbon
CO_2	Carbon dioxide
CNTs	Carbon nanotube
CQDs	Carbon QDs
CQDs	Carbon quantum dots
CL	Cathodoluminescence
CdS@CTS	Chitosan
CTV	Citrus tristeza virus
CB	Conduction band
CLSM	Confocal laser scanning microscopy
$CuInS_2$	Copper indium sulphide
CPMV	Cowpea mosaic virus
CV	Cyclic voltammetry
CymMV	Cymbidium mosaic potexvirus

D

dBSA	Denatured BSA
DFT	Density functional theory
DOS	Density of states
Ds	Dissociatives
DLVO	Derjaguin-Landau-Verwey-O verbeek theory
DSSCs	Dye-sensitized solar cells

E

ENPs	Engineered nanoparticles
EMA	Effective mass approximation
ECL	Electrochemiluminescence
EL	Electroluminescence
E	Energy

F

FOR	Faraday optical rotation
FL	Few-layer

GFP	Fluorescence protein
FRET	Fluorescent resonance energy transfer
FWHM	Full width at half maximum

G

GCE	Glass carbon electrode
Gly-QDs	Glycine conjugated carboxyl quantum dots
Au	Gold
GLRaV	Grapevine leafroll-associated virus
GO	Graphene oxide
GQDs	Graphene quantum dots
GO	Graphite oxide
g-C3N4	Graphitic carbon nitride

H

HOMO	Highest occupied molecular
HRP	Horseradish peroxidase
H_2O_2	Hydrogen peroxide
HA	Hydroxyl-apatite

I

IMI	Imidacloprid
IMP	Immunodominant membrane protein
IPM	Integrated pest management
IL	Ionic liquid
I	Iodine
Fe_2O_3	Iron (III) oxide

L

LCCV	Large cardamom chirke virus
LFIA	Lateral flow immuno assay
LbL	Layer-by-layer
PbS	Lead (II) sulphide

Pb^{2+}	Lead ion
L/ZnO	Leaf-shaped ZnO
LEDs	Light-emitting diodes
LOD	Limit of detection
LEEP	Lipid exchange envelope penetration
LIB	Lithium ion battery
LUMO	Lowest unoccupied molecular

M

MNPs	Magnetic nano-particles
MCMV	Maize chlorotic mottle virus
MS	Mardage and skog
-SH	Mercaptans
MAA	Mercaptoacetic acid
Hg^{2+}	Mercury ion
MSNPs	Meso-porous silica nano-partic
MO	Molecular orbitals
$MoSe_2$	Molybdenum disulphide
MBs	Mung bean
MWCNTs	Multi-walled carbon nanotubes

N

NPs	Nanoparticles
NRAMP	Natural resistance-associated macrophage protein
NADP	Nicotinamide adenine dinucleotide phosphate
$Cd(NO_3)_2$	Nitrogen saturated
N	Nitrogen
N-doped CQDs	Nitrogen-doped carbon quantum dots
Ni-GQDs	Nitrogen-doped graphene quantum dots

O

ORSV	Odontoglossum ringspot tobamovirus
O	Oxygen

P

PCP	Pentachlorophenol
PBA	Phenoxybenzoic acid
-PO	Phosphenes
P	Phosphorous
PEC	Photoelectrochemical
PL	Photoluminescence
PLE	Photoluminescence excitation
PAA-EG	Poly acrylic acid-ethylene glycol
PMAO−PEG	Poly maleic anhydride-alt-1-octadecene−poly ethylene glycol
PANI	Polyaniline
PEG	Polyethylene glycol
PEI	Polyethyleneimine
PPy	Polypyrrole
CHI	Polysaccharides chitosan
PVP	Polyvinyl pyrrolidone
Psi	Porous silicon
PLRV	Potato leafroll virus
PVX	Potato virus X
PVY	Potato virus Y
Ep	Potentials
PRs	Profile of retained
PIXE	Proton-induced X-ray emission

