
The Markets for Flexible Glass 2011

Nano-427

Published October 2011

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NanoMarkets, LC
PO Box 3840
Glen Allen, VA 23058
Tel: 804-270-4370
Web: www.nanomarkets.net

Chapter One: Introduction

1.1 Background to this Report

1.1.1 The Value of Flexible Glass

The value that would be created by a flexible glass material has long been recognized. Supposedly the Roman Emperor Tiberius was presented with a drinking bowl made of flexible glass. The Emperor threw the bowl on the floor and it dented rather than shattered.

But not much seems to have been heard of flexible glass since. NanoMarkets' research has uncovered that over the past few decades the term "flexible glass" has come to be used in a metaphorical sense, to describe a series of materials that were made from resins and plastics and that otherwise had glass-like properties. Unfortunately, these flexible pseudo-glasses could seldom compete with actual glass in terms of transparency or in its barrier qualities.

However, since the early 21st Century a handful of leading glass companies have been developing genuinely flexible glasses that are the heirs to Tiberius' bowl. The firms involved in this work include AGC (more commonly referred to as Asahi Glass), Nippon Electric Glass (NEG), Tokyo Electron Glass (TEG) and Schott Glass. However, the firm that is most closely associated with flexible glass is Corning, which certainly has the greatest mindshare in this space and has done the most business development work to promote the concept of flexible devices.

Nonetheless, actual flexible glass has proved slow to develop and bring into the marketplace. This is surprising in a way since all we are really talking about here is regular glass that has been made exceedingly thin so that it can be flexed. Meanwhile, a few flexible pseudo-glasses remain out in the marketplace, but are sufficiently different from real glass to be a distinct category of product and to be clearly distinguished from regular glass in terms of the value they can offer.

Conversely, as the Tiberius story seems to suggest glass is highly and intrinsically valued, but its inherent rigidity would seem to detract from its value. The story also suggests that flexible glass could address some very large markets indeed and this possibility shouldn't be dismissed lightly. However, for now flexible glass will be used primarily within what would be regarded as the electronics industry.

More specifically, there is an understandable connection made between flexible glass and flexible electronics, because flexible glass would apparently represent an excellent substrate

and barrier material for flexible electronics products. However, NanoMarkets believes that there are more immediate markets for the first wave of flexible glass offerings to tap into.

1.1.2 Glass, Weight and R2R in the Display Industry

Where the flexible glass firms are looking for their *early* revenues is in two places within the display industry:

- As an enabling technology designed to facilitate the use of R2R processes
- As a way of reducing the weight of displays

Flexible glass offers a way for the display industry to smoothly transition to R2R processes. At present, displays are generally created in batch mode. However, there are strong theoretical arguments for using R2R processes in the display industry:

- One of these arguments is the general one that R2R processes are inherently less expensive than batch process. While every industry is always in search of ways to reduce costs, the display industry has never been a very profitable one and so has more incentives for such a search.
- There is also a concern that it will not be easy to scale the current batch processes for making displays much beyond where they are now in terms of substrate size. R2R processes are supposedly easier to scale in this regard.

It has been tacitly assumed that moving to R2R for making displays will involve a changeover to using plastic substrates. This could be challenging:

- The use of plastic raises issues of dimensional and thermal stability during processing and after.
- The need to substitute an entirely new kind of material for glass is also fairly challenging in that it would typically require a rethink of plant design and retraining of operators.

Nonetheless, the opportunity inherent in flexible glass is that R2R manufacturing can be implemented without shifting away from glass. This is potentially a significant market advantage for flexible glass in that it enables the display industry to shift to R2R without having to give up on the inherent advantages of glass.

Another immediate opportunity for flexible glass in the display industry, and again one that has been acknowledged by the firms that are developing this kind of product, is the ability of thin glass to offer lower weight display products:

- This matters most in the mobile display sector, since glass is a major contributor to the weight of the displays in smart phones and especially in tablet and laptop computers, and low weight is a major selling feature for these systems.
- The fact that some of these systems (smart phones and tablets) now represent the fastest growing parts of the computer industry suggest that glassmakers have a way to make money by selling their flexible glass into this sector

1.1.3 A Parallel Market in the PV Sector

The weight and R2R advantages of using flexible glass are mostly directed towards markets in the display industry at the present time, although a few of the suppliers have also tilted their hats towards the opportunities for flexible glass in the solar panel/PV industry. The immediate opportunities for flexible glass in the PV sector parallels those just discussed for the display sector:

- Flexible glass can facilitate the use of R2R in PV in much the same way that it does in the display industry. However, the opportunities that emerge as a result of this factor are somewhat more constrained in the PV industry than in the display industry. This is partly because the PV industry is more likely to use non-glass substrates in the first place, but especially because First Solar's dramatic success in the thin-film PV sector, based on low-cost but without the use of R2R suggests that R2R may not be all that it is cracked up to be.
- Weight can be as big a factor in the PV industry—and especially in the BIPV sector—as it is in the display industry. Solar panels are heavy and costs are added in supporting roofing when heavy glass or metal substrates are used. Therefore, thin/flexible glass solutions appear to be an attractive option for BIPV roofing and perhaps in other sectors of the PV market.

1.1.4 Flexible Glass and Intrinsically Flexible Products

Although the first revenues from flexible glass will almost certainly come from substituting for regular glass to enable lower weight products and R2R processing, the market for flexible glass will eventually be extended when it becomes possible to use flexible glass to enable intrinsically flexible products.

The rise of flexible electronics: "Flexible electronics" is an idea that has been with us for a long time, but is only now beginning to inch towards reality. This concept is strongly associated with flexible displays, but also applies to large-area sensors, PV, OLED lighting and disposable electronics.

Quite apart from the novelty aspect of intrinsically flexible products in these areas, there do appear to be good marketing reasons why these products could generate significant revenues if they are effectively marketed. For example, the concept of displays that can be rolled up and put in a pocket, or solar and lighting panels that conform to contours of a building fabric are attractive ideas, both from aesthetic and practical standpoints.

However, we think there are major hurdles that flexible electronics must overcome before it can make a good market for flexible glass:

- As the above suggests, intrinsically flexible products represent a marketing challenge since they are novel products. Some may "go viral" in the way that (say) the iPhone did, others will take a lot of marketing resources and money to make them succeed in the marketplace. Others will simply fail. *Before the directions that flexible electronics will successfully take have become clear, it will form an uncertain market for flexible glass. In any case, it seems likely that flexible electronics will amount to a sizeable market for some years to come and this will seriously restrict the opportunities for selling flexible glass.*
- A tacit assumption of flexible electronics seems to be that the substrate-of-choice will be plastics of various kinds. This may or may not be the case, but *it is quite possible that firms marketing flexible glass for substrate materials may find that they have to make strong cases for using expensive glass over less expensive plastic. This case can be made, and it will be essential to the success of flexible glass in the marketplace.*
- Intrinsically flexible products require both flexible substrates *and* flexible encapsulation. To date, no really successful flexible encapsulation scheme is available and some of the ones that appeared and proved technically successful have also proved to be too expensive. All this is mixed news for flexible glass. On the one hand, the lack of strong encapsulation hurts the prospects for flexible electronics and therefore restricts the potential market for flexible glass. On the other hand, encapsulation for flexible electronics may actually use flexible glass, although this opportunity has yet to be developed.

1.1.5 Flexible Glass versus the Rest

Flexible glass seems to have a lot of positives in the display, PV and other electronics- and energy-related areas:

- At the core of this is the fact that glass is a familiar product that production managers in these markets work with all the time. And we think that this is an important factor in getting a new plant up and running.
- Other factors that favor glass over other substrates (and encapsulation materials) include transparency, thermal stability, scratch resistance, pinhole-free surfaces and better barrier properties.

To summarize, although glass may run into competition from metals, textiles and even paper, its biggest challenge for flexible applications of all kinds will most certainly come from plastics. This should be no surprise given that the word "plastic" *means* flexible. And while low-cost is not exactly implicit in the definition of plastic, it is certainly a reasonable assumption about plastic; at least it is reasonable to assume that plastics are less expensive than glass of any kind. Nonetheless, in our judgment there are five main areas where flexible glass will be able to compete with plastics in the intrinsically flexible electronics markets considered here. These are:

- Dimensional stability. Flexible glass does not stretch in the way that plastic does. If a stretched substrate means a distorted image on a display, then the display is of little use.
- Glass is an excellent barrier material. As we have already mentioned, flexible glass may ultimately serve as a way of providing flexible encapsulation for intrinsically flexible products. Water can't seep into glass as it can into plastic sheeting. So electronics built on, and encapsulated with, flexible glass can last longer.
- Glass is a better substrate. Glass is smoother than plastics (which at the micro level can be quite rough) and can therefore be easier to fabricate electronics on, compared with plastics.
- Thermal stability. Glass is more thermally stable than any of the other materials we have mentioned here. This assertion applies to flexible glass as much as it does to the more familiar rigid glass. The important consequence of this is that high-thermal fabrication processes can be used alongside glass. This typically results in higher performance electronics and PV, which again suggests the flexible glass may become

widely chosen for substrates/encapsulation in flexible electronics that need high performance.

