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thin film | organic | printable | electronics

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Conductive Coatings Markets: 2009 and Beyond

June 2009

Executive Summary

E.1 Summary of Major Opportunities for Conductive Coatings

Conductive coatings is a term that covers a wide range of materials and an even wider range of applications. Many of the segments served by the conductive coatings business are highly mature and therefore do not present real opportunities, because they are low growth and have established supply chains. In this report, we focus on areas with high growth potential and room for new products and firms.

Our analysis suggests that these areas of opportunity can be broken down into three main areas. These are: (1) electrode materials, (2) anti-static materials and (3) EMI/RFI applications. The most substantial opportunities in area (1) seem mainly to come from the battery/fuel cell, solar panel, display and (perhaps) the sensor sectors. Meanwhile, there is nothing new about anti-statics (2), of course. But the steady move of the semiconductor industry down the path set by Moore's Law is making them of ever growing importance. Finally, EMI/RFI applications (3) remain an area of constant innovation and their importance continues to grow as the result of the rise of wireless computing and communications.

E.1.1 Opportunities for Conductive Coatings in Batteries

Conductive coatings are now being used to create entire new classes of batteries—thin-film and printed batteries. In both cases, though, one has to stretch the definition of coating somewhat; thin-film batteries are manufactured as layered structures using sputtering and printed batteries are really a class of batteries in which the electrodes are screen printed. However, NanoMarkets sees real opportunities in this area for powering smartcards, sensors and eventually RFID tags.

Meanwhile, conductive coatings have been used for quite a while in batteries, to reduce corrosion and oxidation and to increase performance more generally. The use of protective coatings of this kind can also be important as enabling technology, permitting the use of aggressive chemistries, reducing leakage, self-discharge, thermal discharge and extending the battery shelf life. Conductive coatings have, incidentally, proved to be a key enabling technology in the lithium battery segment, because their use has enabled nanomaterials to be used in the electrodes. Lithium batteries are a critical sector, because they are used in both the fast growing mobile computing/communications business and in the even faster growing hybrid vehicle sector.

Many of the coatings used in the battery sector have traditionally been carbon based, but there appears to be a lot of activity in developing both polymer and metallic oxide materials for these applications.

E.1.2 Opportunities for Conductive Coatings in Fuel Cells

Many of the comments made above about batteries also apply to fuel cells. For example, conductive coatings are used in fuel cell applications for acid corrosion protection and electrical conductivity enhancement of bipolar metal plates in much the same way that they are in batteries. However, the opportunities here are clearly limited by the fact that fuel cells have not grown much beyond specialist, off-grid applications. Attempts to use fuel cells for transport or portable computers are still very immature. However, if they ever take off they could prove an important new market for conductive coatings

In the widely deployed proton exchange membrane (PEM) fuel cell, platinum catalysts are widely used. Because of its cost, relative rarity and sensitivity to carbon monoxide, the use of platinum is often seen as a major limiting factor for fuel cells. There are therefore opportunities to replace it. Gold-palladium coating is one possible direction. There are also types of fuel cells that do not use platinum, but rather cheaper materials such as nickel or nickel oxides. These species of fuel cells include solid oxide fuel cells (SOFCs), which have become especially important because they have high efficiency and can use some relatively unrefined materials for a fuel source.

There are also some developments in new materials for fuel cells that are interesting in the context of this report. Researchers at Pacific Northwest National Laboratory (PNNL) have been investigating alternative and durable high-performance cathode supports for use as conductive materials in PEM fuel cells. Several important kinds of novel materials for PEM fuel cells have been utilized in this work including nanostructured carbon materials, conductive oxides and carbides. Conductive polymers are also being investigated for use in fuel cells. Researchers at Monash University have reported on the development of a new fuel cell prototype, which they say may pave the way for a generation of much cheaper, more efficient fuel cells for powering cars. This new fuel cell architecture features a cathode made from PEDOT. Unidym, Johnson Matthey, and Motorola have collaborated on carbon nanotube-based electrodes for direct methanol (DM) fuel cells.

E.1.3 Opportunities for Conductive Coatings in Solar Panels

Solar panels of all kinds use conductive coatings to create top and bottom electrodes as well as reflective layers. The most mature part of this market is in the crystalline silicon (c-Si) PV sector, which always uses screened silver for the top electrode. Almost all the other applications for conductive coatings have a growing number of options. In particular, different conductive coatings are associated with each of the various thin-film PV (TFPV) technologies that are beginning to assume a significant role in the solar industry.

