

Measurement of Film Stacks in Cell Phones and Tablets Using White Light Interferometry

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The field of touchscreen technology is undergoing an explosive growth and development. It is difficult to imagine a personal life without a smartphone, a tablet, or some other touchscreen device. Laptops and desktops alike have acquired touchscreen capabilities. With high pace of the consumer electronics market, there is significant pressure on all aspects of touchscreen business, from improvements in technology, to improvements in quality control, to marketing.

The field of the LCD screens with touch capabilities is not new. Touchscreen technology was first mentioned in literature in 1965 [1], with the first commercially offered touch screen display introduced in late 70's by Magnavox, for use in educational terminals at the University of Illinois. At the turn of the century, the touchscreens became a ubiquitous technology, with extensive multi-touch and high-resolution capabilities.

The most common touchscreen consists of two independent modules, the imaging display and the touch module, with the latter placed on top of the display. The imaging display creates the image, while the touch module allows the user to interact with the device.

The most commonly used type of imaging display is the liquid-crystal display (LCD). There are different varieties of the LCD, such as active and passive matrix LCDs, but the construction concept is the same (Figure 1, left) [2]. The light from a backlight source is distributed throughout the screen by a layer of a diffuser (a light guide with a brightness enhancement film). The light then passes a first polarizer, and travels through a layer containing liquid

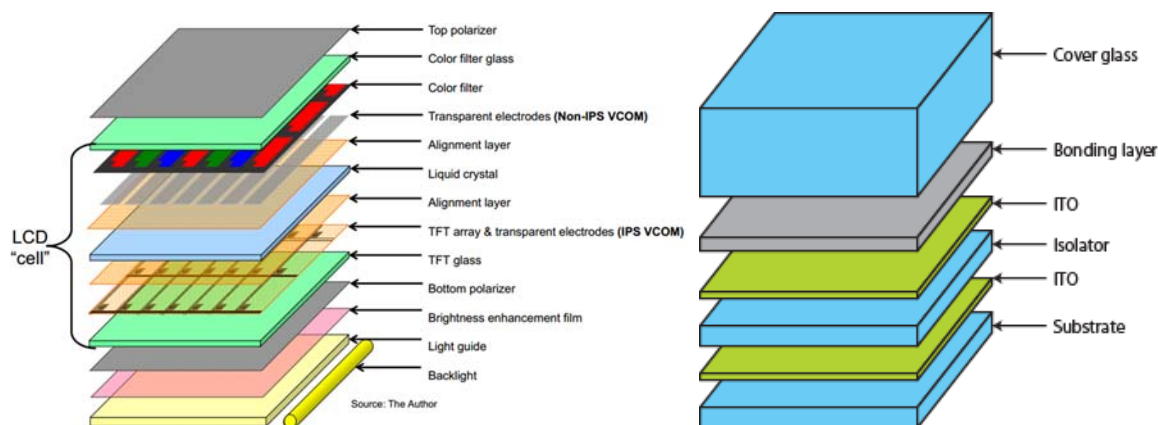


Figure 1. (left) Layer stack of an LCD imaging display. (right) Layer stack of a capacitive touchscreen

crystals, sandwiched between two layers of electrodes. The liquid crystals are activated by the electric signal. In the case of the active matrix display, the bottom electrode layer consists of an

