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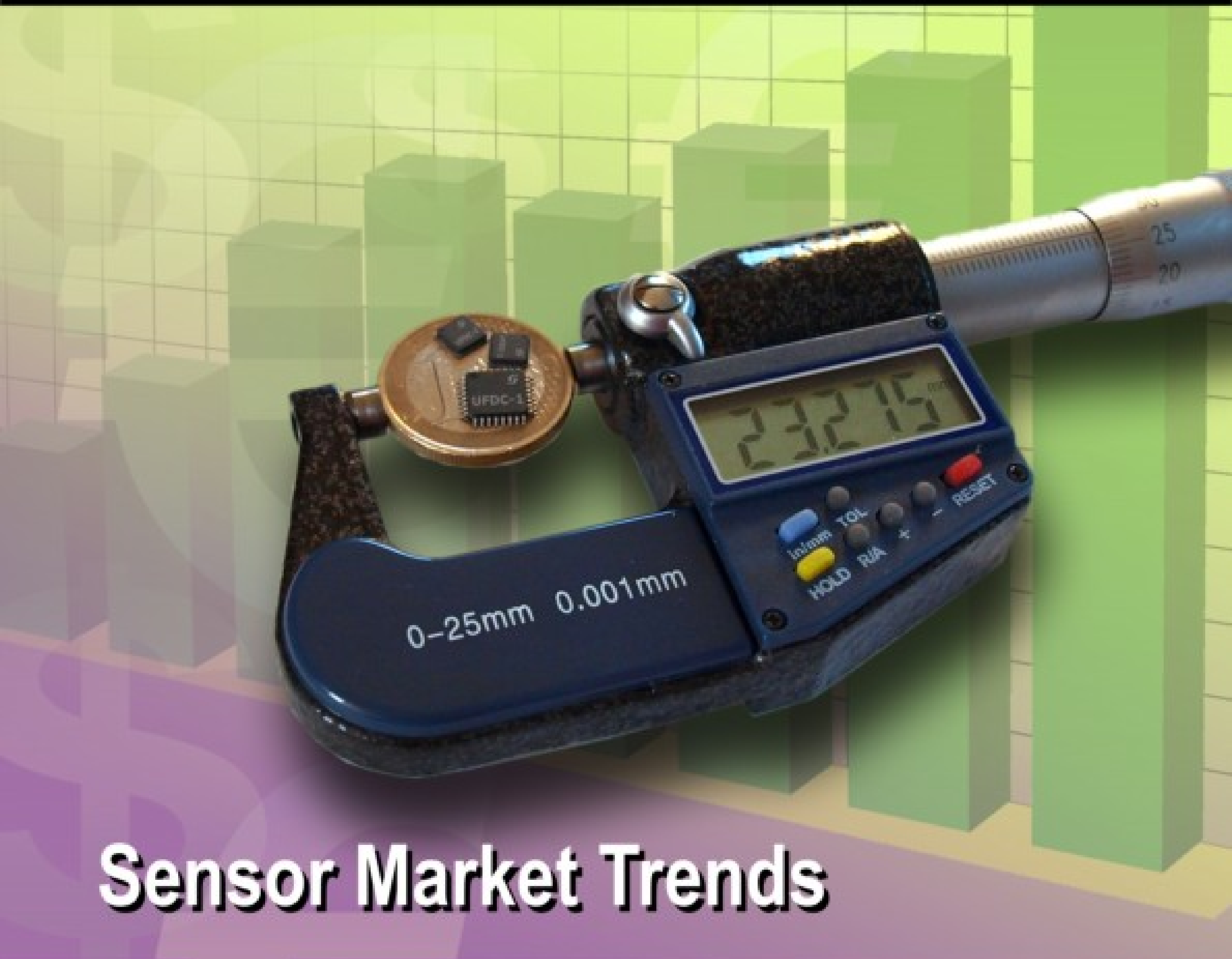

Sensor Market Trends

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Pushing Low-Cost Sensors to Market

