



# Nanosphere Technology: Innovations and Applications

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## Abstract:

Nanosphere technology represents a revolutionary breakthrough in the field of materials science, enabling the design and creation of multifunctional nanoparticles with unprecedented properties. This chapter delves into the fundamental concepts, synthesis methods, and diverse applications of nanosphere technology. From medicine to electronics, energy to environmental remediation, the remarkable versatility of nanospheres is reshaping industries and opening new avenues for scientific exploration. Through a comprehensive review of current research and real-world examples, the only aim is to provide an in-depth understanding of nanosphere technology and its potential to drive innovation in the coming decades. Nanosphere technology represents a groundbreaking field at the intersection of nanotechnology, materials science, and biotechnology. This also delves into the fundamental principles, fabrication methods, and diverse applications of nanospheres. These nanometer-scale spherical particles exhibit unique properties and find applications in various industries, including medicine, electronics, energy, and environmental science. This chapter explores the synthesis techniques, functionalization strategies, and potential challenges associated with nanosphere technology.

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**1. Introduction:** The Nanosphere Revolution is the advent of nanotechnology, has ushered in a new era of materials engineering, with nanospheres standing at the forefront of this revolution [1]. This section outlines the significance of nanospheres and their unique properties, setting the stage for an exploration of their synthesis, characterization, and applications. Nanopore technology is a cutting-edge technique used for the analysis and sequencing of biomolecules, primarily DNA, RNA, and proteins, at the single-molecule level. It leverages the unique properties of nanopores – tiny, nanometer-sized pores – to capture, detect, and characterize these molecules as

they pass through the pore. This technology has garnered significant interest due to its potential for rapid, portable, and real-time analysis of various biomolecules. [2]

The basic principle of nanopore technology involves passing a biomolecule through a nanopore, typically embedded in a membrane. The nanopore can be a natural protein pore, such as the alpha-hemolysin pore from bacteria, or a solid-state pore created using advanced nanofabrication techniques. As the biomolecule translocates through the nanopore, it causes changes in the electrical current passing through the pore. These changes in current are used to infer information about the biomolecule's



properties, such as its size, sequence, and structural characteristics [3].

Here's a more detailed explanation of the key components and steps involved in nanopore technology:

**Nanopore Structure:** The nanopore itself is a critical component. It is a tiny hole, often just a few nanometers in diameter, that can be created using biological or solid-state methods. Biological nanopores are typically proteins with a pore-forming domain that spans a lipid bilayer membrane. Solid-state nanopores are fabricated using advanced techniques in nanotechnology, such as electron beam lithography or focused ion beam milling. [4]

- a) **Translocation of Biomolecules:** Biomolecules, such as DNA, RNA, or proteins, are introduced to the system. The biomolecules can be naturally threaded through the nanopore or driven through it using an external force. As the molecule passes through the nanopore, it causes disruptions in the ionic current flowing through the pore. [5]
- b) **Current Detection:** Electrodes are placed on both sides of the nanopore or embedded within the nanopore system. When a biomolecule translocates through the pore, it obstructs the ion flow, resulting in changes in the electrical current. These changes in current are recorded as voltage signals and are used to identify the type of molecule passing through, its length, and other characteristics. [6]
- c) **Signal Analysis and Interpretation:** The recorded current signals are analyzed using sophisticated algorithms and signal processing techniques. By comparing the signal patterns to known databases or models, researchers can determine the sequence of DNA or RNA molecules or gain insights into the structure and properties of proteins. [7]

## 2. Fundamentals of Nanosphere Technology

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### 2.1 Nanosphere Definition and Structure

#### 2.2 Size-Dependent Properties

#### 2.3 Surface Functionalization

#### 2.1 Nanosphere Definition and Structure:

A nanosphere refers to a spherical nanoparticle with a diameter on the nanometer scale, typically ranging from 1 to 100 nanometers. Nanospheres are a type of nanomaterial that exhibit unique properties and behaviors due to their small size and high surface-to-volume ratio. [8]

The structure of a nanosphere is characterized by its spherical shape and its composition, which can vary widely depending on the material used to create it. Nanospheres can be composed of various types of materials, including metals, semiconductors, polymers, and ceramics. The choice of material often determines the nanosphere's properties and potential applications.

