Large-Area and Printed Sensor Markets: 2009-2016

Chapter One

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About the Report:

The sensor market will take off rapidly in the next decade, driven by the needs for better diagnostics for an aging population, environmental monitoring, national security and military markets and -- in the not too distant future -- small scale robotics. These are diverse applications areas, but one factor that they will have in common will be the need for sensors that are distributed over large-area, flexible substrates. In many cases, these large-area sensors will be created -- in all or part -- with printing technology.

NanoMarkets believes that while some of the most exciting opportunities in this sector lie in the future, there are already ways to tap into this emerging market that can leverage existing technologies, materials, manufacturing approaches and marketing channels into new business revenues. The objective of this report is to identify just where these opportunities are.

Beginning with an analysis of the potential from existing printed sensor products such as sensors with printed electrodes and diagnostic test strips and assays, this new NanoMarkets report provides a roadmap and revenue forecast that will point out where and how the money will be made on the way to fully functional large-area sensor systems.

This report will also show how new developments in printed electronics, substrate materials and sensor materials will enable this new kind of sensing system. It will g on to discuss the commercial implications of current sensor trends from singlet devices such as gas sensors and pressure sensors to complex layered subsystems such as smart noses, smart skins and labs on a chip and how these new kinds of sensors represent a station on the way to true wide-area sensors.

The report will provide a guide to where and when the demand will emerge for wide area and printed sensors in the all key application sectors including military, medical and genomics/proteomics, national security, pervasive computing, robotics, transportation, smart packaging, smart buildings and environmental monitoring, and consumer electronics. Finally, the report will discuss the latest R&D developments in this field as well as the strategies of the firms that are commercializing this new technology and where they are looking for first revenues.

This report will be invaluable to sensor firms, manufacturers of smart materials and nanomaterials, printed electronics companies, applications developers, as well as electronics and medical device firms more generally.

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Chapter One: Introduction

1.1 Background to the Report

1.1.1 Large-Area Sensors and Printed Sensors

Large-area sensors are sensor arrays fabricated together on a substrate, often a flexible substrate. This distinguishes them from the garden variety of sensor, which is typically a single chip or chipset. The inherent performance advantages of large-area sensors are the same as any other sensor array. First, there is extra redundancy because the failure of one sensor in the array doesn't disrupt the entire array. Second—and in practice more importantly—large-area sensors provide for enhanced accuracy. This may be because the input from a sensor array can take the form of an average from all the sensors in the array, thereby factoring out anomalies. Or it may be because sensing over a large area speeds up response time in some critical way. A soldier in a uniform embedded throughout with sensors that can pick up on the first trace of a deadly toxin is better equipped and more secure than one who simply carries an individual sensor device around with him. The latter may detect the toxin only after the soldier is dead.

Large-area sensors are typically associated with "printed sensors," or at least printed sensors of a certain kind. Actually, the term "printed sensors" is somewhat ambiguous, perhaps deliberately so. Many sensors use screen printing for the deposition of electrode materials and have done so for many years. Although this kind of activity in one way or another generates large revenues every year, it is a mature area that hardly represents an opportunity in the usual sense of that word. There is another kind of printed sensor, however, and this is a sensor in which functional printing is used to create the entire sensor. It is this second kind of printed sensor that we are largely interested in here.

The connection between large-area sensors and printed sensors of the second kind is that printing potentially provides a way to create large-area sensors in a low cost manner; we are, after all, talking here about printing onto a flexible substrate, something that printing is very well equipped to do. Printing is also well suited to create multiple layers; in fact this is what functional printing is really all about. This means, at least in theory, that layered sensor products can be created with functional printing. This may mean no more than the fact that both the sensing layer *and* the electrodes are created with printing techniques. But this fabrication concept also may be extended to producing sensors with multiple sensing layers, so that the sensor can sense multiple things. As we discuss in the main body of this report, this multi-sensing function is one of the main trends in the sensor industry today and, as such, printing is in sync with bigger trends in sensing.

