# Silver-Based Transparent Conductor Markets--2011

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# Chapter One: Introduction

## 1.1 Background to this Report

### 1.1.1 Silver as a Transparent Conductive Nanomaterial: The One to Beat?

Transparent conductive coatings and films have attracted both considerable end user interest and investment in the past two years. This is a market that is worth $2.9 billion now and is expected to grow to around $4.9 billion by 2014. It has been traditionally dominated by indium tin oxide (ITO), but this material is expensive, dependent on the vagaries of the indium market (and hence of Chinese industrial and environmental policy), can be expensive to deposit, and is relatively fragile when deposited in films. This last mentioned factor raises questions about how suitable ITO is for the rapidly growing display touch-sensor market. ITO also seems to be completely unacceptable for the flexible displays of the future, although the timeframe for the emergence of flexible displays is far from clear.

In this environment, it is not surprising to find that there are significant efforts to replace ITO with alternative materials and given the fact that the transparent conductor market is as large as it is, capital is being attracted to this apparent opportunity. Investors and entrepreneurs argue that if ITO alternatives take even a small share of the transparent conductor market, they will generate considerable revenues. And in many cases, the materials that are being proposed for alternative transparent conductors have other uses. Thus, the firms that are offering alternative transparent conductors—all other things being equal—look like good investment prospects right now.

These firms include those that offer transparent conductors based on transparent conductive metal oxides other than ITO, conductive polymers and nanomaterials. The nanomaterials in question are mostly carbon nanotubes, graphene and silver. Copper has also been proposed, but so far no firm has invested much money in this type of solution. Carbon nanotubes were the first nanomaterial replacement to be suggested in the transparent conductor market, but they have never taken off to the degree that was once predicted. In part this is because it is hard to separate out conductive carbon nanotubes from semiconducting ones. Graphene is too new as a material to have had much impact. There is much talk about using it for a transparent conductor. But only Samsung seems to be seriously pursuing graphene in this way.

### 1.1.2 The (Evolving) Joys and Challenges of Silver Transparent Conductors

Quite apart from the failings of other alternatives to ITO, silver-based alternatives are attractive because silver has the highest conductivity of any of the elements and its oxide is also fairly conductive, which helps to alleviate oxidation. Ultimately, it is this fact of chemistry that helps explain why there are now as many as 15 firms that supply—or plan to supply—silver-based transparent conductive coatings. This is a higher number of firms than in any other sector of the alternative transparent conductor market. What is especially interesting is the fact that the number of firms seeing an opportunity in the silver sector of the transparent conductor market has grown so rapidly. Just a few years ago, there was really just one firm that was pursuing this opportunity. This was Cambrios, which, at the time, was rather secretive about what it was doing. The fact that Cambrios is now shipping to real customers and in reasonable volumes is an encouragement to the entire silver transparent conductor sector.

Each of the firms making silver-based transparent conductors has somewhat different products and strategies. And, while our focus in this report is on nanomaterials, not all of the silver-based transparent conductors really qualify for that. However, in almost every case, the design of the final product is similar; a silver grid of some kind is created that is fine enough to cause little disruption to viewers (in the case of display). The philosophy here is that if an ITO film provides (say) 85 transparency the same performance can be achieved by covering 15 percent of the surface of the film with silver and leaving the (100 percent transparent) rest of the film unimpaired (Note: These are very simplified calculations; no film is 100 percent transparent, for example.)

In some cases, this kind of grid is simply silver traces deposited on a film. However, more within the "nanosphere," an ink is created that includes silver nanostructures that form a "nanogrid" when it is cured. In either case, silver metal accounts for only a small fraction of the volume of the film; perhaps as low as 1 percent. This means that both suppliers and users of silver transparent conductive coatings and inks need not spend much of their time watching what is going on at the various international metal exchanges. This is a big contrast to the firms supplying more conventional silver inks and pastes, where the price of such materials is largely determined by the price of silver. There is, incidentally, not much overlap between the firms selling conventional silver inks and pastes and those selling transparent conductors that use silver.

None of this is meant to suggest that silver is the ultimate solution for the transparent conductor market, or that it is expected to take a large share of the transparent conductor market any time soon. Indeed, silver-based transparent conductors have their own problems and they are at a very early stage of their evolution, and there are plenty of open questions about pricing and acceptability by customers. One big issue that is often raised is that silver corrodes and that this will ultimately reduce the conductivity of the material. Some silver transparent conductor makers are addressing this issue and, in any case, it may not be a big issue where silver is being used in products that don't have a long product lifetime; for example, cell phones. On the other hand, one possible scenario is that silver solutions will take a rapidly growing share of the transparent conductor market, only to see this growth decline when nanotube (or possibly even graphene) becomes a viable replacement for ITO; nanocarbon solutions do not suffer from the corrosion problem.