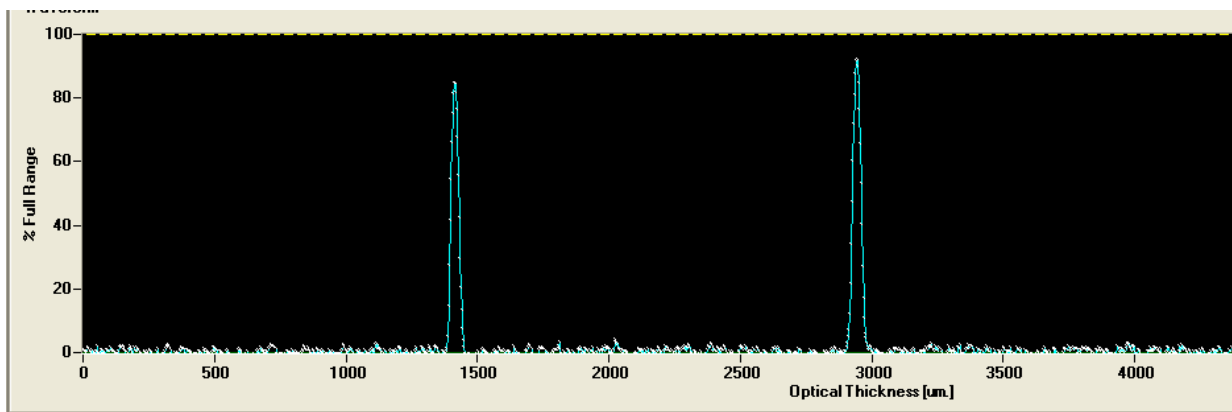


Figure 2. Optical signal obtained for a glass slide. The distance between the signal peaks is equal to the optical thickness of the slide.

array of thin-film-transistors (TFT) located on a substrate. On top of the LCD stack, another polarizer is oriented perpendicular to the bottom polarizer; therefore the second polarizer blocks the transmitted light when the liquid crystal layer is not activated. Once the liquid crystal is activated, it changes the polarization of the transmitted light, thus allowing the light to pass through the top polarizer. The color is achieved by placing an array of color filters above the liquid crystal layer.

Just like in case of the imaging displays, there is a variety of touchscreen technologies, such as resistive, capacitive, optical, acoustic etc. The most common touchscreen technology is capacitive (Figure 1, right). It is based on detecting the change in the capacitance between two arrays of electrodes, when the human finger approaches the surface of the screen. The touch module consists of two layers of electrodes encompassing an insulating layer (e.g. layer of glass), which acts as a spacer for the capacitor. The module is placed on top of the LCD stack, and the overall system is protected by a cover glass (e.g. Gorilla glass). There are also other variations of the LCD-touchscreen combinations, where touch-enabling layers are integrated with the LCD stack – the on-cell and in-cell technologies.

To attach different components of the touchscreen together, manufacturers use a layer of adhesive. Unlike the thickness uniformity of the glass substrates, the uniformity of the adhesive layer is difficult to control. In the past, the non-uniformity of the layers was acceptable to touch-screen manufacturers. However, as the technology of the LCD touchscreens moves ahead with high pace, manufacturers experience more and more pressure to ensure that the layer stacks are uniform, to improve image quality as well as the longevity and the durability of touchscreens.

In order to be able to control thickness of the layer during the manufacturing process, the manufacturer must be able to measure the thickness of the layer during or after the manufacturing process. Measuring thickness of a layer buried underneath other layers, using conventional mechanical methods, requires destruction of the finished product. It increases waste, but also adds significant cost to manufacturing, when large batch of product has to be discarded because the problem was not detected in a timely manner. Recently, manufacturers

have turned to optical inspection methods, which allow 100% inspection, on- or at-line, in real time.

One such method is based on the low-coherence interferometry [3]. In its basic principle, the light from a low-coherence light source is split into two portions. These two portions form so-called sample and reference interferometric arms. The sample portion of the light illuminates the layer stack of a touchscreen or some other device. Each surface within the layer stack reflects back the incident light. The reflected light is then combined with the reference portion of the light. The combined light creates an interferometric pattern. However, in case of the low-coherence light source, the interferometric pattern is visible only under certain conditions, when the path traveled by the light in the sample arm of the interferometer (to and from the corresponding sample interface) is equal to the path in the reference arm of the interferometer. By varying the length of the reference arm of the interferometer, and by measuring the magnitude of the change between the locations where interferometric pattern appears, one can extract the distances between the reflective interfaces within the sample, i.e. the layer thicknesses.

Lumetrics is licensing technology, developed by Kodak Inc, where the interferometer is formed by a communication-grade optical fiber. The path-length change is accomplished by stretching optical fiber using piezo-electric elements. Thus, the distance measurements are accomplished at high speed, with high precision and with reliable long-term continuous operation.

Figure 2 shows an example of the interferometric signal, acquired for a simple single layer of glass material during a single scan of the interferometer. This graph is equivalent of plotting the reflectivity of the sample versus depth. The peaks indicate the locations of the surfaces of the glass slide, with the first peak corresponding to the top surface of the slide, and the second peak corresponding to the bottom surface of the slide (assuming the slide is lying flat, with the incident light coming from the top). The distance between the two peaks is equal to the optical thickness of the layer. The physical thickness of the layer can be obtained by dividing the optical thickness by the material's refractive index (the refractive index can also be measured using this method, in a special configuration, where mirror is placed on the opposite side of the sample from the optical probe).