With all that said, there is no unbreakable link between large-area sensors and printed sensors. Large-area sensors could be created using the conventional deposition and patterning processes found in the semiconductor industry; vapor deposition and photolithography, for example. Or, at the other end of the manufacturing technology maturity scale, one could imagine large-area sensors being created using the tools of nanoscale engineering. We discuss all of these approaches later in this report. However, the prospect that printing will enable large-area sensors to be created at low cost, coupled with the fact that printing is obviously a mature technology seems to ensure that the association between large-area sensors and printing is and will be a strong one.

1.1.2 The Large-Area Sensor Business Today

To date, printed and large-area sensors have played second fiddle to other developments in the thin-film and printed electronics. Thus, the latest developments in this field have already spawned substantial new companies and internal projects by major multinational companies producing solar panels, displays and even RFID tags. Although the processes and materials that are used in fabricating large-area sensors are very similar to those used in these other areas, it is hard to point to the same level of economic activity in large-area sensors as one finds in these other areas. Indeed, NANOIDENT, a commercial firm that tried more than any other to give printed sensors a try for about a year, has now gone out of business. And, even a cursory review of the literature on wide-area electronics quickly indicates that much of the most interesting work in this field is being carried on in university labs. With all this in mind, a cynic might conclude that large-area sensors are a fanciful and futuristic idea whose time has yet to come around and that such sensors have no near-term commercial importance.

Nonetheless, NanoMarkets believes that such a conclusion would be a false one, and that there will soon be significant business opportunities in the large-area and printed sensors sector. For a start, we believe that the large-area sensor business should be judged by the standards of the sensor industry, not by other thin-film and printed electronics businesses. Thus, the sensor industry as a whole is very fragmented, with many rather low-key, medium-sized firms that are often not well known outside of their specialized community of customers and suppliers. Therefore, one should not expect the large-area sensor business to be filled with the large, high-profile firms that one sees in (say) the e-paper, OLEDs, or thin-film solar panel segments.

In fact, when one begins to list the firms that are already active with actual products in the world of large-area or complex printed sensors and combine them with the names of the industrial labs that are making serious efforts to commercialize such devices, the final tally of names is quite impressive. This tally would include—but certainly not be limited to—Agilent, Collotype Labels, Cypak, Frank Sammeroff, Future-Shape GmbH, IMEC, PARC, Peratech, plastic

electronic (*sic*), Sony and VTT. Most of these names are not exactly familiar ones in the average household. However, they are the sort of firm that characterizes the sensor industry as a whole.

1.1.3 The Case for Large-Area and Printed Sensors

With a little digging, one realizes that real products do exist, or are at least heading toward commercialization, that fit into either the large-area sensor category or one that involves printing to create more than just electrodes. This certainly adds credibility to this emerging sector, but is hardly a business case in itself. After all, history is littered with stories of clumps of firms that formed a community of interest around a new technology and maybe even brought a few products to market, only to see their dreams fly out the window.

NanoMarkets believes that large-area sensors are different in this regard mainly because large area and advanced printed sensors seem to have a very broad range of potentially high-growth applications. At the same time, the latest developments in functional printing seem to provide a way to fabricate such sensors at low cost. The combination of these two facts suggests the possibility of a class of sensors that are both novel and with large and fast growing markets. The novelty of such sensors means that there will be good opportunities for suppliers to establish sustainable advantages in the form of proprietary manufacturing approaches and intellectual property.

Applications for large-area and printed sensors: The kind of sensors discussed in this report show little likelihood of generating large revenues in the next couple of years. However, what makes us so bullish on this sector is that these sensors seem especially well suited to—and therefore likely to strongly penetrate—some of the fastest growing segments of the sensor market, which in turn, we believe, are driven by larger socioeconomic forces. While these segments of the market are all very different in terms of their business characteristics, they need similar kinds of large-area and printed sensors.

This means that the cost of developing these sensors can be amortized over a wide range of large applications and that firms supplying the basic sensor subsystem can sell into multiple segments. Of course, a sensor firm may also choose to move up the value chain and capture more of the value added by offering more complete products specialized for a particular application or user segment.