Today, nanosilver films already compare very favorably with ITO on transparency, although ITO can probably still beat nanosilver in this regard. This may be an issue that could keep nanosilver out the high-end LCD business for a while. However, thinner layers of nanosilver or improvements in nanostructures can help make up the difference. Even today, nanosilver can pretty much beat any competing transparent conductor when it comes to conductivity, although there is always a tradeoff between conductivity and transparency that must be made in all transparent conductors.

### 1.1.3 Applications for Silver-based Transparent Conductors: The Touch-Screen Sensor Trap

This enthusiasm for silver-based transparent conductors should not be allowed to obscure the fact that the available market for these materials at the present time is actually not very big and that for it to expand into a sizeable market there will have to be a significant change in consciousness by the major display makers in Asia.

The point here is this. NanoMarkets' research suggests strongly that most (and possibly all) of the firms making silver-based transparent conductors at the present time are looking to the touch-screen display sensor market for their first revenues. This is fair enough in the sense that this is a reasonable place to start and—as we have already mentioned—there does seem to be some real and immediate need for an alternative to ITO in this space. The problem is that—under most scenarios—the touch-screen sensor market is not all that large. Understandably, this isn't mentioned much by manufacturers of alternative transparent conductors, but in one recent interview a manufacturer of these materials did mention—and

almost in passing—that it already had enough capacity installed to produce all the transparent conductor capacity of the touch-screen industry.

In fact, according to NanoMarkets' assessment, the available market for silver-based transparent conductors in the touch-screen sensor sector will reach only $32 million in 2014, which is really not enough of a market for most of the firms in this space to build a substantial business. The reason for this market being relatively small is that only a small share of displays use touch-screen and they tend to be the smaller ones. One can imagine a scenario in which touch became ubiquitous, but this doesn't seem a very likely scenario to us.

To make matters worse, the other immediate opportunities for silver-based TCs do not look any better. There is a bit of an opportunity for these silver-based materials in the thin-film PV business we think; but the thin-film PV seems to be quite happy shifting to alternative TCOs. Otherwise the pickings are slim.

Also, one thing that makers of transparent conductive nanomaterials will tell you is that a key advantage of their solutions when compared to ITO and other TCOs is their flexibility. There is no dispute, of course, that nanosilver (and for that matter nanotube) films offer greater flexibility than ITO films, although there could be a debate over how much more. What remains an open question, however, is how much this matters. ITO films are already widely used in touch-screen displays and in R2R processes today.

So, while nanomaterials may be much more flexible than ITO, it cannot be argued that they are in some sense an enabling technology for R2R or touch displays. On the other hand, there is much talk (but not so much action) with regard to the development of intrinsically flexible displays and here highly flexible transparent conductors may well be an enabling technology. But we think that it could quite a few years before they represent a sizeable market for transparent conductors. Intrinsically flexible displays have yet to be brought to market, although things are beginning to look hopeful for flexible displays again now that a substantial display firm, with the capital to make it happen, namely Samsung, is active in this space.

That said, the dirty little secret of the silver-based transparent conductor market is that without a significant penetration of the conventional LCD market, it is hard to justify an investment in this part of the transparent conducting business. Such a penetration is not going to be easy to achieve, since it will mean that the LCD industry will have to make significant changes with regard not just to materials, but also to deposition and patterning technology.

Although no one expects—nor should they expect—that nanosilver or nanocarbon will replace ITO in LCDs for quite some time to come, NanoMarkets has detected some shifts in the position of the LCD makers in this regard. There are certainly instances of silver-based transparent conductors being used in experimental LCD displays and we believe that it is not impossible that a limited number of products of this kind could ship during 2011 or 2012. The point here is that very small penetrations of the huge LCD industry can bring with it impressive revenues. There is really no other sector into which novel transparent conductors can be sold about which that can be said.

The incentive for LCD firms looking at making a change—for all of the switching costs involved—is in NanoMarkets' opinion likely to have more to do with cost than flexibility. It is true that *materials* cost for nanomaterials is certainly greater than that of the more mature materials. However, this is counteracted by the fact that (1) as new advanced materials, transparent conducting nanomaterials have much more room for price decreases and (2) they can balance the high cost of the material itself with low-cost deposition and (perhaps) patterning.