Q

QC	Quantum confinement
QDs	Quantum dots
GQDs	Quantum dots
QY	Quantum yield
QCM	Quartz crystal microbalance

R

RE	Rare-earth
RE-CQDs	Rare-earth carbon dots
Ip	Redox currents

S

TAMRA	Second oligonucleotide labelled with the dye
Se	Selenium
SELEX	Systematic evolution of ligands by exponents enrichment
SiQDs	Silicon quantum dots
Si	Silicon
Ag	Silver
ALG	Sodium alginate
SMV	Soybean mosaic virus
S	Sulfur
S	Sulphur

T

TGA	Thioglycolic acid
3D	Three-dimensional
3DG	Three-dimensional graphene
TNT	Titanium dioxide TiO_2
TMV	Tobacco mosaic virus
TEM	Transmission electron microscopy
TOP	Trioctylphosphine
WS_2	Tungsten disulphide
2D	Two-dimensional

U

UV	Ultra violet
UCNPs	Up-conversion nanoparticles

V

VB	Valance band
PVA	Viable polyvinyl alcohol
Vis	Visible

X

XPS	X-ray photoelectron spectroscopy

Z

0D	Zero-dimensional
ZZ	Zigzag
ZnO	Zinc oxide
ZnSe	Zinc Selenide
ZnS	Zinc Sulphide
ZIP	Zinc-regulated transporter/iron-regulated transporter related protein

Chapter 1
Introduction

Abstract This chapter illustrates a brief introduction of nanomaterials and their prominence particularly in plant systems. The distinct features of nanomaterials includes quantum effect, surface area, exceptional thermal and electrical conductivity, support for catalysts, and excellent antimicrobial activity. However, various critical challenges including defects, cost-effective synthesis methods, agglomeration, aging, stability of two-dimemsional ultra-thin slabs, reproduciblity need to be addressed prior to utilization of these materials. Further, the significance of engineered nanomaterials particularly quantum dots has been highlighted.

Keywords Nanomaterials · Quantum dots · Plant systems · Applications · Challenges

1.1 Nanomaterials

Nanomaterials have come up as an outstanding class of materials with wide-range practical applications. The nanomater length can be understood through an example of 10 hydrogen atoms or 5 silicon atoms lined up that is equivalent to one nanometer. Their size distinguishes the nanomaterials or having at least one dimension in 1–100 nm range. The utilization of objects in nano-meter range is not exactly known, but a long time ago these materials were used unknowingly. For example, about 4500 years ago, asbestos nanofibers were used to reinforce ceramic mixtures [1]. Egyptain were used PbS nanoparticles in hair-dyeing formula [2, 3]. In the fourth century, the Romans have introduced dichroic cup which shows translucent ruby colour for transmitted light and jade for direct light. The variation in colour depends on incident light and appears because of the presence of silver and gold nanoparticles [4].

Richard Adolf Zsigmondy introduced the word 'nanometer' [5]. Richard Feynman introduced the concept of nanotechnology in 1959 in first academic talk about nanotechnology [5]. The motive was the development of machines at a molecular level [6]. In his talk, he explained that our ability to work at atomic/molecular level is limited because of inappropriate equipment and technologies [7]. Till 1980s, nanotechnology endured for discussion only, but its concept was implanted for

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

A. Majid et al., *Quantum Dots for Plant Systems*, Nanotechnology in the Life Sciences, https://doi.org/10.1007/978-3-031-10216-5_1

researcher to use it for different potentials. Then, nanotechnology is emerged as an excellent technology, contributing engineered materials at nano-scale for potential applications with upgraded execution. At present, materials at nano-scale find industrial roles in energy storage devices, sensors, electronics, surface coating, cosmetics, sports equipment and environmental remediation [8]. Figure 1.1 showed the schematic representation for captivating domains of nanomaterials.