In some cases, nanospheres can consist of a single material, where the entire particle is made up of the same substance. In other cases, nanospheres can be composed of a core-shell structure, where a central core material is surrounded by a shell of a different material. This design allows researchers to engineer properties such as enhanced stability, improved biocompatibility, and controlled drug release for applications in fields like medicine and materials science. [9]

Nanospheres can be synthesized using a variety of methods, such as chemical precipitation, sol-gel processes, and self-assembly techniques. The size and properties of nanospheres can be controlled by adjusting parameters during the synthesis process, enabling fine-tuning of their characteristics for specific applications. [10]

#### 2.2 Size-Dependent Properties:

Nanosphere technology" generally refers to the use of nanoscale spheres or particles for various applications. Nanospheres can be made from a variety of materials, such as metals, polymers, ceramics, and more, and their properties can vary significantly based on their size. Here are some size-dependent properties of nanospheres: [11]

- a) **Optical Properties:** The optical properties of nanospheres, such as

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their color and light scattering behavior, can be strongly influenced by their size. Nanospheres that are similar in size to the wavelength of light can exhibit unique optical effects, such as plasmon resonance in metal nanospheres, leading to enhanced light absorption and scattering.

- b) **Quantum Effects:** At the nanoscale, quantum effects become more pronounced. This can lead to changes in electronic and optical properties, resulting in behaviors that differ from those observed at larger scales.
- c) **Surface Area-to-Volume Ratio:** As nanospheres get smaller, their surface area-to-volume ratio increases dramatically. This enhanced surface area can be advantageous for applications such as catalysis, drug delivery, and sensing, as it allows for greater interaction with other materials and molecules.
- d) **Magnetic Properties:** Magnetic nanospheres can exhibit unique properties at the nanoscale due to the presence of magnetic domains and their interactions. As the size of magnetic nanospheres decreases, properties like super paramagnetism may emerge, making them useful in applications like magnetic resonance imaging (MRI) contrast agents.
- e) **Thermal Properties:** Nanospheres can have altered thermal properties compared to bulk materials. As their size decreases, heat transport and thermal conductivity may be affected, which could be harnessed for applications in thermal management and thermoelectric devices.
- f) **Mechanical Properties:** Mechanical properties such as strength and elasticity can change with nanosphere size. Nanospheres may exhibit improved mechanical properties compared to their bulk counterparts due to factors like reduced defect densities at the nanoscale.

g) **Chemical Reactivity:** The reactivity of nanospheres can differ from that of bulk materials due to their high surface area and the prevalence of surface atoms. This can be advantageous for catalysis and other chemical processes.

h) **Biological Interactions:** In the context of nanomedicine, the size of nanospheres can influence their interactions with biological systems. Small nanospheres can more easily penetrate cells and tissues, making them suitable for drug delivery and imaging applications.

i) **Electric and Magnetic Fields:** Nanospheres can respond to electric and magnetic fields in unique ways based on their size and material properties. This behavior is important in fields like electronics and sensor technology. [12]

It's important to note that the properties mentioned above can vary based on the specific material used to create the nanospheres, as well as their synthesis methods and surrounding environment. As a result, researchers and engineers carefully tailor these properties to suit the desired application by controlling factors such as size, shape, composition, and surface chemistry.[13]

**2.3 Surface Functionalization:** Surface functionalization refers to the process of modifying the surface properties of a material to achieve specific desired characteristics or functionalities. This process involves attaching or grafting molecules, polymers, nanoparticles, or other substances onto the surface of a material, thereby altering its physical, chemical, or biological properties. Surface functionalization plays a crucial role in various fields, including materials science, nanotechnology, biotechnology, and medicine, among others. [14]

The objectives of surface functionalization can vary widely based on the intended application, but some common goals include: The impact and friction between milling media and the bulk material lead to size reduction and formation of nanospheres. [15]

- a) **Electron Beam Lithography:** This is a technique used to fabricate nanospheres by exposing a thin film of material to a focused electron beam. The electrons selectively remove material, creating a pattern that eventually leads to the formation of nanospheres on the surface.
- b) **Plasma Arc Discharge:** In this method, a high-energy plasma arc is generated between two electrodes, causing vaporization and ionization of the bulk material. The vaporized material then condenses to form nanospheres.
- c) **Chemical Etching:** This method involves using chemical reagents to selectively etch away certain parts of a bulk material, leading to the formation of nanospheres. This can be controlled by adjusting the etching time, concentration of the etchant
- Enhancing Biocompatibility:** Functionalizing surfaces of medical implants, devices, or drug delivery systems with bioactive molecules can improve their interaction with biological systems and reduce adverse reactions.
- d) **Creating Hydrophobic or Hydrophilic Surfaces:** Altering surface wettability by attaching hydrophobic or hydrophilic molecules can impact the way liquids interact with the material. This is useful in applications such as self-cleaning surfaces or microfluidic devices.
- e) **Adding Conductivity:** Introducing conductive coatings or nanoparticles can transform insulating materials into conductive ones, expanding their use in electronics and sensors.
- f) **Tailoring Chemical Reactivity:** Modifying surface chemistry can enhance catalytic activity, which is important in catalysis and chemical reaction processes.
- g) **Improving Adhesion:** Coating surfaces with adhesion-promoting molecules can enhance the bonding of materials in applications like adhesives, coatings, and composite materials.

