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Inorganic Nanomaterials in Life Sciences Applications

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The life sciences industry is tasked with solving some of the most complex and vexing problems as it aims to provide the best possible tools for research and public healthcare systems around the world. Difficult solutions often require new approaches and different ways of thinking. However, until recently, many of the efforts within the life sciences industry have focused on recycling existing ideas and technologies instead of exploring some of the novel options available to them.

Conventional medicinal chemistry is not suitable for every scenario and, as such, the life sciences and pharma industries are now turning their attention towards nanomaterials to both improve and solve their medical and research needs. To date, much of the interest in nanomaterials has revolved around organic nanomaterials – such as liposomes and polymeric dendrimers. However, there is a growing focus on using inorganic nanomaterials as well, since their unique properties can be effective in addressing challenges across a number of application areas.

HOW INORGANIC NANOMATERIALS ARE SUITED FOR LIFE SCIENCES APPLICATIONS

In recent years, a wide array of industries has shifted their attention to the use of nanomaterials, due to their unique and varied properties. At the nano scale (100 nm and less), quantum effects created by a significant increase in surface area produce distinct properties not seen in their larger counterparts. Some of these, like the ability to store large amounts of electrical energy, increased surface reactivity, and thermal conductivity make them highly suited to a variety of life science applications, such as diagnostic testing, microscopy/imaging techniques, or therapeutic areas – to name a few. Adjustments in the size, size distribution, surface stabilization, charge and even composition of these materials can be harnessed to “tune” the properties of the material to a user’s highly specific product needs.

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In addition to these general properties shared by many materials at the nano scale, there are also a wide range of element-specific properties that are expressed when in their nano forms. This presents the opportunity for an even higher degree of specialization and tuning of the nanomaterial for use in a product.

There are far too many of these unique properties to mention them all individually, but there are many possibilities that can be tailored to meet requirements in life science applications. One common example is the use of gold nanoparticles in order to exploit their surface plasmons (i.e., oscillating electrons). Such surface plasmons are often utilized in biomedical imaging, diagnostic testing and for understanding biological and drug delivery mechanisms by illuminating relevant biomarkers, which can monitor the severity of a disease or provide a visual means of seeing how biological matter interacts with each other. Since the surface plasmons of gold nanoparticles are so readily excitable by light, they make ideal candidates for highly sensitive detection of these biomarkers.

Another useful example is seen in the antimicrobial properties of silver nanoparticles, which can be used in medical technologies to make a surface or implanted device sterile. Bulk silver has similar properties, however due to its high surface area the nanoform is much more active, requiring less material and overall cost. The internal magnetic properties of iron oxide nanoparticles can also be harnessed in a variety of applications when external magnetic fields are applied. The high spin rates provoked by the magnetic field enable the nanoparticles to perform strong separations for assays, to act as enhanced resolution contrast agents for targeted drug delivery, to generate localized heat to destroy cancer cells, and many other use cases.

These examples represent a small sampling of how it is possible to harness the unique properties of inorganic nanomaterials across a broad range of biomedical and life sciences applications. Proper selection and careful design of the nanomaterial allows for precise expression of the behaviors required to meet the user's needs and specifications.

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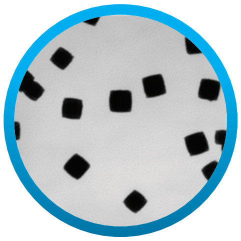

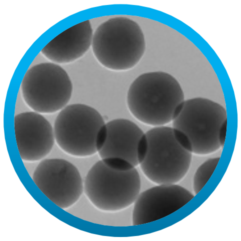

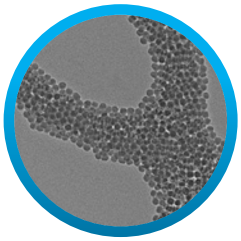

Inorganic nanomaterials are becoming more commercially prevalent in life science applications as it becomes apparent that they can provide a significant enhancement over existing strategies. These materials are being exploited in a wide range of life sciences applications like diagnostics, imaging, medical devices, implants, coatings, wearable sensors, therapeutics and drug delivery applications – some of which are outlined in greater detail below.

DIAGNOSTICS

Diagnostics encompass a fast-growing area, including point of care (POC) biosensors and lab-on-a-chip (LOAC) devices that can be used to diagnose if a patient has specific disease, virus or ailment. The high electrical conductivities of some inorganic nanomaterials, coupled with their increased surface area, have made numerous inorganic nanomaterials an ideal sensing surface. Functionalizing the nanomaterials with biological receptors has become a common approach for creating highly sensitive and specific POC and LOAC devices.

One of the main reasons that companies are moving towards POC diagnostics is because there is a drive for quick, accurate, reliable, and cost-effective results – something which was showcased all too well during the COVID-19 outbreak. To date, the main inorganic nanomaterials used in POC and LAOC devices are gold, silver, and zinc oxide nanoparticles as well as quantum dots. The small size and inherent flexibility of nanomaterials has also opened the field of flexible and wearable sensors that can be used to track a patient's health in real-time.