There are three general areas where NanoMarkets believes printed/large-area sensors could command a large market in the next five years or so. These are:

- Military and national security applications: Large-area sensors of various kinds seem extremely well suited for protecting large public buildings from terrorist threats as well as for use in military uniforms at a time when security concerns are heightened throughout the world.

- Environmental monitoring: Large-area and low-cost printed sensors have the potential for broadening the coverage of government and private environmental monitoring efforts. In particular, they are likely to serve as important components for the next generation of smart buildings. Thus, these sensors can be seen as an essential part of the "green tech" trend, which in itself is useful to sensor suppliers for market messaging.

- Biomedical markets: Defined broadly enough this is already the largest market for printed sensors, because both diabetic test strips and DNA assays are already printed. The latter application is especially important because DNA testing is assuming a growing role in our society and because a new wave of biological testing based on proteomics is about to take over. In addition, large-area sensors are a vital component for the emerging product/market categories of smart bandages and human enhancement. Many of these opportunities for sensors are being driven by the needs of aging populations in the developed world.

These are by no means the only applications in which we see a market for the kinds of sensors discussed here. They have been considered by major aircraft firms to provide additional comfort and safety for passengers, for example. In addition, there are a number of other areas that could provide substantial markets for the kinds of sensors considered here, but not until the closing years of the forecasts considered in this report. There are three areas that seem to present longer-term opportunities for advanced printed sensors and large-area sensors. These are:

- Robotics: In the past four or five years, personal robotics in the form of robotic lawnmowers and vacuum cleaners has shown itself to be a sustainable source of revenue. In addition, and in Japan especially, impressive humanoid robots have been built as companions and concept products. Sensors are inevitably a part of robotics and the type of sensors discussed in this report may have a special role to play in robotics; printed sensors in the form of lowering costs and large-area sensors in the form of smart skin technology. Robotics could be the next big technology revolution, akin to the PC revolution in its ability to generate new business. But this revolution is not likely to occur for several years.

- Pervasive computing: There has been much talk in the past five years of a new kind of computing that involves the "Internet of Things," in which smart objects are connected over Internet-like networks. As with robotics, printed and large-area sensors could play

an important role in this sector. However, it seems to us that pervasive computing is still some way from proving itself commercially, so the size of its potential for generating sales of sensors remains to be proved.

- Smart packaging: This is another area that still has to prove itself. There already seem to be some niches where smart packaging can make economic sense. Two examples are compliance packaging for pharmaceuticals and packaging designed to ensure the authenticity of branded products. Typically in the smart packaging area, cost points are very important and printing may help with that, especially since printing is already intrinsically a part of the packaging industry.

The reality of printing sensors and the alternatives: Printed electronics is either a new business or an old one, depending on how one defines the term. Thus, screen printing has been used for many years to create electrodes, membrane switches, capacitors, PCBs, etc. In these cases, printing was used almost as a coating technology or for the creation of large features. The new form of printed electronics, which has mostly emerged in the last five years, is intended to create complete devices with relatively small features, including sensors, although sensors has not been the area where most of the focus of printed electronics has been.

We consider both kinds of printed electronics in this report, because some of the more established areas of the printed sensor business (e.g., DNA assays) use printing in a traditional way. However, the focus here is on the newer kind of printed electronics, which seems to offer the potential for fabricating complex sensors at very low cost points. In addition, as we have already noted, printing seems a natural fit for creating sensors on a large-area substrate. This is the dream anyway. However, the new kind of printed electronics has had teething problems and has not advanced as fast as expected, a fact that needs to be considered in assessing the future of printed sensors. The current thinking on printed electronics is that initially printing will be used only for certain layers of making a device; the idea of creating a device entirely with functional printing has been put off for a while.

The term "printed electronics" typically refers to either screen printing, inkjet, or flexo/gravure processes. Functional inkjet has received a lot of attention because of its cited ability to create very small features and this fact could make inkjet highly suited to fabricating sensors. Flexo/gravure are very high-throughput processes and are therefore suited to (say) diabetic test strip products.