- h) **Enabling Selective Binding:** Surface functionalization can allow specific molecules, ions, or particles to selectively bind to the material, enabling applications such as biosensors and separation processes.
- i) **Creating Antibacterial or Antifouling Surfaces:** Incorporating antimicrobial or antifouling agents onto surfaces helps prevent the growth of bacteria or unwanted substances.
- j) **Enhancing Optical Properties:** Introducing nanoparticles or molecules that interact with light can modify the optical properties of materials, enabling applications in photonics and sensors.
- k) **Drug Delivery:** Functionalizing nanoparticles or microparticles with targeting ligands can improve drug delivery by specifically targeting certain cells or tissues.
- l) **Creating Responsive Surfaces:** Incorporating stimuli-responsive polymers can result in surfaces that change properties in response to external factors such as temperature, pH, or light. [16]

Methods for surface functionalization include chemical methods, physical methods, and biological methods. Chemical methods often involve reactions such as grafting, crosslinking, or coating with functional molecules. Physical methods might include physical vapor deposition, chemical vapor deposition, or plasma treatment. Biological methods could involve using biomolecules like proteins, enzymes, or DNA to modify the surface.

Surface functionalization has wide-ranging applications across industries and scientific disciplines, from biomedical devices to electronics, from environmental sensing to energy conversion. It is a versatile approach that enables researchers and engineers to tailor materials to meet specific requirements and push the boundaries of what materials can achieve. [17]

### 3. Synthesis Methods for Nanospheres [18]

- a) **Top-Down Approaches:** Top-down approaches in nanosphere synthesis



involve the reduction of bulk materials or structures to smaller nanospheres through various methods. These methods offer control over particle size, shape, and composition, making them useful for tailoring nanospheres for specific applications. Here are some common top-down synthesis methods for nanospheres:

- b) **Laser Ablation:** In this technique, a high-energy laser is focused on a bulk material, causing it to ablate and generate nanoparticles. The resulting nanoparticles can be collected and processed to obtain nanospheres of desired size and composition.
- c) **Mechanical Attrition or Milling:** This method involves the mechanical grinding or milling of larger particles to reduce them into nanoscale particles. The process can be carried out using ball mills, attritor mills, or other milling equipment, and other reaction parameters.
- d) **Ultrasonication:** Ultrasonication involves subjecting a bulk material to high-frequency sound waves, which induce cavitation and mechanical forces that break down the material into smaller particles. By controlling ultrasonication parameters, nanospheres can be obtained.
- e) **Ion Beam Sputtering:** In this technique, high-energy ions are bombarded onto a target material, causing atom ejection and the formation of nanoparticles. These nanoparticles can then be manipulated to form nanospheres.
- f) **Template-Assisted Methods:** In some cases, templates such as micelles, emulsions, or sacrificial templates can be used to guide the formation of nanospheres. The bulk material is deposited or grown on these templates, and subsequent removal of the template results in nanosphere formation. [19]

Top-down approaches offer excellent control over particle size and shape, allowing for

precise customization of nanospheres for specific applications in fields like nanomedicine, electronics, catalysis, and more. However, they may require more complex equipment and processing conditions compared to bottom-up approaches, which involve the assembly of nanoparticles from smaller building blocks. [20]

### 3.1.1 Lithography-Based Methods:

Lithography-based methods are commonly used for the synthesis of nanospheres with precise control over size, shape, and arrangement. These methods utilize photolithography or electron beam lithography techniques to create patterns on a substrate, which then serve as templates for the formation of nanospheres. Here are some lithography-based synthesis methods for nanospheres: [21]

#### a) Top-Down Lithography: [22]

- I. **Photolithography:** In this method, a photosensitive polymer is spin-coated onto a substrate. A photomask with the desired pattern is placed over the polymer, and UV light is shone through the mask. The exposed regions of the polymer become insoluble and are developed away, leaving behind a pattern that can be used as a template for nanosphere deposition.
- II. **Electron Beam Lithography (EBL):** EBL uses a focused electron beam to write patterns directly onto a substrate. The beam is controlled to create the desired pattern, and subsequent processes like etching or deposition can be used to create nanospheres on the substrate.

