AMLCD Substrates Trends in Technology

Technical Information Paper

TIP 102
Issued: November 2004
Supercedes: February 2003

Dr. Josef C. Lapp
SP-PR-02 Corning Incorporated, Corning NY

Biography

Dr. J. C. Lapp is a Development Associate in the Science & Technology Division of Corning Incorporated. His area of expertise is in glass composition and property relationships. Dr. Lapp was co-inventor of Corning's Code 1737 glass substrates, the industry standard for TFT-LCD applications. Most recently, he co-invented the innovative Corning EAGLE^{2000} glass. Dr. Lapp has authored more than 30 technical publications and holds 16 U.S. patents for glass compositions invented during his 15-year tenure at Corning Incorporated.

Abstract

The utilization of TFT-LCD's is rapidly increasing in laptop, desktop monitor, TV and other high resolution applications. Each of these applications has their own unique set of market drivers. This presentation explores the catalysts behind these trends, what they mean in terms of the glass substrates used and how glass manufacturers are responding to the demands of the market.

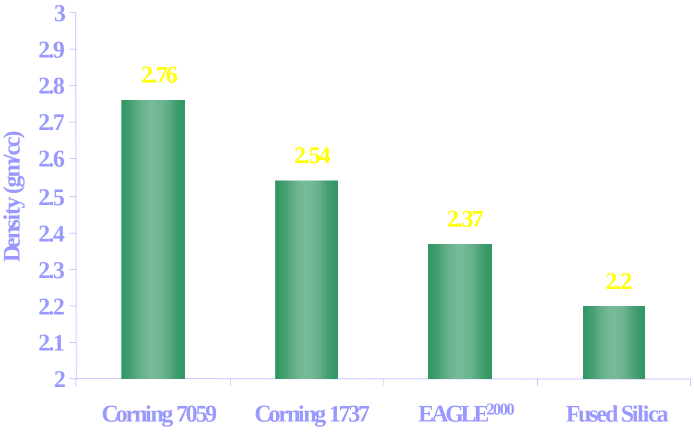
Data

Although portable applications still account for the majority of the sales of TFT-LCD's, the utilization of these displays is rapidly expanding into the desktop and TV markets[1]. Each of these applications has their own unique set of market drivers.

For portable applications, the focus for the TFT-LCD manufacturer has shifted as the earlier problem of pixel yields has been solved. Today, weight is the key driver for portable panels. Panels with weights as low as 420 gms for a 14.1" have been reported[2].

TFT-LCD manufacturers have gone to the extreme of physically grinding off tenths of millimeters of the glass substrate after panel manufacture to save a few grams. Substrate manufacturers have responded by modifiing the glass composition to lower the glass density while maintaining the other attributes of importance for this application. An example of this trend is given in Figure 1 which tracks the density of three generations of Corning Incorporated TFT-LCD glass substrate

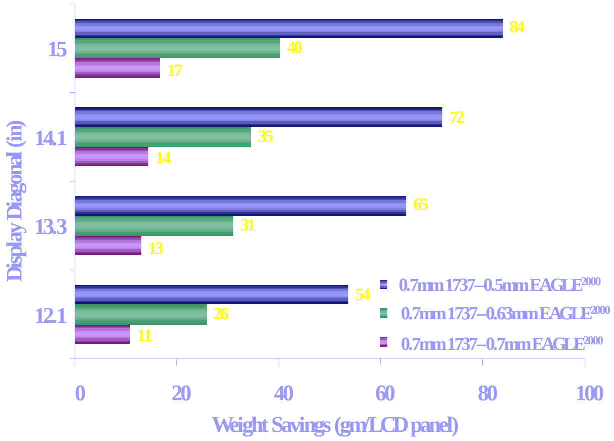
Figure 1. **Trend in glass density**



Corning 7059 glass, with its density of 2.76 gm/cc, was the first alkali-free glass used for TFT-LCD applications. Corning 1737 glass (density of 2.54 gm/cc) was first introduced in 1994 and is currently the industry standard. EAGLE^{2000} glass (2.37 gm/cc density) is Corning's newest product for TFT-LCD's having been introduced last year[3]. A steady progression of decreasing density is obvious with the development of these new glasses. It is interesting to note that the density of these glasses is rapidly approaching that of fused silica. This is generally considered to be the lower limit for the silicate family of glass compositions to which all current TFT-LCD glasses belong.

