NanoMarkets Report

Nanosensor Markets 2014

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Summary

Nanosensors—devices capable of detecting nanoparticles—are already in use in the medical diagnosis field, but are expected to see near-term commercialization in military, domestic security and environmental monitoring applications, as well as several other areas. NanoMarkets believes that longer-term revenue generation from nanosensors will also emerge from a variety of uses for such sensors in microelectronics manufacturing and in the construction market. In addition, we also believe that the near-term development of nanosensors will be an important enabling technology for the "Internet-of-Things" and robotics.

This report identifies where and how the commercial opportunities presented by nanosensors will appear and provides detailed projections of the size of these opportunities over the coming eight years. Each nanosensor application is analyzed in detail, showing how it will be brought to market. The report also discusses the strategies being deployed by nanosensor firms and also provides an overview of noteworthy nanosensor commercialization initiatives.

In addition, to being a valuable guide for marketing and product management in the sensor industry, this report will also be required reading for executives in the specialty chemical industry, since it discusses how specific biological and nanomaterials will be used in nanosensors. Coverage of materials includes biological materials and inorganic nanomaterials including graphene and quantum dots. This report also analyzes the business implications notable trends in the fabrication of nanosensors including developments in bottom-up assembly, self-assembly and top-down lithography.

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Chapter One: Introduction

1.1 Background to this Report

Nanosensors—devices capable of sensing nanoparticles—have made remarkable advances during their relatively short history, and NanoMarkets expects to see continued growth in a variety of applications.

The primary forces governing the growth of nanosensors are: (1) the possibility of improved sensitivity and (2) the ability to sense multiple chemical compounds simultaneously. The most immediate opportunities are in the biomedical and healthcare industries. However, NanoMarkets also believes that longer term revenue generation will come from a much wider variety of uses for nanosensors. Several other sectors that are further behind in commercialization but which we believe will have great potential for future profitability include:

- Security, surveillance and military
- Environmental monitoring
- Food management
- Transportation, construction and energy storage
- Robotics and the Internet-of-Things

These sectors are not completely independent, since nanosensors developed for a particular purpose, such as detecting chemical contamination, may be used in many different types of applications. Growth in each sector will also influence the market as a whole, and drive the progression of research activities for components within an individual device or an entire system.

NanoMarkets believes that in aggregate the opportunities for nanosensors are immense and need for small systems to double as analyzers and data storage entities will drive market growth. But participants in this market must remember that nanosensors are still a new technology, however, and, just as for sensors based on microtechnology, it will take some time for nanosensors to start earning significant revenues,

Continuing progress in nanotechnology tools and increasing understanding of nanoscale phenomena, will be necessary to further enhance performance of existing nanosensors and allow researchers to develop nanosensors based on novel mechanisms.

1.1.1 Nanosensors Begin: Healthcare and Biomedical Sector

NanoMarkets believes that the biggest initial market for nanosensors is in the field of healthcare and biomedicine, due to growing demand for faster, smaller portable diagnostic sensing systems that are also more accurate. The capabilities of nanosensors fit very well into this. One example is blood sensors that can detect multiple chemical compounds or pathogens:

- Nanosensors can be used for point-of-care diagnostics that can be used at a doctor's clinic or at home. The development of specialized analytical and medical diagnostic facilities across the globe is driving growth here.

- Current trends also suggest that in the near future preliminary diagnosis or screening will be carried out using nanosensors and nano-enabled integrated systems in large populations. These systems have an edge over existing pathological or microbiological methods since they take less analysis time and are small enough to be easily transported to places that do not have access to medical facilities. They also have the ability to take the market by storm since they have better sensing efficiency than macro-sensors.

- Meanwhile, research in the field of in-vitro nanosensors for diagnostics is progressing and there are a few products that are nearly ready for market testing. For example, researchers at Northeastern University have developed portable nanosensors for monitoring diabetes using an optical nanobiosensor. Vista Therapeutics has recently commercialized a nanowire-based biosensor (NanoBioSensor) that offers real-time monitoring of multiple cancer biomarkers in very low concentrations not achievable by macro-sensors.

Although NanoMarkets believes that medical applications for nanosensors represent the best hope of making money in the nanosensors space, we think that – precisely because medical devices are involved – consideration of the risks inherent in applications that impact human health will tend to impact the market in a somewhat negative way:

- Nanomaterials have to be biocompatible and non-toxic, especially when they are used as in-vivo sensing applications.

- Toxicity issues have curtailed the use of quantum dots (QD) in the medical sector because of the cadmium content in these materials, and QDs have not so far been able to achieve their apparent potential in medical applications.