#### B) Bottom-Up Lithography: [23], [24]

- I. **Nanoimprint Lithography:** In this technique, a master mold with the desired nanosphere pattern is created using EBL or other methods. The mold is then pressed onto a polymer film or other suitable material, transferring the pattern onto it. The polymer is then cured to create the nanospheres.



- II. **Step-and-Flash Imprint Lithography (SFIL):** Similar to nanoimprint lithography, SFIL uses a transparent template and UV light to cure a photosensitive material, creating the desired pattern of nanospheres.

**c) Self-Assembly Lithography: [25], [26]**

- I. **Block Copolymer Lithography:** Block copolymers are composed of two or more chemically distinct polymer chains. By controlling the composition and molecular weight, self-assembly of these polymers can result in regular patterns of nanospheres.
- II. **Colloidal Lithography:** This method involves depositing a monolayer of colloidal particles onto a substrate, followed by additional processing steps to create a pattern. The deposited particles can serve as masks for further etching or deposition processes.

These lithography-based methods offer excellent control over nanosphere size, shape, and arrangement. However, they often require specialized equipment and expertise. The choice of method depends on factors such as desired scale, material compatibility, and required precision. Additionally, hybrid methods that combine lithography with other techniques, such as chemical vapor deposition or electrodeposition, can further enhance the versatility of nanosphere synthesis. [27]

**4. Characterization Techniques for Nanospheres:** characterization techniques for nanospheres involve various methods to analyze and understand their properties, structure, size, shape, composition, and behavior at the nanoscale. Nanospheres can be made from a wide range of materials, including polymers, metals, ceramics, and more. Here are some common techniques used for characterizing nanospheres: [28], [29]

- a) **Transmission Electron Microscopy (TEM):** TEM provides high-resolution images of nanospheres, allowing researchers to visualize their size, shape, and internal structure at the nanoscale. It can also provide

information about the distribution of nanospheres in a sample.

- b) **Scanning Electron Microscopy (SEM):** SEM offers topographical information and 3D surface imaging of nanospheres. It is useful for studying the external morphology and size distribution of nanospheres.
- c) **Atomic Force Microscopy (AFM):** AFM is used to study the surface properties of nanospheres by scanning a sharp tip over their surfaces. It can provide information about surface roughness, particle size, and interactions with other surfaces.
- d) **Dynamic Light Scattering (DLS):** DLS measures the Brownian motion of nanoparticles in a suspension to determine their hydrodynamic diameter and size distribution. It is especially useful for measuring the size of nanospheres in liquid dispersions.
- e) **Zeta Potential Analysis:** This technique measures the electrostatic potential at the nanoparticle surface, providing information about the surface charge and stability of nanospheres in a solution.
- f) **X-ray Diffraction (XRD):** XRD is used to determine the crystalline structure of nanospheres, providing information about their composition and crystallography.
- g) **Fourier Transform Infrared Spectroscopy (FTIR):** FTIR helps identify functional groups and chemical bonds present on the surface of nanospheres, aiding in their characterization and composition analysis.
- h) **UV-Vis Spectroscopy:** UV-Vis spectroscopy is used to measure the absorption and scattering of light by nanospheres, providing information about their optical properties, size, and concentration.
- i) **Thermogravimetric Analysis (TGA):** TGA measures changes in mass as a function of temperature, allowing researchers to determine the thermal



stability and decomposition behavior of nanospheres.

- j) **Electron Energy Loss Spectroscopy (EELS):** EELS, often used in combination with TEM, provides information about the elemental composition and chemical bonding of nanospheres.
- k) **Small Angle X-ray Scattering (SAXS):** SAXS is used to study the nanostructure and arrangement of nanospheres in a sample, providing information about their spatial arrangement.
- l) **Nuclear Magnetic Resonance (NMR):** NMR can be used to study the molecular composition and interactions of nanospheres in solution, offering insights into their surface chemistry and functionalization. [30]

## 5. Applications of Nanosphere Technology: Applications: [31], [32]

- a) **DNA Sequencing:** One of the most prominent applications of nanopore technology is DNA sequencing. As DNA strands pass through the nanopore, each of the four nucleotide bases (A, T, C, G) generates a distinct current signature. By analyzing these signatures, researchers can reconstruct the DNA sequence in real time.
- b) **RNA Analysis:** Nanopore technology is also used to sequence and analyze RNA molecules, including mRNA and non-coding RNAs, providing insights into gene expression and regulation.
- c) **Protein Characterization:** Researchers are exploring the use of nanopores for studying proteins, their folding, and interactions, which could have implications for drug discovery and understanding biological processes.
- d) **Medicine and Drug Delivery:** Nanospheres can be loaded with drugs and targeted to specific cells or tissues, allowing for controlled and localized drug release. Their small size can enable them to penetrate

biological barriers and improve drug delivery efficiency.