Figure 2 illustrates what this decrease in density means in terms of weight savings in the final display. In this figure, the weight savings to be realized upon the replacement of Code 1737 glass with the EAGLE^{2000} glass are plotted for several popular portable panel sizes. A simple one for one substitution of EAGLE^{2000} glass for Code 1737 results in weight savings of ~6% or 17 grams in a 15" diagonal display. Combining this with a reduction of glass thickness can result in even larger weight reductions. For example, replacing 0.7mm Code 1737 with 0.5mm EAGLE^{2000} glass results in a 35% reduction in weight or 84 grams in a 15" diagonal display.

Figure 2. **Panel weight savings**



For desktop applications, the weight of the display is a secondary issue compared to those attributes which impact the viewing performance. This includes such features as wide viewing angle and high resolution. Recently, there have been several technical innovations to improve both of these attributes.

Many TFT-LCD manufacturers are exploring the use of reduced cell gap, multiple vertical alignment and in-plane switching techniques for wide viewing angles[4]. While not thought to be directly related to the substrate material properties, all of these new technologies have a direct impact on the substrate product properties. In particular, thickness control and smoothness of the glass substrate become even more important for tight control of the cell gap.

By its definition, a high resolution display incorporates more and smaller subpixels. As a result, the subpixel yield tends to be more sensitive to small particles in and on the glass substrate. In addition, the advanced metal lines required to drive these subpixels tend to be more sensitive to digs and scratches on the substrate surface[5]. A pristine, fire-polished glass surface, such as found on Fusion formed glass, would seem to be the ideal surface for these demanding applications.

The tighter pixel pitch found in high resolution displays demands a tighter alignment between the color filter and TFT plates. Small temperature differences at the time of manufacture can result in an offset of the corresponding subpixels due to the thermal expansion of the substrate. Substrates with lower thermal expansion coefficients are less sensitive to these effects. Figure 3 shows the trend in thermal expansion coefficients for the three generations of Corning glasses.

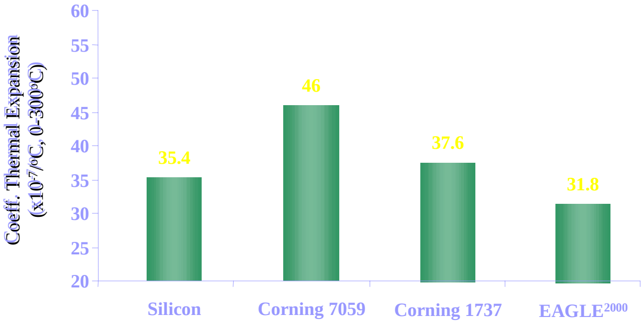
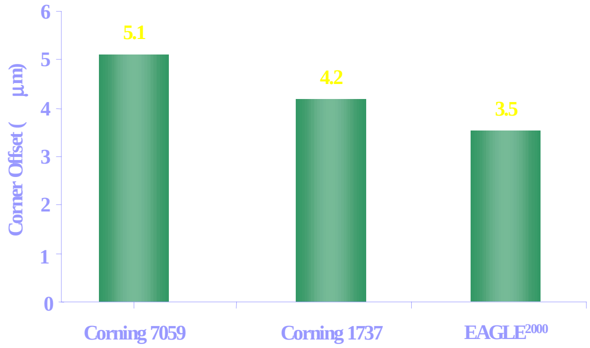


Figure 3. **Trend in thermal expansion cooefficient**

With the recent introduction of EAGLE^{2000} glass, the coefficient of thermal expansion of the glass has been reduced from 46 x10^{-7}/^{o}C to 31.8 x10^{-7}/^{o}C. What this means in terms of offset between the CF and TFT plate is illustrated in Figure 4. This figure plots the difference in the corner positions of the CF and TFT plates when the opposite corner is aligned and there is a slight temperature differential at the time of manufacture of the two plates. For this figure, it was assumed that the plates where 680x880mm in size and the CF plate was manufactured at a temperature 1^{o}C higher than the TFT plate.

Figure 4. **Corning offset between CF and TFT plates**



As shown in Figure 4, by using EAGLE^{2000} glass it is possible to reduce the offset between the CF and TFT plate from 5.1 µm to 3.5 µm for mother glass sizes of 680x880mm. This 30% reduction should enable tighter registration between the CF and TFT plates. In turn, this should enable the use of a finer black matrix and help open the window in the tradeoff between higher resolution and lower aperature ratio.