A NanoMarkets White Paper
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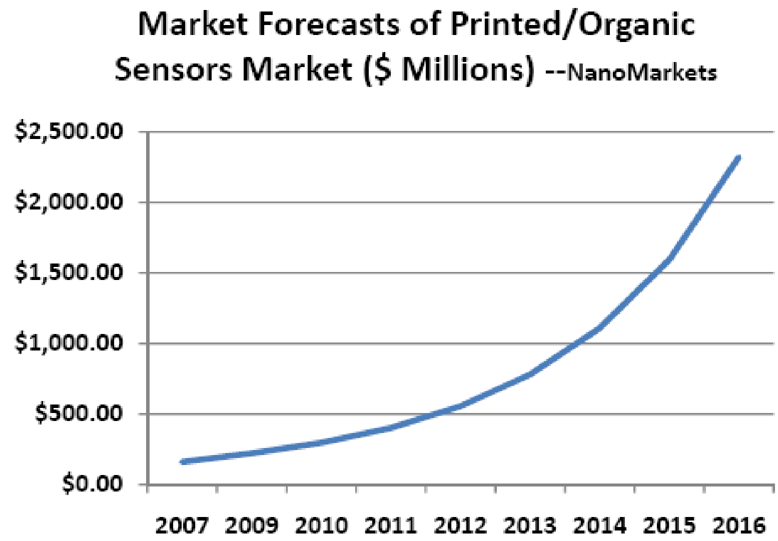
Synopsis: One of the less talked about markets for printed and organic electronics is sensors. In fact, printed electronics is already used for sensor electrodes and to fabricate DNA arrays. In the future, NanoMarkets expects much wider use of printed electronics, including the printing of the on board processing power. New materials – such as printed silicon and rubrene transistors – will help in this regard. And, while most printed sensors have used screen printing the past, other printing modes are looking promising for fabricating sensors; flexo can do it in greater volumes and inkjet with more accuracy. *Copyright © 2008 IFSA.*

Keywords: Nanomarket, Printed electronics, Organic electronics, Rubrene transistors, Printed silicon

1. Introduction

There are many promising markets today for electronic sensors, if mainstream silicon technology could produce sensors at a cost that's low-enough for most of these markets. Bringing diagnostics closer to the patient and improving the coverage of both environmental and security monitoring in major public buildings are just two that spring to mind. This leaves a wide-open opportunity for alternative materials and manufacturing technologies. Two of the strategies that suggest themselves in this regards are the use of functional printing and the use or organic electronic materials. And both of these approaches are already in play.

NanoMarkets believes that sensors using organic and/or printed electronics are poised to surpass $ 220 million in revenues in 2008 and will surge ahead to exceed the $1 billion mark in 2013. However, in a recent report entitled *Printed and Organic Sensor Markets: 2007- 2015*, we predict that the application mix of the market will undergo some very interesting changes over this time period.



2. The Application Mix

Perhaps not surprisingly, much of the revenue generation that NanoMarkets expects from printed and organic sensors from now until 2015 will have much to do with biology. DNA microarrays are routinely fabricated using printing and, as a result, genetic applications will provide the lion's share of sensor revenues through 2012, at which point environmental monitoring applications will take over the number one position. Medical diagnostic and therapeutic applications will also play a major role in printed sensor markets throughout the period considered in the report.

Other important applications areas for printed and organic sensors will include smart packaging, robotics and homeland security. One of the most interesting applications for these kind of sensors will be found in smart textiles, which is a business that is just getting started, but has a very high growth potential; applications for printed and organic textiles will grow consistently over the period, accounting for about a 10% share of a total $2.3 billion market for organic and printed sensors by 2015. The range of applications for printed and organic sensors is quite broad as shown in Table 1.

