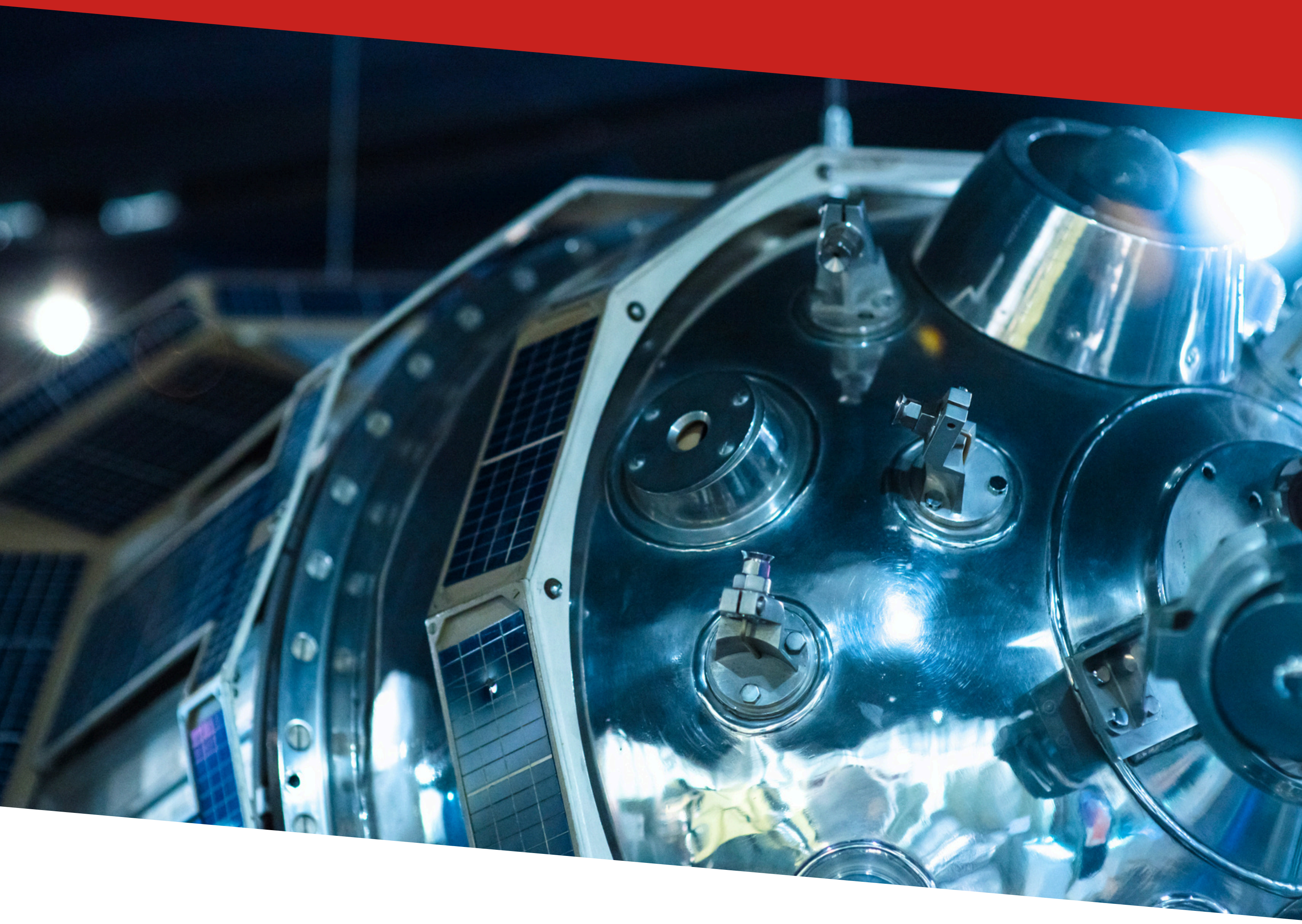
Industry Focus



Advanced Materials

An exclusive collection featuring top-tier articles, visionary experts, and essential industry insights

AZO NETWORK sponsored by CRAIC TECHNOLOGIES

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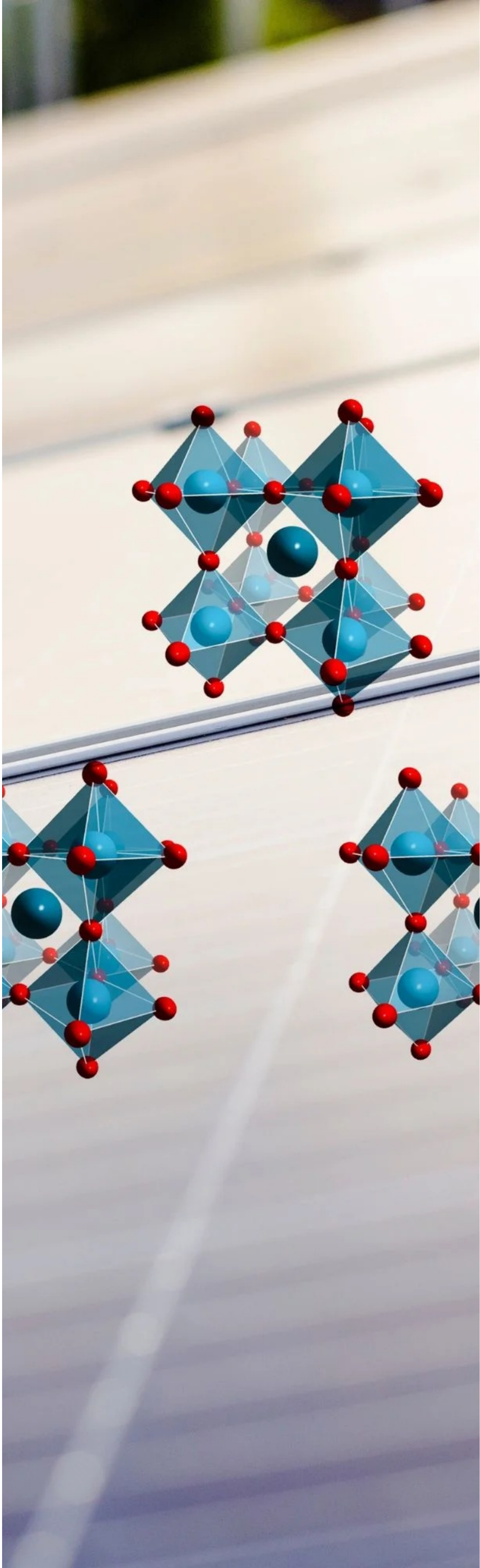
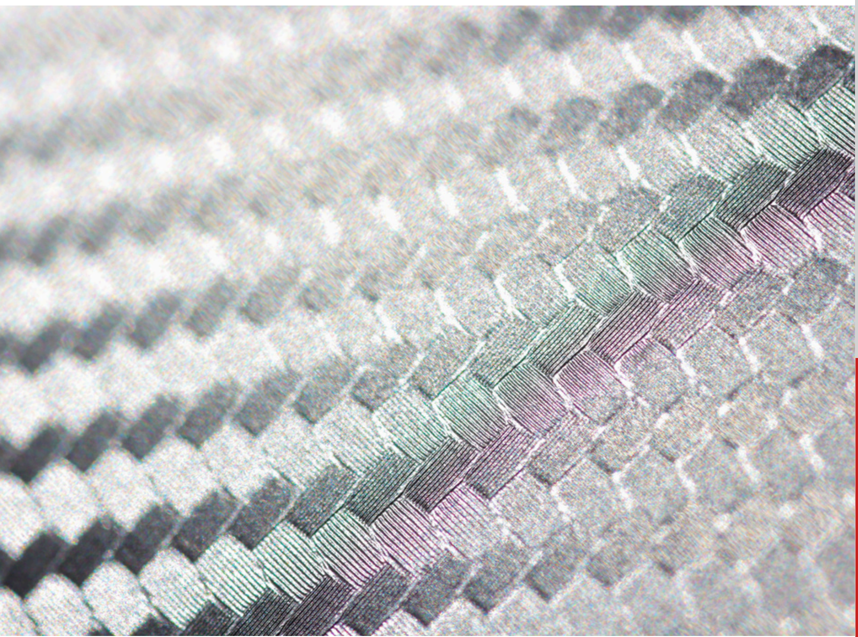


Foreword

Welcome to the latest edition of the Advanced Materials Industry Focus eBook, where we delve into the cutting-edge innovations shaping the world of materials science. This curated collection of articles brings together insights from leading researchers, technologists, and industry experts who are redefining the boundaries of material science and its applications.

This edition explores nanotechnology's vast potential in *What Can Nanotechnology Do?* followed by an inspiring dialogue with Wanhua Chemical in *Unlocking a Sustainable Future With Green Chemistry.* The innovative use of quantum dot sensors for gas detection and the transformative role of metamaterials highlight the diverse approaches researchers are employing to tackle complex problems.

Determine Thickness and Identify Defects in Graphene with Microspectroscopy explores how CRAIC Technologies' advanced microspectroscopy techniques, including UV-VIS-NIR and Raman microspectroscopy, enable precise, non-destructive analysis of graphene's properties and structure, driving innovation in 2D material research and applications. Thanks to our sponsors CRAIC Technologies.



In *Perovskite Analysis: The Role of UV-Visible-NIR Microspectroscopy in Optoelectronic Research*, CRAIC Technologies discusses how UV-Visible-NIR microspectroscopy enables advanced, non-destructive characterization of perovskite materials at the microscale, driving innovation in optoelectronics through device performance optimization.

Discover how *Raman and UV-Vis-NIR Microspectroscopy to Sort Carbon Nanotubes* looks at how CRAIC Technologies' advanced UV-Visible-NIR and Raman microspectroscopy systems enable precise, non-destructive analysis of graphene and carbon nanotubes, facilitating research, quality control, and property optimization in carbon-based nanomaterials.

We also examine advanced packaging materials for semiconductor chips and groundbreaking techniques like ultrasonic imaging with micro-metalenses for material diagnostics. Closing this collection is an exploration of flawless nanocellular graphene, an exciting breakthrough in material science with immense implications.

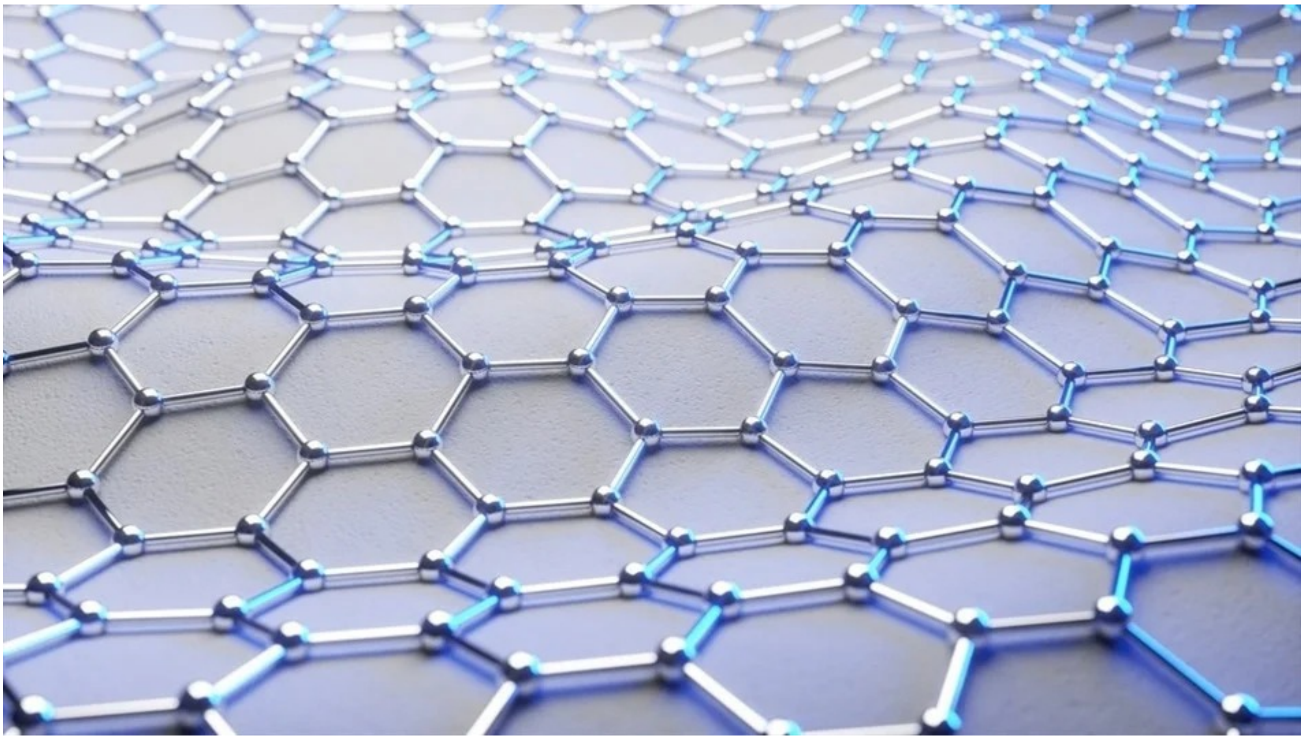
At AZoM, we are dedicated to showcasing the people and technologies driving innovation. Whether you're a seasoned professional or new to the field, we hope this eBook serves as a source of knowledge, inspiration, and collaboration as we collectively strive to shape a better future.

Lexie Corner
Editor

AZO NETWORK

What Can Nanotechnology Do?

Nanoscience and nanotechnology is an innovative field of research that has accomplished a great deal in the decades since Nobel Prize Laureate Richard Feynman introduced the concept in 1959. In the simplest terms, it deals with materials and devices with nanometer dimensions.



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What Can Nanotechnology Do?

Over the past two decades, research and development have led to nanotechnology innovations, producing tailored materials with specific properties at the nanoscale. This has significantly expanded the materials science toolkit available to researchers, process engineers, and companies.

Lighter, stronger, more durable, and more reactive nanomaterials have been manufactured. Research has produced materials with enhanced electrical conductivity and complex architectures, making them suitable for multiple applications at the cutting edge of materials science and in numerous scientific fields.

Nanotechnology is a broad discipline that includes diverse scientific fields such as surface science, molecular biology, molecular engineering, organic chemistry, energy storage, and semiconductor physics.

The field has undergone a rapid evolution, with many nanoscale materials and processes making their way out of the laboratory and into everyday commercial products. Specifically, nanotechnology holds the greatest promise for electronics, energy, biomedicine, the environment, and food.

Carbon nanotubes are predicted to replace silicon as the key material for developing next-generation products in electronics. Carbon nanotubes can produce faster and more efficient microchips and quantum nanowires with strength and high conductivity. Carbon nanotubes can create electronics with greater storage capacities, longer battery life, and increased security.

Energy, specifically clean energy, has greatly benefited from nanotechnology. Nanostructured catalysts, for example, are used to improve the efficiency of fuel cells, nanofluids are used to enhance the transfer efficiency of solar connectors, and quantum dots and carbon nanotubes are used to boost energy absorption in solar cells. Nanotechnology will undoubtedly be fundamental to helping the world switch from fossil fuels to renewable energy sources.

In addition, nanotechnology is further helping the environment in its application in improving carbon capture technology. A new carbon capture platform, for example, was developed in 2019 by MIT researchers that used carbon nanotubes in its design. Nanotechnology has yet to reach its full potential in this field, and research continues to explore how it can further improve carbon capture methods.

Nanotechnology has numerous noteworthy applications in biomedicine; however, its biggest achievements lie in the development of novel diagnostic tools, drug delivery systems, and vaccines. There are many potential uses of nanotechnology in biomedicine that are currently being explored; further research in this area has the potential to revolutionize healthcare.

Finally, nanotechnology is being leveraged in the food industry to help us tackle one of the biggest challenges to humanity: the food crisis.

As the world's population continues to swell, our already-stretched agricultural systems will need to produce significantly more food. Scientists have recognized that reducing food waste is an important tool in addressing food availability, given that a third of food is wasted. Recently, scientists have used nanoparticles to create novel coatings for fruit that extend its shelf-life. Innovations in nanotechnology such as this will be fundamental to helping us increase food security in the future.

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The Global Nanotechnology Market

Many experts believe that nanotechnology will bring about a new era of productivity and wealth, and this is reflected in the growth in public investment in technologies and research over the past two decades.

The global nanotechnology market was valued at $1.76 billion in 2020. By 2030, this is predicted to rise to around $33.63 billion, representing a compound annual growth rate of 36.4%. However, the COVID-19 pandemic and associated lockdowns limited the market's growth in 2020 and 2021.

Segments of the global nanotechnology market are also showing promising growth. The global graphene market was valued at 175.9 million in 2022 and is expected to grow at an impressive CAGR of 46.6% from 2023 to 2030. In addition, the global lipid nanoparticle market was valued at 777.4 million in 2022 and is expected to grow at a CAGR of 13.6% through 2029.

Nanotechnology research has a global footprint, with major players in the US, UK, Europe, and Asia-Pacific region. Globally, according to the US National Nanotechnology Initiative, there are around 20,000 researchers working in the field. The Asia-Pacific region is predicted to see the highest growth in the coming decade.

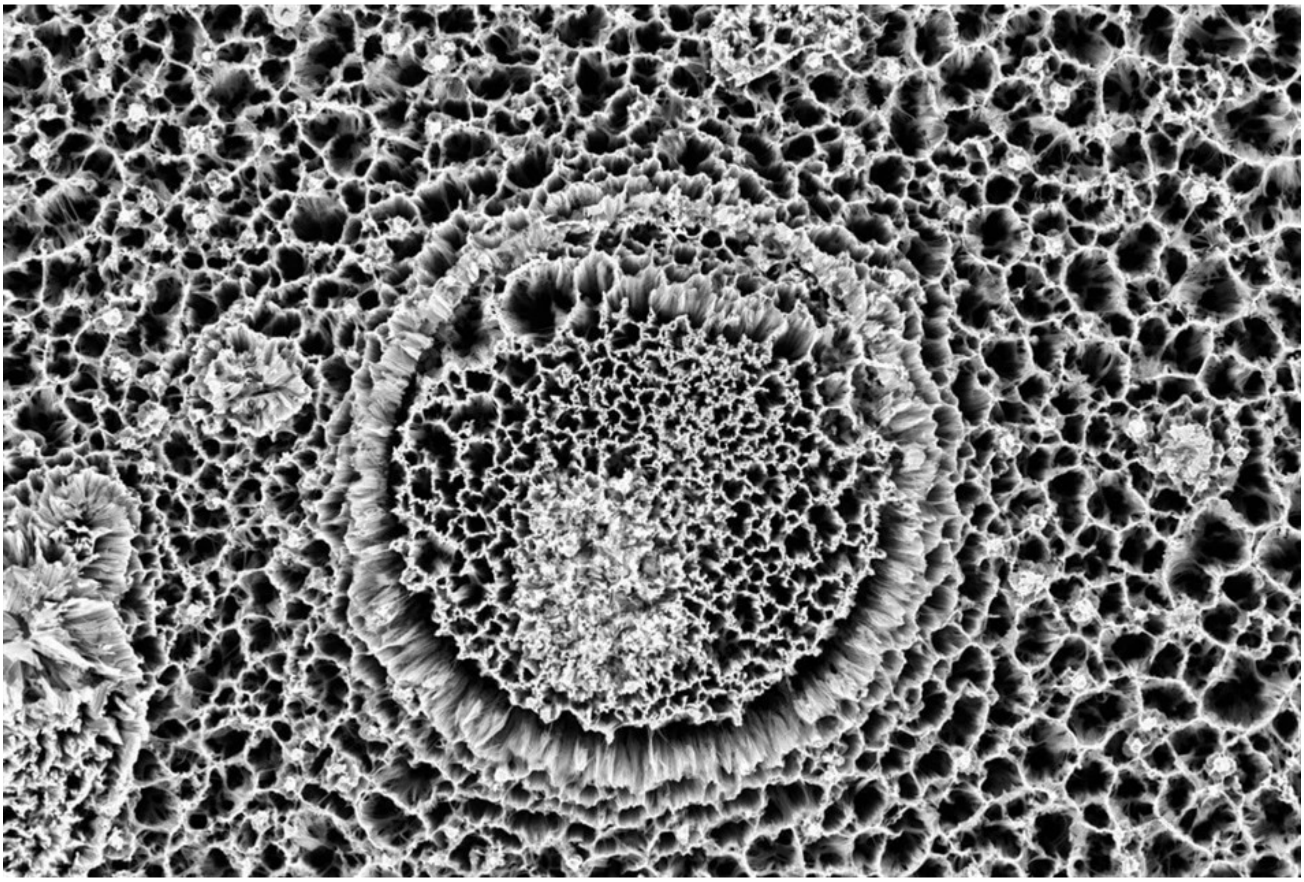
Many global organizations are now investing in emerging applications in the nanotechnology market. Nanodevices are predicted to be the most lucrative market segment over this decade, and many emerging trends are accelerating growth in the nanotech field.