IMAGING

Modern-day imaging technologies strive to obtain the highest resolutions possible. Many scientists are now using these tools to explore small biomolecules in detail, as well as to look at the structure of various tissues and organs, oftentimes for signs of damage or disease. This enhanced imaging also provides a better fundamental understanding of the many biological processes that underpin the everyday function of our bodies and other organisms.

No field better highlights the rapid use of inorganic nanomaterials than bioimaging. These materials have aided advances in contrast agents for both magnetic resonance imaging (MRI) and computed tomography (CT), as well as fluorescent and luminescent probes for optical imaging techniques. For MRI applications, the use of superparamagnetic iron oxide nanoparticles can improve detection sensitivity, while also producing less side effects than the standard gadolinium-based materials. Similarly, various lanthanides have been explored for their ability to improve detection and reduce cost and toxicity in CT imaging. Importantly, unlike the previous state of the art materials used in these imaging technologies, nanoparticles can be functionalized with various biomolecules and receptors. This allows for higher degrees of molecular targeting and specificity and in some cases, lower dosages requirements.

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ANTIMICROBIAL COATINGS FOR MEDICAL DEVICES, IMPLANTS AND HEALTHCARE SETTINGS

The unfortunate and rapid rise of antibiotic-resistant healthcare-acquired infections (HAI) has become a critical issue that the healthcare industry has been working to address. Bacterial, fungal, and viral infections pose potential dangers to healthcare patients, especially when undergoing treatment. These pathogens represent a threat in both the healthcare facility setting, as well as in any clinical materials utilized for short- and long-term medical care, from bandages and wound dressings to surgical implants and medical devices. With the rise in HAIs, attention has turned to new technologies, including nanomaterials, to solve this seemingly intractable problem.

There are a number of inorganic nanoparticles in use today which have antimicrobial properties. These materials are being coated onto surfaces or directly incorporated into various substrates, providing a durable long-lasting solution. Nanomaterials can additionally be incorporated onto the surface of implants and devices in an effort to prevent biofilm formation in the body. Furthermore, in some cases, the actual implant is built with metallic or ceramic nanocomposites, making incorporation or coating more facile. Common examples of inorganic nanomaterials used in antimicrobial applications in the healthcare environment and implant and medical device coating include titanium oxide, silver, zinc oxide, and copper.

DRUG DELIVERY AND THERAPEUTICS

Perhaps the earliest and most well-known examples of utilizing nanomaterials in life sciences and therapeutics is seen in the enhancement of drug delivery approaches. Therapeutic payloads that would otherwise be too toxic to administer to the entire body (e.g., chemotherapy), can be encapsulated and directed to the target treatment area with a high degree of specificity. While this has typically been achieved using nano-scale polymers or liposomes, there are many inorganic materials that are also being explored for their drug delivery capabilities – from metals, to nanoclays and silica. Such nanoform drugs are typically carried by the inorganic delivery agent, where they are protected until an external stimulus triggers their release at the target area. Similar to imaging technologies, nanoparticles can be surface functionalized with molecules such as receptors, ligands, or antibodies in order to target the nanoparticles to interact directly with the desired ligands, receptors, antigens or biomarkers at the desired target locations, allowing highly specific delivery of the drug payload.

While nanoparticles play a critical role in technologies to deliver therapeutic payloads of conventional drug molecules, inorganic nanoparticles are also being employed directly as therapeutics that make use of their unique properties. Some of the common examples used for therapeutics include gold, silver, ceria and iron-based nanoparticles. In these cases, the inherent properties of the nanoparticle are exploited for therapeutic treatment. This includes the photothermal and radiosensitizing properties of gold in cancer treatments, the free-radical scavenging capabilities of ceria nanoparticles for a host of diseases and injuries displaying oxidative damage, and the magnetic and photothermal characteristics of iron oxide nanoparticles. Also, as previously noted, the small size and ease of surface functionalization make these nanoparticles highly amenable for targeting to specific cells and tissues for therapeutic treatment. All of these inorganic materials have their own distinct targeting and therapeutic mechanisms, but their use as therapies is growing now that their potential has been uncovered.

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SUMMARY

Utilizing the myriad unique properties and behaviors of inorganic nanomaterials presents a significant opportunity to create new tools that enhance existing approaches or solve previously intractable problems in life sciences and pharma applications. The ability to fine-tune and optimize these materials is both a crucial requirement and benefit to these applications, where highly specific parameters are often required in order to maintain biocompatibility and performance. For more than a decade, companies around the globe have relied on Cerion for the development of metal, metal oxide and ceramic nanomaterials to enhance the performance of their products or systems. Cerion's approach provides a dedicated team and full product lifecycle support for the precision design, robust scale-up and high-volume manufacturing of nanomaterials for our customers who are leveraging them in their products or systems. Our team of experts works to understand your specific application, processing conditions and desired end-state of the nanoparticle to design a custom-tailored solution that will seamlessly integrate into your product.