- Low weight and R2R suitability. We have already discussed these advantages as they apply generally to using flexible glass in electronics. However, they are no less applicable when *intrinsically* flexible products are involved.

Based on all of this, there appears—*a priori*—to be a future market for "flexible glass." As we have already noted, such a product has been produced in small quantities by a handful of suppliers and for several years, and is only just beginning to make an impact on the market.

NanoMarkets believes that a substantial share of flexible substrate and encapsulation markets will be achieved by "flexible glass" over time; although we note that "over time" may be the operative words in this market; manufacturing of flexible glass by the glass makers remains challenging although good progress has been made. Also, as we have discussed above, manufacturing challenges are by no means the only ones that the emerging flexible glass business faces. There will be big marketing challenges too, and we think *these* challenges are probably being underestimated at the present time.

The first markets for flexible displays seem likely to emerge in low-weight products, which is a product/market development path that has already been established by the thin-glass programs that have been in place at many glass makers for a long time. Then will come the flexible glass in R2R fabrication, because all that is needed is to demonstrate that R2R can bring down the cost of fabrication. Finally, we see a role for flexible glass in intrinsically flexible products; but this will take some time, because a lot of aspects of these products are still quite uncertain.

The biggest opportunities for flexible glass in intrinsically flexible products are almost certainly in displays and PV, but this could be just the beginning. We have already mentioned the use of flexible glass in sensor and lighting markets and there appear to be quite a few hints of how this interesting new flexible material could be used in many other areas, including areas well outside the semiconductor-related industries. Perhaps flexible drinking bowls, of the kinds that impressed the Roman emperor, will be a product of the future as well as a product of the past.

1.2 Objective and Scope of this Report

With all this in mind, NanoMarkets is publishing this report, whose main objective is to analyze and quantify the market for flexible glass over the next eight years:

- This eight-year scope, we believe, provides an understanding of how big this market could ultimately become, that is, what its revenue potential is. In addition, eight years is also within the planning timeframe of many large businesses.
- However, we also have a secondary and near-term focus in this report, which is directed to where the opportunities are right now, since early revenues will be of enormous importance to many firms in an economic climate in which capital is very hard to come by.

Despite this second point, no one could seriously doubt that the big potential for flexible glass lies in the future and this is emphasized by the fact that it has clearly proved harder than expected to bring flexible glass to market:

- This is also one of the reasons why we provide a critical profile of the firms currently manufacturing flexible glass and the products that they are offering. However, one interesting aspect of the flexible glass market is that all—or almost all—of the participants are very large companies that have the resources to be proactive in the flexible glass/flexible electronics marketplace.
- Taking a conservative approach to our analysis and forecasts, we think, adds a much needed sense of reality to our analysis. Flexible glass is a somewhat "cool" product and it is all too easy to ignore the serious challenges that flexible glass faces with regard to achieving market penetration.

Scope of the report: This report examines the flexible glass products currently on the market and where they are likely to generate new revenues. While this report deals specifically with "flexible glass," we note that the definition of such a product keeps changing with the capabilities of the industry. Thus, one standard text in the field of flexible displays defines flexible glass as glass that is below 0.2 mm thick. However, the most recent products in this space—from AGC and Corning, for example, are half this thickness: 0.1 mm.

In fact, it is impossible to keep the discussion in this report entirely focused on genuinely flexible glass. This is because the trend towards flexible glass should be seen as part of a larger trend towards thinner glass. This trend has been ongoing for at least two decades and has apparently been quite successful, and most of the firms that are now working on developing flexible glass are part of this trend. Although the scope of this report is not on thin glass, we have certainly discussed this trend as it impacts the market evolution for flexible glass.