3. Stage I: Printed Electrodes in Sensors

Where the sensor makers have seen the value of organic and printable electronics to date is mostly in the area of printed electrodes. The feeling in at least some segments of the sensor industry is that printing can potentially reduce manufacturing costs for sensors of all kinds, and that's extremely important for smart packaging and point-of-care medical diagnostics, where there is pent-up demand for less expensive devices. The ability to print large sensor arrays on flexible substrates will find particular favor in a number of sensor segments--in architecture and construction, for example, protective clothing and military uniforms, smart labels and packaging, robotics, aerospace, the automotive industry and most certainly homeland security. But what inks does one use? In the past few years, a slew of new conducting, insulating and semiconducting materials have appeared for use in organic and printable electronics. Silver has historically been the most common electrode material used in thick-film (i.e., screen printed) electronics. Not only is silver the most conductive material known, but when it oxidizes, the oxide is also reasonably conductive. Silver is, of course, relatively expensive, but NanoMarkets believes it will remain the preeminent printed electrode material for some time, especially considering the enhanced performance demonstrated by the latest nanoparticle silver inks.

Table 1. Opportunities for Flexible Sensors.

Application Area	Type of Sensor
Architecture and construction	Sensor arrays on flexible substrates that will conform to the contours of walls and ceilings. Such sensor arrays would have immediate application for sensing toxins or atmospheric quality. It might have future uses for imparting ambient intelligence to buildings
Protective clothing and military uniforms	Sensor arrays embedded in clothing would help protect soldiers, police, fire, and power plant workers from exposure to toxins. Clothing of this kind could be targeted towards detecting just one toxin (e.g. radiation) or multiple toxins. The latter kind would be especially appropriate for military uniforms.
Smart labels and smart packaging	Printed sensors on paper or plastic labels that could indicate tampering, freshness, frequency of use (of pills.) Still some way from being cost effective, but fairly close to commercialization
Robotics	Artificial skin would consist largely of tactile and (perhaps) heat sensors on a plastic substrate
Automotive and aerospace	Extension of the current wide use of sensors to arrays that cover entire surfaces, both inside and outside the vehicle. Applications could range from security, through atmospheric controls, to passenger comfort.

It’s hard to see silver being pushed out of its prominence, short of an apocalyptic price rise. But should it do so, copper might provide an alternative. But copper oxide is non-conductive and in particulate form, copper is quite dangerous, with a nasty tendency to burst into flames. There are, however, new processes such as special forms of electroplating that favor the use of copper for the electrodes in electronic sensors and other devices. Nickel inks are also a possible silver replacement if push comes to shove and such inks have found use in some thick-film electronics applications.

Then there’s gold ink. For obvious cost reasons, gold is not widely used in printed electronics today, but because it has long been established as safe for medical implants, gold may have a special role to play in medical sensors. When NanoMarkets talked with firms that produced gold inks recently we found that they were doing a brisk – if niche-like – business with their products.

4. Stage II: Printed and Organic Processing

While printed conductors of various kinds set the stage for the printed sensors of the future, the hope is to go further; much further. In the gradually emerging view of the future, printed and organic electronics will be used to provide the actual processing power or the sensing fabric of the sensor, not just the electrodes. And as Table 2 shows, there are a lot of ways that printed and organic electronics can be used in the sensor business.

Table 2. Organic/Printable Electronics-Generated Opportunities in Sensing.