Figure 3 shows the interferometric signal acquired for a smartphone touchscreen. The multitude of peaks indicate numerous layers present under the surface – one can see the top cover glass, the substrates containing ITO electrodes, the spacer between the electrodes, and the adhesive layer between the touch module and the display. Below the adhesive layer (toward the right portion of the graph) are the polarizers and the layer containing thin film transistors (TFT). Some of the layers, such as the ITO and TFT, are much thinner than what the low-coherence interferometer is able to measure. In this case, the two interfaces of such thin

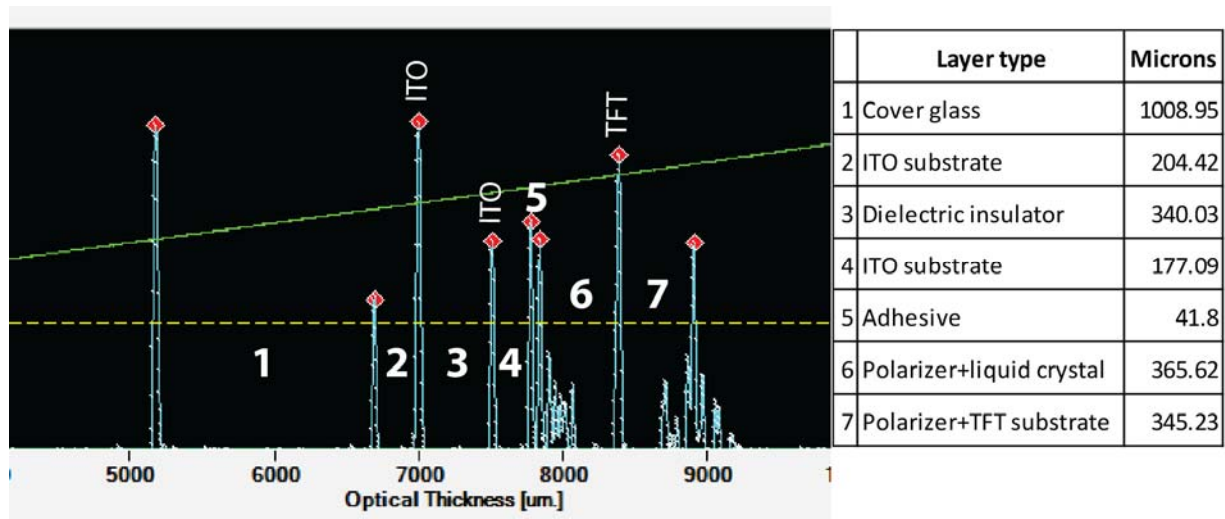


Figure 3. Example of an optical signal obtained for a touchscreen. The table on the right shows corresponding thicknesses.

layer appear as a single peak, and the measured thickness of the adjacent layers can therefore be slightly larger than the actual material.

In general, without some kind of prior knowledge, it is difficult to ascribe the peaks to exact interfaces. Fortunately, in many applications, the layer structure is known. In addition, manufacturers are often interested in the thickness of a specific layer, which is typically a layer of adhesive. Figure 4 measurement results for four different touchscreens from the same manufacturing line. The numbers indicate measurement locations. The measurements immediately show that the thickness of the adhesive layer varies between the different screens, and that the thickness of the adhesive in the lower right corner of the screen, with the exception of the screen 4, is consistently smaller than in the other corners. It indicates consistent manufacturing problems. It appears that the screens were selected from different batches manufactured under different manufacturing parameters. The parameters appear to be optimal in case of screen 4.

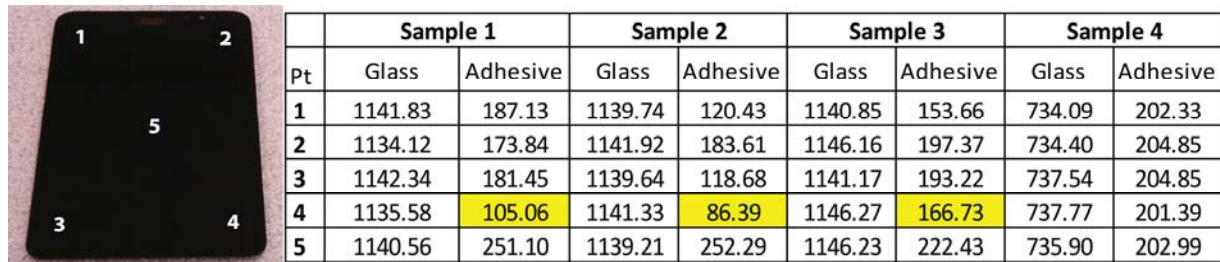


Figure 4. Identified inconsistency in the adhesive layer thickness.