The main applications that are discussed in this report for flexible glass are displays and solar panels/photovoltaics. These are core areas of expertise for NanoMarkets, but they are also the areas on which flexible glass makers appear to be focusing their efforts. Within these areas, we have given special consideration to intrinsically flexible end products such as rollable displays and conformable BIPV products.

However, these are by no means the only products that the manufacturers of flexible glass have targeted. In this report, we have discussed some of the other opportunities for flexible glass, especially in the sensor and microelectronics field, but we also note that flexible glass could eventually bring a revolution in a wide range of product areas, many of which have nothing to do with electronics or energy markets. It also discusses where the next wave of flexible glass and similar products will be coming from and what sectors of the display and solar panel industry will be most likely to make use of flexible glass for both substrates and encapsulation.

1.3 Methodology of this Report

The methodology of this report is spelled out in more detail in Chapter Four of this report, where we examine, in particular, the forecasting approach that brings together most of the other aspects of the methodology, too.

Information sources: The information sources for this report are quite diverse. We have relied on data sheets and similar sources for information on the flexible glass and related products that are reviewed in this report. However, many of the sources are primary. NanoMarkets conducts interviews across the spectrum of flexible and printed electronics on a regular basis; from the level of the display and PV panel maker and other OEMs, all the way to the materials maker. This gives us a very broad perspective on how flexible glass is being used at the present time and how it is likely to be used in the not-too-distant future.

In addition to product data sheets, we have also drawn on other secondary sources including the usual financial documents, trade press reports, and corporate home pages. NanoMarkets' analysts frequently attend—and present at—major conferences at which flexible electronics and the materials used for flexible electronics are key themes. In this report we have drawn heavily on what we have heard at such conferences, both in terms of formal presentations and from informal discussions.

The core analysis in this report is entirely the work of NanoMarkets' analysts and most of it was developed for this report alone. However, we have also drawn on other NanoMarkets

reports in order to ensure that the forecasts and the general strategic story being presented here are consistent across the entire collection of NanoMarkets' current reports.

The forecasting methodology is also similar to that used in other NanoMarkets reports. In particular, we have examined the addressable markets for flexible glass and, based on how we see the pros and cons of flexible glass in each of the markets considered in this report, we have developed a revenue and volume forecast:

- The data that we have used to quantify the addressable markets is largely taken from existing NanoMarkets reports. In these reports we have, for example, provided numerical estimates for OLED displays, e-paper displays, flexible PV, etc.
- The penetration estimates used for flexible glass are those that we believe are realistic given the history so far in the markets which we have considered here. In particular we have been fairly conservative in creating our forecasts. This is primarily because R2R processing and flexible glass itself have been ideas that have been "out there" for quite some time, but which have yet to generate any significant revenues. So conservatism seems to be required in any forecasts of this kind. This probably does not apply to the same degree in the case of low-weight products, because there is already a well-developed trend to using lighter glass for displays.

1.4 Plan of this Report

Chapter Two of this report is focused on the products and technologies that underpin flexible glass technology. In particular, we examine the flexible glass products that have made it, or at least are close to making it, into the marketplace and some of the research that appears to be directed towards making flexible glass more of a viable product commercially. Included here is also a survey of the main current efforts towards producing "thin glass" of which flexible glass can reasonably be considered a part. We also look at how flexible glass compares to mature substrate materials used today and also examine some products which, while they are not exactly "flexible glass" in the strictest sense of the term, appear to be very closely related to it from a conceptual point of view.

In Chapter Three we examine the actual markets into which flexible glass can plausibly be expected to be sold. This is the core of the analysis presented in this report, since it ultimately determines what the revenues for flexible glass products could turn out to be in the future. The focus of this chapter is on the display industry, although there appear to be other markets towards which flexible glass could be directed and which are sometimes mentioned by firms working on flexible glass development.

In Chapter Four we have provided detailed forecasts in volume and value terms for flexible glass. Here we have provided breakouts by volume and value and segmentation into the type of product in which flexible glass might be used in the future. More specifically, we have broken the market into four key areas (1) substrates for R2R processing of otherwise rigid products, (2) flexible substrates used primarily to reduce the weight of the final product, (3) substrates for intrinsically flexible products, and (4) encapsulation for intrinsically flexible products. For the categories related specifically to intrinsically flexible products, we have broken out the market further by the type of products involved; primarily flexible displays and flexible PV.