While the growing adoption of nanoscale materials and devices in biomedical and engineering fields is driving significant growth in the global nanotech market, there are some key challenges that hinder the widespread commercial adoption of devices.

Major restraining factors are the high cost of technologies and their performance and reliability in extreme weather conditions. However, increased government support and funding and the emergence of innovative self-powered devices are predicted to offer lucrative opportunities for the market in the coming years.

There are several companies currently investing in nanotechnology research, including Thermo Fisher Scientific, eSpin Technologies Inc., Biosensor International, Kleindiek Nanotechnik GmbH, and Altair Nanotechnologies Inc. Several collaborations between companies and academic institutions are ongoing.

Countries such as Brazil, India, the Philippines, Chile, Mexico, and South Africa have established government-funded programs and research institutes, with many developing nations emerging as frontrunners in nanotechnology research. The nanotechnology market is one of global cooperation and endeavor.



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Types of Nanomaterials

Nanomaterials can broadly be categorized into four types: inorganic-based nanomaterials, carbon-based nanomaterials, organic-based nanomaterials, and composite-based nanomaterials.

Inorganic-based nanoparticles are generally non-toxic, hydrophobic, biocompatible and highly stable. They are often used in biomedicine applications due to these properties. Examples of inorganic-based nanoparticles include metal and metal oxide nanomaterials.

Carbon-based nanoparticles have low toxicity, are stable, and have high electrical conductivity, flexibility and optical transparency. Their properties lend them for use in sensing applications, among others. Examples of carbon-based nanoparticles include graphene, fullerene, and carbon nanotubes.

Organic nanoparticles are biocompatible, biodegradable, and non-toxic. Examples of organic nanoparticles include liposomes, layered biopolymers, dendrimers, protein aggregates, lipid bodies, and milk emulsions.

Composite-based nanoparticles have properties such as ductility, high strength, electrical conductivity, heat resistance, and increased barrier properties. They are often used in sensor technology. Composite-based nanoparticles encompass a vast range of materials that are constructed by combining various pairs of nanoparticles. Many composites use carbon nanotubes, quantum dots and graphene within the pairs of materials.

Quasi-one dimensional nanowires have been produced from materials such as carbon, silicon, germanium, and conductive metals such as copper. Polymer and carbon nanofibers have a large surface area-to-volume ration, good mechanical strength, high porosity, and functionalization flexibility compared to microfibers.

Carbon nanotubes have remarkable thermal and electrical conductivity and exceptional tensile strength. The properties of carbon nanotubes have led to interest in them in multiple fields. Quantum dots are semiconducting nanocrystals with unique properties between discrete molecules and bulk semiconductors.

Nanocomposites are manufactured from two different constituent materials (typically a polymer and an inorganic solid such as clay or oxide) with their own unique chemical or physical properties, producing a material with superior properties to its constituent materials. Some are up to 1,000 times tougher than bulk components.

Graphene is perhaps the most well-known nanomaterial. It was discovered in 2004 by Andre Geim and Konstantin Novoselov. The material has unique properties; it is strong yet flexible and lightweight with high resistance. It is also the thinnest material ever discovered and is 200 times stronger than steel.

Thanks to these advantageous properties, the material has found applications in electronics, energy storage, composites, coatings, biomedical devices, sensors, drug delivery, tissue engineering, and more. One of its most memorable applications was its use in a groundbreaking graphene-based MRI contrast agent, which allows for improved disease diagnosis.

MXenes are two-dimensional layered ceramic materials made from a bulk crystal called MAX. These materials have excellent conductivity and volumetric capacitance and are often used in energy storage, optoelectronics, and in medicine. They have great potential as antibacterial agents.

Lipid nanoparticles are simply nanoparticles made from lipids. They have made headlines recently due to their use in COVID-19 mRNA vaccines as mRNA carriers. The material has also been used successfully in small-molecule delivery in nanomedicine.

Quantum dots are nanoscale crystals with semiconducting properties that were first discovered in 1980. Their core is often made of heavy metal, such as cadmium selenide, lead selenide, or indium selenide. They can convert the spectrum of light into different colors and are used in an array of applications, including drug delivery, diagnostics, medical imaging and solar cells. Quantum dots also have the potential to support the development of the quantum computer.

Carbon nanotubes are constructed from rolled-up sheets of graphene. Their excellent electrical conductivity and mechanical strength have seen carbon nanotubes adopted by a number of industries in a range of applications, including targeted drug delivery, nerve cell regeneration, aircraft construction, energy storage, water purification, coatings, electronics and more.

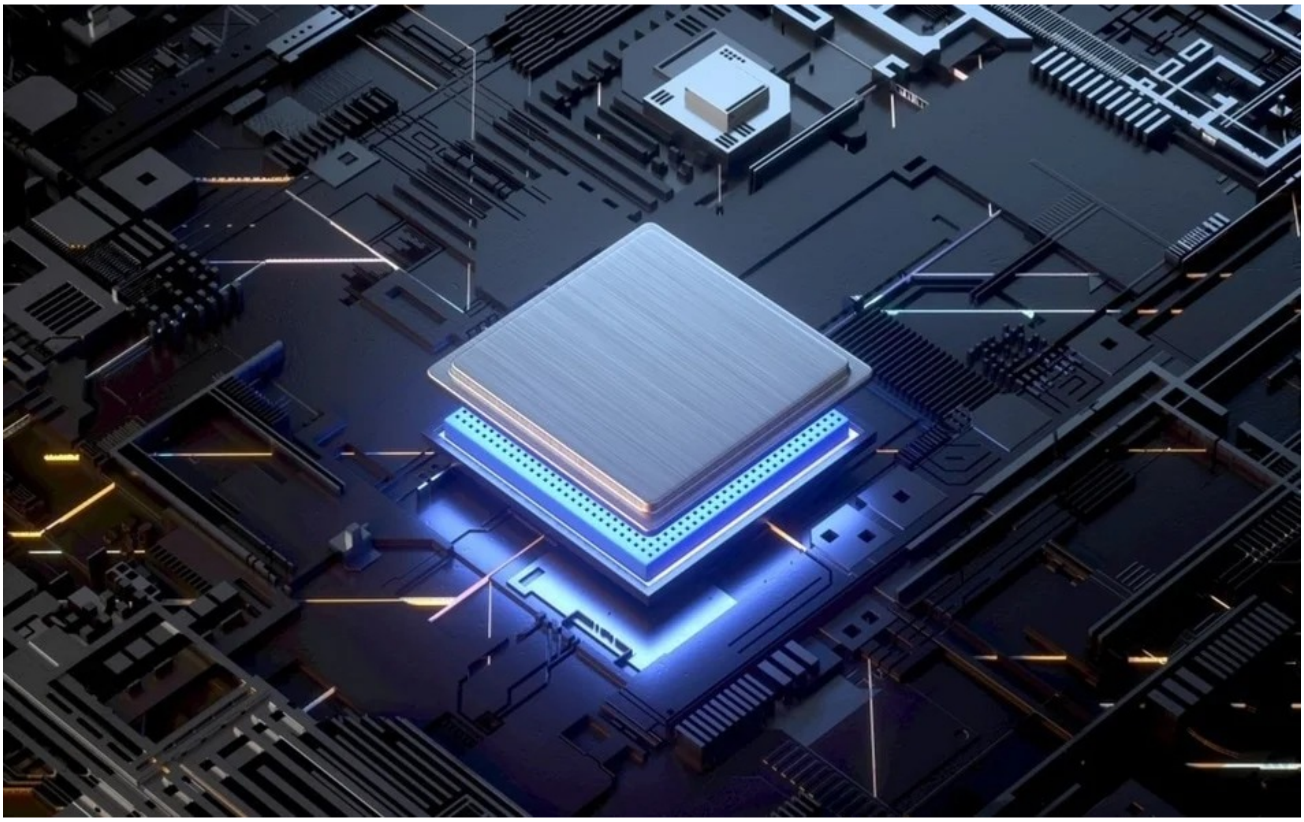
Applications of Nanotechnology

Materials and Processes

Nanotechnology can make many everyday materials stronger and provide enhanced functionality. Many commercial products containing nanomaterials are commercially available. These include:

- Durable, washable smart fabrics with embedded flexible nanosensors and electronics for use in medicine, health monitoring, kinetic energy harvesting for self-power purposes, and environmental monitoring in industries such as mining.

- Clear nanoscale films for displays, eyeglasses, and windows to improve waterproofing, enhance self-cleaning capabilities, improve electrical conductivity, and protect against UV radiation.
- Nanoscale additives for lightweight ballistic armor.
- Nanoscale materials in automotive components such as low rolling-resistance tires, thin-film smart solar panels, and battery systems.
- Nanoscale catalysts to boost chemical reactions.
- Nanomaterials in improved personal care products and household products.
- Smart packaging for the food industry with embedded nanoscale sensors to detect issues such as spoilage.



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IT and Electronics

Nanomaterials are already being used in many IT and electronics applications (listed below). There is also much work undergoing to leverage the materials' excellent electrical conductivity along with other beneficial properties to shift the electronics sector, making quantum computing and atomic electronics possible.

- Nanoscale transistors.
- Magnetic random access memory systems that utilize nanometer-scale magnetic tunnel junctions.
- Ultra-high definition displays incorporating quantum dots.

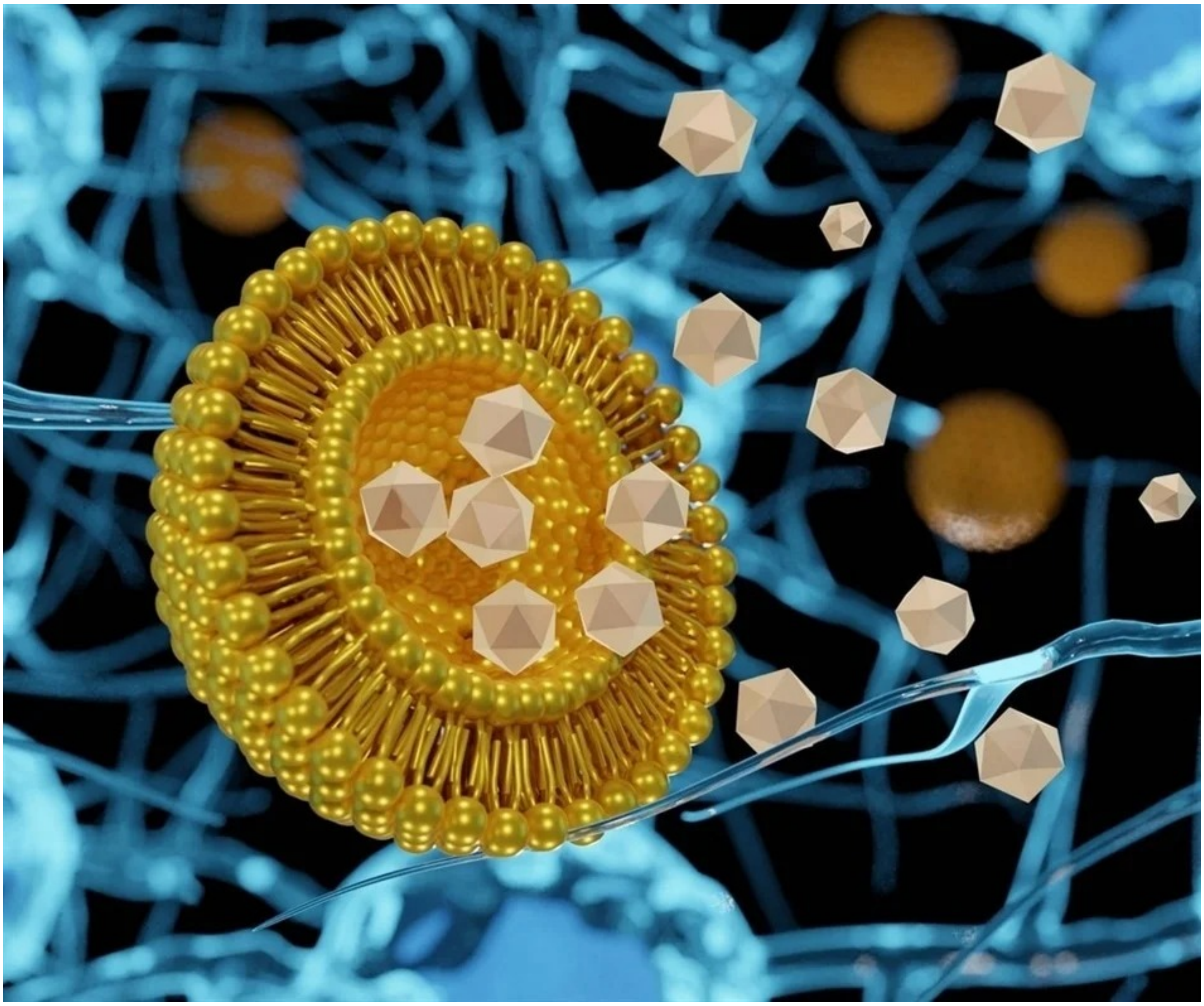
- Mechanically flexible electronics which can withstand mechanical deformation for use in wearable electronics, medical applications, IoT devices, and smartphones.
- Conductive inks for printed electronics.
- Improved flash memory chips for thumb drives and smartphones.
- Electronic paper.
- Light-emitting diodes (LEDs).
- Lasers.
- Batteries.

Biomedicine and Healthcare

Nanotechnology holds vast promise for the fields of healthcare and medicine, providing benefits such as better drug delivery, enhanced diagnostic and prevention capabilities, and novel therapies. Nanomedicine is an emerging field that takes inspiration from biological phenomena. Most notably, nanomaterials were fundamental in the development of SARS-CoV-2 (COVID-19) vaccines. Its applications include:

- Gold nanoparticle-based probes for the detection of targeted gene therapies.
- Gold nanoparticle-based treatments for cancer and other diseases.
- Improved diagnostic and imaging tools.
- Advanced solid-state nanopore materials enable low-cost, high-throughput single-molecule detection and novel gene sequencing technologies.
- Targeted drug delivery using nanocapsules for improved treatment of diseases such as cancer with minimal side effects.
- Regenerative medicine and neural and bone tissue engineering.
- Graphene nanoribbons for spinal injury treatment and regeneration.
- mRNA carriers in vaccines.
- Needle-free vaccine delivery.
- Drug carriers.

Restorative nanomaterial-based dental resins and materials that mimic human bone crystal mineral structure.



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Energy

Nanotechnology is being utilized in alternative energy production and harvesting to meet the world's clean energy demands. Many scientists are investigating the use of nanoscale materials and devices to reduce energy consumption, environmental toxicity burdens, and develop clean, affordable energy. Applications include:

- Nanoscale catalysts for improved fuel production efficiency.
- Reducing fuel consumption in power plants and vehicles by optimizing combustion efficiency and decreasing friction using nanomaterials.
- Nanotechnology-enabled gas lift valves to improve offshore oil and gas extraction.
- Carbon nanotube membranes and scrubbers for CO_2 filtering and carbon capture in power plants.
- Carbon nanotube wires to reduce transmission power loss in electric grids.
- New generations of nanomaterial-based batteries and energy storage devices.
- Carbon-nanotube epoxies create stronger, lightweight, and longer wind turbine blades.

- Thin-film photovoltaic solar panels for enhanced solar harvesting.

Environmental Remediation

Environmental remediation applications include:

- Water purification: Durable graphene-based water filtration membranes to remove environmental contaminants such as heavy metals from industrial wastewater with self-cleaning capabilities and long lives.
- Nanoparticles for cleaning industrial wastewater pollutants in groundwater.
- Thin-film nanoporous MoS_2 membranes for energy-efficient desalination.
- A potassium manganese oxide nanowire-based nanofabric "paper towel" for oil spillage clean-up applications.
- Nanotechnology-enabled sensors for environmental pollution monitoring and air quality sensing.

Transportation

Nanotechnology provides benefits to the transportation industry by producing lightweight, energy-efficient multifunctional materials for multiple components and applications in automobiles, planes, ships, space exploration, and infrastructure. These include:

- Polymer nanocomposite structural components.
- High-powered rechargeable batteries.
- Thermoelectric materials for temperature control.
- Low-cost, highly efficient nanoscale sensors and electronics.
- Nano-engineered transport infrastructure materials such as concrete, cementitious materials, steel, and polymer composites to improve resilience and longevity.
- Nanotech-enabled lightweight, high-strength materials for the aerospace industry.[7][8]

What Are the Concerns With Nanotechnology?

Some experts have urged caution in nanotechnology research over the years due to existential concerns about its progress. Eric Drexler, who coined the term "nanotechnology" in 1974, warned against the unchecked development of nanodevices and the potential threat they could cause to society.

Although Drexler's warnings have been widely discredited, many concerns remain regarding the effects of nanotechnology on human and environmental health.

Activists worry that the science and development of nanotechnology will progress faster than policymakers can devise appropriate regulatory measures. According to activists, an informed debate must take place to determine the balance between benefits and risks.

Toxicology

Research has shown that nanoparticles accumulate in the nasal cavities, lungs and brains of rats, and that carbon nanomaterials known as 'buckyballs' induce brain damage in fish.

Vyvyan Howard, a toxicologist at the University of Liverpool in the United Kingdom, has warned that the small size of nanoparticles could render them toxic and warns that full hazard assessments are needed before manufacturing is licensed.

Many parties have expressed their concern over releasing tiny nanoscale particles, which, because of their small size, are able to penetrate far into the environment.

Some experts have warned that we do not yet know how these particles will act in the environment or what chemical reactions they will trigger upon meeting other particles. However, experts concur with nanotechnology advocates who feel the field may offer 'cleaner' technologies, and, ultimately, a cleaner environment.

The primary concern is that there is a lack of research into nanotechnology's potential threats to human health, society, and the environment.

Long-Term Safety of Nanomaterials

Similar to the concerns raised over the toxicity of nanomaterials are the concerns regarding their long-term safety. Given the growing body of research suggesting that, due to their small size, nanomaterials may have a toxic effect on humans and the environment, it is sensible to consider how exposure to this potential toxicity may accumulate over time.

Some research has suggested that nanoparticles do have the power to accumulate in the body over time, particularly those that do not degrade rapidly. Some research has indicated that, in particular, these nanoparticles can accumulate in the liver and spleen. Studies have also linked nanoparticle exposure to chronic inflammation and it is even theorized that the materials may drive the spread of cancer. More research is needed to gain a deeper understanding of how nanomaterials impact the body in the long-term.

Commercialization

While nanotechnology has caused waves in many industries, having been developed for several groundbreaking applications, nanotechnology still faces some barriers before it can reach its full potential. One concern relates to its scaling up for mass manufacture. This requires a sizable investment that many industries are not prepared to make. It also requires a drastic amount of ups killing, which, again, comes at a cost.

There is also a noticeable difference between manufacturing nanomaterials in the lab to manufacturing them on an industrial scale. It requires careful planning and the adjustment of complex methodologies that require expert guidance.

Availability of Resources/Materials

While there is some concern over the availability of resources required to produce nanomaterials, particularly if their production is scaled up, many of the required materials are easily accessible. Although many of the metals used in nanomaterials are mined, some of the most common, e.g. silicon, titanium, iron, are abundant on the Earth.

Regulation

Given the relative newness of the sector, regulations surrounding nanotechnology are still in development. The FDA has stated that it will regulate nanotechnology under existing statutory authorities. It intends to ensure predictable and transparent pathways regarding their regulation. It should be considered, however, that it is an evolving industry, which will likely correspond to evolving regulations, which manufacturers must keep up to date with.

The ISO has around 100 standards regarding nanotechnologies. These may be difficult to navigate while the industry is new and companies enter the space for the first time. Over the years, this will be less of a problem as employees develop expertise in this field.

Where is Nanotechnology Going?