- e) **Catalysis:** Nanospheres made of certain metals or metal oxides can be used as catalysts for chemical reactions due to their high surface area and unique catalytic properties.
- f) **Electronics:** Nanospheres made of semiconducting materials can find applications in electronic devices, such as nanoscale transistors and sensors.
- g) **Optics:** Nanospheres made of materials with specific optical properties can be used in applications like imaging, photodetectors, and light manipulation.
- h) **Environmental Remediation:** Nanospheres can be designed to remove pollutants and contaminants from water and air due to their high surface area and reactivity.
- i) **Energy Storage:** Nanospheres can be incorporated into energy storage devices, such as batteries and supercapacitors, to enhance their performance. [33]

## Challenges and Future Prospects nanosphere technology: [34]

6. Challenges and Future Prospects Nanosphere technology, often referred to as nanotechnology, involves the manipulation and control of matter at the nanoscale, which is typically on the order of one billionth of a meter. This field has shown immense promise across various industries, including electronics, medicine, energy, materials science, and more. However, like any emerging technology, nanosphere technology also faces several challenges and offers future prospects:

### Challenges: [35]

- a) **Safety and Health Concerns:** Due to the tiny size of nanoparticles, they can have unique properties that might pose potential health and environmental risks. Understanding the toxicology and long-term effects of these particles on humans and ecosystems is crucial.

- b) **Regulation and Standardization:** The rapid development of nanotechnology has outpaced the establishment of comprehensive regulations and standards. Ensuring the safe and responsible use of nanomaterials requires international cooperation and robust regulatory frameworks.
- c) **Ethical and Societal Concerns:** As with any transformative technology, there are ethical questions regarding the potential misuse of nanotechnology. Issues such as privacy, surveillance, and the impact on socio-economic disparities need to be carefully addressed.
- d) **Manufacturing and Scalability:** The precise manipulation of nanoscale materials can be challenging to scale up for commercial production. Developing cost-effective and reliable methods for manufacturing nanoscale products is a significant hurdle.
- e) **Characterization and Metrology:** Measuring and characterizing nanoparticles accurately is complex due to their small size and unique properties. Developing advanced metrology techniques is essential for quality control and accurate assessments. [36]

#### Future Prospects: [37], [38]

- a) **Medicine and Healthcare:** Nanotechnology holds great potential in drug delivery, diagnostics, and targeted therapies. Nanoparticles can be engineered to deliver drugs directly to specific cells or tissues, reducing side effects and improving treatment efficacy.
- b) **Electronics and Computing:** Nanoscale materials could revolutionize electronics by enabling smaller, faster, and more energy-efficient devices. Quantum dots, for example, are being explored for applications in displays and computing.
- c) **Energy and Environment:** Nanotechnology can contribute to more efficient energy storage,

generation, and conservation. Nanomaterials are being investigated for solar cells, energy storage devices, and pollution remediation.

- d) **Materials Science:** Nanotechnology enables the creation of materials with novel properties, such as increased strength, enhanced conductivity, and improved thermal resistance. These materials have applications in aerospace, construction, and more.
- e) **Environmental Sensing:** Nanosensors can be designed to detect pollutants, pathogens, and other substances at extremely low concentrations. This has potential applications in environmental monitoring and public health.
- f) **Water Purification:** Nanotechnology can play a significant role in water treatment by developing advanced filtration systems and adsorbents to remove contaminants from water sources.
- g) **Space Exploration:** Nanoscale technologies could be employed in space exploration for creating lightweight materials, developing miniaturized spacecraft components, and aiding in extraterrestrial resource utilization.

In conclusion, nanosphere technology has both challenges and exciting prospects. While addressing safety concerns, ethical considerations, and regulatory frameworks is crucial, the potential benefits across a wide range of fields make the continued research and development in this area highly promising. As advancements are made, responsible innovation will be essential to harness the full potential of nanotechnology for the betterment of society.[39]

#### Advantages: [40], [41]

- a) **Real-Time Analysis:** Nanopore technology enables real-time analysis of biomolecules, making it suitable for applications that require rapid results.
- b) **Portability:** Some nanopore sequencers are portable and can be used in the field, offering potential for



point-of-care diagnostics and environmental monitoring.