### 1.2 Objective and Scope of this Report

Given all of the above, nanosilver-based transparent conductors seem well on their way to being a significant business opportunity and revenue generator. In a larger context—assuming that we are talking about nanosilver—there is the potential for the silver-based transparent conductor space to emerge as an important success story for the nanomaterials industry. (However, the transparent conducting nanotube business is certainly part of the same story and nanomaterials as a whole seem to be doing quite well these days.)

That said, NanoMarkets believes that to understand where the real opportunities are in the nanosilver-based transparent conductor space a deeper analysis is required. And with this in mind, we have compiled this report, which is intended to provide an analysis of the new business available from silver-based conductors. More specifically, the purpose of this report is to examine the opportunities available for transparent conductors that use silver either in the forms of grids on film, or as inks. These materials are intended as alternatives to sputtered ITO and (more directly) ITO films and also compete with all the newer transparent conductors—other TCOs, conductive polymers, and carbon nanotube films—that are being used or have been proposed recently.

The ultimate goal of this report is to quantify what this new business amounts to in dollar and value terms and we believe we have accomplished this in the closing chapter of this report.

This is where we have provided a granular eight-year forecast, with breakouts by type of application and type of nanosilver solution used. We have also included Exhibits showing how much of the entire transparent conductor market silver-based transparent conductors can be expected to take and how these silver products will be delivered; nanosilver inks/coatings, films and non-nanosilver products.

Subsidiary goals are (1) to discuss which sectors of the market, considered by application are likely to be the most friendly to silver-based solutions and (2) to examine the various product and market strategies of firms operating in this sector. There are quite a few applications in which silver-based transparent conductors could be used, but they differ in size and the expectations for penetration by silver-based solutions. And as we have already mentioned, there are about 15 firms that are active in this space to one degree or another and each has a rather different way of looking at how this market should be attacked.

The report is part of NanoMarkets' ongoing coverage of the transparent conductor market that covers ITO, alternative TCOs, conductive polymers and transparent conductive nanomaterials. NanoMarkets has been covering these materials and their applications for six years and has produced a variety of in-depth industry analyst reports on this topic during this period of time.

### 1.2.1 Scope of Report

This report covers the use of silver-based transparent conductors in a number of applications sectors including flat-panel displays (FPDs), touch-screen sensors, OLED displays, e-paper displays, OLED lighting, thin-film photovoltaics (TFPV), organic photovoltaics (OPV) and dye sensitive cell photovoltaics (DSC), antistatics and EMI shielding. However, not all of these applications areas are given equal coverage, since they vary in importance in the context of the products analyzed in this report.

As we have already seen, the LCD/FPD and touch-screen sensor sectors seem to be critical to the future development of the silver-based transparent conductor market, while the EMI shielding market is not very important at all. (It is not widely targeted by the firms considered in this report and would not need—or be able to afford—a product such as high-performance silver nanomaterials):

- Much of the current business activity in the silver transparent conductor space seems to be targeted towards the touch-panel display market or, more specifically, the firms that make the touch sensors. With this in mind, we have provided a comprehensive

coverage of this application and how it is likely to buy into nanosilver. Although our focus is on the dominant analog resistive and pro cap touch technologies, but we also examine some of the new touch technologies and what their arrival might mean to the TC business.

- Although the LCD/FPD market has stubbornly refused to have anything to do with any kind of transparent conductor other than ITO, much depends on the degree to which they embrace silver. In the past year, NanoMarkets has noticed the LCD industry shift a little on its total commitment to LCD and with this in mind, we have considered more seriously than in the past the possibility that alternatives to ITO may find their way into the LCD market.

This is the first time that NanoMarkets has produced a report specifically dealing with silver-based transparent conductors, but we have ongoing industry analysis programs that cover transparent conductors and silver inks, pastes and nanomaterials. However, although this is a "first time" report, it draws heavily on these other programs. In particular, some of the information that is used in this report comes directly from our recent overview of the entire transparent conductor market, the industry analysis report, "*Transparent Conductor Markets – 2011*." (Our forecasts in this current report are largely based on those in this larger report, for example.)

While there is an overlap between the two reports, this report covers silver conductors in considerable more detail. More specifically, this report:

- Provides a more thorough account of the strategies and products of the leading suppliers of silver-based transparent conductors than in the previous report. We have also included some companies that were not mentioned in the earlier report. (A few companies in this space do not do much to draw attention to themselves).