Although there has been significant growth in technological capability and knowledge over the past few decades, there are still some unanswered questions about nanotechnology's future. Ethical concerns are largely unresolved and still up for debate. However, it is undeniable that nanotechnology is here to stay.

Assessing the role of nanotechnology and guiding its progression will require cross-sectoral involvement of scientists, governments, civil society organizations and the general public.

In the next three years, we can expect continued development from nanotechnology, and along with it, further scientific breakthroughs. Given the focus on and heavy amount of research in the field, it is likely that nanotechnology will achieve significant advances in nanomedicine for diagnostics, targeted therapy, and imaging.

We will also likely see developments in smart devices thanks to nanotechnology, such as improvements to hygiene and cleanliness of devices, the development of novel surfaces and nanocoatings, increased performance and battery life, and miniaturization. It is also likely that advanced 2D nanomaterials like graphene and MXenes will see further commercialization.

Pinpoint the top 5/6 applications that nanotechnology is relevant to and expand on these applications. Mention why nanotechnology is a 'game-changer' for these applications.

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Multiple Techniques In One Powerful Instrument

2030PV PRO™ Microspectrophotometer

The **2030PV PRO™** microspectrophotometer is a bespoke instrument built to meet your exacting needs. A powerful, modular system that combines multiple spectral techniques, the 2030 PV PRO™ represents the cutting-edge standard for microspectrometers. The 2030 PV PRO™ is a turnkey system configured and built to your requirements. Featuring a spectral range from the deep ultraviolet to the near-infrared, this microspectrophotometer is capable of measuring the spectra of even sub-micron samples by absorbance, reflectance, kinetics, polarization, fluorescence, and photoluminescence. The 2030 PV PRO™ is also offered with Raman, thin film thickness measurements, and 5D mapping. Incredibly, the system is also capable of high-resolution UV-visible-NIR imaging.

Incorporating the latest engineering advances, the 2030 PV PRO™ features the latest in Lightblades™ spectrometers, a technology designed specifically for high-performance Microspectroscopy. 2030 PV PRO™integrates advanced optics, software, hardware, and Lightblades™ in a powerful yet flexible instrument. CRAIC's **APOLLO M™ Confocal Raman Microspectrometer** can be added to the 2030PV PRO to measure Raman in addition to UV-Vis-NIR and fluorescence microspectra.

Contact CRAIC Today!

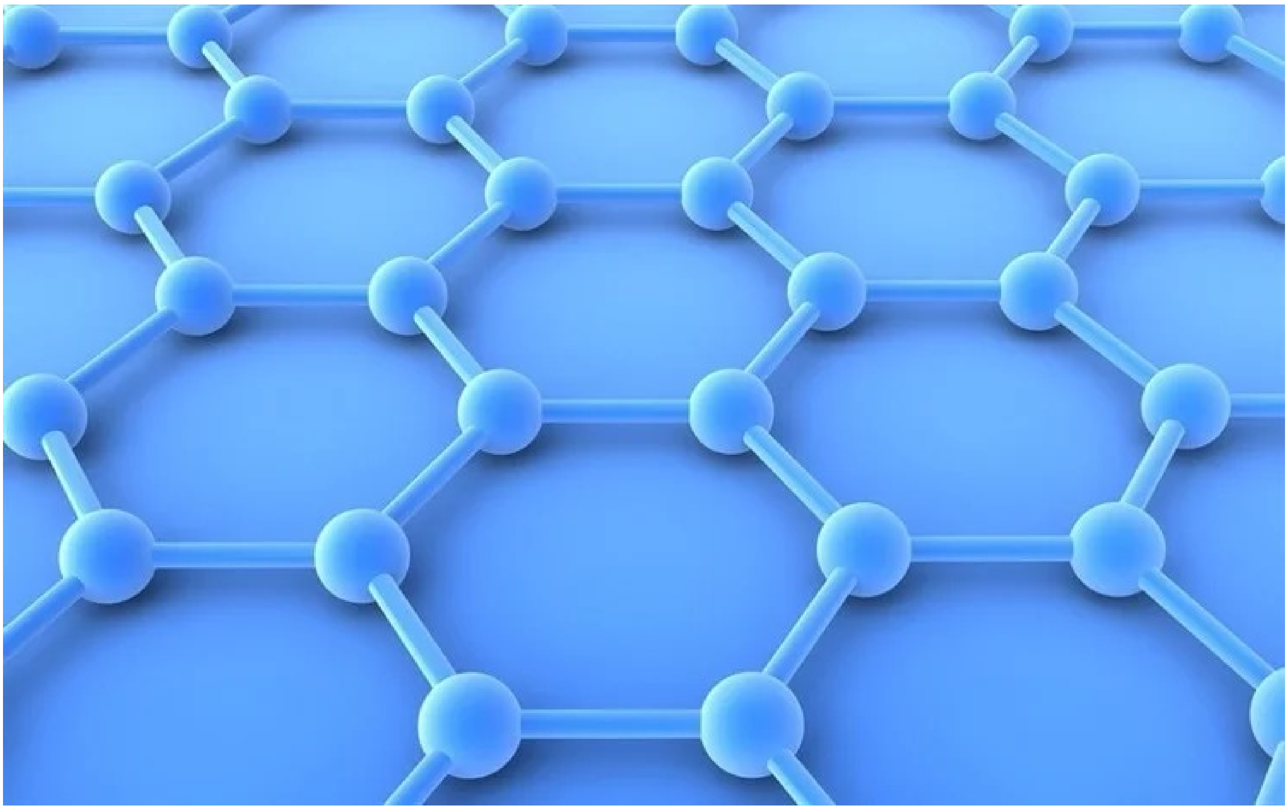
2030PV PRO™ Key Features

- Confocal spectroscopy of even sub-micron samples.
- Multiple spectroscopy techniques combined in one instrument.
- Multiple imaging techniques all in a single UV-vis-NIR microscope.
- Permanently calibrated, absolutely reproducible measurement areas.

CRAIC TECHNOLOGIES

Determine Thickness and Identify Defects in Graphene with Microspectroscopy

Graphene is a 2D form of carbon arranged in one-atom thick layers. Carbon atoms in graphene are tightly packed in a regular hexagonal pattern. Mathematically, it can be treated as an substantially large aromatic molecule and thus can produce some novel electronic effects due to this electronic and unique physical structure.



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Its novel physical characteristics provide graphene with the potential to form the basis for a number of new applications and devices.

Optical spectroscopy is a robust tool for the non-destructive analysis of devices and their elementary properties. Microspectroscopy is particularly useful in that these instruments are used to examine microscopic sample areas and understand their optical properties. CRAIC Technologies has formulated many different techniques that can be integrated on a single microspectrometer and used in the research of graphene and other carbon-based structures.

Transmission microspectroscopy in the UV-VIS-NIR region is a method that has been established to be very useful for the identification and characterization of graphene and graphene-based molecules. One reason for this is that graphene oxides display an absorption peak at 230 nm related to the p-p* transition of the aromatic C-C bond and a shoulder at 300 nm that is caused by n-p* transitions of the C=O bond, making the deep UV spectra highly vital for identifying oxidation.

Figure 1. *The 2030PV PRO™ UV-VIS-NIR microspectrophotometer from CRAIC Technologies. This instrument can be configured for transmission, reflectance, photoluminescence, and Raman spectroscopy and imaging.*

Another reason is for the capability to easily and non-destructively measure the number of layers in the sample. In the VIS-NIR regions, pristine graphene absorbs ~2.29% per layer of graphene[3]. As illustrated in Figure 2, the transmission spectra obtained from graphene samples with increasing layers demonstrates this property. From these spectra, the thicknesses of the samples match 1, 2, 4, and 6 layers of graphene at the sampled locations.

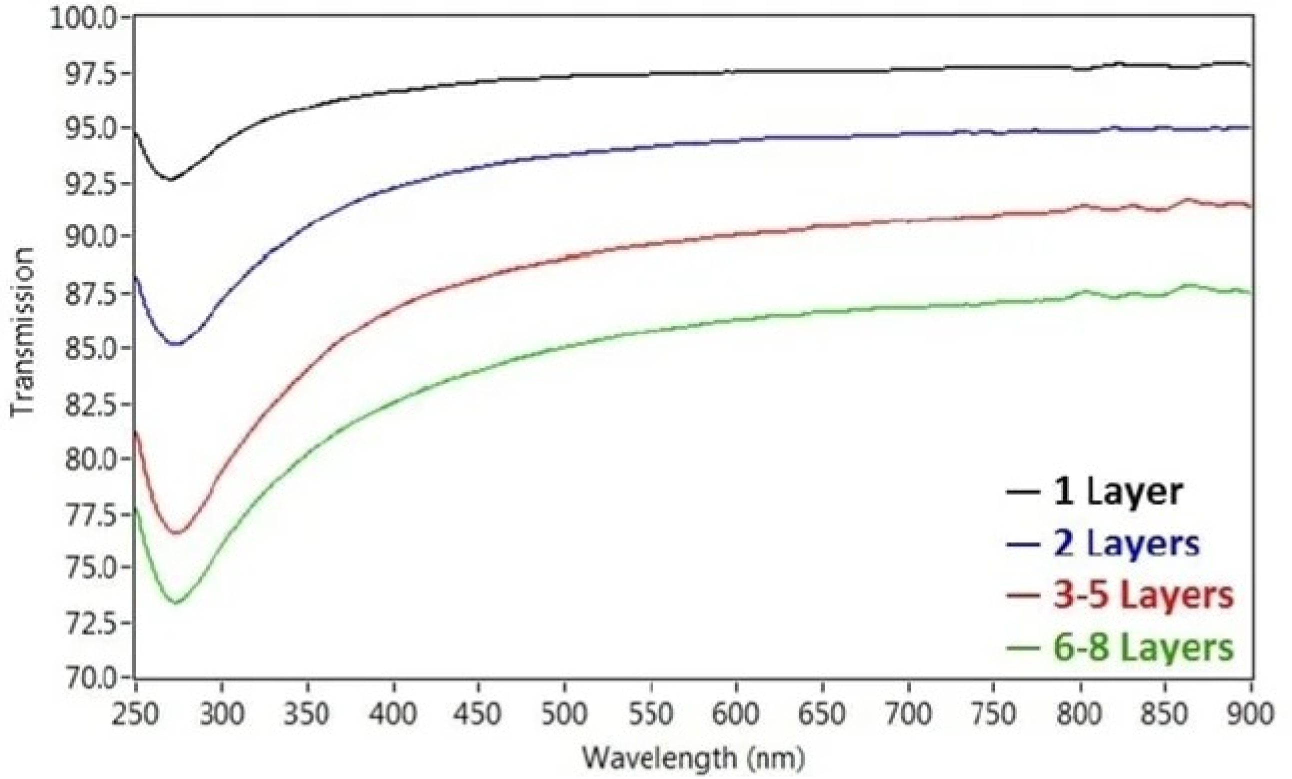

Figure 2. *Transmission microspectra™ of single, dual, and multi-layered graphene samples acquired with the 2030PV PRO™ microspectrophotometer, illustrating the change in transmission spectra in the deep UV region corresponding with an increase in graphene layers.*

As the number of layers increases, interference patterns become obvious and standard film thickness measurement procedures may be used.

Such interference spectra are revealed in Figure 3. By joining the optical constants of graphene with the Fresnel equations, the algorithms in CRAIC FilmPro™ software can be used in order to compute the thickness of these graphene films as well.

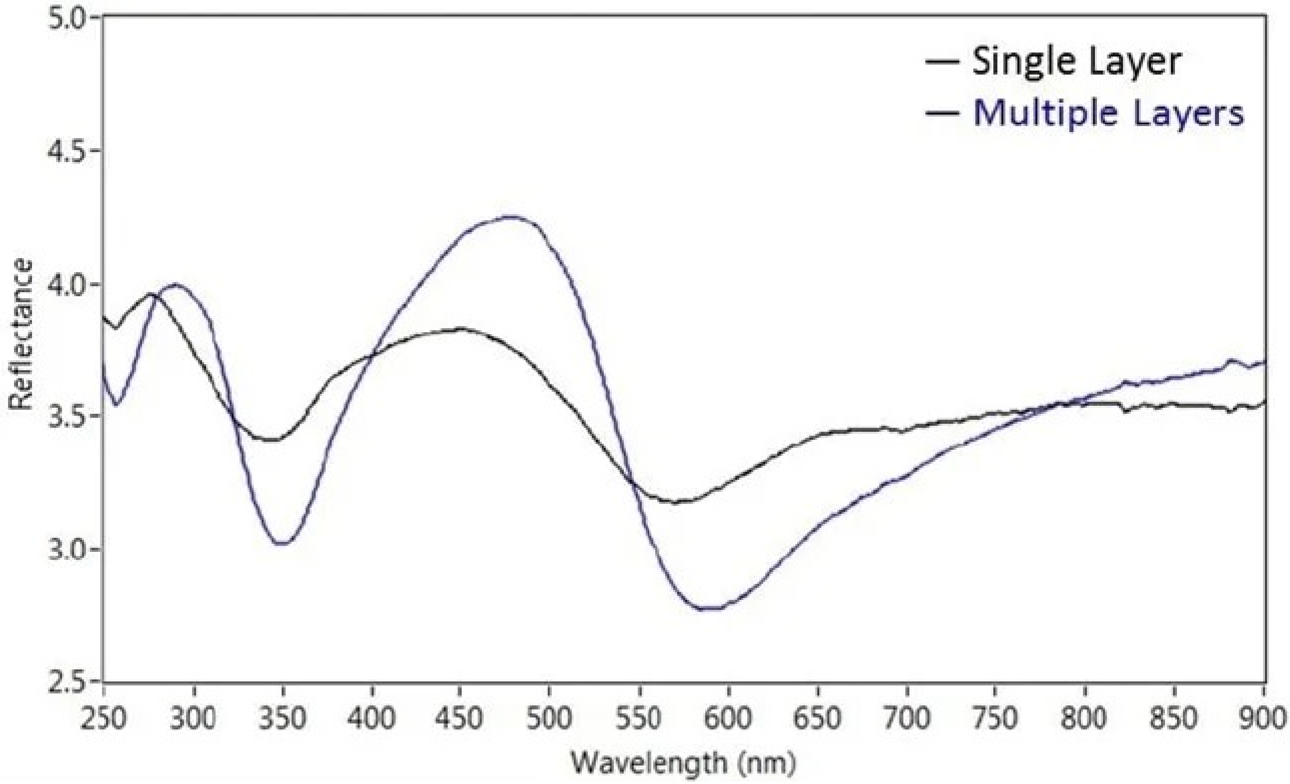

Figure 3. *Absolute reflectance microspectra of single and multiple layer graphene acquired with the 2030PV PRO™ microspectrophotometer illustrating the change in interference peaks due to sample thickness.*

Raman Microspectroscopy

Raman microspectroscopy is another very useful spectroscopic instrument, because the vibrational spectra attained can be used to identify molecular bonds and spot differences in local environments. This is because the bonds created between atoms have specific vibrational frequencies that match each atom's mass and the strength of the bond between the atoms.

Complex molecules thus display many peaks and can be readily identified by the pattern or "fingerprint" formed by those peaks. This is particularly useful for 1 and 2D materials because the sampling area is restricted by the size of the laser spot, and it can detect differences in local environments.

In graphene based materials, there are three typical peaks that are characteristically observed in the Raman spectra, as presented in Figure 4. Specifically, these are known as the D-peak at 1360 cm^{-1}, G-peak at 1600 cm^{-1} and 2D peak at 2700 cm^{-1}. The G-peak is because of the carbon-carbon bond stretching, while the D-peak indicates disorder or impurities in the Graphene sample.

The 2D peak is common to all graphite samples, and the width, intensity and location of this peak can be used so as to define the number of layers of the sample. The existence of the D peak in this spectrum represents disorder in the sample and the intensity of this peak can be used to measure the disorder in the sample. The exact frequency of these vibrations will be impacted by the local environment, such as solvents, substrate and localized defects.

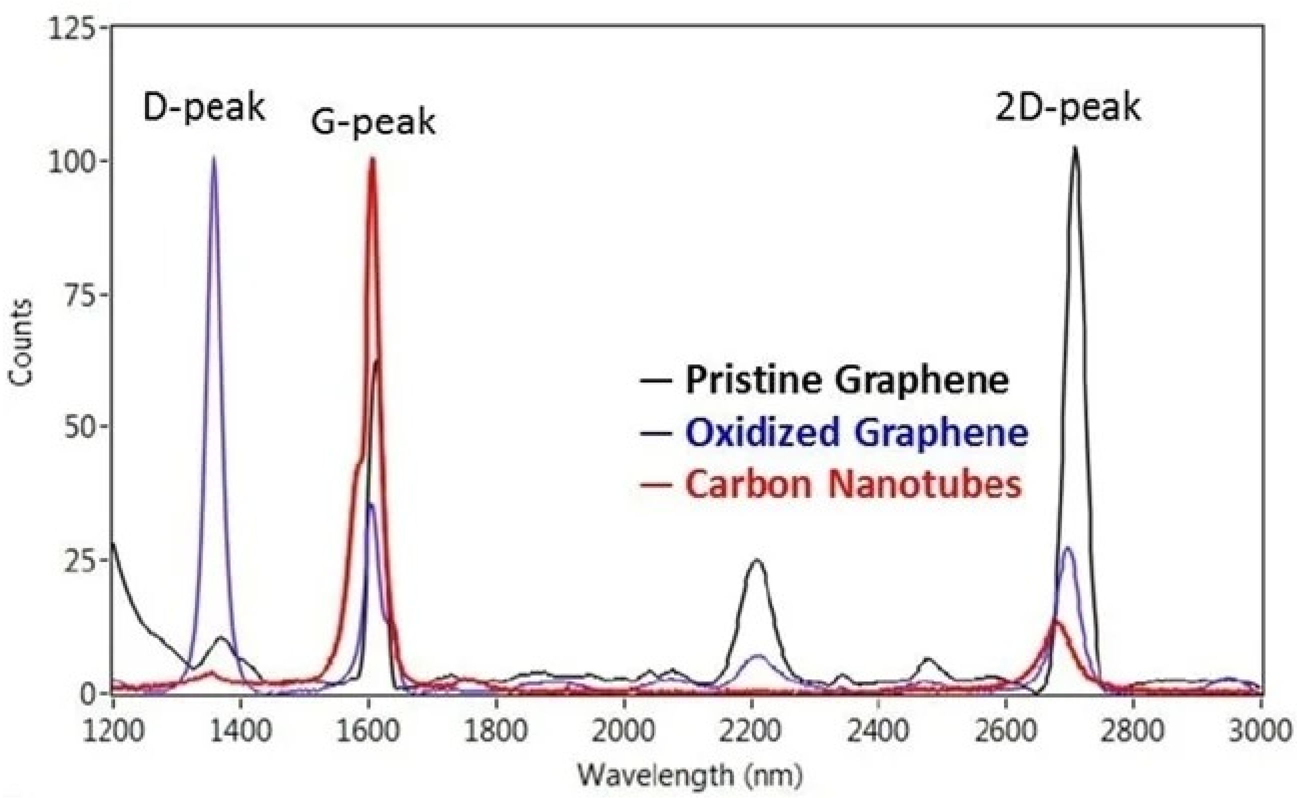

Figure 4. *Raman spectra of graphene and carbon nanotube samples. The D, G, and 2D peaks are clearly visible in all three samples. The additional band observed at ~2205 cm^{-1} is due to the substrate that the graphene samples were mounted on.*

Microspectroscopy

CRAIC designs and builds UV-visible-NIR range microspectrometers for a number of different applications. They integrate many different spectroscopic methods into one instrument that is capable of measuring the spectra of micron-scale sample areas.

A microspectrophotometer is configured for transmission microspectroscopy and shown as an optical diagram in Figure 5. The light is focused onto a sample, in this case the graphene and the transmitted light is gathered and imaged onto the entrance aperture of the spectrophotometer. Since the entrance aperture is mirrored, an image is also the entrance aperture superimposed over the sample measurement area. This makes for quick and simple alignment.

