**The rise of nanomaterials**

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Nanomaterials represent a rapidly emerging industry that is impacting a large number of products ranging from electronics and agriculture to medicine and the defence industry.

Nanotechnology depends on the discovery that when materials are reduced to the size of 1 to 100 nanometres (several thousand times less than the width of a human hair), they start exhibiting strange and unique properties.

As the size of a material decreases, the proportion of atoms located at the surface increases significantly, resulting in enhanced surface reactivity and interactions. This property is exploited in various applications, such as catalysis, sensing, and drug delivery. This was discovered about five decades ago, and the field has evolved in a dramatic way since then.

In Pakistan, the foundations of nanotechnology were laid by me when I was the federal minister of science and technology in 2002 and later as the chairperson of the HEC. I realized the huge potential of this field and established the National Commission on Nano Science and Technology (NCNST).

Prof NM Butt, a scientist of international eminence and former director general of PINSTECH, was appointed to head the commission and develop the trained workforce needed by academia and industry. With the efforts of the NCNST, the Pakistan government, through the Ministry of Science and Technology and the HEC, funded nanotechnology research projects at three universities and two research centres to the tune of about Rs800 million from 2003-2008. This was an exciting and important beginning of this field in Pakistan.

More recently I highlighted the importance of this field to the attention of Mr Latif Ebrahim Jamal, and as a result the Latif Ebrahim Jamal Nanotechnology Center was built from a magnificent grant by the Husein Ebrahim Jamal Foundation at the International Center for Chemical and Biological Sciences located in the University of Karachi.

It has state-of-the-art facilities, and it is carrying out cutting-edge research in various frontier areas of nanopharmaceuticals and other nanomaterials in this rapidly growing field.

Nanotechnology covers almost every sphere of human endeavour today. In agriculture, nanotechnology offers innovative solutions to enhance crop productivity, mitigate environmental impacts, and improve food security. Nanomaterials such as nanoparticles and nano fertilizers can be tailored to release nutrients gradually, thereby improving nutrient uptake efficiency and reducing fertilizer runoff.

Nanofiltration devices can provide pure water instantly. Nanosensors enable real-time monitoring of soil conditions, pest infestations, and plant health, facilitating precise management practices. Nanotechnology also contributes to the development of nanopesticides with enhanced efficacy and reduced environmental toxicity, promising sustainable pest management strategies.

Turning to the electronics industry, we find that it has been revolutionized by nanotechnology, leading to the miniaturization of electronic components and the development of novel materials with enhanced properties. Nanoscale transistors, such as carbon nanotubes and graphene, offer superior conductivity and thermal stability, enabling faster and more energy-efficient electronic devices.

Nanolithography techniques allow for the precise patterning of nanoscale features, paving the way for advanced integrated circuits and high-density storage devices. Furthermore, quantum dots and nanowires exhibit unique optoelectronic properties, enabling the fabrication of next-generation displays, sensors and photovoltaic devices.

Nanotechnology has implications for engineering too, enabling the design and fabrication of materials with tailored properties and functionalities. Nanocomposites, composed of nanoscale reinforcements embedded in a matrix, exhibit superior mechanical, thermal, and electrical properties compared to conventional materials. These advanced materials find applications in aerospace, automotive and construction industries, where lightweight, durable, and high-performance materials are essential.

Nanotechnology also enables the development of nanomachines and nanorobots capable of performing precise tasks at the molecular level, opening new avenues for nanomanufacturing, nanoelectromechanical systems (NEMS), and nanomedicine.

In medicine, nanotechnology holds tremendous promise for revolutionizing diagnosis, treatment and drug delivery. Nanoparticles and nanocarriers can be engineered to target specific cells or tissues, enhancing the efficacy and reducing the side effects of therapeutic agents. Nanomedicine approaches, such as nanoparticle-based imaging contrast agents and targeted drug delivery systems, enable early detection and personalized treatment of diseases, including cancer, cardiovascular disorders, and neurological conditions.

Nanoscale biosensors and diagnostic devices offer rapid and sensitive detection of biomarkers, pathogens, and toxins, advancing disease monitoring and healthcare management.

Nanotechnology finds applications across many other diverse fields, including energy, environment, textiles and cosmetics. In the energy sector, nanomaterials contribute to the development of high-performance batteries and fuel and solar cells, enabling efficient energy storage and conversion technologies.

Nanotechnology also plays a crucial role in environmental remediation, wastewater treatment, and pollution control, offering sustainable solutions to mitigate environmental degradation. Moreover, nanofabrication techniques enable the production of functional textiles with enhanced properties, such as stain resistance, UV protection, and antimicrobial properties.

In the cosmetics industry, nanoparticles are utilized in sunscreens, skincare products and hair care formulations, offering improved performance and aesthetics.

The convergence of nanotechnology and military science has led to groundbreaking innovations that are reshaping the landscape of modern warfare. Nanotechnology offers unique capabilities to enhance military systems, ranging from improving soldier performance to developing advanced weaponry and surveillance technologies. Nanotechnology enables the development of lightweight, flexible, and highly durable body armour by incorporating nanomaterials such as carbon nanotubes and graphene.

These materials offer superior strength-to-weight ratios and enhanced ballistic protection, ensuring better survivability for soldiers on the battlefield. Flying nanorobots can recognize enemy faces in a crowd of thousands and fire bullets accurately, killing them without collateral damage.

Nonenergetic materials, such as nano-thermite, offer enhanced performance, stability, and controllability compared to traditional propellants and explosives, enabling the development of safer and more powerful munitions for defence purposes. Nanorobots or nanomachines can perform various tasks autonomously or under remote control, including reconnaissance, surveillance, repair, and maintenance of military infrastructure, enhancing operational capabilities and reducing human risk.

Nanophotonic devices, such as photonic crystals and plasmonic structures, enable the development of advanced optical technologies for imaging, communications, and sensing applications in military reconnaissance and surveillance. Nanotechnology enables the development of lightweight and high-performance materials, propulsion systems, and sensors for space exploration, satellite deployment, and space-based surveillance in support of military missions and national security objectives.

The government needs to utilize the applications of this important field for the manufacturing and export of high-tech products. The Pakistan-Austria Fachhochschule, a new university of applied science and engineering built under my supervision, is already involved in teaching and research in this field with its focus on the commercialization of nano products such as nanocoatings of surgical goods and nanosensors.

If it wants to stay on the path to progress, Pakistan must invest in such emerging fields as nanotechnology, artificial intelligence, quantum computing, and industrial biotechnology as these represent the value-added industry that will help us to transition to a strong knowledge economy.

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