1.1.1 Silent Feature of Nanomaterials

Matter at the nano-scale has distinct properties as compared to the bulk materials. At nano-scale, size-dependent effects become more notable. For instance, Au solution at nano-scale appears to be red or purple but yellow in the bulk. The properties of nanomaterials can be tuned by changing their size [10, 11]. The electronic properties of nanomaterials at nano-scale are dominantly changed compared to bulk counterpart and are controlled by quantum mechanical deliberations. For example, two-dimensional (2D) network of boron, i.e. borophene, is considered as 2D metal where boron in bulk isn't considered as metal [12]. The distinct mechanical properties at nano-scale have been improved by minimizing the defects or enhancing the crystal perfection [13]. The materials having a diameter between 1 and 10 nm are named as quantum dots. Further, the properties of such materials have a strong dependence on size and shape [14]. A photo-generated electron-hole pair has the same diameter as an exciton between 1 and 10 nm. Therefore, absorption/emission of light through semiconductors can be controlled by size-variation in this range.

Among various unique properties of nanomaterials, following are some key properties, which can be acquired by shape and/or size variations

- Quantum effects: At nano-scale, quantum effects become highly prominent and the range at which these effects will appear strongly depends on characteristics of semiconductor material [15]
- Surface area: Nanomaterials have substantially high surface areas in contract with bulk materials, and these properties applied to all nanomaterials [16]
- High thermal & electrical conductivity: Nanomaterials have high electrical and thermal conductivity in comparison with bulk materials. For example, graphene achieved from graphite [17]
- Exceptional mechanical properties: In contract with bulk counterparts, nanomaterials have extra-ordinary mechanical properties [18]
- Support for Catalysts: The functionality of catalysts can be substantially enhanced via good dispersion of nanomaterials of active catalyst. For example, atomic dispersion of catalyst on two-dimensional sheets of nanomaterials has enhanced performance [19, 20].
- Antimicrobial Activity: Various nanomaterials have been used for anti-bacterial, anti-fungal and anti-viral properties and have distinct capabilities against pathogen-related diseases [21, 22]