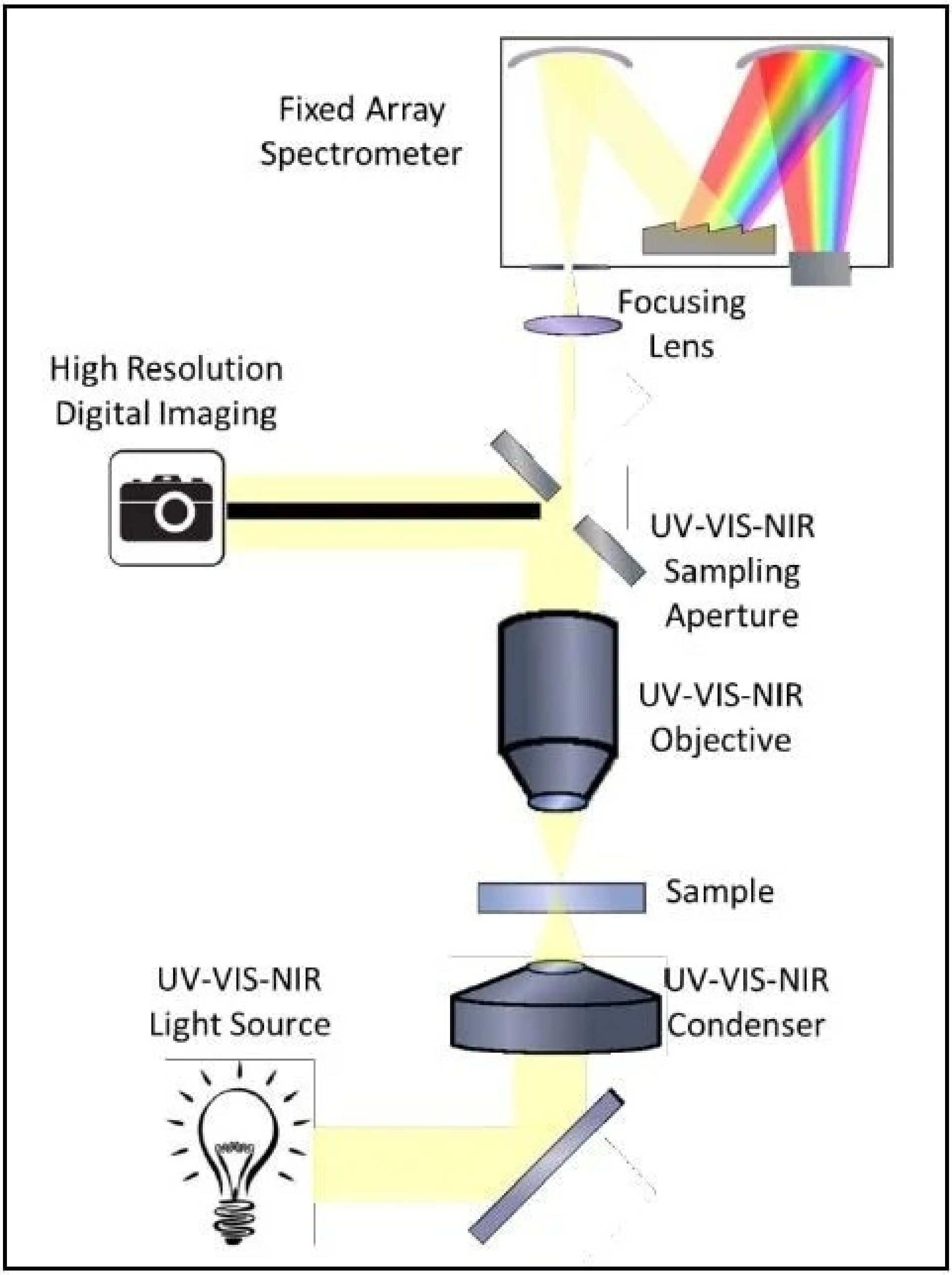

Figure 5. *Optical diagram of a microspectrophotometer configured for UV-VIS-NIR transmission microspectra™.*

With Raman microspectroscopy, the optical diagram is marginally different because of the nature of these types of experiments. Figure 6 is an optical diagram of a microspectrometer configured for Raman microspectroscopy.

The laser is aimed at a sample, in this case the graphene, by incident illumination. The Raman scattered light is gathered and imaged onto the entrance aperture of the spectrophotometer. A Raman microspectra™ is then gathered.

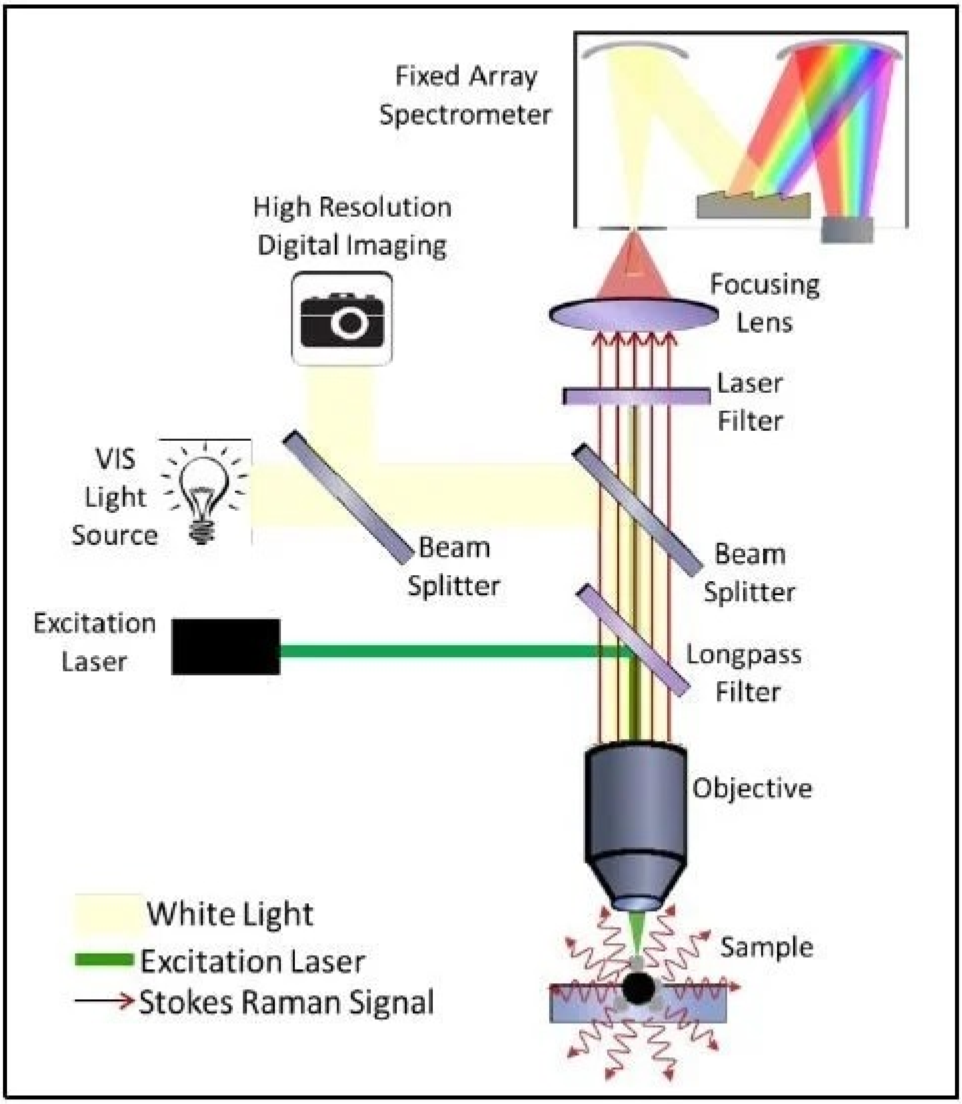

Figure 6. *Optical diagram of a microspectrometer configured for Raman microspectra™.*

The microspectrometer also has capabilities for NIR and UV imaging, besides the standard color imaging, and it can be configured for photoluminescence, reflectance, polarization microspectroscopy, kinetic spectroscopy, small spot thin film thickness measurements and 5D spectral surface mapping.

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Unlocking a Sustainable Future With Green Chemistry: A Conversation With Wanhua Chemical

In this interview, AZoM speaks with Dr. Weiqi Hua, the Executive Vice President of Wanhua Chemical and Director of the Wanhua Chemical Research Institute, about his pivotal role in spearheading innovation and sustainability initiatives within the company, and his vision for the future of the chemical industry.

Dr. Weiqi Hua, could you please introduce yourself and describe the professional journey that led you to your current role as CEO of Wanhua Chemical?

Thanks for having me. I am currently serving as the Executive Vice President of Wanhua Chemical and the Director of the Wanhua Chemical Research Institute. My background in chemical engineering, bolstered by a Ph.D. and an MBA, as well as my inclusion in national talent programs, has prepared me for my current responsibilities.

With a focus on engineering technology applications, I have dedicated my career to advancing technological innovations in high-end chemicals and new materials. Since joining Wanhua Chemical in 2001, I have spearheaded numerous national technological research projects, which have propelled advancements in MDI technology and achieved significant milestones like the development of ADI and MDI waste brine recycling.

For those unfamiliar, could you provide an overview of Wanhua Chemical Group and its core business areas?

Wanhua Chemical Group Co., Ltd. is among the leading global suppliers of innovative chemical products. Relying on continuous innovation, commercialized facilities, and efficient operation, we provide customers with more competitive products and solutions.

Wanhua Chemical has always adhered to innovation and the optimization of industrial structures. Our business covers polyurethanes, petrochemicals, performance chemicals, and emerging materials.

From China to the far side of the globe, we have 10 production bases, 18 overseas subsidiaries and offices, and a worldwide logistics network. With over 29,000 employees, we are committed to leveraging collaborations with leading global research institutions and universities to enhance our technological capabilities and sustain our leadership in the chemical industry.

Wanhua Chemical has always adhered to the mission of "Advancing Chemistry, Transforming Lives". We are committed to providing customers with stable, high-quality, competitive products and efficient services, as well as being a responsible supplier and industry leader.

Our products are designed to meet the needs of a wide range of industries, including homeware and furniture, sports and leisure, automobiles and transportation, building and construction, electronics and electrical appliances, personal care, and green energy.

We will continue to innovate in the field of chemical new materials, lead the development of the industry, and create a better life for mankind!

Wanhua operates globally and has numerous facilities and offices. Could you discuss the strategies used to manage and integrate these global operations?

Wanhua Chemical operates numerous facilities and offices worldwide. We effectively manage and coordinate our global operations, ensuring high efficiency, innovation, and customer satisfaction across diverse markets.

1) Innovative Products

Wanhua Chemical has been an innovator and pioneer in the development and application of high-performance materials that meet the evolving demands of various industries. Innovation is at the core of Wanhua Chemical's strategy. We provide more competitive products and solutions to global customers with "good products, good service, good brand". We continuously invest in research and development to create cutting-edge solutions that address the evolving needs of our customers. In the future, we will make use of AI to accelerate the exploration of cutting-edge technologies and become a leader in synthetic biology, electrochemistry, CO_2 comprehensive utilization, and other technologies.

2) Global Services

We manage our global operations through a robust network of production facilities and offices strategically located in key markets worldwide. Wanhua Chemical has built up 10 key production complexes in Yantai, Penglai, Ningbo, Sichuan, Fujian, Zhuhai and Ningxia in China, and Hungary, Czech Republic, which are integrated with complete supporting facilities. To provide our customers worldwide with competitive products and comprehensive solutions, Wanhua has established 6 R&D centers in Yantai, Ningbo, Shanghai, and Beijing in China, as well as in Spain and Hungary, set up 18 subsidiaries and offices in more than ten countries and regions across Asia, Europe, the United States, etc. Wanhua Chemical effectively manages and coordinates its global operations, ensuring high efficiency, innovation, and customer satisfaction across its diverse markets.

3) Global Supply-chain Network

Wanhua Chemical has developed an extensive global supply network to ensure efficient logistics, warehousing, and supply chain management. We establish warehouses in strategic locations around the world to facilitate quick distribution and minimize delivery times. Implementing advanced logistics solutions to streamline the transportation of raw materials and finished products. This includes strategic partnerships with leading logistics providers to enhance delivery speed and reliability. Utilizing state-of-the-art technology to integrate the supply chain, enabling real-time tracking and management of inventory, orders, and shipments. This ensures a seamless flow of materials and products, reducing lead times and costs.

We leverage local expertise while maintaining global quality standards, ensuring responsive supply chain management. Our strategy includes forming strong local partnerships, understanding regional market dynamics, and adhering to local regulations while maintaining global standards. We foster innovation through regional R&D hubs that cater to local customer needs while being part of a globally integrated R&D strategy.

Image Credit: NicoElNino/Shutterstock.com

Innovation is a key pillar at Wanhua. Could you elaborate on how this focus has driven the company's success in the chemical industry?

Innovation is a central pillar for Wanhua Chemical and has been instrumental in driving our success in the chemical industry. In 2023 alone, our investment in R&D was substantial, amounting to 4.08 billion yuan. From 2018 to 2023, we invested a total of 16.02 billion yuan in R&D-related expenditures, including salaries for our researchers and various technological studies. Our approach to innovation encompasses several key areas:

1) **Integrated R&D Innovation System**

We have established a multi-faceted innovation system that includes fundamental research, process development, scaling, industrialization, and product application R&D. This system is supported by our global R&D center, regional technical service centers focused on application innovation, technical centers at major production bases for process optimization, and collaborative labs with universities and research institutes. This comprehensive framework ensures that our innovation efforts are well-coordinated and targeted towards both core and emerging technologies.

2) Culture of Innovation and Equity

We emphasize a culture where innovation is supported and rewarded. We have abandoned the notion of relying on imported technology, focusing instead on indigenous innovation. This shift is underscored by our historical attempts to negotiate technology transfers with foreign companies, which underscored the importance of self-reliance. Our high-quality growth is a direct result of prioritizing technological innovation, which is centrally managed and generously funded. We offer significant incentives for the development of new products and technologies, including profit-based bonuses and substantial rewards for successful long-term strategic research projects.

3) Reform and Efficient Management for Innovation

After our company's overall listing in 2019, we streamlined our management structure to enhance efficiency and de-bureaucratize research activities. This reorganization has not only increased our operational efficiency but has also elevated the status of scientists and senior researchers, aligning their compensation with senior executives to reflect their contribution and value.

> “*We also foster a tolerant attitude towards failure, recognizing that innovation is challenging and often accompanied by setbacks. For instance, our development of ADI and other core technologies like PC and Nylon 12 took over a decade each, marked by both progress and delays. However, we maintain a culture that encourages persistence and resilience, inspiring our teams to overcome obstacles and achieve technological breakthroughs.*
>
> *Wanhua Chemical has developed proprietary technologies in core materials, leading to more efficient, sustainable chemical processes and products. This innovation-driven approach has not only strengthened our competitive edge but also positioned us as industry leaders in environmental stewardship and high-performance materials, which are crucial for maintaining our lead in the chemical sector globally.*

With a strong emphasis on high-tech and high-value-added chemical new materials, could you discuss how Wanhua's technological innovations are shaping the industries you serve?

Wanhua Chemical's technological innovation in high-tech and high-value-added new materials promotes the development of the industry in which it operates and meets the growing social demand for high-end materials.

1) Societal Demand for High-End Materials

POE (Polyolefin Elastomer)

Wanhua Chemical's WANSUPER® POE product represents a significant breakthrough after years of technological development. As a high-end polyolefin material, POE has high technical barriers and unique performance advantages, making it widely applicable in photovoltaics, modifications, medical fields, and packaging.

In the photovoltaic sector, WANSUPER® POE films exhibit high moisture barrier properties, excellent weather resistance, outstanding transparency, and strong anti-PID performance. These features significantly enhance the efficiency of photovoltaic modules and extend their lifespan. This innovation aligns with the rapid rise of N-type cells, which require higher performance from encapsulation films. Additionally, Wanhua has established a joint venture with Foster and Trina Solar to develop a new POE film ecosystem, enhancing the competitiveness of photovoltaic power generation in the global energy transition.

In the automotive industry, the trend towards lightweight vehicles drives the demand for advanced composite materials. WANSUPER® POE's low density and excellent weather resistance make it ideal for blending with PP for use in automotive parts such as bumpers, airbag covers, and sound insulation pads. As the penetration of new energy vehicles increases, the demand for POE is expected to grow rapidly.

Nylon 12

In response to the booming new energy sector, Wanhua Chemical has developed Wanamid® Nylon 12, which is crucial for enhancing the safety and durability of lithium-ion battery packs. Nylon 12 boasts low water absorption, ultra-low density, and exceptional dimensional stability. It performs well in harsh environments, with excellent low-temperature impact resistance, high-temperature endurance, and corrosion resistance. These properties make it indispensable in the new energy industry, particularly for battery packs in electric vehicles, which require materials that support lightweight and efficiency.

Busbars, crucial for current collection and distribution in battery systems, benefit from Nylon 12's superior solvent resistance, explosion resistance, and insulation properties. Compared to traditional processes like plastic dipping and injection molding, extruded Nylon 12 busbars offer higher production efficiency, lower overall costs, and greater design flexibility.

2) Continuous technological upgrading

To meet the growing demand for faster and more efficient refrigerator production, Wanhua Chemical's researchers have spent decades developing a revolutionary demolding solution. By innovating in the molecular structures of raw materials, developing composite catalysts, and refining system formulations, Wanhua has introduced a world-leading ultra-fast demolding solution for home appliances. This breakthrough achieves a 60-second demolding time, significantly enhancing production efficiency—leading the industry by reducing the demolding time by 30 seconds—and also reducing energy consumption. This technological advancement is driving transformation and upgrading within the home appliance industry.

> “ *Wanhua's technological innovations are not merely about developing new materials but are also about redefining how these materials can contribute to global sustainability goals. By continuing to focus on high-tech and high-value-added solutions, we ensure that the industries we serve are equipped with materials that are efficient, effective, and environmentally responsible, leading to a more sustainable future.*

Wanhua is committed to green and intelligent development. Can you provide examples of how this commitment is reflected in your operational practices or product development?

Wanhua is dedicated to sustainable development, as evident in our strategies to reduce carbon emissions and our investments in green technologies.

1) Development of Biodegradable Materials

Wanhua Chemical has introduced the Waneco® series, which includes PBAT, PLA, and PBS resin and modified material solutions. These biodegradable materials are designed for various applications such as food utensils, daily packaging, express packaging, agricultural mulch films, medical use, and 3D printing. By promoting the use of biodegradable materials, Wanhua is actively working to reduce plastic pollution and lower the carbon footprint, ensuring a more sustainable coexistence with nature.

2) Physical/Chemical Recycling

Wanhua Chemical emphasizes the importance of advanced recycling methods. Through continuous research and development, we aim to enhance the efficiency and effectiveness of physical and chemical recycling processes. As a successful business model, Waneco® rPC is made from recycled polycarbonate automotive lamps and water buckets, with a carbon emissions reduction of up to 50 % compared to the virgin material. Another example is our Wanthane® G7530, which contains 30 % recycled TPU; it is traceable digitally throughout the value chain and reduces carbon emissions by 20 %. Wanhua Chemical has proposed a full life cycle solution for polyurethane rigid foam with an innovative chemical recycling process. The foam made from re-generated polyol recovered from waste foam shows comparable performance and cost to virgin ones.

3) CCUS Technology

Wanhua has established a Carbon Capture, Utilization, and Storage (CCUS) platform. This platform leverages advanced catalyst development and production integration to facilitate the recycling of CO_2. The captured carbon is repurposed for sustainable production across various industries, significantly reducing greenhouse gas emissions and contributing to global climate change mitigation efforts.

These examples illustrate Wanhua Chemical's active role in pursuing green and intelligent development through innovative materials and technologies that address critical environmental issues.

How does Wanhua Chemical integrate Corporate Social Responsibility (CSR) into its daily operations and long-term strategy? Could you provide examples of impactful CSR initiatives?

Wanhua Chemical integrates Corporate Social Responsibility (CSR) into its daily operations and long-term strategy through various impactful initiatives, focusing on safety, sustainability, and community engagement.

1) Safety in Parks and for Employees

Wanhua Chemical places a strong emphasis on the safety of its industrial parks and employees. We believe all incidents can be avoided. Our overarching goal is to achieve "zero harm, zero accidents, zero emissions" while building a sustainable, ecologically conscious, and modern chemical enterprise. To realize this vision, we have devised a long-term safety management strategy and invested in advanced safety systems and protocols to ensure a safe working environment. This commitment to safety is also reflected in the rigorous safety training programs for employees and regular safety audits of our facilities.