- c) **Long Reads:** Nanopore sequencers can produce long reads of DNA, which is beneficial for assembling complex genomes and detecting structural variations.
- d) **Challenges:**
- e) **Signal Noise:** The electrical signals generated during translocation can be noisy, making accurate analysis challenging.
- f) **Base Calling Accuracy:** While nanopore sequencing has improved significantly, achieving high base-calling accuracy, especially in homopolymeric regions, can still be a challenge.
- g) **Sample Preparation:** Efficient sample preparation techniques are needed to ensure molecules pass through the nanopore in a controlled manner.

In summary, nanopore technology is a revolutionary approach to biomolecule analysis and sequencing, offering advantages like real-time analysis, portability, and long read lengths. As the technology continues to evolve, it holds the potential to impact fields ranging [42]

**Conclusion:** In conclusion, nanosphere technology is poised to reshape industries and drive scientific advancements in the 21st century. Its unique properties, versatile synthesis methods, and diverse applications make it a cornerstone of modern materials science. As researchers continue to explore and refine nanosphere-based technologies, the potential for breakthroughs in fields ranging from medicine to energy is boundless. Nanosphere technology holds promise for a wide range of applications, impacting industries from medicine to electronics. As research continues, innovations in fabrication methods, functionalization strategies, and applications will undoubtedly drive the evolution of this field, paving the way for transformative technologies with profound societal implications.

## References

1. Ouyang, Yuge, Xiaofei Li, Fei Ding, Liuyang Bai, and Fangli Yuan. "Simultaneously enhance thermal conductive property and mechanical properties of silicon rubber composites by introducing ultrafine Al<sub>2</sub>O<sub>3</sub> nanospheres prepared via thermal plasma." *Composites Science and Technology* 190 (2020): 108019.
2. Osipov, Artem A., Alina E. Gagaeva, Anastasiya B. Speshilova, Ekaterina V. Endiiarova, Polina G. Bepalova, Armenak A. Osipov, Ilya A. Belyanov, Kirill S. Tyurikov, Irina A. Tyurikova, and Sergey E. Alexandrov. "Development of controlled nanosphere lithography technology." *Scientific Reports* 13, no. 1 (2023): 3350.
3. Tsukada, Yusuke, Aiko Sasai, Hiroyuki Tsujimoto, Hiromitsu Yamamoto, and Yoshiaki Kawashima. "PLGA Nanosphere Technology for Novel Nanomedicine and Functional Cosmetics." In *Nanoparticle Technology Handbook*, pp. 461-467. Elsevier, 2018.
4. Gazit, Ehud. "Self-assembled peptide nanostructures: the design of molecular building blocks and their technological utilization." *Chemical Society Reviews* 36, no. 8 (2007): 1263-1269.
5. Du, Xin, and Junhui He. "Fine-tuning of silica nanosphere structure by simple regulation of the volume ratio of cosolvents." *Langmuir* 26, no. 12 (2010): 10057-10062.
6. Wang, Wei, Hongliang Wang, Jie Zhao, Xin Wang, Chuansheng Xiong, Liying Song, Rui Ding, Peng Han, and Weihua Li. "Self-healing performance and corrosion resistance of graphene oxide-mesoporous silicon layer-nanosphere structure coating under marine alternating hydrostatic pressure." *Chemical Engineering Journal* 361 (2019): 792-804.
7. Cheng, Ruilin, Honglin He, Zonghua Pu, Ibrahim Saana Amiinu, Lei Chen, Zhe Wang, Guoqiang Li, and Shichun Mu. "Shrunken hollow Mo-N/Mo-C nanosphere structure for efficient hydrogen evolution in a broad pH