It is also worth noting that conductive coatings may play an important role in creating what the solar industry calls the “champion cells,” meaning cells with very high performance that are fabricated in the lab, but whose technology and performance may not be easy extensible to the real world. Though these high performance champion cells may achieve their success with specially engineered absorber layers, special electrodes can also play a role. In addition, most building integrated PV (BIPV) applications are forced to match the warranties of roofing contractors, which is commonly up to 30 years, and the life of the cells over such an extended time period is very much dictated by the choice of the TCO used.

In addition to its use in c-Si PV, silver is also used for electrodes in the thin-film PV sector and in the recent past several prominent manufacturers of silver pastes have seized the opportunity presented by the growth of the solar industry and created special formulations targeted toward solar contacts.

While silver has established itself in this area, there seems to be an opportunity for an intrinsically transparent top contact for solar panels; thus, the search is on for TCOs, transparent nanomaterials or some other formulation that would enable a more cost-efficient alternative to silver for top contacts. As we discuss below, fairly complex materials have been tried in this context and have sometimes resulted in superior performance. NanoMarkets’ research suggests that part of the thrust toward building higher performance solar cells may come from contact coatings using novel and more complex materials.

Silver pastes are also used as a reflective layer and/or back electrode to reflect unabsorbed light through the cell again, to boost efficiency. Obviously, transparency is not a requirement here, which means that there are more materials to choose from, although aluminum is the most used silver substitute. However, because the back electrode is less demanding in its requirements, cost considerations have a greater weight.

Amorphous silicon: ITO is used in about 50 percent of a-Si cells. The half of the a-Si market that does not use ITO as the front electrode is split mostly between AZO and FTO. Regular tin oxide is also sometimes used.

An interesting opportunity that is beginning to emerge is a combination of silver and TCO. The thinking here is that the combination can better optimize the cost/performance ratio of the materials being used for contacts. Creative Materials recently introduced a series of silver conductive inks specifically for thin-film PV. These conductive inks are designed for use in grid lines and buss bars printed onto the TCO's in thin-film solar cells, and can be printed using common printing processes. The company claims that the inks offer high conductivity and contact resistance along with excellent adhesion to a variety of TCOs. Although a-Si PV has already begun an apparent transition to aluminum as the back electrode/reflector, other options for the back reflector exist including silver-containing alloys such as Mg:Ag, which has a very low work function.

CdTe: For the most part, CdTe PV uses fluorine-doped tin oxide (FTO) as the front electrode, although other forms of tin oxide have also been used. The most efficient CdTe/CdS PV cells, with efficiencies of more than 16 percent, have been produced using a Cd_2SnO_4 (CTO) TCO layer, which is more transmissive and conductive than the commonly used SnO_2-based TCOs. The inclusion of a Zn_2SnO_4 (ZTO) buffer layer has been found to improve the quality of the device interface. Meanwhile, Eikos and NREL have developed a new PV device, which uses CdTe with carbon nanotube-coated back contacts; the device produced efficiencies of 12.2 percent. The opportunities for supplying coatings—or indeed any material—into the CdTe sector is constrained by the fact that there is only one major supplier of CdTe, hence only one major customer for materials suppliers.

CIGS: A molybdenum film is the predominant base electrode material for CIGS, but some of the metal foil-substrate approaches dispense with the molybdenum and use the substrate itself as the base electrode. The top electrode is usually AZO, but some use ITO or metallic wires, similarly to c-Si PV, as well. The junction layer is usually cadmium sulfide or cadmium selenide, but there are development efforts aimed at eliminating the cadmium. AZO is a common choice of TCO, because of its low cost and relatively good optical transmission performance in the solar spectrum. However, the AZO coating is vulnerable to even small amounts of moisture. One opportunity in this area, which has already been taken up by several groups, is to optimize ZnO for CIGS solar cells, by fabricating Zn_{1-x}MgxO:Al films from ZnO:Al and MgO. However, so far this work has not gone anywhere and with CIGS at a relatively early stage of commercialization it is hard to be sure what materials a mature CIGS industry will settle on for contacts. As with the other areas that we have discussed in the solar sector, CIGS efficiencies may benefit from coatings using complex materials to create electrodes. Even today, Miasolé is said to use a screen-printed silver decal on top of the zinc oxide front electrode of its CIGS PV cells. We also believe that the TCO chosen as the top contact for CIGS PV cells is critical to the long-term performance of the cell. It is doubtful that a flexible seal can be created on a thin-film CIGS cell to withstand storms on a rooftop for long periods of time. This seems to suggest that even though ITO is a more costly option, given its better performance especially in terms of its chemical resistance to moisture, it may be chosen for CIGS cells that need to survive for 30 years on a rooftop.