Feature of organic/printable electronics	**Description**	**Impact on Sensors**	**Other Comments**
The ability to create circuitry with modest upfront investments	A full-scale plant capable of turning out perhaps millions of sensors per year might entail a capital investment of $100 million or much less. Industrial printing equipment is much less costly than the semiconductor industry's standard photolithography equipment	Complex sensors can be built and sold at lower prices. This can turn expensive medical diagnostic equipment into lower cost point-of-care or even home diagnostic equipment, with the obvious benefits. Or it can enable the wider deployment of important homeland security or environmental testing gear.	At present, this is the aspect of organic/ printable electronics that is seeing the broadest application. Sensors are often layered devices and it is now not uncommon for sensor firms to consider using printing as a way of depositing such layers.
The suitability of organic/printable electronics to create wide area electronics	Transistors, memory, photo-sensitivity can be deployed over a large surface to create unique products	It is possible to create large arrays of sensors using printable electronics relatively easily. These could have applications in many fields	Sensor arrays have been a mainstay of the sensor business for many years. Printable electronics offers a new and easy way to make them
The ability to create flexible products	Organic, metallic and other inks can be printed on flexible substrates including plastic, metal foil and even paper	Sensor arrays can be made to conform to the shapes of products and buildings more easily. Low cost substrates can be used to create disposable sensor products that would be useful in medical and other fields	The ability to print functional devices onto flexible substrates is just beginning to see full commercialization in the display area, but clearly has some potential in the sensor area too
The ability to manufacture in very large or very small quantities	Maskless printing techniques, such as inkjet, can create functional devices economically in very small quantities; or even in "one offs." Highthroughput printing techniques, such as flexo, can be treated as low-cost manufacturing approaches for high volumes of devices	These new manufacturing techniques may be used to create cost effective sensors for specialist scientific, medical or military applications. Or they may be used to create millions of sophisticated sensors for mass deployment.	The low-volume capabilities of printing fits well with the perceived general marketing trend towards the customization of products. The highvolume capabilities of printing adds a new kind of tool to tool kit commonly used to create mass market functional devices.
Organic electronics may be the precursor to molecular electronics	The idea of a new paradigm for electronics using complex molecules has been around for years and has enjoyed periodic vogues in the research community.	Sensors would certainly be part of any molecular electronics that actually developed, but this has not been a major research focus as far as we are aware.	Research funding has fallen off in recent years amidst criticism that there are fundamental problems with the whole molecular electronics project.

Printed silicon approaches are now being pursued by a number of firms and would have the advantage of drawing on the high performance of silicon and the vast knowledge of silicon as an electronic material. However, printed silicon is at a very early stage of its evolution. The most likely approach here is using organic semiconductors to manufacture transistors. Pentacene is the most used material today for organic thin-film transistors (OTFTs,) but other materials such as rubrene promise faster processing in the future. The development of OTFTs is mostly going on in the context of developing flexible backplanes for displays and on-board processing power and memory for RFID. However, organic semiconductors may offer one characteristic that makes them extremely attractive for sensors: the ability to chemically tailor the structure of the organic molecule to detect a particular thing.

The organic compounds contending for use in printable electronics are about 1,000 times less conductive than metals. The electron mobility of organics lags even that of amorphous silicon, which is far less mobile than polycrystalline silicon and single-crystal silicon. Even at their sub 1 cm/V-s mobility level, however, organic materials will be adequate for low-end sensor applications, including many biosensor scenarios.

Because sensors are often based on unusual properties of unusual materials, this will be one area of printed electronics where we should expect the unexpected. Consider the following; there's also a new class of materials, called Quantum Tunneling Composites (QTCs) that may hold some promise for sensors. Constructed of polymers filled with carbon, they operate by responding to physical deformation: compression, twisting or stretching, for example. At one point, a highly efficiency insulator, and at the next a metal-like conductor, these composites have a tunable transition from insulator to conductor that follows a smooth and repeatable curve.

Outside of QTCs, Carbon – including carbon nanotubes – are finding a growing range of applications in sensors. In fact, carbon pastes and inks have been thick-film deposited and screen-printed for a number of years. Screen-printed carbon inks have already found commercial success in the glucosesensing field. And carbon electrodes have properties that make them ideal for electroanalytical applications. Meanwhile, carbon nanotube sensors have been discussed in the literature for years, while printing is beginning to seem like the way to go for low cost nanotube deposition, for example. Printed nanotubes have been at the core of some recently high-efficiency lighting proposals for example.

5. Printer's Choice

Just as there's a variety of candidate materials for the different parts of an electronic sensor, so too is there a broad choice of methods available for material patterning and deposition. While photolithographic processes provide are clearly the way to go as we progress down the Moore's Law curve to the 45 nm curve and beyond. But for many low- and moderate-complexity devices, printing can do the job and is a far more cost-effective way to go. Printing equipment is inexpensive (certainly compared to the plant used in an Intel fab,) and it is relatively good when it comes to material wastage.