The application of TFT-LCD's for television is a natural extension of the use of these displays for desktop monitors, and most of the technical challenges are the same. This includes for example, the need for high pixel yield and wide viewing angle. The need for video response rates is evident; and the solutions, advanced metal lines and smaller cell gaps, are similar to those found in the monitor applications. As described above, all of these solutions are dependent upon the pristine nature of the glass substrate surface.

The real challenge in television is twofold. The first is in ensuring a pristine surface as the substrate size dramatically increases. Again, maintaining the naturally firepolished surface obtained with the Fusion process would seem to be easier and more preferred process when compared to the process of trying to recreate a surface with minimal defects by a grinding and polishing process.

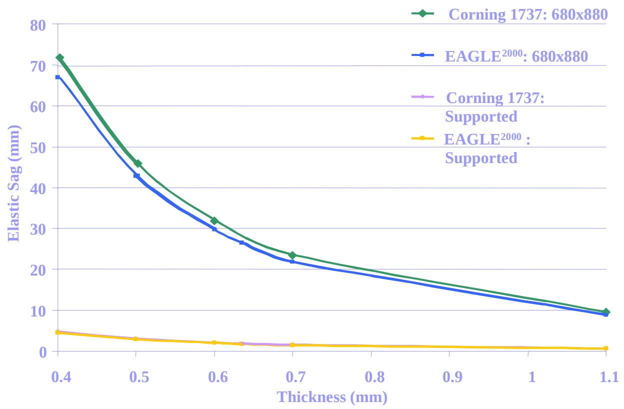
The second challenge lies in the ability to physical process large, thin substrates. Of primary concern is sag in this regard. Sag of an elastic material is proportional to:

$$S \; \alpha \; L^4 \rho g(1-\nu^2)/t^2 E$$

Where S is the sag, L is the unsupported span, ρ is the density of the material, g is the gravitational constant, ν is Poisson's ratio, t is the thickness and E is the Young's modulus. Sag can be directly proportional to the substrate density and inversely proportional to the Young's modulus. EAGLE^{2000} glass with a density ~6% less than Code 1737 and equivalent Young's modulus has ~6% less sag for the same size substrate. However, a much more dramatic effect can be realized by reducing the length of the unsupported span.

In Figure 5, the maximum sag of Code 1737 and EAGLE^{2000} glass is plotted as a function of glass thickness. For this plot, a substrate size of 680x880mm simply supported along the two long edges and one of the short edges is considered. The position of maximum sag is located on the midpoint of the unsupported short edge.

Figure 5. **Elastic sag as a function of glass thickness**

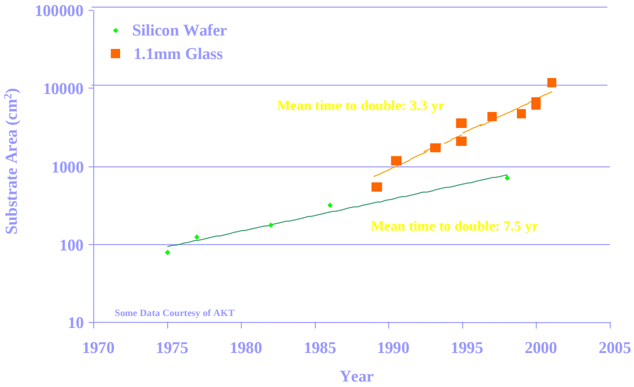


For this simple three edge support condition, the sag of Code 1737 ranges from 10mm for a substrate thickness of 1.1mm to greater than 70mm for a substrate thickness of 0.4mm. At 0.4mm, EAGLE^{2000} glass sags about 68mm.

By adding a fourth line of support parallel to the long axis, but located at the midpoint of the short axis, the sag can be dramatically reduced. These are the curves in Figure 5 labeled as Supported. In this case, the sag is less than 5mm for all substrates with thickness from 1.1mm down to 0.4mm. The still elusive part of this is in finding a way to contact the B side of the substrate without permanent damaging or marking the glass.