2) Building a Sustainable Ecosystem

Wanhua Chemical collaborates with both upstream and downstream partners to create a sustainable ecosystem. The company is a member of the Together for Sustainability (TfS) initiative, which aims to enhance sustainability practices across the chemical industry supply chain. Additionally, Wanhua Chemical has implemented significant improvements and upgrades in packaging practices, introducing a green packaging model featuring shared turnover boxes to replace conventional steel drums. Throughout the lifecycle of a turnover box with a volume of one cubic meter, it undergoes approximately 70 cycles. As a result, the cumulative number of traditional disposable steel drums that can be substituted is approximately 349.67 (each drum having a specification of 208 liters). This substitution significantly diminishes the cost associated with solid waste treatment. Compared to iron drum transportation, the adoption of turnover boxes substantially reduces carbon emissions throughout their entire lifecycle. Specifically, each turnover box results in a reduction of approximately 11.84 metric tons of CO_2equivalent emissions.

3) Social Responsibility Activities

Wanhua Chemical actively engages in various social responsibility activities. We donate to charitable causes and participate in educational activities such as the "Wonder Lab," which aims to stimulate and educate young students' interest in chemistry so that more people can understand that chemistry is all around and makes life better! These initiatives reflect our commitment to giving back to the community and supporting educational development.

These initiatives contribute to societal and environmental betterment and enhance our corporate reputation and stakeholder trust, which are integral to our sustainable business model.

You have set ambitious carbon reduction goals in green chemistry. What specific strategies are you employing to ensure these targets are met, particularly the goal of achieving net zero emissions by 2048?

Wanhua Chemical announced the company's carbon reduction goals in 2023, promising to achieve a carbon peak by no later than 2030 and strive to achieve carbon neutrality by 2048, and continuously promoting the low-carbon development of the whole industrial chain with technological innovation, energy transformation, and cooperation along the value chain.

Guided by this goal, we are transforming our energy structure to clean electricity and other low-carbon energy sources and taking measures to decarbonize our production and operations progressively.

Image Credit: Phalexaviles/Shutterstock.com

1) Clean Energy

Wanhua Chemical's goal for achieving zero-carbon electricity is to ensure that by 2030, over 50% of the electricity used at all its production bases in China comes from clean sources, with the aim of reaching 100% by 2035.

In 2023, we deliberately raised our clean electricity share through cooperative purchasing. The introduction of renewable energy sources and nuclear power will significantly increase the share of low-carbon electricity, facilitating the transformation of clean energy. Wanhua Chemical is also increasing our clean energy share, including wind power, solar PV, and nuclear through direct equity investment:

Zhaoyuan Agricultural-Photovoltaic Complementary Project

Wanhua Chemical's 120 MW agricultural-photovoltaic complementary solar power generation project, invested in and constructed in Zhaoyuan, Yantai City, Shandong Province, was officially connected to the grid and put into operation in 2023. The project will generate 170 million kilowatt-hours of electricity annually, equivalent to reducing 170,000 tons of carbon emissions.

Longkou Offshore Wind Power Project

The offshore wind project Wanhua invested in Huaneng's BW site in the north of the Shandong Peninsula was partially connected to the grid in 2023. The project has a planned installed capacity of 510 MW. It is planned to install 60 offshore wind turbines with a single capacity of 8.5 MW, with an annual on-grid capacity of 1.6 billion kWh and an annual CO_2 emissions reduction of 1.24 million tons.

Fujian Offshore Wind Power Project

Following the registration of Lianjiang Longyuan Wanhua New Energy Co., Ltd. in 2023, a joint venture of Wanhua Chemical and Guoneng Group, a 310 MWp offshore wind power project located on the main island of Matsu Islands, the largest island in Fujian Province, is under construction. It is planned to install 23 wind turbines with a single capacity of 13.6 MW, realizing an annual power generation of 1.45 billion kWh and an annual CO_2 emissions reduction of more than 800,000 tons.

2) Energy Efficiently

Wanhua Chemical has made significant strides in reducing energy intensity through continuous optimization measures, including facility energy-saving initiatives, energy integration, and improvements in energy efficiency across its industrial parks. These efforts have resulted in steam savings of 223 tons per hour and a reduction in greenhouse gas emissions by 450,000 tons per year.

Wanhua Chemical -Hehai Heat Integration Project

Fully operational by the end of 2023, this innovative project employs "zero-carbon" heating technology to provide heating for residents in Yantai without burning coal, thus significantly reducing carbon dioxide emissions. By recycling and processing waste heat generated from chemical production and integrating energy distribution stations within the park into the civilian heating network, the project delivers clean energy to numerous households across the city. Additionally, it supplies a high-quality alternative heat source for various facilities within the industrial park, utilizing proprietary technologies. This groundbreaking initiative is set to supply clean heating to 79 million square meters of residential buildings in Yantai, benefiting over 100,000 families.

Hydrogen Chloride Circulation

Wanhua Chemical adopts innovative HCl catalytic oxidation technology to convert the by-product HCl from the MDI facility into chlorine gas. This technology features a world-pioneering non-precious metal catalyst and fluidized bed process and is able to directly convert HCl under mild conditions. The process has the advantages of high reaction efficiency, environmental friendliness, low fixed investment and operating costs, and it has become the first Chinese case to enter the finalist of Chemical Week's Sustainable Award: best recycling/circularity initiative. Recently, the hydrogen chloride recycling and oxidation project has been further improved in efficiency and capacity by technological upgrades, including catalyst and facilities, contributing to our path to circular economy.

Fujian Nitric Acid Electrification Project

In 2023, China's largest nitric acid facility with the lowest carbon emissions was established in Wanhua Chemical Fujian Industrial Park. Through designs such as process electrification and nitrous oxide emission reduction, etc., the single unit had an annual GHG emission reduction of 925,000 tons annually. With the combination of clean electricity and cutting-edge process technologies, we are reshaping our industrial layout.

3) Innovative Technology

"Road to Water" Project for Container Cargo

In 2023, Wanhua Chemical, in collaboration with Fugang Group and OOCL, initiated the "Road to Water" project in Fujian to transition full container load (FCL) cargo from road to water transport. This shift reduces the carbon footprint and reliance on land transportation, which can often be less timely and available. Additionally, Wanhua is advancing its sustainability efforts by working to replace internal combustion engine (ICE) trucks with electric ones, aiming to achieve further social and economic benefits.

New Green Practices in Transportation of PVC Bulk

In November 2023, Wanhua Chemical initiated the first truckload of bulk PVC delivery, transitioning from conventional packaging to tank storage for PVC powders. This change significantly reduces solid waste and the carbon footprint. This initiative follows the company's innovative implementation of "FFS Film Packaging" and "Shared Pallet" systems, further enhancing its environmental sustainability efforts.

> “*Relying on continuous technological innovation and operational optimization, Wanhua Chemical is minimizing the impact of its own business on climate, environment, and resources and will work with partners to continuously promote carbon reduction in the value chain.*

Wanhua has seen significant expansion over the years. Can you share some insights on the company’s growth strategy and how it aligns with its global aspirations?

Wanhua Chemical has experienced significant growth over the years by focusing on high-tech, high-value-added chemical products and materials. Our strategy is deeply rooted in a commitment to innovation, operational excellence, and the development of human resources. We nurture a culture of continuous improvement and technological advancement, positioning ourselves at the forefront of the chemical industry. By integrating green and sustainable practices into our operations, we ensure that environmental stewardship remains a central element of our growth. Additionally, our embrace of digital transformation has enhanced our operational efficiency and effectiveness, making our processes smarter and more adaptive.

Wanhua’s global expansion strategy is designed to bolster our presence in international markets, with the aspiration to become a leading Fortune 500 company. We concentrate on delivering high-end, integrated chemical solutions that cater to a wide array of customer needs. Overall, our growth strategy is in harmony with our global ambitions, setting the stage for continued expansion and success on the world stage.

Image Credit: Wanhua Chemical

The Barcelona R&D Center is a significant addition to Wanhua's global presence. What led to the decision to establish this center in Barcelona, and what does it signify for the company?

The decision to establish the Barcelona R&D Center was driven by several strategic factors, some of which I have outlined below.

1. **Showcasing Wanhua Innovation to Central and Western Europe:** Barcelona serves as a gateway to Europe and a hub of innovation, making it an ideal location for Wanhua to showcase its technology and products to clients and partners in Central and Western Europe. Establishing the technology center will help strengthen our brand and reputation in Europe, further increasing our market share.
2. **Access to Industry Talent**: Barcelona boasts a large pool of highly skilled and diverse talent, with leading universities and research centers in the city. This will provide Wanhua with a range of industry experts and professionals who can help drive innovation and enhance our technical and R&D capabilities.
3. **Collaboration with Leading Research Institutions**: Barcelona is home to several

leading research institutions, such as the Catalonia Institute of Chemical Research (ICIQ) and the Barcelona Institute of Science and Technology (BIST). These institutions offer Wanhua opportunities to collaborate with leading scientists and researchers, leveraging their expertise and resources.

4. **Collaborative Cooperation between Business Departments**: By co-locating different specialized chemical departments in a technical center in Barcelona, Wanhua Chemicals can benefit from rich collaboration and knowledge-sharing ecosystems with clients, local industries, and research institutions, leading to productive cooperation, accelerated innovation, and business development in Europe.
5. **Unique Advantages for the North African and Latin American Markets**: Situated on the Mediterranean coast, Barcelona boasts a strategic location that is conducive to business dealings with the North African and Latin American regions. As a key representative of Latin culture within Spain, Barcelona shares a language and cultural background similar to Latin America, which facilitates closer connections with the Latin American market. This commonality helps reduce cultural barriers and communication costs, enhancing business interactions and partnerships.
6. **Proximity to the Flavor and Fragrance Chemical Industry:** Barcelona is a significant global flavor and fragrance chemical hub, home to numerous leading companies and research centers. This positioning provides our flavor and nutrition business with valuable opportunities to stay updated on the latest industry trends. Additionally, it facilitates collaboration for knowledge-sharing and forming partnerships, further enhancing our capabilities and reach in this dynamic market.

What are the immediate goals for the Barcelona R&D Center, and how do they align with Wanhua's broader strategic objectives?

By co-locating different specialized chemical departments, the R&D center will focus on rapid response to customer needs, technical consultation, product development support, and quality improvement in fine chemicals and material sciences. These areas are crucial for enhancing our product offerings and support services in the coatings, adhesives, and engineering plastics industries, such as Acrylic resins, Waterborne resins, PMMA, and PC/ABS, which have significant demand in Western Europe and Latin America.

Sustainable development is a key research and development cooperation direction at Wanhua Chemical's Barcelona Technology Center, reflecting our sense of responsibility and strategic planning in facing global sustainable development challenges. We will actively collaborate with local universities, research institutions, and businesses to explore innovative projects and best practices in sustainable development, contributing to the our sustainable development goals.

Currently, ongoing research and development directions include:

1) Green Chemical Technology Research

The Barcelona Technology Center will focus on the cooperative development of green chemical technologies, such as biosynthesis, biomaterials, and biodegradable materials. These technologies can help reduce resource consumption, minimize environmental pollution, and save costs in the production process.

2) Utilization of Renewable Energy

The technology center will collaborate with local energy research institutions to explore the application of renewable energy in chemical production. For example, using clean energy sources like solar and wind energy for processes like electrolytic hydrogen production and electrolytic oxygen production to achieve carbon neutrality and energy conservation.

3) Circular Economy and Waste Utilization

Research in the circular economy focuses on maximizing resource utilization through waste and recycling. Technological innovations enable the transformation of waste into valuable chemical products, thereby minimizing resource waste and mitigating environmental pollution. This approach not only promotes sustainability but also adds economic value by turning what would otherwise be discarded into useful materials.

4) Sustainable Product Development

The technology center can collaborate with customers to develop products that are in line with the concept of sustainable development. These products may have characteristics such as low carbon emissions, environmental friendliness, and biodegradability, meeting consumers' demand for environmental protection and health and enhancing our market competitiveness.

5) International Cooperation and Standard-Setting

Actively participating in international cooperation, collaborating with other industry-leading companies, research institutions, international organizations, etc., to jointly establish sustainable development standards and technical specifications, promoting the sustainable development process of the industry.

In closing, could you share any upcoming projects or initiatives that stakeholders and investors should be particularly excited about?

> *Wanhua Chemical is set to launch its latest product, the Nylon 12 Elastomer-PEBA. This high-performance elastomer boasts unique physical and chemical properties, offering immense potential for innovative solutions in the elastomer platform.*

Leveraging our comprehensive industrial chain, Wanhua is dedicated to delivering products with unique value, thereby enhancing our customers' product capabilities and driving industry-wide innovation. Our PEBA, along with TPU and POE products, are set to enhance our foam shoe material solutions, providing diverse and superior options. We are eager to collaborate with partners to build an "ecosystem" centered on technological innovation and the development of high-performance products, all aimed at enhancing consumer experiences.

About Dr. Weiqi Hua

Dr. Weiqi Hua, born in March 1972, holds a Ph.D. in Chemical Engineering and is recognized as an expert with a State Council Government Special Allowance. He has dedicated his career to the innovation and transformation of high-end chemicals such as isocyanates and new chemical materials, leading an innovation team of over 2,000 members. Mr. Hua has headed more than 10 major national technical projects, including those under the National Programs for Science and Technology Development, the National Sci-Tech Support Plan, and the National High-tech R&D Program of China (863 Program).

His leadership has driven significant advancements in MDI manufacturing and the green manufacturing of Halcon-method PO, among other industrial key technologies. Mr. Hua has also successfully addressed several critical technologies, including aliphatic isocyanates (ADI), Nylon 12 (PA12), and high-performance polyolefin elastomers (POE), resulting in over 200 invention patents. His efforts have led to the establishment of China's first Nylon 12 unit and the world's largest MDI and ADI industrialization units, which have collectively generated sales revenues exceeding 230 billion RMB. These achievements have substantially strengthened China's chemical industry in terms of independent innovation and high-quality development.

Under his guidance, the ADI team was honored with the 'National Outstanding Engineer Team' award in its inaugural presentation. Mr. Hua himself has been recognized nationally, being selected for the 'WR Plan' as a leading talent and acknowledged as a Young and Middle-Aged Leading Talent in Technology. His contributions have earned him numerous accolades, including the China Youth Science and Technology Award, the Qiu Shi Science and Technologies Foundation Award, and the Shandong Province Highest Award in Science and Technology. Additionally, he has received the National Science and Technology Progress Award (one first prize, one second prize) and the National Technological Invention Award (one second prize).

Perovskite Analysis: The Role of UV-Visible-NIR Microspectroscopy in Optoelectronic Research

Perovskites have emerged as a breakthrough material in optoelectronics, especially where solar cells and light-emitting devices are concerned. Their unparalleled light absorption and charge transport properties make them a key focus of today's research.

Advanced characterization techniques are crucial to better understanding how perovskite materials are developed. CRAIC Technologies has shown how well its UV Visible-NIR microspectroscopy performs in the detailed examination of perovskite materials, offering deeper insights into their optical and electronic properties at the microscale.

UV-Visible-NIR Microspectroscopy: An Overview

UV-Visible-NIR microspectroscopy incorporates the principles of UV-Vis spectroscopy in combination with high-resolution microscopy. This technique facilitates the analysis of materials across a broad spectral range (ultraviolet to near-infrared) at microscopic spatial resolutions.

CRAIC Technologies' microspectroscopy systems come equipped with state-of-the-art optics and detectors, allowing researchers to precisely measure absorbance, reflectance, and photoluminescence spectra at sub-micron scales.

Key Findings in Recent Perovskite Research

Recent studies that have leveraged the power of CRAIC Technologies' UV-Visible-NIR microspectroscopy have managed to make significant progress in the characterization of perovskites.

1. Enhanced Optical Absorption and Reflectance Mapping:

Researchers have frequently applied this method to map the optical absorption of perovskite thin films, single crystals, and nanostructures alike.

2. Flexible Optoelectronic Device Development

Steady-state optical characterization of flexible devices with an active layer of ultrathin single-crystalline perovskite film supported the demonstration of high-performance flexible photodetectors.[1]

3. Development of Stable Infrared Photodetectors

Perovskites demonstrate good potential when it comes to developing cost-effective infrared (IR) photodetectors. However, when exposed to prolonged IR wavelengths, they tend to show signs of degradation. New, stable IR photodetectors have been developed and characterized using absorbance microspectroscopy.[2]

4. Engineering of Perovskite Optical Emissions

Metal halide perovskite quantum dots possess exceptional photoluminescence properties. Here, adaptable luminescence properties were engineered and the polarization reflectance microspectroscopy was applied for characterization of the samples.[3]

5. Building Near-infrared Nanolasers

Near infrared nanolasers are currently in development for use in optoelectronic circuitry. UV-Visible-NIR microspectroscopy is being used to measure the absorbance spectra of the new classes of wavelength tunable planar nanomaterials.[4]

6. Creating Two-Dimensional Semiconductors

Reflectance and transmission microspectroscopy can be applied to characterize the optoelectronic properties of two-dimensional tin perovskite crystals in sequence at the same location for each point to establish a relationship between the absorption spectrum and wavelength.[5]

Advantages of CRAIC Technologies' Microspectroscopy Systems

- **High Spatial Resolution**: Facilitates in-depth mapping and analysis of microscopic features within perovskite samples.
- **Broad Spectral Range**: Covers UV to NIR regions, offering complete optical characterization.
- **Multiple Measurement Techniques at the Same Location**: Absorbance, reflectance and emission spectra can all be acquired at the same points, facilitating direct comparisons of results.
- **Mapping of Surfaces**: Absorbance, reflectance, emission spectra as well as thin film thickness maps are possible.
- **Non-Destructive Analysis**: Ensures delicate perovskite remain intact materials during measurement.
- **Versatility**: Applicable to an extensive range of perovskite materials and device assemblies.

Image Credit: CRAIC Technologies

Conclusion

CRAIC Technologies' UV-Visible-NIR microspectroscopy has shown itself to be a practical tool with the power to characterize perovskite materials at an advanced level. The capability to conduct detailed optical analysis at the microscale improves the understanding of perovskite materials' properties, accelerating the advances in perovskite-based technologies. Researchers and developers can use this technique to improve material quality, optimize device performance, and accelerate the commercialization of perovskite optoelectronics.

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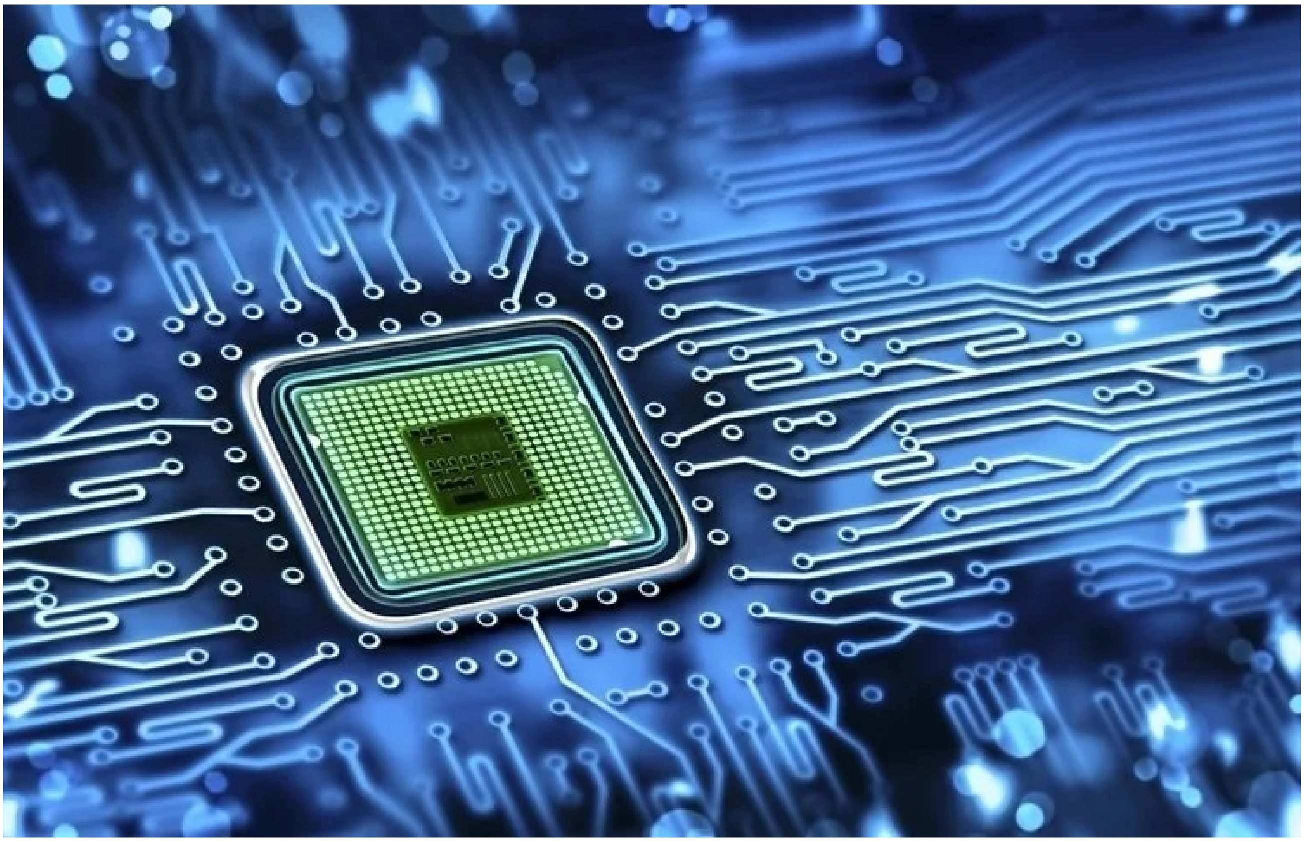
Advanced Packaging Materials for Semiconductor Chips

The field of electronics, particularly integrated circuit (IC) technology, has advanced rapidly in recent years. With the development of 5G/6G mobile technology, semiconductor devices are evolving to be smaller, lighter, and more powerful. Packaging is crucial for semiconductor chips, serving roles in physical protection, electrical connection, and adhering to standard specifications.