Traditional mask-based patterning and deposition of materials is extremely wasteful. Sequentially depositing red, green and blue phosphors through three masks, for instance, essentially wastes twothirds of the material applied. As an additive process, printing reduces material costs, a factor that becomes more important the higher the cost of the material being used. (Certain organic inks and – more obviously gold and silver inks – used in sensors are quite expensive.) Finally, printing also has another unique advantage when it comes to sensors. Printing is effective in covering large areas very quickly, which is an important feature for manufacturing larger sensor arrays.

Almost any kind of printing approach can be used to create sensors, and several techniques are already being used in both commercial and R&D environments. Screen printing is the old stalwart from the days when "printed electronics" meant thick-film electronics, and there is a wealth of materials and accumulated expertise in this arena that could be leveraged for new-generation devices. Electrodes for electronic devices—-including sensors—-have in fact been screen printed for years. Screen-printed electrodes have low unit costs in line with low-end requirements, including the production of disposable sensors. Screen printing is (for a printing technology), wasteful of materials and not generally conducive to high-volume production.

Higher volumes of printed sensors would probably be made using flexography, which has currently found a home in functional printing in the form of printing RFID antennas on labels. Gravure may also ultimately have a role in printing electronic sensors, when demand for volume production justifies its high set-up cost. Where a lot of excitement has been generated is in the ink-jet sector. Ink-jet is economical to use for small volumes and, thus, valuable for R&D and rapid prototyping; which is where a lot of the more advanced organic and printed sensor activity is right now. In addition, because inkjet uses relatively small quantities of material, it's very appealing for high-volume operations.

The higher the material cost, the higher the value placed on inkjet printing and alternatives that minimize materials usage. Applications requiring gold and silver will doubtlessly try to move in this direction. On the other hand, there is a real question about just how far ink-jet could scale up. Inkjet printing, further, has the added benefit of excellent registration, which can be critical for devices such as sensors that typically require precise alignment of multiple layers.

The Nanomarkets report***, Printed and Organic Sensor Markets: 2007-2015*** describes some of the more exciting work being done today in organic and printable electronic sensors. One example, just the tip of the iceberg, may give some impression of the type of promise printing techniques and novel materials hold for the future.

Agilent Technologies, the world's second-largest manufacturer of nucleic acid microarrays, is making quite a splash with its ChIP-on-Chip (chromatin immunoprecipitation-on-chip) DNA microarrays, manufactured using a variation of the company's SurePrint inkjet technology. Agilent can design and print a custom microarray at about one-tenth of the price of microarrays fabricated using traditional photolithography. According to Agilent, its printed arrays are extremely accurate and reproducible, as well as being capable of precise measurement of low levels of differential gene expression.

This example shows that printed and organic sensors are already moving well beyond devices that use printing only for electrodes. NanoMarkets believes that the sensor market represents an attractive opportunity for printed and organic electronics manufacturers in part because unlike FPDs and radiofrequency identification (RFID), this segment of electronic devices is underserved by existing manufacturers. There are many indications that the market for sensors will grow rapidly, especially in the security and medical arenas.

To obtain a copy of the NanoMarkets report, **Printed and Organic Sensor Markets: 2007 2015**, please visit our website at www.nanomarkets.net or contact us at sales@nanomarkets.net or by calling our offices at (804) 270-7010.

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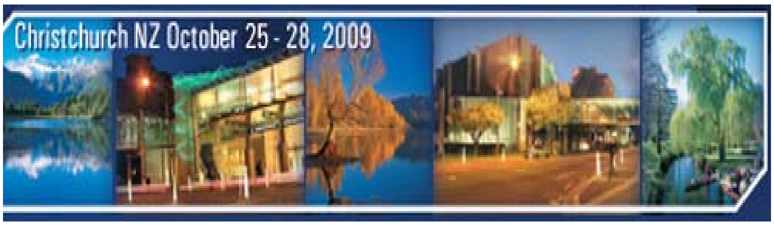

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Guide for Contributors

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Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

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Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

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- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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