There are, in fact, dozens of different kinds of printing and almost all of them have been tried at one time as a means of fabrication for electronics devices including some sensors. One is perhaps worth a special mention here because it seems to have special relevance to sensors;

this is transfer printing. In transfer printing, semiconductor devices are created using the conventional processes of the semiconductor industry. Then the devices are lifted off an existing rigid substrate and onto the flexible substrate. This process may be particularly suitable to sensors since it potentially enables high-performance arrays to be created on a flexible substrate, while, at the present time, more conventional printing methods tend to produce products with limited performance.

The mention of semiconductor industry processes raises the question as to whether any of the processes used in this industry are appropriate to creating large-area sensors. The answer is probably yes, but only in the cases where performance trumps cost. And then finally, there is the possibility that some of the advanced tools of nanotechnology, such as nanoimprint lithography (NIL) or dip pen nanolithography (DPN), may have a role to play in the markets.

1.2 Objectives and Scope of this Report

This report analyzes and quantifies the opportunities for printed and large-area sensors that are appearing as the result of the market and fabrication developments discussed in this report. A very broad range of sensor types are considered here including (in no particular order) gas and liquid sensors, mechanical sensors, diagnostic test strips, sensors for smart textiles, smart noses and tongues, smart skins, biochips and microarrays, labs-on-a-chip and optical/image sensors.

While we have aimed at covering as broad a range of printed and large-area sensor types as possible, there are a few areas that we have specifically excluded. Both RFIDs and photovoltaics (PV) could to some extent be considered sensor technologies; both are likely to use a growing amount of printing in their fabrication, and PV is certainly a large-area technology. However, both PV and RFID are really self-contained markets and industries with their own rules and are usually considered separately from the general sensor industry.

NanoMarkets has covered both sensors and printed electronics in numerous reports over the past five years. This report brings together NanoMarkets' deep experience in this field with its analysis of the latest developments, new products, technology breakthroughs, new licensing and marketing arrangements and recent M&A activity. And while the main objective of this report is to focus on the evolving opportunities in printed and large-area sensors, it will also seek to explain where there have been apparent failures and analyze why these have occurred.

In addition to analyzing the printed and large-area sensor market, another major goal of this report is to provide detailed forecasts of the main product/market segments addressed by such products. In the forecast section, we have also discussed how our projections may vary under different scenarios and how likely those scenarios are to occur. Last but not least, we

have presented an account of the roles and strategies of important firms and other organizations active in the market and their apparent successes and failures.

1.3 Methodology of this Report

As with all NanoMarkets' reports, our assessment of the business prospects for printable and large-area sensors is based on analysis of the underlying needs for the features and capabilities that such products can potentially offer. We therefore believe it is vital to understand where the actual demand will come from and what type of capabilities the market is looking for.

To determine where printed and large-area sensors are headed commercially we based this report on both primary and secondary research. The primary research came from NanoMarkets' ongoing interview program in which we conduct regular interviews with key executives throughout the entire thin-film, organic and printable electronics value chain—including manufacturers of equipment and materials and of devices and subsystems themselves.

The secondary research for this report drew on the World Wide Web, commercial databases, trade press articles, SEC filings and other corporate literature to fill out what is going on in this sector. NanoMarkets' researchers have also been frequent attendees and speakers at important trade shows and conferences.

In this report, we match the demand-side analysis with an assessment of what is going on in the area of printed and large-area sensor commercialization at major technology developers and—where it seems relevant—at the universities. This enables us to develop a view on what the opportunities in this space are going to be and what the appropriate business models are. The forecast approach taken in this report is explained in more detail in Chapter Four.

1.4 Plan of this Report

Chapter Two of this report analyzes the main technology trends in the printed/large-area sensor space, while Chapter Three does the same thing for the markets in which this type of sensor competes. Chapter Four includes our forecasts of printed and large-area sensor products broken out by technology and applications.

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