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Modern packaging not only protects chips and improves thermal conductivity and reliability but also acts as a link between the chip's internal components and the external circuit. Recent strides in manufacturing and materials science have significantly advanced semiconductor chip and electronics packaging.

Advanced Packaging for Modern Semiconductors

Modern semiconductor packaging has progressed significantly. The latest trends in semiconductor packaging have been discussed in a recent article published in *IEEE Transactions on Components, Packaging, and Manufacturing Technology*.

The semiconductor packaging landscape includes various integration approaches. 2-D IC integration is prevalent, involving at least two chips on the same package substrate or fan-out redistribution layer (RDL) substrate. Systems-in-Package (SiP) is a common 2-D IC integration used in consumer products like smartwatches and smartphones.

The 2.1-D IC integration involves fabricating fine metal layers directly on top of a build-up package substrate or high-density interconnect (HDI). In 2.5-D IC integration, chips are supported by a passive through-silicon via (TSV) interposer, attached to a package substrate—AMD's Radeon R9 Fury X GPU utilizes this technology.

3-D integration encompasses both 3-D IC packaging and 3-D IC integration, stacking chips vertically. The key distinction is the use of TSVs in 3-D IC integration, which is not present in 3-D IC packaging.

Chiplet design and heterogeneous integration packaging have recently gained significant attention.

Prominent examples include Intel's field-programmable gate array (FPGA) like Xilinx/TSMC's Virtex, microprocessors such as AMD's Extreme Performance Yield Computing (EPYC), and Intel's Lakefield, which are in high-volume manufacturing (HVM), utilizing chipset designs and heterogeneous integration packaging.

This innovative approach involves breaking down the System-on-Chip (SoC) into smaller chipsets. These chipsets, which are often diverse in materials and functions, and originate from different fabless design houses, foundries, wafer sizes, feature sizes, and companies, are then integrated using advanced packaging technology.

This enables the creation of a cohesive system or subsystem with enhanced flexibility and performance.

In the context of electrical performance for insulation materials, there is a growing preference for materials with low dissipation factor (D_f or loss tangent) and low dielectric constant (D_k or permittivity), especially in the realm of 5G applications.

In scenarios involving multilayer substrates or Redistribution Layers (RDLs), dielectric films (insulating materials) serve as interlayer adhesives between the conductor layers. These materials play a crucial role in maintaining the integrity and efficiency of electronic components.

What Are the Challenges for Advanced Materials in Semiconductor Packaging?

In the post-Moore era, the significance of advanced packaging has intensified to address the enduring requirements of electronic products, encompassing smaller sizes, enhanced performance, and reduced cost.

As per the article published in *Fundamental Research*, there has been rigorous development in advanced packaging, such as TSMC's InFO (integrated fan-out) and CoWoS (chip on wafer on substrate), ASE's FOCoS (fan-out chip on substrate), as well as Amkor's SLIM (siliconless integrated module) and SWIFT (silicon wafer integrated fan-out technology).

These advancements aim to push the boundaries of electronic packaging capabilities.

There are several challenges faced by TSV-based 3D packaging technology. Yield poses a significant challenge in 3D stacking, especially when integrating multiple chips. The failure of a single chip during manufacturing can fail the entire module.

The bonding methods employed for 3D IC integration demand stringent conditions, including high surface cleanliness, surface flatness, and cleanroom class. Additionally, effective thermal management becomes a challenge in 3D packaging due to the high packaging density, requiring innovative solutions to address these complexities.

How Are Novel Epoxy Composites Used for Semiconductor Packaging?

Approximately 90 % of Integrated Circuits (ICs) are enclosed in plastic electronic packaging using underfill materials that consist of an epoxy matrix and high levels of silica with a low coefficient of thermal expansion (CTE).

However, the existing epoxy-based underfill materials (EUMs) commercially available have a low thermal conductivity of only 0.4 W/m·K. This thermal conductivity falls short of meeting the rigorous heat transfer requirements for the next generation of high-power electronic devices.

Enhancing the thermal conductivity of epoxy composites is not the sole factor to ensure their practical application as EUMs. Other processing considerations and the demands of electronic devices in service must also be considered.

For instance, liquid epoxy-based encapsulants should exhibit favorable fluidity at room temperature, allowing them to effectively fill spaces during capillary flow processes in completed Integrated Circuits (ICs).

According to the article published in *Composites Science and Technology*, strategies aimed at optimizing the thermal conductivity of EUMs without compromising factors such as processability, electronic insulation, Coefficient of Thermal Expansion (CTE), and mechanical properties are currently attracting significant attention but remain challenging.

The researchers conducted experiments to demonstrate that incorporating small quantities

(0.5 vol %) of silver nanowires (AgNWs) into EP/S-Al_2O_3 composites significantly increased thermal conductivity without compromising processability.

The rigid nanowires bridged the main spherical particles, resulting in a 106.5 % increase in thermal conductivity in the micro nano EP/AgNWs/S-Al_2O_3 composites with 40 vol % S-Al_2O_3 and 0.5 vol % AgNWs, compared to those without AgNWs.

These findings suggest that incorporating multiscale fillers into epoxy composites can address the tradeoff between thermal conductivity and processability, making them suitable for applications in high-power-density electronic devices.

Si-Based Reinforced Metal Matrix Composites for Electronics Packaging

Power chips used in high-tech equipment generate significant heat. However, the absence of micro-cooling technology results in elevated chip temperatures, leading to reduced lifespan, diminished capabilities, and lower reliability. Research to enhance chip cooling primarily centers on two approaches.

The first involves creating efficient micro-scale heat dissipation mechanisms, such as advanced heat sinks. The second concentrates on developing high-performance thermal management materials, optimizing overall chip cooling.

The latest article in *Micro-machines* has highlighted that metal matrix composites (MMCs) composed of a matrix metal with high thermal conductivity (TC) and reinforcing phases show significant potential for development. SiC/Al composite materials possess exceptional properties, including high specific strength, high specific modulus, elevated hardness, wear resistance, good thermal stability, and strong fatigue strength.

Their manufacturability using conventional methods makes them highly promising for applications in electronic packaging materials.

Building on the success of SiC/Al electronic packaging materials, there is a growing interest in SiC-based composites featuring a Cu matrix (SiC/Cu). Leveraging microfabrication techniques, SiC/Cu composites are emerging as prime contenders for the next wave of electronic packaging materials.

These composites are particularly sought after for high-performance heat dissipation devices and electronic packaging applications, thanks to their high thermal conductivity (TC) and low coefficient of thermal expansion (CTE).

The trend toward higher packaging density and thinner chips in chip manufacturing processes introduces increased sensitivity to stress, contaminants, and inconsistencies. Addressing these challenges requires the development of new techniques, including low-cost high-performance bonding and large-scale metrology with high precision.

These advancements are crucial to tackle manufacturing issues such as yield and reliability. Advanced packaging emerges as a promising solution to maximize the advantages of scaling down by exploring new architectures, reducing communication distances, and achieving higher packaging density.

To realize these goals, standardization, the adoption of new techniques, co-design tools, and multi-scale multi-physics simulation techniques are essential for the sustainable development of advanced packaging technology.

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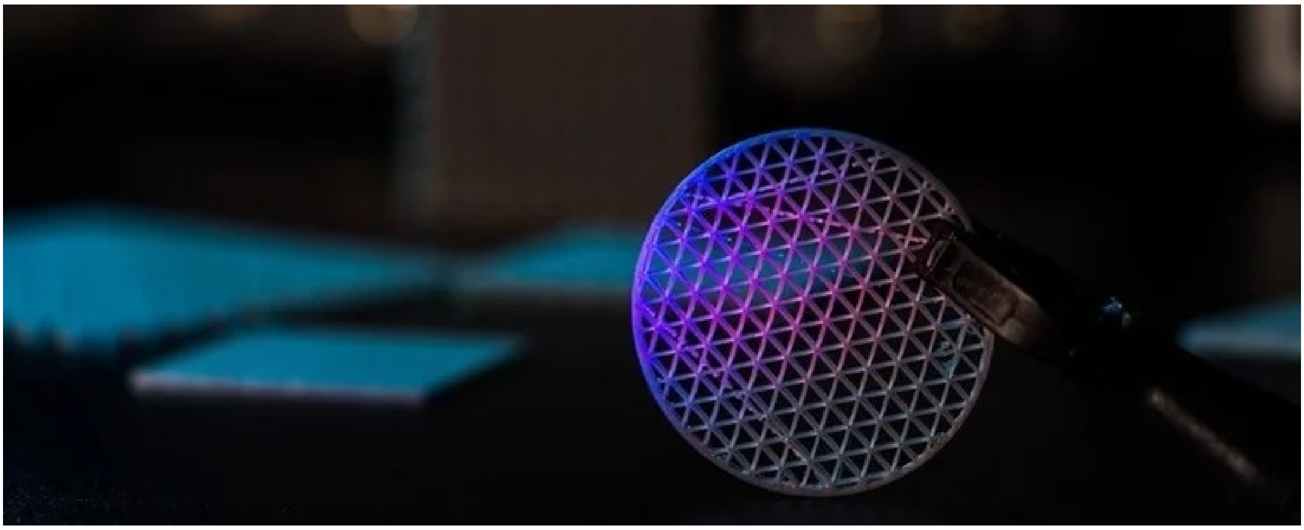
Metamaterials: Transforming Technology with Engineered Materials

The field of materials science has evolved significantly. Material design and development have progressed from traditional, expensive experimentation techniques to contemporary, data-driven AI-based algorithms.[1]



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The rapid development of materials through digital techniques has accelerated progress in various industries, particularly electric vehicle battery materials, renewable energy, construction, and aerospace. Among the various classes of materials, metamaterials stand out due to their remarkably unusual properties, such as electromagnetism, which are not typically found in conventional substances.[2]

Metamaterials: A Unique Artificially Engineered Material Type

Metamaterials are artificial materials comprised of an array of nanostructures, which serve as the building blocks, or "meta-atoms." Unlike natural materials, the properties of metamaterials are not determined solely by the intrinsic characteristics of their chemical constituents but rather by the precise arrangement of these meta-atoms.

The intricate interactions between incident electromagnetic (EM) waves and the meta-atoms endow metamaterials with remarkable light-field manipulation capabilities and other unique physical properties, some of which surpass those found in naturally occurring materials.[3]

Initially, the design of metamaterials was focused on optical and electromagnetic properties. However, it has now expanded to encompass mechanical (including both quasi-static and elasto-dynamic behavior), acoustic, biomedical, and thermal properties.[4]

This innovative class of functional materials is artificially engineered with unique micro- and nanoscale patterns or structures, enabling unprecedented interactions with light and other forms of energy. These composite materials are intentionally designed and fabricated to exploit their internal microstructures, efficiently achieving distinctive properties.

Their structure consists of multiple identical elements made of traditional materials, such as metals or non-conductive substances. These are often described as customizable artificial "atoms" and "molecules." The individual unit cell (or meta-atom) is typically much smaller than the waves interacting with the metamaterials.

The distribution between the individual structures is also relatively smaller than the wavelength of general EM waves. Engineers can tailor the shape, size, and lattice constant of these structures while manipulating the interactions between them. Strategically positioned "defects" can additionally be employed to enhance desired characteristics.[5]

Metamaterials: Applications Across Industries

Metamaterials find applications across various fields, including public safety, sensor identification, high-frequency battlefield communications, enhanced ultrasonic sensors, solar energy management for high-gain antennas, and remote aerospace applications.

In the military sector, scientists utilize metamaterials for several purposes, including the detection of explosive substances and the identification of contaminants and biological materials.[6] Metamaterials also play a significant role in the development of compact and high-speed photonic devices.

Nano-scale metamaterials are employed to manipulate optical or acoustic signals, enhancing ultrasound resolution and material distortion. Metamaterials are also utilized in antennas to improve the efficiency of compact antenna systems. Metamaterial antennas leverage their exceptional bandwidth characteristics and unique structure to enhance antenna performance.[6]

Designing and Fabricating Metamaterials: An Overview

In the design phase of metamaterials, the primary objective is to engineer microscale architectures that can be manipulated to bestow specific macroscale properties on the final product. This design process typically involves the application of physical reasoning, analytical models, and computational techniques, collectively known as "rational design" approaches.[7]

The metamaterial design process is also becoming faster due to the emergence of rapid fabrication techniques, such as additive manufacturing (AM), which enables the construction of complex 3D structures through a layer-by-layer material deposition process.

While subtractive manufacturing predominates in the production of mechanical metamaterials, AM is an equally important cutting-edge technique. Two-photon polymerization (TPP) has been employed to manufacture structures with resolutions approaching 100 nm, resulting in microscale unit cell sizes.[8]

Selective laser sintering (SLS) has also been utilized in the fabrication of 3D metamaterials using plastic in 3D printing processes. Unlike previous 3D printing technologies, SLS involves sintering and fusing a preheated polymer powder with a laser to produce the printed metamaterial piece.[9]

Most of the proposed optical metamaterials with nanometer-sized features have been fabricated using conventional nano-patterning methods, such as Electron Beam Lithography (EBL) and Focused Ion Beam milling (FIB). However, these methods typically restrict the size of the fabricated metamaterials to very thin and, at most, micrometer-sized areas, significantly limiting the practical applications of metamaterials.

What Are the Main Challenges in Metamaterial Fabrication?

The fabrication of metamaterials has faced several limitations, including restricted pattern design, design inflexibility, material selection challenges, uncontrollability, and long-range disorder.[10]

One major barrier to the rapid commercialization of metamaterials is the operational challenges they present, as these substances operate at scales much smaller than the wavelength of the incident waves, such as light or microwaves.

Fabricating these functional materials with precise dimensions at the subwavelength level is exceptionally challenging, requiring extreme precision with tightly controlled reaction parameters and highly specialized equipment. These factors also increase the fabrication costs of metamaterials.

Many metamaterials also exhibit narrow bandwidths due to their resonant nature. Materials scientists are struggling with the design of wideband metamaterials that maintain their properties over a broader frequency range.

Artificial Intelligence and Tech Innovations: Transforming Metamaterials

The advancement and accessibility of computational techniques, including those leveraging artificial intelligence (AI), combined with the availability of cloud computing resources, have facilitated the enhanced exploration of the design space for metamaterials. These computational tools enable more comprehensive analyses and more sophisticated approaches to the rational design of metamaterials.[7]

Machine learning techniques have introduced new possibilities in the design of metamaterials. Firstly, they enable the solution of inverse design problems using deep learning and other AI tools. Secondly, generative models like generative adversarial networks (GANs) and variational auto-encoders (VAEs) can now assist in the rational design process by generating designs that match specific target properties.[7,11]

Multilayer perceptrons (MLPs) are a type of feedforward artificial neural network featuring fully connected neurons, nonlinear activation functions, and a structure consisting of at least three layers. MLPs have been used to predict various properties of phononic metamaterials. In the design of phononic metamaterials, an MLP can be trained using target properties as inputs and design variables as outputs.

Integrating MLPs with genetic algorithms has also facilitated the design of multifunctional elastic metasurfaces for precise control over wave refraction angles, yielding satisfactory results. MLPs can predict transmission coefficients and local phase shifts across different frequencies.[11]

Practical applications of mechanical metamaterials often involve solving inverse problems to identify microarchitectures that exhibit desired properties. However, the limited resolution of AM techniques necessitates tailoring these inverse solutions for specific specimen sizes.

Addressing the multi-objective inverse design challenges is vital for the real-world application of mechanical metamaterials. To overcome this size-agnostic inverse design problem, deep learning (DL) and deep generative models are employed within the random-network (RN) mechanical metamaterials framework.[12]

Recently, a modular approach called "Deep-DRAM" has been introduced to address size-agnostic inverse design challenges in mechanical metamaterials.[12] Deep-DRAM combines four independent models, including two DL models, a deep generative model utilizing conditional variational autoencoders, and direct finite element (FE) simulations.

This integrated framework enables the identification of multiple solutions to the multi-objective inverse design problem, particularly focusing on random-network unit cells. Combining deep generative models with forward predictors has effectively generated mechanical metamaterials that meet various design criteria, including minimum peak stresses. This approach enhances the durability and endurance of these materials, making them suitable for practical applications in the real world.

In a recent development, the University of Exeter has secured significant funding to spearhead a groundbreaking collaboration to advance research into manipulating metamaterials in the fourth dimension: time. This initiative involves experts from Exeter's Centre for Metamaterial Research and Innovation (CMRI), who will play a pivotal role in a newly formed consortium named Meta4D.

The consortium aims to explore the manipulation of waves, including light waves or acoustic waves, by utilizing tailored metamaterials that exhibit variations in time instead of space.[13] This initiative underscores the scientific community's belief in the critical role of metamaterials for future innovations.

Metamaterials are the subject of extensive research, and the integration of modern digital tools such as AI and data-driven models is driving the accelerated development of these substances, along with controlled manipulation of their properties. The future of metamaterials is promising, with expectations of significant advancements in the field in the coming years.