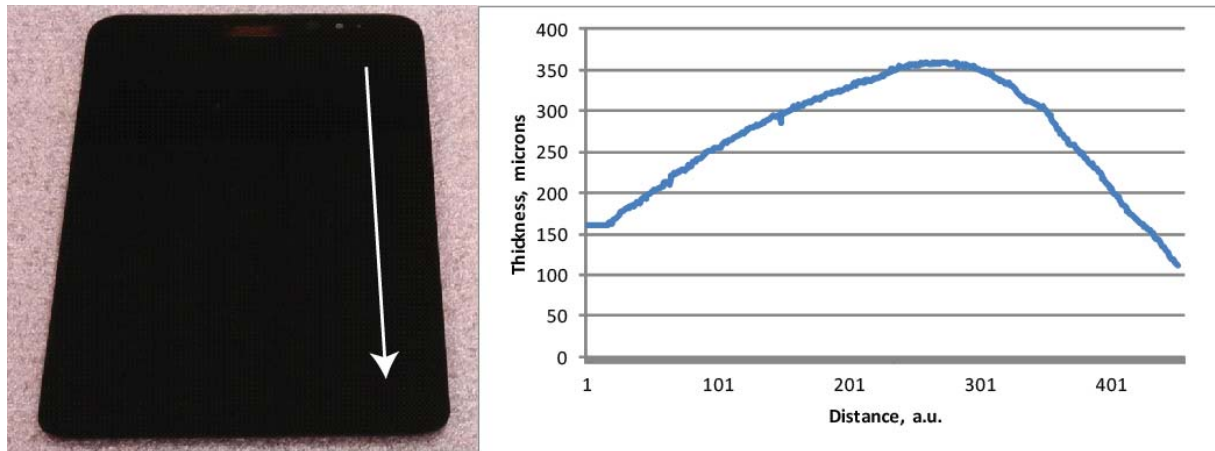


Figure 5. Identified inconsistency in the adhesive layer thickness.

The layer thicknesses in the touchscreens can also be measured within a continuous scan, instead of a single point. To obtain thickness variation along the scan, the screen (or alternatively the optical probe) is moved along the predetermined path, while the thickness of the layers is being continuously measured. The speed of the scan is defined by the measurement rate of the instrument and the required data point density. For example, at the rate of 100 measurements per second, and the scan speed of 100 mm per second, the resulting density of the thickness measurements is 1 measurement per mm. Figure 5 shows the thickness variations of an adhesive layer, acquired during a scan along the right edge of the screen. The graph shows that the adhesive layer thickness changes by over 100% along the scan path. The scan identifies a significant inconsistency in the manufacturing process that cannot be seen with a naked eye, and cannot be directly measured by any mechanical means.

In addition to thickness graphs, the low-coherence interferometer can be used to generate a visual representation of the cross-section of the screen stack. Such cross-sectional images are extensively used in medical field, where this technology is called Optical Coherence Tomography (OCT) [3].

Figure 6 shows the cross-sectional OCT images obtained for two smartphones, Samsung Galaxy S3 and S5, as well as two different generations of Ipad. These cross-sections were obtained while moving the optical probe in the middle of a screen, along the long dimension. The devices were lying flat, with the screens facing upward. The graphs match this orientation. The lines represent the interfaces between the inner layers, with the top line corresponding to the outer surface of the cover glass. The brightness of the lines corresponds to the reflectivity of the interfaces – the brighter the line, the more reflective is the surface. The units of vertical axis are in microns.