- Companies dealing with nanomaterials for sensors in medical applications need to consider toxicity, molecular characteristics, leachants, possible secondary reactions generating any toxic side products, and what happens when these materials degrade.

Regulatory factors influence the medical market, so companies dealing in substances that do not require FDA approval are best-positioned to succeed in this market. NanoMarkets sees compelling opportunities for nanosensors in the future to sell products not only to big industries or hospitals but also to consumers in their homes. Miniaturization has already paved the way for customization of technology and fabrication of nanobiosensors as point-of-care diagnostic tools.

1.1.2 Coming Soon: Opportunities for Nanosensors in Environmental Monitoring, Military Applications and Food Management

Environmental Monitoring: Mandatory regulatory checks for waste-producing industries are driving interest in nanosensors for testing environmental samples and continued improvement in nanosensor design. In this context, there is an opportunity for nanosensors to enhance environmental safety, working as check zones for various polluting chemicals, including gases, solid particulates, and ions, along with biomolecules such as pathogenic microorganisms.

Food Management: NanoMarkets believes that nanosensor firms have considerable opportunities to turn their products into indispensable testing methodologies to improve quality control for food and beverage production, transportation, packaging, and storage. Food management is a large industry that could eventually provide significant revenue for companies that can produce high volumes of effective nanosensors.

The market for nanosensors in food management is, however, still very much in development and is expected to increase slowly with improvements in integration of microtechnology and nanotechnology. Once nanosensor companies can provide proof-of-concept, demand for these products is likely to materialize.

Military Applications: NanoMarkets also believes that chemical nanosensors and nanobiosensors will also make a huge impact as security surveillance devices for detecting potential harmful explosives, chemicals, and biological warfare agents. Political unrest and socio-economic disturbances are fast becoming indirect factors for the rise of nanosensors market since countries are willing to invest huge sums on security: In military applications, these sensing units can be deployed in war zones owing to their small size.

Military applications can be very demanding, however, and reliability in this sector is critical. Nanosensors for military applications require exhaustive and extensive pre-testing to calibrate sensing parameters and ensure their ability to check multiple samples accurately and quickly, which could provide barriers to entry for companies that cannot meet the military's stringent requirements.

1.1.3 Expanding the Market for Nanosensors: Improving on Microsensors, Robotics and the Internet-of -Things

The dramatically enhanced sensing properties of nanosensors suggest that in the longer term there are going to be significant revenue generating opportunities to expand the use of these sensors into broader areas.

Improvements on microsensors: NanoMarkets foresees that nanosensors will find a significant addressable market in the medium-to-long term by "stealing" markets from existing macrosensors:

- One example is integrated storage components, where small transducer chips inside the nanosensor are cell membrane penetrable and work as "nanobots."

- In another example, researchers at Tel Aviv University (TAU) in Israel have developed a powerful electronic sensor that makes use of arrays of silicon nanowires coated with specialized chemicals that facilitates detection of dangerous explosives. This nanotechnology-based sensor is quick and highly portable and is more sensitive than macro systems in detecting minute levels of harmful chemicals.

Robotics and Internet-of-Things: Applications in robotics and the Internet-of-Things (IoT) have not yet emerged for nanosensors, but any talk of nanosensors immediately raises thoughts of these two applications:

- In the case of robotics this is probably because of the fact that nanotechnology was originally characterized by the concept of tiny robots engaged in fabrication of macrostructures of various kinds.

- Meanwhile, IoT can be thought of as the deployment of billions of sensors that make our everyday environments more responsive. Some of those sensors would be nanosensors, thereby creating a new addressable market for nanosensors.

Design and problem complexity have so far resulted in very few working examples of nanosensors in these applications. It will probably take a successful prototype to serve as an example in order for this sector to embrace nanosensors. Wireless sensor networks (WSN), which have an edge

over traditional sensors in terms of sensing capabilities, are a promising path for nanosensors to gain entry in this space.

Collaborations: Nanosensors' foray into the commercial sensing market has already begun with collaboration between researchers and industry partners in joint ventures. Companies such as Vista Therapeutics, NanoWorld, LambdaGen, and Nano Engineered Applications, are already participating in such collaborations. These openings are small and localized today but they are poised to grow at a fast pace in niche sectors of security and medical industries that are relatively price-insensitive.

In order to further expand into commercial markets, nanosensors will need to justify the initial investment for developing nanosensor-based products and their associated higher costs. Some of these businesses may be able to justify costs if nanosensors can meet technical requirements that macro sensors cannot, but very cost-sensitive markets cannot justify using nanosensors in their current state of development.

Sensor developers will have to overcome the present high costs of production in order for their sensors to be used in consumer products. As is the case with any developing technology, prices will eventually go down once lifetime, usability and production yields increase sufficiently to enable economies of scale.

