Emerging Markets for non-ITO Transparent Conductive Oxides

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Chapter One: Introduction

1.1 Background to this Report

1.1.1 Uses of alt-TCOs as Transparent Conductors

Forms of zinc and tin oxide have been proposed as an alternative to indium tin oxide (ITO) in the display and photovoltaic (PV) industry for many years, with mixed commercial success. In the thin-film PV space, alternative transparent conducting oxides (alt-TCOs) have done well with fluorine tin oxide (FTO) and aluminum zinc oxide (AZO) becoming quite common at this point in time. However, attempts to sell indium zinc oxide (IZO) into the display space have not succeeded to any strong degree.

The motivation for using alt-TCOs is usually that money can be saved on materials and most likely, specific materials that use large amounts of indium can be avoided. This matter has taken on a new urgency in view of recent Chinese industrial and trade policy, which favors controls on exports of indium. The Chinese government has also shut down environmentally unsound indium extraction facilities in China. The potential opportunities for alt-TCOs seem to have increased as a result, although these TCOs also now have to compete increasingly with next-generation transparent conductors that will almost certainly outperform them given time.

Adding to the fun, are new applications for alt-TCOs and the emergence of new kinds of TCOs. One new application that we see as being of considerable importance for these materials is so-called smart windows. Such windows have enjoyed niche status for many years, but may well emerge as a mass-market product, if the Green building market continues to fulfill its promise.

Finally, with the help of a semantic stretch, one might consider the use of the metal oxide materials considered in this report in TFTs as part of the opportunity space for alt-TCOs. Here one is, in effect, saying that a transparent conducting oxide is also a semiconducting transparent oxide. Taken literally, this is simply a contradiction in terms. However, given that these alt-TCOs are neither very conductive nor very semi conductive, we hope that the reader will forgive our embracing of this contradiction. We should perhaps mention that some of the most interesting new alt-TCOs are emerging in the context of TFTs.

1.1.2 The Joys and Otherwise of Sputtering

While such new applications are certainly the most interesting from a purely intellectual point of view and we think may also turn out to be the most profitable opportunities for alt-TCOs in that they are certainly also the most risky. It also seems likely that they will take quite a while before they generate significant revenues.

Given the extraordinarily difficult business climate that exists at the present time, it seems that many makers of alt-TCOs will be looking for more immediate and less risky opportunities. The least risky of these opportunities is certainly in the TFPV space, where suppliers of AZO and CIGS can simply expect to see sales rise as CIGS and CdTe continue to experience growing sales revenues. This is a low risk opportunity in that the alt-TCO producer only has to follow the TFPV industry onwards and upwards.

Alt-TCOs can only substitute for ITO when their performance is good enough, and the choice of an alt-TCO may be for quite mundane reasons. For example, First Solar, which dominates the CdTe panel market, adopted FTO for a transparent electrode because of the ease with which it could be applied to glass. But the main claim of alt-TCOs lies in their cost advantage. Usually, this is taken to mean that the alt-TCO in question uses a less expensive metal than indium or at least less indium than ITO. But the real unique claim for alt-TCOs is that they continue to use sputtering and therefore minimize economic switching costs for firms that adopt TCOs, although switching costs are never zero.

The point here is that in any existing operation that already uses ITO, production-scale sputtering equipment exists and is often depreciated; often fully depreciated. Furthermore, at such production plants the sputtering process and its controls are understood. Any new material will have a much higher likelihood of success if it can be used with existing production equipment and this is the case with alt-TCOs. While printing and solution deposition are the vision of the newer transparent conductors (TCs) that use nanomaterials or polymers, the harsh reality is that no sane manufacturing facility will adopt a new TC technology unless it brings them 30-50 percent savings in manufacturing costs or the current manufacturing practices cannot deliver the products that an organization has targeted.

Their use of existing sputtering facilities is therefore a key competitive advantage that *alt*-TCOs have over all other replacements, where alt-TCOs are being considered for existing operations. However, we note that even in such cases, economic switching costs cannot be avoided entirely. No firm could move from (say) ITO to ZnO without some kind of a learning curve.

1.1.3 The New TCO Palette

The alt-TCOs and the applications mentioned so far are well established and the impact of Chinese indium policy seems certain to be a key driver for alt-TCOs going forward. Indeed, if it hadn't been for the Japanese tsunami and its consequences that led to low production by Japanese display firms, there may have been an ITO shortage in Japan at the beginning of 2011. It seems likely that this problem has only been put off and will result in alt-TCOs receiving more attention in 2012.

Of course, in time the indium market will adjust to any likely supply constraints imposed by the Chinese authorities, although it could take several years for this to happen. In addition, alt-TCO suppliers that are attacking the ITO replacement market face growing competition from nanomaterials that are likely to exceed them in terms of performance in a short while and are also inherently flexible, something that TCOs are not. With flexible displays and PV panels now inching towards commercialization, this is something that works against the expansion of the alt-TCOs market.