- Offers a more comprehensive discussion of silver-based transparent conductors compared with other transparent conductor solutions.

- Includes a discussion of how the nanosilver transparent conductors fit into the evolution of silver nanomaterials more broadly. This discussion is to be found in the executive summary of this report.

- While the forecasts for silver-based transparent conductors presented in this report are the same as in our more comprehensive transparent conductor report with respect

to silver-based transparent conductors, we have provided some additional granularity. As we have already mentioned, this consists of Exhibits showing the expected share that silver-based transparent conductors will have of the entire transparent conductor market and a break out of silver transparent conductors by product types.

With regard to the comparison of nanosilver transparent conductors with other transparent conductors, we have focused especially on carbon nanotube-based solutions, which is an approach that promises very similar results to the silver-based solutions. In particular, we devote some space to how the two types of material will compete in the marketplace and how their two roadmaps will interplay. Silver-based transparent conductors also compete with other kinds of transparent conductors of course, but the path forward in these cases seems to be more clear cut.

This report is international in scope. The forecasts herein are worldwide forecasts and we have not been geographically selective in the firms that we have covered in this report or interviewed in order to collect information. We note, however, that many of the suppliers of the products on which this report focuses are located in the U.S., while their customers (actual and potential) are found in Asia.

### 1.3 Methodology of this Report

The information for this work is derived from a variety of sources, but principally comes from primary sources, including NanoMarkets' ongoing interview program of business development and marketing managers and technologists involved with emerging electronics of all kinds, including the application areas covered in this report.

In addition, this NanoMarkets study drew on an extensive search of the technical literature, relevant company Web sites, trade journals, government resources, and various collateral items from trade shows and conferences. Some of the historical and background information came from the various specialist industry analyst reports that NanoMarkets as published in the recent past in the transparent conductor market and related fields. Where information has been used in an earlier report, it has been reinvestigated, reanalyzed, and reconsidered in light of current developments and updated accordingly.

The forecasting approach taken in this report is explained in more detail in Chapter Four, but the basic approach taken here is to identify and quantify the underlying needs and markets that are served by transparent conductors; consider the specifics of the applications and the types of products available or under development; and assess the competitive landscape to

determine the suitability and likely volume for silver-based transparent conductors over the next eight years. In coming up with this assessment, the stated plans of key firms are of course of special interest, although NanoMarkets critically considers these claims in light of all available data.

Forecasting for the materials covered in this report is especially difficult at the present time, because of the many economic and other risks that seem to be present in the marketplace. Uncertainty extends not only to the quantities of the devices that will be shipped that will be using silver-based transparent conductors, but also to the price of these conductors and the price points for these materials will assume over a period of time. To this must be added considerable levels of technological uncertainty associated with many of the materials covered in this report.

The impact of broader events must also be considered. It is very difficult to know quite which way the world economy is headed in the next few years. It seems reasonable to assume that there is going to be no immediate period of very rapid growth, although one can certainly not make the same claim about the entire period considered in this report. In a shorter time frame, however, are we looking at slow growth or actual recession. The reason all of this is important is that the markets for silver-based transparent conductors are heavily dependent on consumer electronics, which in turn depends on the economy to a large degree.

Despite all of these difficulties and uncertainties, we have made determinations to quantify and forecast the markets for silver-based transparent conductors. In Chapter Four we will explain in more depth our approach to these uncertainties, and alternative scenarios we have considered in making the forecasts.

### 1.4 Plan of this Report

In Chapter Two, we have considered the technologies and companies that lie behind the growing success of silver-based transparent conductors. As we have already noted, each of these firms has its own approach to silver transparent conductors and also brings its legacy strengths and weaknesses to bear on this market. We have also looked at recent developments that are relevant to the silver-based transparent conductor market, and the strategies and prospects for achieving significant market penetrations. The Chapter also takes a look at the generic advantages and disadvantages of silver as a material for transparent conductors.

In Chapter Three, we analyze the applications that use silver-based transparent conductors, explaining how this kind of material is likely to be used in these applications, the unique needs of each of the application areas, and the strategies that will produce the greatest opportunities for growth and new revenues for the manufacturers considered in this report. As we noted earlier, some applications are "more equal than others" when it comes to considering the penetration of silver-based transparent conductors.

Finally, Chapter Four contains our eight-year forecasts of the markets for silver-based transparent conductors. We have broken the market out by applications, but also include a forecast by type of product and of the share of the entire transparent conductor market that we expect to be taken by the silver-based species.