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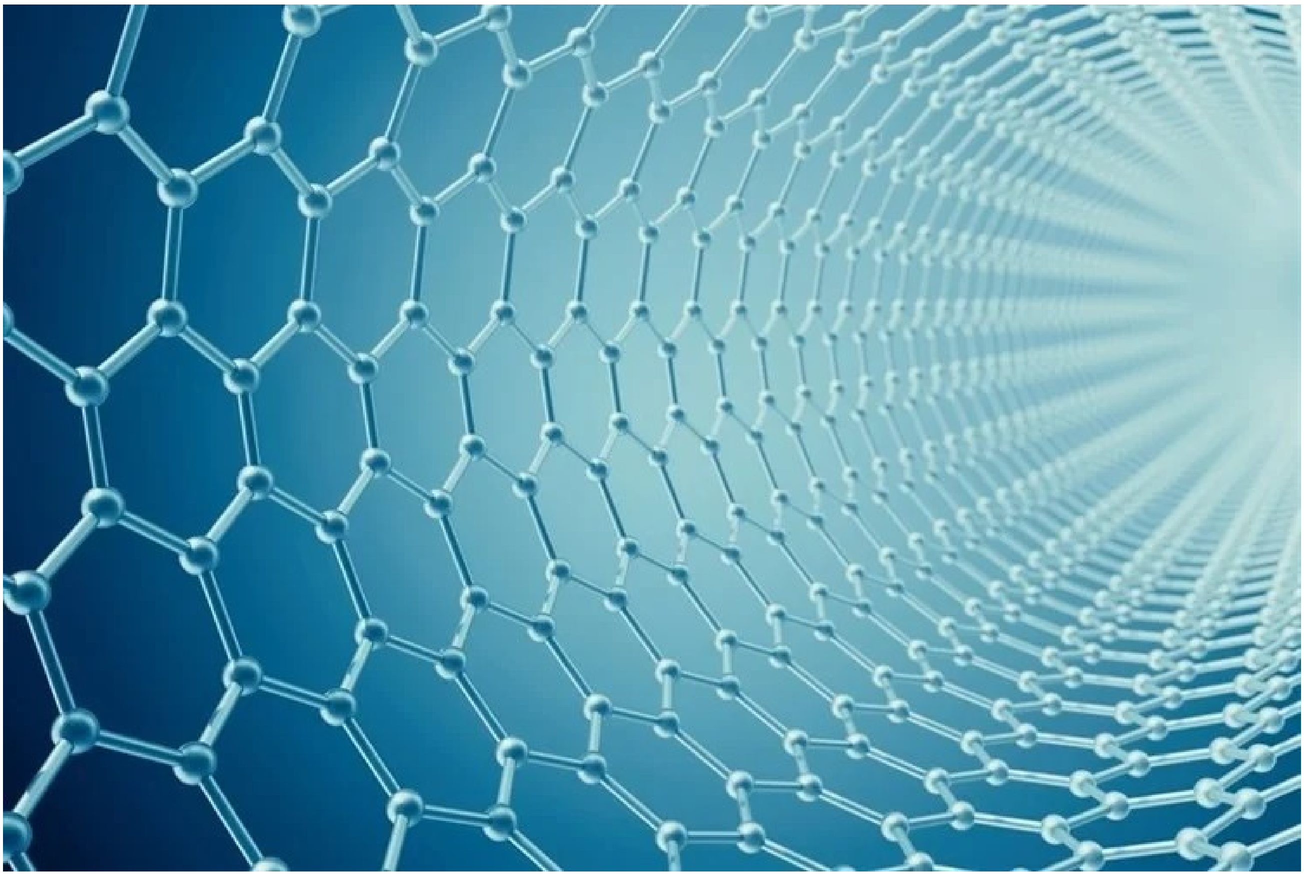
Raman and UV-Vis-NIR Microspectroscopy to Sort Carbon Nanotubes

Graphene is a two-dimensional form of carbon arranged in one-atom thick layers. Carbon atoms in graphene are tightly packed in a regular hexagonal pattern. Mathematically, graphene can be treated as a considerably large aromatic molecule, and due to this electronic and distinctive physical structure, can create new electronic effects.



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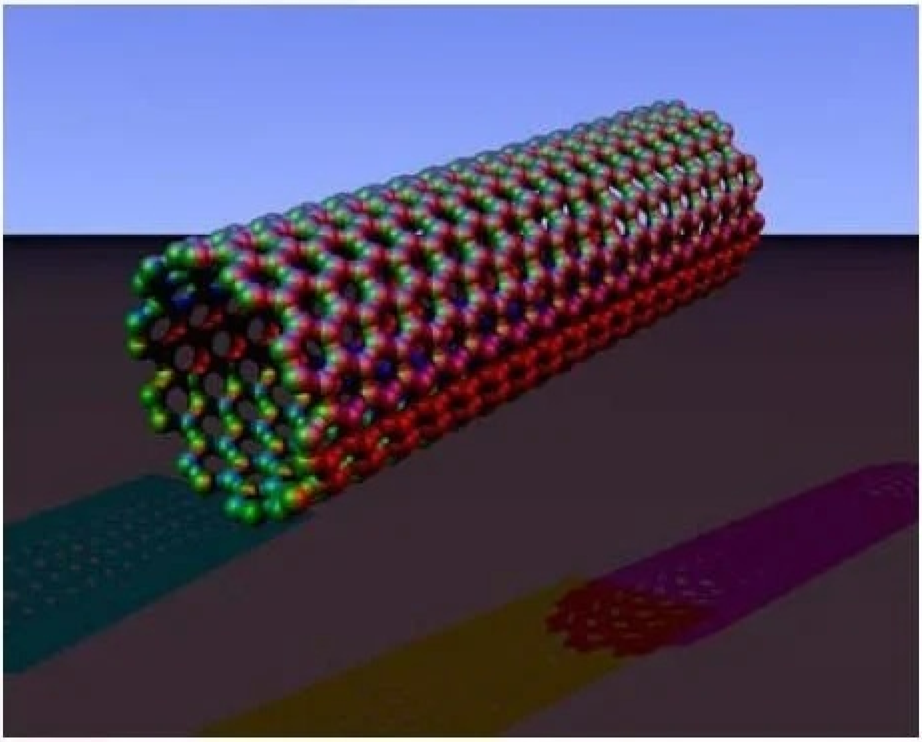
Carbon nanotubes (CNT) can be considered as graphene which forms a tube instead of a sheet. CNT is considered to be a one-dimensional material composed of a different set of properties than two -dimensional carbon. In terms of structure, the CNT material is a long, hollow tube that contains a single graphene layer rolled at a particular angle to form a cylinder, and it is this angle that affects the tube's electronic properties.



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Nested tubes can be formed with many layers of graphene, which are commonly referred to as multi-walled nanotubes. CNTs are formed of many sp^2 bonds between separate carbon atoms, which results in the enormous tensile strength possessed by individual CNTs. In addition, this structure promotes multiple other characteristics that can be advantageous to a wide range of industries, including unique mechanical, optical, thermal and electrical properties.

Photoluminescence, absorbance and Raman spectral characteristics are clearly exhibited by CNTs. This makes optical microspectroscopy an excellent tool for nondestructive analysis of CNTs, enabling engineers and scientists to investigate and "tune" the properties of newly developed forms of CNTs. One key application of microspectroscopy to CNTs lies in quality control, where it is employed to find out contaminants and structural defects, and validate preferred properties.

Figure 1. *The 2030PV PRO™ UV-VIS-NIR microspectrophotometer from CRAIC Technologies. This instrument can be configured for transmission, reflectance, fluorescence, photoluminescence and Raman spectroscopy and imaging*

Several methods have been developed by CRAIC Technologies that can be integrated on a single instrument and can be used for studying CNTs, graphene and other one, two and three-dimensional structures.

UV- Visible-NIR Microspectroscopy

In the near infrared and ultraviolet regions, transmission microspectroscopy is a method that has been shown to be useful for the identification and characterization of CNTs. There are some fascinating optical absorptions that emerge from v_1-c_1, v_2-c_2, etc. electronic transitions, also known as van Hove singularities.

As a result, the spectrum has sharp features. If the CNT structure is changed, the optical properties can be tuned which can help in the identification and characterization of CNTs. Sample preparation for UV transmission microspectroscopy is a simple process, and therefore this has become a reliable method for identifying the type of CNTs in a sample in addition to their structure and purity.

Pure, single walled CNTs, for example, display strong absorbance maxima at 280 nm because of the CNT. In pure, single-walled materials, the van Hove transitions occur well into the NIR region at about 1240 nm for v_1-c_1 (also known as S_{11} transition) and 700 nm for v_2-c_2 (also known as S_{22} transition).

These transitions are depicted in Figure 2, showing the transmission microspectra™ of aggregated single walled CNT dropcast on a quartz slide from an acetone suspension.

The characteristic single walled CNT peak is clearly seen at 280 nm, but the van Hove transitions are broadened and red-shifted because the dispersion creates a CNT network in van der Waals in contact with each other. Therefore, the peaks' wavelength can be used to characterize the extent the aggregated CNTs are tightly bound together.

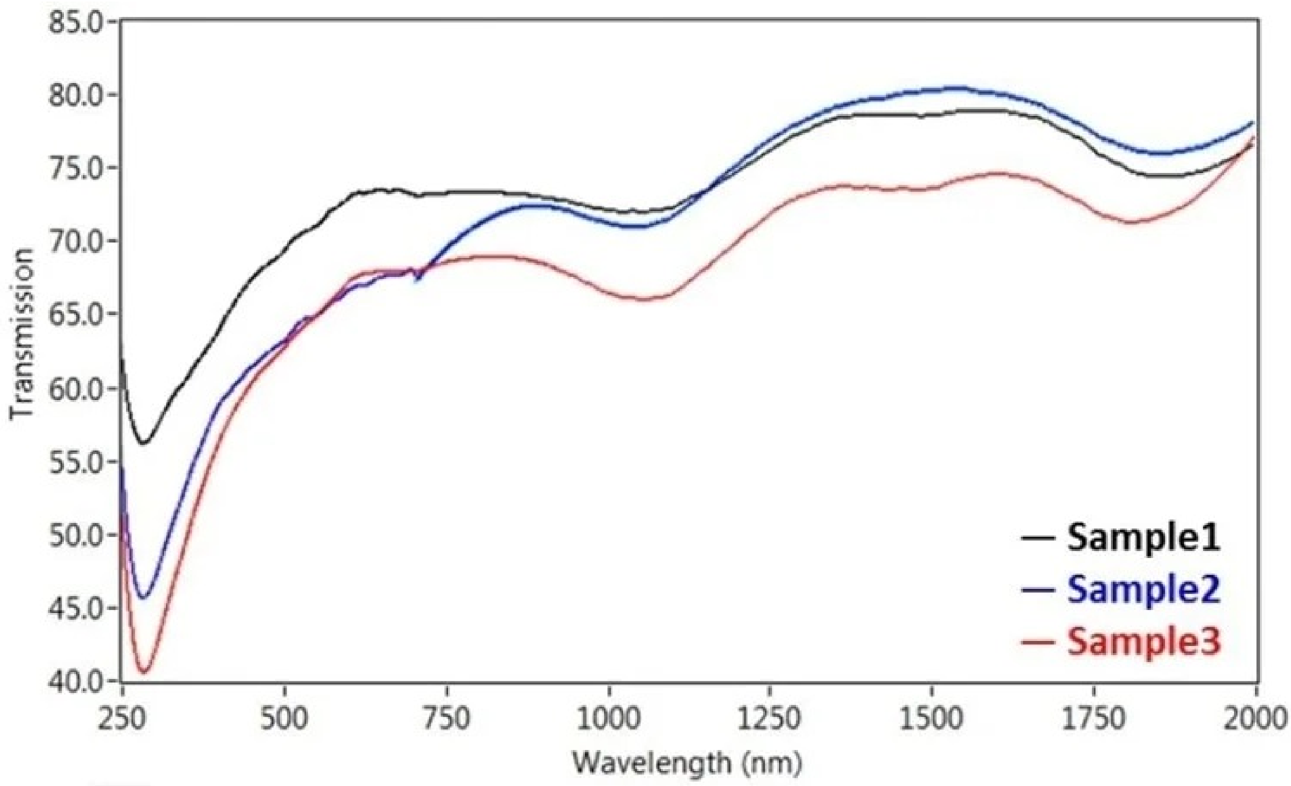

Figure 2. *Transmission microspectra™ of single walled CNT dropcast on a quartz slide from an acetone suspension, with peaks at ~280, 1050, and 1850 nm.*

Ultraviolet Microscopy

Although standard microscopy using visible wavelengths can be useful, another major tool available for rapid detection of CNT locations is through UV microscopy.

The CNT locations can be easily and quickly confirmed with microscopy (Figure 3), by utilizing a bandpass filter at an absorption peak of the sample (i.e. 280 nm) and imaging with a UV-capable camera.

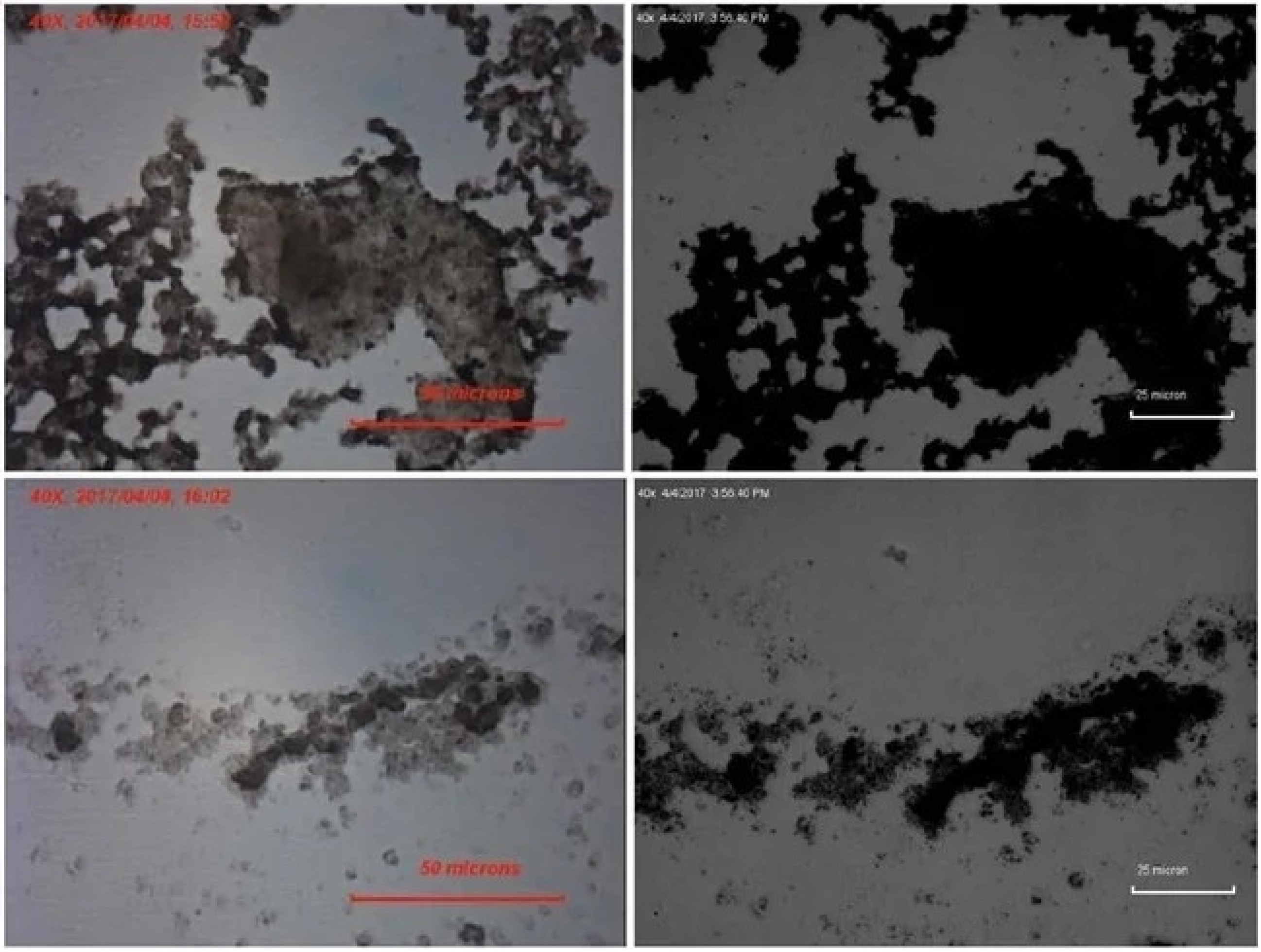

Figure 3. *Standard visible images (left) and corresponding UV images at 280 nm (right) of single walled CNT dropcast on a quartz slide from an acetone suspension.*

Photoluminescence Microspectroscopy

When single walled CNTs are excited by photon with an energy corresponding to the S_{22} transition, they produce NIR light. Initially absorbed by the CNT molecule, the photon relaxes through the S_{11} transition and the photon emitted corresponds in energy to the S_{11} transition.

The emission wavelength is highly variable and depends on the CNT structure. The PL of single walled CNTs is also linearly polarized along the long axis of the CNT. This enables the monitoring of CNT orientation without any extra effort.

Raman Microspectroscopy

Yet another extremely useful spectroscopic tool is Raman microspectroscopy, because the vibrational spectra acquired can be used to detect molecular bonds and spot the differences in local environments.

This is because specific vibrational frequencies are possessed by the bonds formed between atoms. And these frequencies correspond to an atom's strength and mass of the bond between the atoms. Hence, complex molecules show many peaks and can be quickly identified by the "fingerprint" or pattern produced by those peaks. For one and two-dimensional materials, this is particularly useful because the sampling area is restricted by the size of the laser spot, and it is capable of detecting the differences in local environments.

There are three characteristic peaks in graphene based materials that are often seen in the Raman spectra (Figure 4). These are specifically called the D-peak at 1360 cm^{-1}, 2D peak at 2700 cm^{-1}, and G-peak at 1600 cm^{-1}. The D-peak is indicative of impurities or disorder in the carbon-based structure, while the G-peak is the result of carbon-carbon bond stretching. In addition, the 2D peak is common to all graphite samples, and its width, intensity and location can be used to find out the number of sample layers.

This spectrum containing the D peak indicates disorder in the sample, and this peak's intensity can be used to determine the disorder in the sample. The local environment, such as solvents, substrate and localized defects will influence the exact frequency of these vibrations.

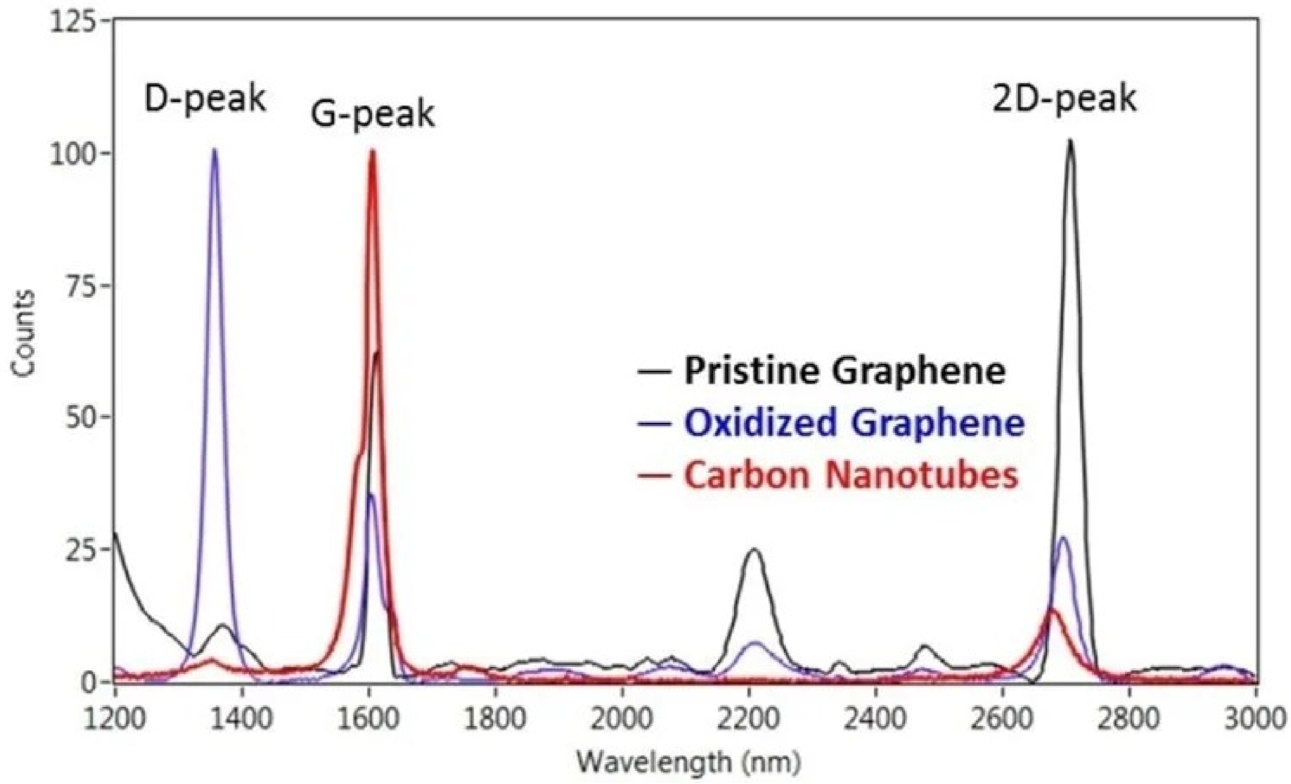

Figure 4. *Raman spectra of graphene and carbon nanotube samples. The D, G, and 2D peaks are clearly visible in all three samples. The additional band observed at ~2205* cm^{-1} *is due to the substrate that the graphene samples were mounted on.*

Microspectroscopy

CRAIC Technologies design and develop UV-visible-NIR range microspectrometers for a wide range of applications. The company integrates several different spectroscopic techniques into a single instrument that can measure the spectra of micron-scale sample areas.