1.1.4 Developing New Nanotechnologies for Sensors

Novel synthetic approaches for nanomaterials: The "top-down approach" to nanotechnology, whereby nanostructures are created, manipulated, and modified by machine, is sometimes incapable of offering complexity and economy. However, with the advancement of manufacturing processes, this approach can be extended for developing nanosensors with many such sensors created on a bulk surface.

Meanwhile, the focus of synthesis of nanomaterials has increasingly shifted to other processes, principally those that use molecular self-assembly (MSA) or "bottom-up" methods. Under the right conditions, the atoms, molecules, and larger units combine strategically with one another forming self-assembled moieties such as hybridization of DNA molecules:

- Nucleic acid self-assembled nanostructures are going to be very important in sensing systems particularly as biosensors for the detection of pathogenic micro-organisms, cancerous tumors and biological warfare agents.

- Companies such as Sigma Aldrich (U.S.), and Life Technologies (U.S.) have a good number of manufactured self-assembled structures. The market for these molecules at present is restricted to research activities across the globe however most of the dedicated laboratories are manufacturing their own molecules and are expected to grow slowly.

These nanofabrication processes are a pre-requisite for designing physical nanosensors and their development will facilitate nanosensing device preparation which had been a difficult task owing to technical limitations of fabrications.

Flourishing nanomaterials like graphene, CNTS and their chemical derivatives: Newer classes of nanomaterials are continuously sought for improved characteristics for better sensing capabilities. There are many such materials being looked at, especially single-walled carbon

nanotubes and graphene. For example, pressure nanosensors based on graphene are a promising line of research with many interesting results.

NanoMarkets believes that the market for these novel nanostructures is bound to expand owing to their high quality. Importantly they will help the sensor industry since many of their potential applications are already patented. The nanomaterials are all relatively new, so the market for nanomaterials will be a research space before nanosensors are validated.

1.2 Objective and Scope of This Report

NanoMarkets' latest report on nanosensors details the advances in sensing devices capable of detecting nanoparticles. The objective of this report is to analyze and forecast the space of nanosensors in the coming eight years, in light of ongoing research activities in both academia and industry.

The report includes a comprehensive analysis of both conventional and less common or emerging applications of nanosensors. The goal of the analysis is to project the market growth of nanosensors in sectors where these devices may be capable of revolutionizing our lifestyle. We provide eight-year forecasts based on projected growth in each segment of the market.

This report provides detailed information about many factors influencing the future of nanosensors. It covers noteworthy developments in nanotechnology that influence sensor design and assesses some of the key materials that will govern the evolution of nanosensors.

We evaluate the technical and market strategies of existing nanosensor producers and budding entrepreneurs in this industry and look at the changing dynamics of small and large manufacturers. The report also discusses the synergy between academia and industry and how that will affect future development efforts.

The report examines current markets trends, looking at both market drivers and factors that will impede market growth in nanosensing devices. It also evaluates the demographic pattern of the existing market and how that may change in the future.

1.3 Methodology for This Report

The information in this report was gathered through both primary and secondary sources. Primary sources include discussions with entrepreneurs, business owners, business development and marketing managers, and technologists.

We gathered secondary research from trade association publications, scientific review and research articles, online journals, news articles, and online research including third-party references. We also used company marketing information, advertising, press releases, and news sources.

The forecasting approach in this report identifies and quantifies the underlying addressable markets using mathematical forecasting models. The final market figures are estimated after assuming plausible penetration levels of nanosensors in each application and appropriate estimates for pricing of nanosensors. In each of the applications, we consider potential growth rates in order to arrive at the final market figures. We also evaluate the stated plans of the key firms in the market in our forecasting analysis.

The market size is estimated for each of the major application areas of nanosensors. These applications areas include security, surveillance military, healthcare, environmental monitoring, food management, transportation, construction, energy storage, and nanoelectronics.

1.4 Plan of This Report

Chapter Two details the advantages and limitations of the use of nanotechnology in sensing applications. Successive sections illustrate the continual advances in all aspects of nanosensing technology, emphasizing grey areas and key innovations. We identify notable technological and commercial trends for both raw supplies and nanomaterial production techniques, explaining how those translate into novel systems for sensing various analytes. We give special attention to nanosensor technologies and suppliers that have the greatest potential of becoming dominant in the market and are most likely to provide significant benefit to a global population.

Chapter Three examines primary and secondary applications where the capabilities of nanosensors are best suited. We discuss current and future approaches for medical and non-medical applications, pointing out specific examples of applications that can benefit from nanosensors. This chapter includes eight-year forecasts of nanosensor revenue for each market segment.