Nonetheless, the uncertainties associated with ITO replacement by alt-TCOs are limited by comparison when compared with the risks associated with creating and marketing new alt-TCOs. Here we find significant—and novel—risks at the level of the materials themselves, in terms of the applications and also in terms of business structure and leadership.

New alt-TCOs, new applications, new companies: Recent research asserts that there exists a "sweet spot" on the periodic table where one can find the elements that have the highest figure of merit for effective *alt*-TCOs. Unfortunately, this includes some very bad players like cadmium and mercury. But excluding bad players, this still leaves a mind-boggling amount of opportunity space to explore for both old and new applications.

Obviously, the creation of alt-TCOs could be addressed to older applications, most notably ITO replacement. However, what is more likely is that these newer materials will be used for newer applications:

- A key goal for TCO innovators is the creation of robust *p*-type semiconductors. Most TCOs are *n*-type semiconductors (e.g., ITO). But significant effort devoted to developing *p*-type semiconductors would lead to needed innovations such as robust *transparent thin-film transistors (TTFTs).* Copper based p-type TCOs are already known.
- Several companies including Sony, Sharp and Toshiba have demonstrated AM-OLED displays with transparent TFTs of amorphous indium-gallium-zinc-oxide (IGZO).

- There is now considerable interest in transparent displays that would either use OLEDs or quantum dots (QDs) as their core technology. These would need transparent TFTs, with ZnO being the most likely alt-TCO to be used in this context. Samsung has built a QD-based prototype display using TFTs made from the alt-TCO amorphous hafnium-indium-zinc oxide (HIZO).

- There may be new applications for alt-TCOs in smart windows.

The inherent risks of these new applications are only added to by likely changes in business structure. Here we offer the cautionary tale of IZO, which has been used by Samsung as a transparent conductor because it was supposedly more easily etched than crystalline ITO. At one time there was talk that IZO might take as much as 30 percent of the display market, but it has never come close. One reason seems to be the fact that Idemitsu Kosan holds important patents governing the use of IZO. This adds to the price of this material and the high price in turn reduces its use.

Many of the newer TCOs are going to be dependent on IP from companies in much the same way as we indicate above for IZO. Therefore pricing strategy is likely to be an important factor for firms in the alt-TCO markets of the future in a way that is not the case for the current breed of TCO firms that operate in a much more commoditized market.

1.2 Objectives and Scope of This Report

The purpose of this report is to explore the opportunities for alt-TCOs and is part of NanoMarkets' ongoing coverage of the transparent conductor and PV/display materials markets.

In this report, we mostly cover materials that are at or near commercialization. This means, of course, that we analyze in detail the alt-TCOs that are already extensively used in the PV space. But we also give extensive coverage to new alt-TCO materials which have progressed out of the lab and into (at least) pilot or demonstration stage technologies. That said, we will also give NanoMarkets' take on "breakthrough" announcements in Chapter Three which we believe should be monitored for future opportunity.

1.3 Methodology of This Report

The information for this report comes mostly from interviews with business managers and technologists, and other key personnel participating in the TCO space to understand how they see the *alt*-TCO market evolving and changing. In an attempt to avoid an *alt*-TCO only spin and to balance the excitement of discovery with the realities of commercialization, we interviewed participants in all TCO sectors, including traditional users/consumers of ITO and those who are actively seeking new TCO products with breakthrough potential.

In addition, this NanoMarkets study draws the historical and background information presented in previous NanoMarkets reports. Where information has been used from an earlier report, we reanalyzed our data in order to validate our own statements.

We have also gathered information for this report from numerous secondary sources. These include Web sites, technical literature, trade show pieces and collateral, trade and technical journal.

The forecasting approach taken in Chapter Four is similar to that used in other recent NanoMarkets reports. We identify and quantify the underlying needs and markets that are served by *alt*-TCOs; 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 of each of the transparent conductor types over the next eight years. Plans presented by key firms covered are critically evaluated in light of all available data.

1.4 Plan of this Report

Chapter Two is a materials-focused chapter. Consideration is given to each present and emerging type of *alt*-TCO material that we identified as being of current commercial importance or if we believe it will allow a commercial breakthrough. We look at *who* makes the material and *how* it is manufactured. We explore the applications and discuss major materials market participants. We will then present forecasts for the materials markets for each product in current and emerging markets.

Chapter Three is an applications-focused chapter. Here we compare and contrast how different *alt*-TCOs are used in specific applications and explore their strengths and weaknesses. We will present opportunities for materials players to participate and gauge the market sizes. Additionally we will focus on how *alt*-TCOs compete among themselves, rather than against ITO. Chapter Four contains our granular eight-year forecasts for alternative transparent conductors.