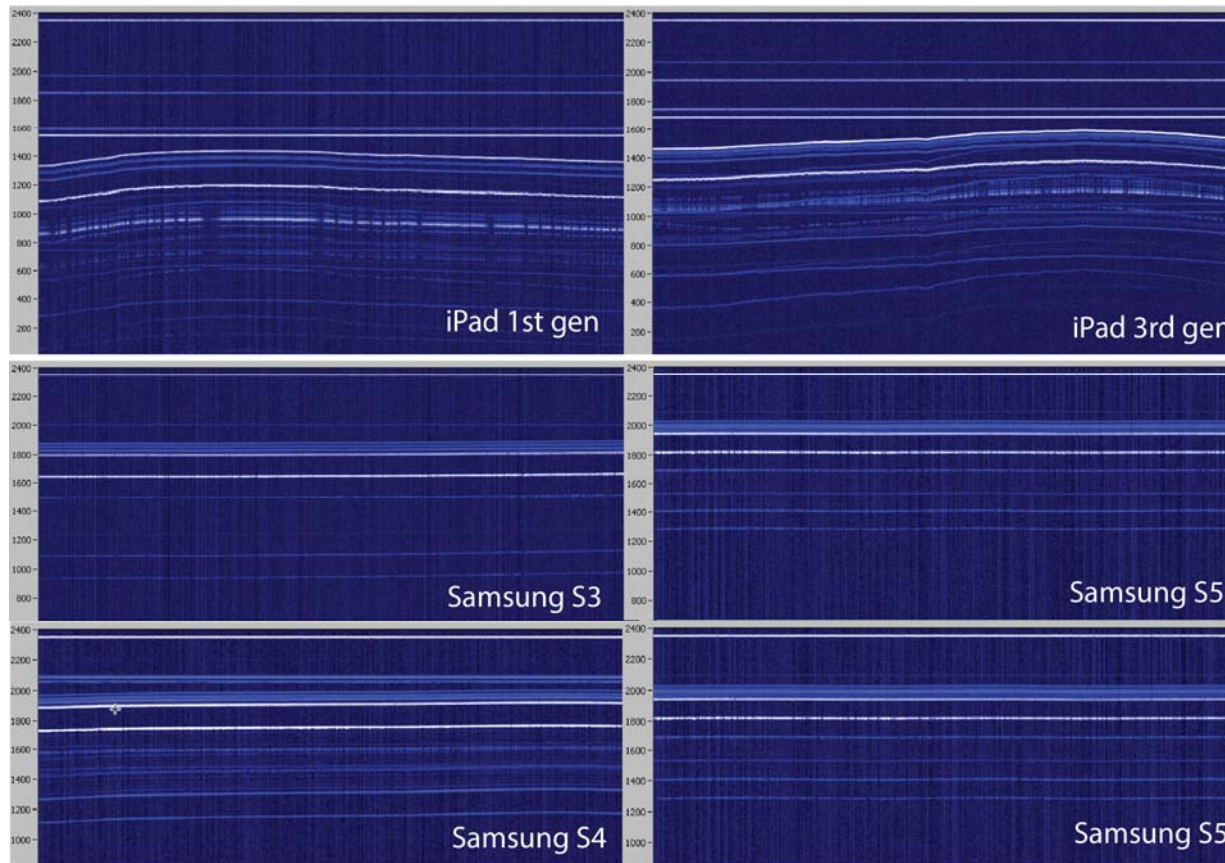


Figure 6. Cross-sectional images of different devices.

One can immediately spot two principal differences between the scans. First, the scans for Ipad clearly show inconsistent adhesive layer thickness. Second, the thickness of the cover glass becomes thinner for more recent versions of the devices. It is consistent with the manufacturing trends for the display cover glass. Note, that because the Ipad cross-sections were mapped by assuming that the top-most surface is flat, the layers beyond the adhesive layer appear to be deformed due the adhesive layer inconsistency. However, most likely both the touchscreen and the image display layers experience some sort of the deformation. The cross-sectional image can be reacquired by mapping the top surface with respect to a known flat surface in order to map out the deformations exactly.

In conclusion, we have demonstrated that the low-coherence interferometry can be a comprehensive practical tool for non-destructive product metrology and quality control during and after the manufacturing process.

[1] Johnson, E.A. (1965). "Touch Display - A novel input/output device for computers". Electronics Letters 1 (8): 219–220, 1965

[2] Geoff Walker, "Fundamentals of projected-capacitive touch technology", www.walkermobile.com

[3] Mart Brezinski, "Optical Coherence Tomography: Principles and Applications", Academic Press, 2006.