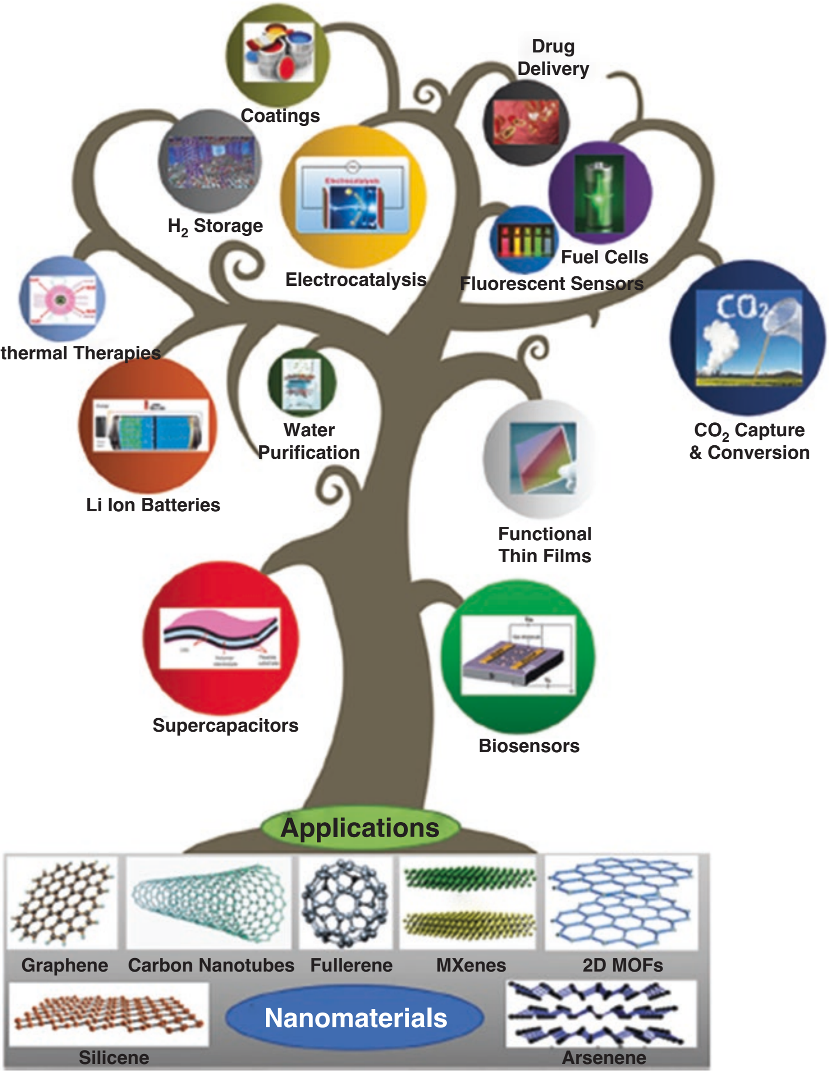

Fig. 1.1 Schematic Representation of various nanomaterials and their applications. (Reprinted with permission from Baig et al. [9])

1.1.2 Challenges for Nanomaterials

Many nanomaterial-based studies have been reported to date. The effectual manipulation of materials at nano-scale can be used for different industrial applications. However, the evolution and potent exertion of nano-based materials may encompass many challenges. Few critical challenges have been stated below:

- The defects in nanomaterials can affect their intrinsic properties and their performance. For example, impurities, random orientation, discontinuous length of carbon nanotubes can significantly lessen their tensile strength [23].
- The economical route for the production of nanomaterials is another contend. The finest nanomaterials have been synthesized in harsh environments and urbane instrumentation, thus limiting their extensive production as for the synthesis of 2D nanomaterials. For large-scale production, low-cost methods have been acquired, which results in the synthesis of defect-containing materials. Therefore, the controlled synthesis of materials at nano-scale is still an arduous task. For example, attaining chiral conductivity, selectivity, and accurately controlled diameters for carbon nanotube synthesis [24, 25]. Theoretically calculated properties have only got the structurally pure nanomaterials. So, additional dedicated efforts are required to introduce cost-effective and efficient methods that overwhelmed insufficiencies in conservative synthesis procedures.
- At nano-scale, agglomeration of particles is a key problem, which considerably affects the functionality of the material. Nanomaterials agglomerate when coming across each other. This may be because of the electrostatic interaction, physical entanglement, or high surface energy [26]. For instance, carbon nanotubes experience van der walls interaction and make bunches, thus finding difficulty in alignment and/or properly dispersion in polymer matrices [27].
- The development of three-dimensional (3D) architectures can tune the efficiency of nanomaterials. Porous architectures of nanomaterials have been advanced for enhancing their functionality through interior availability. For instance, the 3D architectures of 2D graphene have provided fast mass, high specific surface area, and electron transport kinetics. It happened because of the combination of 3D porous structures and inherent characteristics of graphene [28]. The amalgamation of carbon nanotubes assemblies and graphene in 3D architectures has been the most studied research area.
- Experimental evolution of 2D ultra-thin materials is required, as these materials representing outstanding theoretical characteristics. The major challenges associated with 2D ultra-thin materials are their stability and synthesis. Therefore, more focused studies are needed for their preparation and industrial utilization.
- The utilization of nanomaterials in the industry has been raised, and large-scale material synthesis is in demand. Although nano-based materials have vast skylines, there is a need to explore new materials with captivating features and thus introduce new research areas. As the toxicity of nanomaterials is still a major concern for domestic, industrial, and environmental utilization. For instance, the range in which nanoparticle-based materials cause cellular toxicity is quite blurr [29]. Therefore, a proper understanding of materials is much needed to promote their industrial usage.

The industrial revolution has also been linked to the advancement in nanomaterials. The development of clean energy production was possible with the innovation in nanomaterial-based engineering strategies. Researchers widely used the nanomaterials for a new generation of solar and hydrogen fuel cells, efficient catalysts for