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- range." *Electrochimica Acta* 298 (2019): 799-805.
8. Xiong, Ranhua, Sangram Keshari Samal, Jo Demeester, Andre G. Skirtach, Stefaan C. De Smedt, and Kevin Braeckmans. "Laser-assisted photoporation: fundamentals, technological advances and applications." *Advances in Physics: X* 1, no. 4 (2016): 596-620.
  9. Nanda, Arun, Sanju Nanda, Tuan Anh Nguyen, Susai Rajendran, and Yassine Slimani, eds. *Nanocosmetics: fundamentals, applications and toxicity*. Elsevier, 2020.
  10. Chen, Zhihan, Pavana Siddhartha Kollipara, Hongru Ding, Agatian Pughazhendi, and Yuebing Zheng. "Liquid optothermoelectrics: fundamentals and applications." *Langmuir* 37, no. 4 (2021): 1315-1336.
  11. Huang, Peng, Lijing Zhang, Qingfeng Yan, Dan Guo, and Guoxin Xie. "Size dependent mechanical properties of monolayer densely arranged polystyrene nanospheres." *Langmuir* 32, no. 49 (2016): 13187-13192.
  12. Fukasawa, Tomonori, Hiroyuki Shinto, Hiroyuki Aoki, Shinzaburo Ito, and Masahiro Ohshima. "Size-dependent effect of gold nanospheres on the acoustic pressure pulses from laser-irradiated suspensions." *Advanced Powder Technology* 25, no. 2 (2014): 733-738.
  13. Jia, Kun, Jiandong Zhang, Xu Huang, and Xiaobo Liu. "Size dependent electromagnetic properties of Fe<sub>3</sub>O<sub>4</sub> nanospheres." *Chemical Physics Letters* 614 (2014): 31-35.
  14. Cai, Xinjie, Kena Ma, Yi Zhou, Tao Jiang, and Yining Wang. "Surface functionalization of titanium with tetracycline loaded chitosan-gelatin nanosphere coatings via EPD: fabrication, characterization and mechanism." *RSC advances* 6, no. 9 (2016): 7674-7682.
  15. Schiestel, Thomas, Herwig Brunner, and Günter EM Tovar. "Controlled surface functionalization of silica nanospheres by covalent conjugation reactions and preparation of high density streptavidin nanoparticles." *Journal of Nanoscience and Nanotechnology* 4, no. 5 (2004): 504-511.
  16. Song, Xiao-Jie, Jun Hu, and Chang-Chun Wang. "Synthesis of highly surface functionalized monodispersed poly (St/DVB/GMA) nanospheres with soap-free emulsion polymerization followed by facile "click chemistry" with functionalized alkylthiols." *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 380, no. 1-3 (2011): 250-256.
  17. Tang, Fan, Lifeng Zhang, Jian Zhu, Zhenping Cheng, and Xiulin Zhu. "Surface functionalization of chitosan nanospheres via surface-initiated AGET ATRP mediated by iron catalyst in the presence of limited amounts of air." *Industrial & engineering chemistry research* 48, no. 13 (2009): 6216-6223.
  18. Zhang, Pengfei, Zhen-An Qiao, and Sheng Dai. "Recent advances in carbon nanospheres: synthetic routes and applications." *Chemical Communications* 51, no. 45 (2015): 9246-9256.
  19. Zhang, Pengfei, Zhen-An Qiao, and Sheng Dai. "Recent advances in carbon nanospheres: synthetic routes and applications." *Chemical Communications* 51, no. 45 (2015): 9246-9256.
  20. Santos, M. L., R. C. Lima, C. S. Riccardi, R. L. Tranquilin, Paulo Roberto Bueno, José Arana Varela, and Elson Longo. "Preparation and characterization of ceria nanospheres by microwave-hydrothermal method." *Materials Letters* 62, no. 30 (2008): 4509-4511.
  21. Fu, Xinxin, Jingxuan Cai, Xiang Zhang, Wen-Di Li, Haixiong Ge, and Yong Hu. "Top-down fabrication of shape-controlled, monodisperse nanoparticles for biomedical applications." *Advanced drug delivery reviews* 132 (2018): 169-187.
  22. Aryal, Susmita, Hyungkyu Park, James F. Leary, and Jaehong Key. "Top-down fabrication-based nano/microparticles for