OPV and DSC: PV using organic materials includes both "pure" OPV and dye sensitive cells (DSC) and requires special considerations with regard to electrodes. As befits a technology that is at such an early stage of development, the materials used for contacts for organic PV are also not settled. TCOs have again—and not surprisingly—been widely used for the top contact. AZO and ITO have been widely used for OPV, but so have more unusual materials such as boron doped zinc oxide (ZnO:B).

But there are many other materials that companies are evaluating for creating electrodes in the OPV/DSC sector. These include PEDOT, carbon nanotube (CNT) formulations, and other metallic nanomaterials or composite formulations. Recent work has shown that carbon nanotubes may enable the replacement of commonly used TCO materials in OPV cells. There is also obviously a natural fit using organic conductors (especially PEDOT) with organic PV material and several firms are already supplying such materials. Another solution is the use a polymer anode combined with a conductive metallic grid. Several TCO materials are being used in the design of electrodes for DSCs; these include ITO, ATO (especially by Fraunhofer ISE) and ZnO, as well as conductive polymers. In April 2008, Scientists at the Korea Institute of Science and Technology (KIST) demonstrated a novel transparent conductive oxide film based on a triple layer, comprising ITO/ATO/TiO_2 for use in DSCs.

E.1.4 Opportunities for Conductive Coatings in LCD Displays

LCD displays are now the dominant display technology in almost every application from small displays without backlights on consumer appliances to giant television monitors. However, the opportunity for conductive coatings in the LCD sector is constrained by the impact of the current recession and even before that disaster hit, the LCD industry appeared to be nearing the end of its most rapid growth phase. The transition of computer monitors from CRT displays to LCD displays was nearly complete and—except at the low end of the market—more or less the same thing can be said of the television business.

All LCD displays are based on controlling the polarization of liquid crystals with electricity passed to them via transparent electrodes. These electrodes are typically polymer-coated ITO. There has long been a perceived opportunity to replace this ITO, but this has lessened over the past year or so as indium prices have stabilized or declined. Now the opportunity is primarily to replace ITO to achieve better performance, which would mean improved conductivity, transparency or physical resilience.

Alternatives, including polymers and TCOs, have been evaluated in this context, but these have not exceeded the portfolio of performance properties offered by ITO; it is also fairly clear that these kinds of materials will never really be able to beat ITO on performance, although they may be better on price and in certain niche applications. In NanoMarkets' opinion, the great hope for ITO replacement lies in the area of nanomaterials, which have yet to achieve any real penetration of the market, but as an early stage technology have, at least, the potential for a "great leap forward." Cambrios and Unidym have made interesting announcements in the nanomaterials ITO replacement space, although one would hardly call them revolutionary.

Given the lower price of indium today, ITO has a stronger foothold on the conventional flat-panel display markets than might have been expected a year ago, and this strength has been enhanced to some degree by improved manufacturing methods and better reclamation of waste ITO from sputtering plants and discarded monitors and televisions. So while we believe there is a genuine opportunity for ITO alternatives to make some mark on the LCD industry in the near future, sizeable revenues from ITO replacement in this segment will not appear until indium prices start going up again and ITO replacement materials improve in performance. Fortunately or unfortunately (depending on who you are) the prospects for a rise in the price of indium seem good, given current worldwide tendencies toward general inflation.

E.1.5 Opportunities for Conductive Coatings in Other Display Products

The other display products considered in this report are plasma displays (PDPs), OLED displays and e-paper/flexible displays.

PDPs: PDPs are—by common consent—in long-term decline. However, there is a surprisingly large amount of R&D still going on in the PDP area, suggesting that there is some interest in keeping the technology going or at least finding some other applications for it. As usual, ITO is widely used for PDP electrodes and as usual there are attempts to replace ITO. In this case, the coating that has been seen as having the greatest opportunity for replacing ITO is FTO. However, FTO is still not widely used because of poor accuracy in its etch. Work is being done, however, to alleviate the etch problems and there is also some work being done on laser processing of tin oxide films with the goal of applying it to PDPs.

Whether all of this turns out to have some commercial importance will ultimately depend on whether PDP technology can itself be shown to be a long-term revenue generator. And this seems somewhat unlikely at the present time.