The issue of handling large substrates goes beyond just the application of TFT-LCD for television applications. For over-riding all three of these applications is the continuing need to reduce cost. One classic and still used approach by the industry is to reduce cost through the manufacture of multiple display panels on a single mother substrate. To reduce costs further, ever larger mother substrates are being used. Figure 6 is trend plot comparing the increase in size of silicon wafers with TFT-LCD substrates 1.1mm in thickness. While wafer sizes typically took 7.5 years to double in surface area, TFT-LCD substrates are doing this in half the time (3.3 years). If one considers other thicknesses (such as 0.6-0.63mm substrates used in laptop applications), the trend is even faster at ~2.8 years.

Figure 6. **Increase in size of silicon and TFT-LCD substrates**



Other approaches to reduce costs include reducing the number of mask steps[6], and/or increase the throughput and yield by taking advantage of improvements in the physical properties of the substrate. These improvements include such things better chemical durability of the substrate which allow for the use of more aggressive etching conditions enabling faster turnaround. For example, after a three minute immersion in a solution of 1 part NH_4HF: 10 parts HNO_3 (a solution used to mimic the etching of silicon) at room temperature, EAGLE^{2000} glass has a weight loss ~30% less than Code 1737. Of even more significance is the marked decrease in the appearance of hillocks on the EAGLE^{2000} glass. These formations are the result of the precipitation of insoluble etching reaction products on the glass surface, masking the glass, and resulting in an uneven etching pattern. Formation of such defects can lead to defects in subsequent deposited layers.

Conclusion

The demand for larger, thinner, more uniform and pristine glass substrates with improved physical properties continues to drive the need for innovation on the part of the substrate manufacturers. With the introduction of EAGLE^{2000}, Corning introduces a new generation of glass substrates specifically designed for the TFT-LCD market.

Acknowledgments

The author wishes to acknowledge P. Bocko, A. Fadul, L. Hamilton, T. Itoh, and K. Shindo for their inputs to this manuscript. Special thanks go to J. Terry for all his help with this manuscript and presentation.

References

1) S. Matsuno, *“Display Search Forecast, Display Search US FPD Conference”*, Paper 8.1, Austin, TX, 3/21-22/01.

2) LCD/PDP International 2000 Seminar, Yokohama, Japan, 10/25/00.

3) 10th FineProcess Technology for Flat-Panel Display, Tokyo, Japan, 7/5-7/00.

4) S. Morozumi, *“Active-Matrix Liquid-Crystal Displays”*, SID2000 Seminar M-8, Long Beach, CA, 5/15/00.

5) H. Kinoshita et. al., *“High-Resolution AMLCD Made with a-Si:H TFTs and an Al Gate and IZO Structure”*, SID1999, Paper 32.3, San Jose, CA, 5/18-20/00.

6) C.W. Kim et. al., *“A Novel Four-Mask-Count Process Architecture for TFT-LCDs”*, SID 1000, Paper 42.1, Long Beach, CA 5/16-18/00.

North America and all other Countries
Corning Display Technologies
MP-HQ-W1
Corning, NY 14831
United States
Telephone: +1 607-974-9000
Fax: +1 607-974-7097
Internet: www.corning.com/displaytechnologies

Japan
Corning Japan K.K.
Main Office
No. 35 Kowa Building, 1st Floor
1-14-14, Akasaka
Minato-Ku, Tokyo 107-0052 Japan
Telephone: +81 3-5562-2260
Fax: +81 3-5562-2263
Internet: www.corning.co.jp

Nagoya Sales Office
Nagoya Bldg., 7 F
4-6-18, Mei-eki, Nakamura-ku
Nagoya-shi, Aichi 450-0002 Japan
Telephone: +81 52-561-0341
Fax: +81 52-561-0348

China
Corning (China) Ltd., Shanghai Representative Office
31/F, The Center
989 Chang Le Road
Shanghai 200031
P.R. China
Telephone: +86 21-5467-4666
Fax: +86 21-5407-5899

Taiwan
Corning Display Technologies Taiwan Co., Ltd.
Room #1203, 12F, No. 205
Tun Hua North Road,
Taipei 105, Taiwan
Telephone: +886 2-2716-0338
Fax: +886 2-2716-0339
Internet: www.corning.com.tw

Korea
Samsung Corning Precision Glass Co., Ltd.
20th Floor, Glass Tower Building
946-1 Daechi-Dong
Kangnam-Ku, Seoul 135-708
Korea
Telephone: +82 2-3457-9846
Fax: +82 2-3457-9888
Internet: www.samsungscp.co.kr