5700



- molecular imaging and drug delivery." *International journal of nanomedicine* (2019): 6631-6644.
23. Yang, Mi-Sun, Changhoon Song, Jihoon Choi, Jeong-Sik Jo, Jin-Hyun Choi, Byung Kee Moon, Heeso Noh, and Jae-Won Jang. "Fabrication of diffraction gratings by top-down and bottom-up approaches based on scanning probe lithography." *Nanoscale* 11, no. 5 (2019): 2326-2334.
  24. Arole, V. M., and S. V. Munde. "Fabrication of nanomaterials by top-down and bottom-up approaches-an overview." *J. Mater. Sci* 1 (2014): 89-93.
  25. Razaualla, Talha, Michael Bekeris, Haidong Feng, Michael Beeman, Ugochukwu Nze, and Roseanne Warren. "Multiple linear regression modeling of nanosphere self-assembly via spin coating." *Langmuir* 37, no. 42 (2021): 12419-12428.
  26. Oh, Jeong Rok, Jung Ho Moon, Hoo Keun Park, Jae Hyoung Park, Haegeun Chung, Jinhoo Jeong, Woong Kim, and Young Rag Do. "Wafer-scale colloidal lithography based on self-assembly of polystyrene nanospheres and atomic layer deposition." *Journal of Materials Chemistry* 20, no. 24 (2010): 5025-5029.
  27. Domonkos, Mária, and Alexander Kromka. "Nanosphere Lithography-Based Fabrication of Spherical Nanostructures and Verification of Their Hexagonal Symmetries by Image Analysis." *Symmetry* 14, no. 12 (2022): 2642.
  28. Kumar, MNV Ravi, U. Bakowsky, and C. M. Lehr. "Preparation and characterization of cationic PLGA nanospheres as DNA carriers." *Biomaterials* 25, no. 10 (2004): 1771-1777.
  29. Ma, Lei, Xiaoyin Chen, Junhua Li, Huazhen Chang, and Johannes W. Schwank. "Electronic metal-support interactions in Pt/FeOx nanospheres for CO oxidation." *Catalysis Today* 355 (2020): 539-546.
  30. Torres-Lugo, Madeline, and Nicholas A. Peppas. "Preparation and characterization of P (MAA-g-EG) nanospheres for protein delivery applications." *Journal of Nanoparticle Research* 4 (2002): 73-81.
  31. Qiu, Tengfei, Eser Metin Akinoglu, Bin Luo, Muxina Konarova, Jung-Ho Yun, Ian R. Gentle, and Lianzhou Wang. "Nanosphere lithography: A versatile approach to develop transparent conductive films for optoelectronic applications." *Advanced Materials* 34, no. 19 (2022): 2103842.
  32. Nieto-Márquez, Antonio, Rubí Romero, Amaya Romero, and José Luis Valverde. "Carbon nanospheres: synthesis, physicochemical properties and applications." *Journal of Materials chemistry* 21, no. 6 (2011): 1664-1672.
  33. Divyashree, A., and Gurumurthy Hegde. "Activated carbon nanospheres derived from bio-waste materials for supercapacitor applications—a review." *Rsc Advances* 5, no. 107 (2015): 88339-88352.
  34. Guo, Jiuchuan, Fanyu Zeng, Jinhong Guo, and Xing Ma. "Preparation and application of microfluidic SERS substrate: Challenges and future perspectives." *Journal of Materials Science & Technology* 37 (2020): 96-103.
  35. Guo, Jiuchuan, Fanyu Zeng, Jinhong Guo, and Xing Ma. "Preparation and application of microfluidic SERS substrate: Challenges and future perspectives." *Journal of Materials Science & Technology* 37 (2020): 96-103.
  36. Sajjadi, Mohaddeseh, Fatemeh Ahmadpoor, Mahmoud Nasrollahzadeh, and Hossein Ghafari. "Lignin-derived (nano) materials for environmental pollution remediation: Current challenges and future perspectives." *International Journal of Biological Macromolecules* 178 (2021): 394-423.
  37. Saravanan, A., P. Senthil Kumar, R. V. Hemavathy, S. Jeevanantham, Marie Jyotsna Jawahar, J. P. Neshaanthini, and R. Saravanan. "A review on synthesis methods and recent applications of nanomaterial in wastewater treatment: Challenges and future

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- perspectives." Chemosphere (2022): 135713.
38. Xia, Shuixin, Xinsheng Wu, Zhichu Zhang, Yi Cui, and Wei Liu. "Practical challenges and future perspectives of all-solid-state lithium-metal batteries." Chem 5, no. 4 (2019): 753-785.
  39. Zhuang, Jianjian, Juxin Yin, Shaowu Lv, Ben Wang, and Ying Mu. "Advanced "lab-on-a-chip" to detect viruses—Current challenges and future perspectives." Biosensors and Bioelectronics 163 (2020): 112291.
  40. Lin, Bo, Jianan Hui, and Hongju Mao. "Nanopore technology and its applications in gene sequencing." Biosensors 11, no. 7 (2021): 214.
  41. Zeng, Xiaoqing, Yang Xiang, Qianshan Liu, Liang Wang, Qianyun Ma, Wenhao Ma, Delin Zeng, Yajie Yin, and Deqiang Wang. "Nanopore technology for the application of protein detection." Nanomaterials 11, no. 8 (2021): 1942.
  42. Taylor, Tonya L., Jeremy D. Volkening, Eric DeJesus, Mustafa Simmons, Kiril M. Dimitrov, Glenn E. Tillman, David L. Suarez, and Claudio L. Afonso. "Rapid, multiplexed, whole genome and plasmid sequencing of foodborne pathogens using long-read nanopore technology." Scientific reports 9, no. 1 (2019): 16350.