Touch-screen displays: Touch-screen displays are seen as a considerable opportunity by firms manufacturing novel transparent conductive coatings, partly because these displays seem to be of greater need of an ITO alternative than any other segment of the display industry and partly because this segment is already large in size. Touch screens are now routinely found in retail point-of-purchase environments, ATMs and in cell phones/PDAs.

These LCD touch displays use ITO not only for the LCD electrodes, but also in the touch mechanism. The major disadvantage of resistive touch screens—the kind in most common use—is that they tend to wear out after a certain number of touches and this can be largely attributed to the physical limitations of ITO. Two ITO layers move into contact at the point where they are touched and the ITO deteriorates with repeated flexing. Capacitive touch screens, on the other hand, do not have moving parts. They work by detecting changes in the electric field of the touch-screen surface at the point of contact.

The message that is obtained from worn-out touch screens is that there is clearly an opportunity here and manufacturers of ITO substitutes are anxious to seize it. Today, resistive touch screens use ITO almost exclusively. NanoMarkets is aware of one exception: Fujitsu has introduced a resistive touch screen using a polythiophene conductive polymer (the same class of material as PEDOT). Although Fujitsu claims sufficient stability in high humidity and ultraviolet exposure, there have been reports that the polymer electrodes still degrade with heat and light exposure. There is clearly room for improvement here.

There also seem to be major opportunities for nanotube formulations in the touch-screen display segment, because these formulations seem to have the potential for a great leap forward in terms of transparency, conductivity and physical resilience. Several firms are working hard to establish carbon nanotubes as an ITO replacement, but this work seems to be at a relatively early stage of development. As to alternative TCOs, these are less likely to replace ITO as they are typically just as brittle as ITO in this context.

All of the above applies primarily to resistive touch screens. Capacitive touch-screen technology needs fewer ITO layers and the visual quality is better than for resistive technology. Such screens have received a major boost recently as the result of the adoption of capacitive technology for the Apple iPhone and some of Apple's iPod products. Since capacitive touch screens do not flex, ITO is much better suited to this technology than it is to resistive touch screens. Other TCOs can also be a fairly good fit, depending on their conductivity and transparency. Some of the TCOs are better than ITO in their ability to create thinner uniform layers. However, they are all less transparent than ITO, a drawback since image quality is emphasized in capacitive touch screens. Alternative TCOs may capture sizable portions of the capacitive touch-screen market if they can be applied in a thin enough layer to have transparency similar to that of ITO, or if they are used in more cost-sensitive, less image quality-sensitive applications. While conductive polymers may be suitable for capacitive touch screens, they lose much of their appeal in capacitive touch screens since flexibility is not required. The bottom line is that the rise of capacitive touch screens lowers the opportunities for ITO replacement.

OLED displays: OLEDs can be used in both displays and lighting, although the only mass market for OLEDs right now are in MP3 players and cell phone sub-displays. From the perspective of conductive coatings, there is not all that much difference between the two categories. ITO is commonly used as the transparent electrode in OLEDs, but as usual, no one is thrilled about using ITO and a variety of firms see an opportunity for replacing it. Whether this is a real opportunity or not depends on whether OLED displays ever make a move beyond the small OLED displays that now dominate the market. It is still an open question as to when or whether that is going to happen.

The materials that are being proposed as ITO replacements in the context of OLED displays include other TCOs, such as IZO, AlZnO and ZnO. Because OLED technology is based on organic chemistry, there is a natural fit between this type of display and organic electrode materials. The first attempt to substitute ITO by PEDOT:PSS in OLEDs took place more than a decade ago. It has also been shown that the deposition of a thin layer of PEDOT:PSS on the ITO surface increases the maximum luminance of OLED devices by up to three orders of magnitude, reducing the threshold voltage by more than 50 percent, and increasing the lifetime by a factor of ten. Furthermore, the PEDOT:PSS layer can act as a physical barrier against the many defect sites known to be present in ITO. The bottom line here is that a real breakthrough by OLED displays into cell phone main displays and televisions could create a new opportunity for makers of high-quality PEDOT, etc.

E.1.6 Opportunities for Conductive Coatings in Sensors

Sensors are seldom identified as an opportunity by conductive coating manufacturers. Nonetheless, it seems likely that enhanced conductive materials/coatings could be important in meeting the needs of the sensor industry because high conductivity often translates into more sensitivity; this would seem to favor the use of metallic or nanomaterials coatings for electrodes. In addition, the arrival of large-area, flexible sensors could mean a substantial market for flexible conductive materials to create electrodes for these new subsystems.