Shown in Figure 5 is an optical diagram of a microspectrophotometer that is configured for transmission microspectroscopy. Here, the light is focused onto a sample, which is graphene in this case and the transmitted light is collected and imaged onto the spectrophotometer's entrance aperture.

As the entrance aperture of the spectrophotometer is mirrored, an image is also the entrance aperture superimposed on the sample measurement area. This allows for simple yet fast alignment.

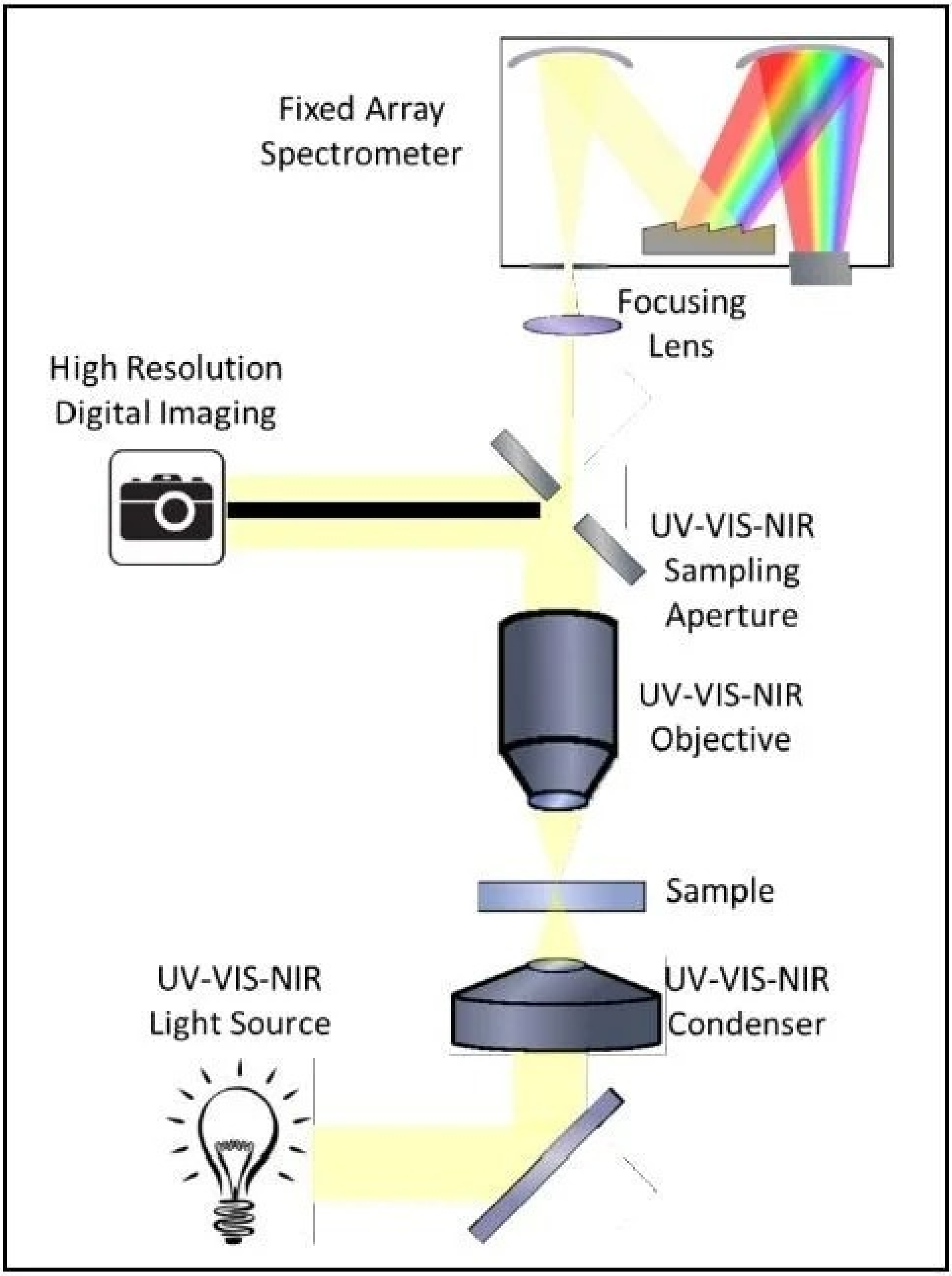

Figure 5. *Optical diagram of a microspectrophotometer configured for UV-VIS-NIR transmission*

microspectra™.

In the case of Raman microspectroscopy, the optical diagram is somewhat different which is attributed to the nature of these types of experiments. Shown in Figure 6 is an optical diagram of a microspectrometer configured for Raman microspectroscopy.

Through incident illumination, the laser is focused onto a sample (graphene) and the Raman scattered light is collected and imaged onto the spectrophotometer's entrance aperture, and this is followed by collecting a Raman microspectra™.

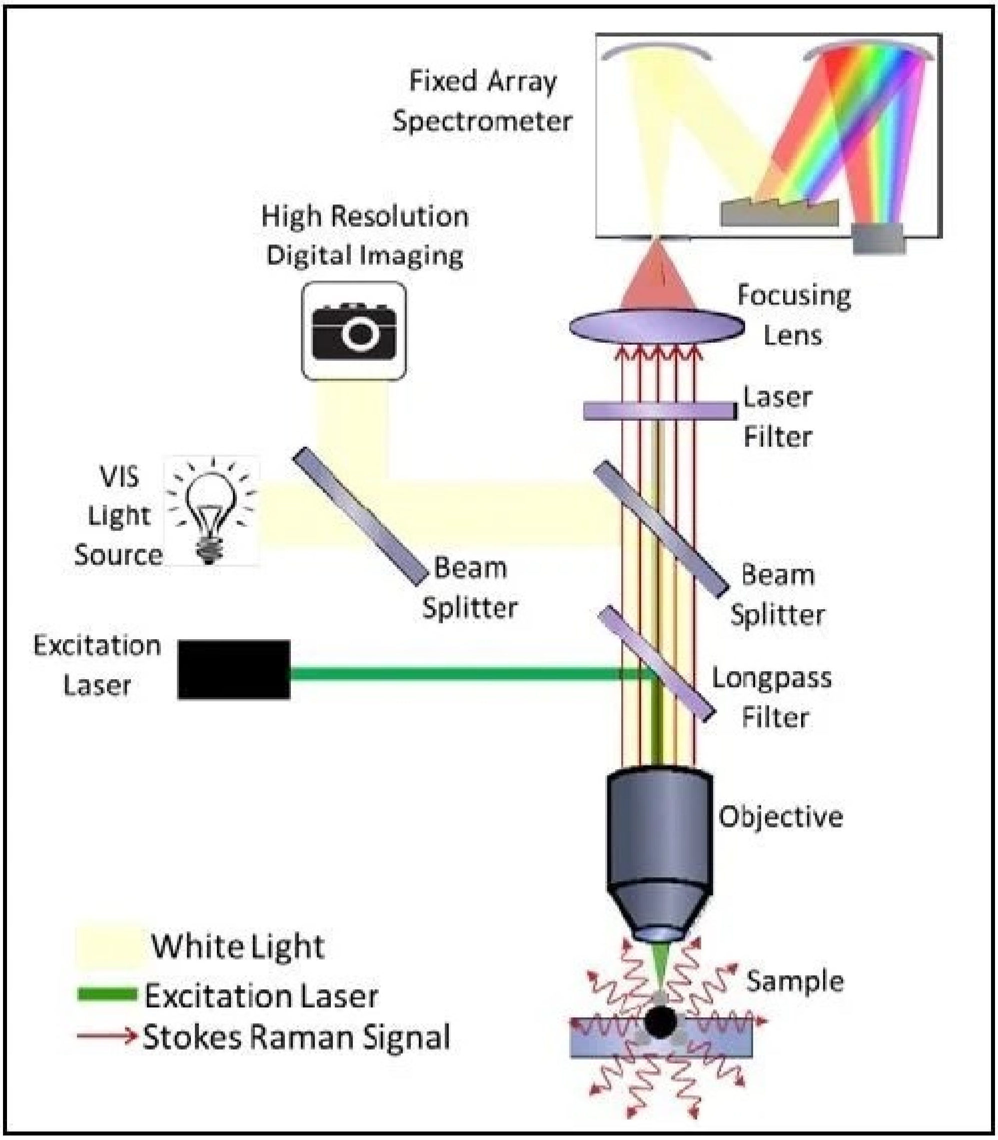

Figure 6. *Optical diagram of a microspectrophotometer configured for Raman microspectra™.*

Apart from the standard color imaging, the microspectrometer also has capabilities for NIR and UV imaging. This instrument can be configured for photoluminescence, reflectance, polarization microspectroscopy, kinetic spectroscopy, 5D spectral surface mapping and small spot thin film thickness measurements.

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Ultrasonic Imaging with Micro-Metalenses for Advanced Material Diagnostics

In an article recently published in *Scientific Reports*, researchers from the USA and India explored advancements in ultrasonic imaging, focusing on achieving micron-scale resolution using bulk ultrasonics. They addressed key challenges in non-destructive testing and material diagnostics, particularly in industries where detecting microscopic defects is essential.

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Advancement is Material Evaluation

Evaluating materials at greater depths with high resolution is crucial in fields such as high-energy physics, quantum materials, nuclear power generation, biomedical diagnostics, and aviation. Traditional methods, like radiographic (X-ray) testing, provide high resolution but have limited penetration in solids and involve ionizing radiation, making them costly and less practical for widespread use.

In contrast, ultrasound can penetrate thicker samples, is cost-effective, and is non-ionizing, making it ideal for rapid, large-scale diagnostics. However, conventional bulk ultrasound struggles with imaging microscopic defects due to longer wavelengths.

Techniques like scanning acoustic microscopy (SAM) offer higher resolution but are limited to surface imaging. Thus, achieving high-resolution imaging with low-frequency bulk ultrasonics could significantly improve deeper material diagnostics inside solids.

Developing Micro-Metalenses for Ultrasonic Imaging

The authors aimed to overcome the diffraction limit that restricts imaging resolution to half of the operating wavelength. They developed silicon-based, micro-fabricated metamaterial lenses with arrays of 10-micron square holes.

To enhance wave detection, a custom micro-focal laser with a sub-micron spot size was created, allowing for precise measurements. This setup combined laser technology with advanced signal processing to achieve micron-scale resolution of defects, focusing on identifying synthetic slit-type defects in silicon samples.

The experimental setup included an ultrasonic transmitter connected to a computer-controlled scanning stage, which held a tank with the samples and metalens. The transmitter was powered by a pulser, while a laser receiver detected displacements from the sample, converting these into ultrasonic signals for sub-wavelength imaging.

Micron-scale square holes were fabricated in silicon using Deep Reactive Ion Etching (DRIE), and a thin gold layer was added to enhance reflectivity for non-contact, laser-based detection. The metalens channels were also oxidized to make them hydrophilic, ensuring consistent water levels within the channels.

Key Findings and Insights

The study achieved a resolution of 50 microns using micro-fabricated metalenses. Line scans were conducted on silicon samples with synthetic slit defects, both with and without the micro-metalenses. The results confirmed that the hydrophilic properties of the metalens allowed ultrasonic waves to propagate and interact with the defects, which were detected by the micro-focal Laser Doppler Vibrometer (LDV).

Post-processing of the experimental data validated sub-wavelength resolution at the micron scale. A-scan data for ultrasonic inspection of slits spaced 50 microns apart showed defect separation down to this resolution in the bulk ultrasonic regime.

Additionally, a quantitative evaluation of the B-scan profile using metrics such as Peak-to-Side Lobe Ratio (PSLR), Signal-to-Noise Ratio (SNR), and Contrast Ratio (CR) revealed moderate contrast and clear defect visibility, indicating that while the main peak is stronger, the presence of side lobes remains notable.

Finite element (FE) simulations were performed to estimate the resolution limit of the micrometamaterial, confirming that resolution below the periodicity of the metalens was not achievable.

Practical Implications

Advancements in low-frequency ultrasound, combined with micro-fabricated holey metamaterials, show potential for fine imaging. This method is beneficial for detailed *in situ* analysis of electronic materials and devices, such as integrated circuits (ICs) and microelectromechanical systems (MEMS).

The research also has applications in Non-Destructive Evaluation (NDE) and biomedical imaging, where high-resolution imaging of complex structures is essential. Achieving high-resolution imaging at greater depths can improve diagnostics in various fields, including quantum materials, high-energy physics, nuclear power generation, aviation, and biomedical diagnostics.

Additionally, the non-ionizing and cost-effective nature of ultrasonic techniques makes them ideal for large-scale inspections, potentially replacing more expensive and hazardous electromagnetic methods.

Conclusion and Future Directions

In summary, micro-fabricated metalenses proved effective in achieving resolution with a 2.25 MHz commercially available bulk ultrasonic transducer. Their development offers a promising alternative to traditional imaging techniques, enabling high-resolution inspections at greater depths.

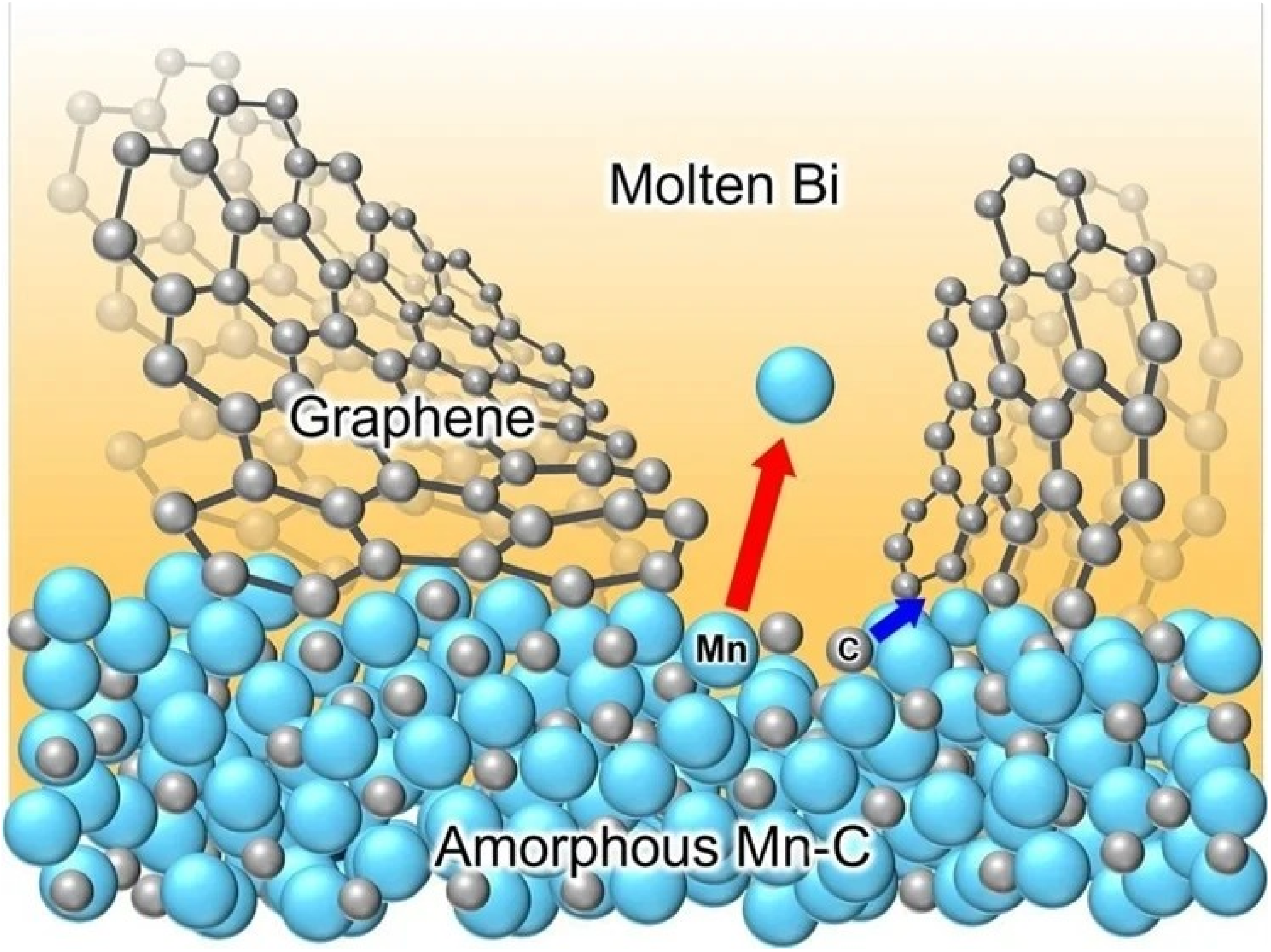
Future work should optimize the micro-metalens parameters and experimental setups, particularly in maintaining water levels within the channels and improving scanning speed. This research paves the way for advanced material diagnostics and imaging across multiple scientific and industrial fields.

Journal Reference

Chandran, L., *et al*. (2024). Micron-scale imaging using bulk ultrasonics. *Sci Rep*. DOI: 10.1038/s41598-024-72634-2, https://www.nature.com/articles/s41598-024-72634-2

New Approach to Flawless Nanocellular Graphene

Since its discovery in 2004, graphene has been transforming materials science and related fields. Graphene is made up of two-dimensional carbon atom sheets combined to form a thin, hexagon-shaped, one-atom thick structure. It has exceptional chemical and physical qualities.



Schematic illustration for the formation NCG during liquid metal dealloying of amorphous manganese-carbon (Mn-C) alloy in a molten bismuth (Bi) to induce selective dissolution of manganese (Mn) atoms and self-organization of carbon (C) atoms into graphene layers. Image Credit: ©S.H. Joo & H. Kato.

Despite its thinness, graphene is extremely transparent, strong, light, and flexible. It also shows exceptional thermal and electrical conductivity, a large surface area, and gas impermeability. Its unparalleled versatility in applications extends to high-speed transistors and biosensors.

A specialized type of graphene called nanocellular graphene (NCG) is created by stacking multiple graphene layers and manipulating its internal structure using a nanoscale cellular morphology. This allows NCG to achieve a large specific surface area.

NCG is highly sought after due to its ability to enhance the functionality of energy devices, sensors, and electronic devices. However, flaws that arise in the manufacturing process have halted its advancement. When NCGs form, cracks frequently appear. Scientists are searching for new processing technologies to create homogeneous, seamless, and crack-free NCGs at suitable scales.

> *We discovered that carbon atoms rapidly self-assemble into crack-free NCG during liquid metal dealloying of an amorphous Mn-C precursor in a molten bismuth.*
>
> *Won-Young Park, Graduate Student, Tohoku University*

Dealloying takes advantage of alloy constituents' different degrees of miscibility in a molten metal bath. Through this process, some alloy components are selectively corroded while remaining intact.

After graphitization, Park and colleagues showed that NCGs using this technique had high conductivity and tensile strength. They also tested the substance in a sodium-ion battery (SIB).

> *We used the developed NCG as an active material and current collector in a SIB, where it demonstrated a high rate, long life, and excellent deformation resistance. Ultimately, our method of making crack-free NCG will make it possible to raise the performance and flexibility of SIBs - an alternative technology to lithium-ion batteries for certain applications, particularly in large-scale energy storage and stationary power systems where cost, safety, and sustainability considerations are paramount.*
>
> *Won-Young Park, Graduate Student, Tohoku University*

Soo-Hyun Joo from the Institute of Materials Research (currently based at Dankook University) collaborated with Hidemi Kato from the same institute, working alongside Park. The details of their research were published in the journal *Advanced Materials* on February 23rd, 2024.

Researchers from Pohang University of Science and Technology, Johns Hopkins University, Tohoku University's Frontier Research Institute for Interdisciplinary Sciences, and the Fracture and Reliability Research Institute collaborated to make their efforts possible.

Journal Reference:

Park, W., *et al.* (2024) Mechanically Robust Self-Organized Crack-Free Nanocellular Graphene with Outstanding Electrochemical Properties in Sodium Ion Battery. *Advanced Materials*. doi.org/10.1002/adma.202311792

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