In fact, sensors have used almost every conductive material known to man. Again, there is a trend toward flexibility—in large area sensors, for example—and this may perhaps be best achieved through the use of conductive polymers. As we have already noted, nanomaterials, such as nanosilver inks, would be most likely used in sensors when highly conductive contacts are required to enhance performance or (to a lesser extent) when high temperature sintering would damage the substrate. However, the problem with the sensor business is that it is so fragmented—both in terms of potential customers (i.e., sensor makers) and (to a lesser extent) in terms of the number of different applications—that it is hard to see it as one whole industry. This is certainly a real issue since it makes it hard to design a cost-effective marketing strategy that reaches all parts of the sensor market.

E.1.7 Opportunities for Conductive Coatings in Lighting

Most, if not all, of the efforts to produce better lighting at the present time, involve solid-state technologies. Principally, the technologies concerned are electroluminescent (EL) lighting, high-brightness LEDs and OLED lighting.

Although EL lighting is in decline and does not have the brightness for extensive use in the general illumination market, NanoMarkets does not expect EL lighting to disappear any time soon. ITO or tin oxide is commonly used as the front (transparent) electrode, while the back electrode is usually a reflective metallic coating; often this is silver. Occasionally, PEDOT or carbon nanotubes have been used in EL lighting. The opportunity, such as it is here, may be for better electrode materials that do not easily deteriorate.

The great hope of solid-state lighting at the present time lies in LEDs. The electrode materials used for high-brightness LEDs have varied over the years, but do not seem to have received as much research attention as for OLEDs. Typically, the electrodes are made of common metals deposited with classic deposition methods used by the semiconductor industry, so there are no real opportunities here, except in the sense that HB-LEDs are expected to take off in the general illumination market, which will add a little to the market for gold, silver, etc. Various nanomaterials have been used in certain research environments for HB-LEDs, so perhaps there may be some new revenue generation possibilities coming from this direction. OLED lighting also has considerable promise, with most of its conductive coatings issues being identical with the OLED displays sector. However, it is worth noting that the EU-funded OLLA OLED lighting project was the source of the first reported large-sized ITO-free OLEDs. These used PEDOT:PSS.

E.1.8 Opportunities for Conductive Coatings in EMI/RFI Shielding

While the whole area of EMI/RFI shielding is in many ways extraordinarily mature, the explosion of wireless communications has focused interest in the materials community on how EMI/RFI shielding can be done better. Higher levels of shielding might be required as may improved physical qualities for the shielding used, since the latest electronic devices insist on a high level of miniaturization, low weight, short manufacturing lead times and recyclability, which all provide additional challenges.

Designing the enclosures in plastic rather than metal, offers some advantages, but conventional plastic suffers from one major drawback—as a non-conductor, it is transparent to electromagnetic radiation, which once again, makes EMI/RFI of especial importance. The wireless communications "revolution" is also expanding the role of EMI/RFI protection. In the past, it was almost solely about minimizing annoying interference. However, the niche TEMPEST functionality deployed by the military in the past is now being extended to the consumer realm; RF shielding is being used to prevent access to data stored on RFID chips embedded in various devices.

Many materials can be used, but in almost every case a conductive coating used for EMI/RFI has to compete with other (non-coating) materials and some fairly exotic approaches are being tried, including superconducting materials. Some of the more interesting materials in this space for mass-market applications include nanomaterials; the effectiveness of metallic EMI/RFI shielding depends on the small size of the metal particles. Thus, the kind of product that may have some potential is represented by (say) Cima NanoTech's nanosilver-based emulsion, which is being targeted toward the EMI/RFI sector. Nanotubes have also attracted attention for EMI/RFI shielding and for ESD applications (see below).

Recently, there have been increasing cost pressures on electronic equipment manufacturers due to the stagnant world economy, which has only helped the development of cheaper shielding alternatives, such as conductive polymers. Also, the environmental pressures associated with the safe use and disposal of metallic coatings have been a major problem affecting their usage.

E.1.9 Opportunities for Conductive Coatings in ESD Protection/Antistatic Coatings

A closely related application for conductive coatings is protection against electrostatic discharge. Like EMI/RFI shielding, the goal of this application is to drain away unwanted electrons to prevent the buildup of static electricity. In the context of this report, perhaps the most important application is in bags that contain delicate electronics parts. This application is likely to be increasingly seen as an opportunity, because Moore's Law is about to take the semiconductor industry down to the 32-nm and 22-nm nodes where chips will become exquisitely vulnerable to ESD. Typically, these bags are made from metalized PET film or polyethylene. Polythene may be used in bag form, but also as an antistatic foam or bubble wrap. Concern with ESD in the semiconductor industry also promotes the use of antistatic clothing and these are also used in a wide variety of other industries where workers have to deal with flammable materials of various kinds. Antistatic treatments are also used on windows, displays and digital camera image sensors, not just to protect against damage to electronics and fire hazards but to prevent the build-up of dust that reduces transparency and can permanently damage the surface. Coatings of this kind can also be IR-reflecting, allowing improved energy efficiency or for industrial heat-reflecting applications.

Many materials can be used for antistatic agents and/or ESD coatings. In many cases, ESD coatings are the same conductive coatings that are being used in EMI/RFI applications, although they may be used in slightly different formulations.

E.2 Firms to Watch

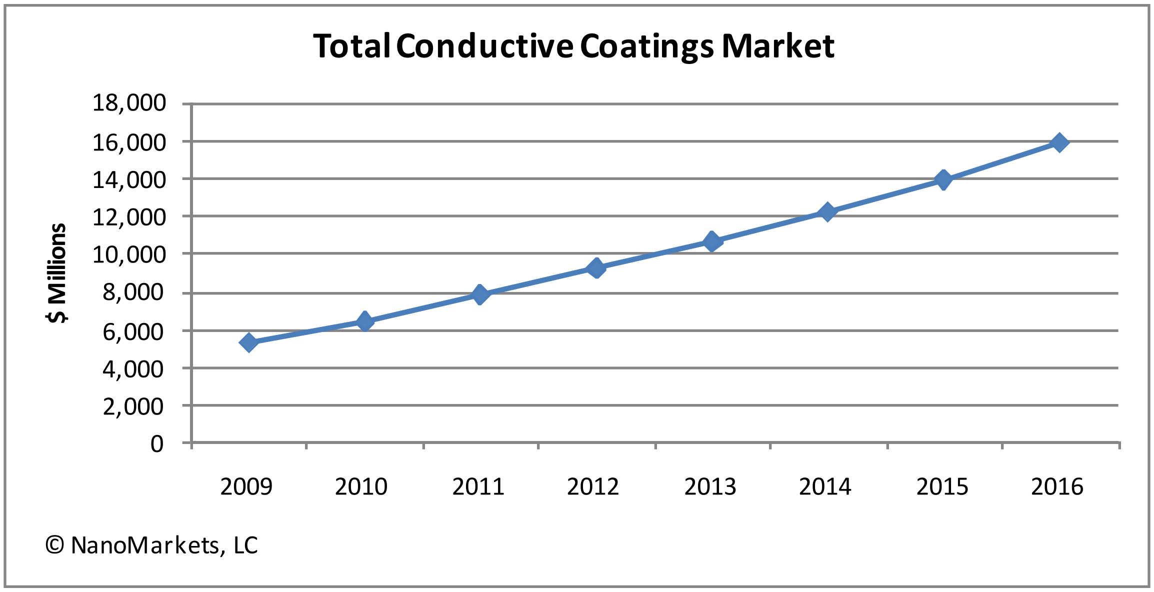
There are so many firms offering conductive coatings that it is hard to pick out those that are especially worthy of attention. In compiling this report, we have looked at the offerings of many dozens of firms. A few companies stand out in this work as exemplars of key trends in the conductive coatings business.

In the metallic coatings/pastes business, for example, we have found ourselves frequently examining the product lines of what is now Henkel, which is very broad both in terms of what is offered and in the applications covered. In the area of conductive polymers, H.C. Starck and Agfa stand out and, as the report discusses, these firms are actively pursuing more sophisticated markets with their formulations. In the nanomaterials area, we note that both Unidym and Eikos have been developing what are, in effect, conductive coatings based on carbon nanotubes for several years. Unidym especially seems worth watching in the future; Eikos has gone rather quiet of late. Then there is Cambrios, which is creating coatings based on metallic nanomaterials.

Many of the world's largest chemical firms are also active in this space including BASF, Bayer, DuPont and Evonik Degussa, although they often belie the huge range of their products by making their major contributions in a limited number of areas.

E.3 Summary of Forecasts

Exhibit E-1 summarizes NanoMarkets' latest revenue forecasts for conductive coatings opportunities. The forecasts are worldwide in scope and their derivation and further break outs of these numbers are shown in the main body of this report.


Total Conductive Coatings Market
$ Millions
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
2009
2010
2011
2012
2013
2014
2015
2016
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