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Enhanced Reliability of Reinforced Ultrathin Cores for Embedded Passive and HDI Applications

Abstract:
Embedded capacitance has long been used as a tool in the design of high-layer count printed circuit boards. It is a means toward providing a capacitive layer and reducing EMI, impedance and the need for discrete capacitors. Embedded passives will become increasingly important with the advent of wearable technologies and growth embedded systems. Manufacturing thin (less than 25 micron) reinforced capacitive cores has proven to be elusive and film-based solutions present a host of problems such as mismatched expansion coefficients leading to delamination, dimensional instability and inconsistency. The paper introduces a breakthrough technology that enables the production of 25 micron or less dielectric (capacitive) spacings. Comparison data, with respect to incumbent technologies, illustrates the benefits of this technology. Data on thermal reliability improvements and signal integrity is also discussed.

Introduction

As consumers demand more economical, powerful and efficient PCs, electronic tools, tablets, phones and toys, manufacturers must develop more reliable, cost effective, power-conserving, thinner, lighter and faster devices to stay competitive. As the complexity of technology evolves, consumers look for products that enable the ability to connect to the Internet, stream music and video, and collect and mine data within the blink of an eye. The technology users of today have lost patience in buffering and want immediate gratification at the push of a button or tap of the screen.

In the world of electronics, this becomes a reality when high-speed digital signals, power, radio frequencies or software comes to life as copper traces on printed circuit boards (PCBs) bring the necessary energy to electronic components. Isola's new innovative ultrathin material, Ultra-EC™25, a 25 micron, reinforced core that enables rapid-response technology for passive components placed between the interconnecting substrates of a printed circuit board (PCB).

Industry-driven, Thermally-robust Materials

The increasingly smaller form factors of today's electronics require that materials used be robust, reliable and easy to process. Ultrathin film-based laminates (<0.002" in thickness) were historically used for applications where embedded capacitance or thin dielectrics were necessary. Robustness of thin dielectrics has been a handling and processing challenge ever since "thin" was defined as dielectric materials measuring below 5 mils thick. Drivers for robustness were no doubt related to processing yields, surviving thermal excursions, reduced moisture absorption and having appreciable dimensional stability, to name a few.

While being able to manufacture a thin dielectric with the aforementioned attributes is quite significant, Isola has also been able to achieve producing a material that is compatible and can be converted into a multilayer board (MLB) using standard FR-4 processes.

A significant element of robustness in the industry is related to thermal properties. Ultra-EC25 has been designed with a dielectric base that has 180°C glass transition temperature (Tg) and is capable of hybrid lamination with many of Isola's products. The cross section shown on Figure 1 depicts a 14-layer MLB made primarily with Isola's FR408HR laminate and prepreg and two-layer Ultra-EC25. This particular board survived a six-time pass through infrared (IR) reflow oven set at 260°C. This hybrid board with Ultra-EC25 manifested no delamination, cracks, fractures or any other form of defects.

Ultra-EC25 Laminated (Dotted Box) with FR408HR
6x IR Reflow @ 260°C

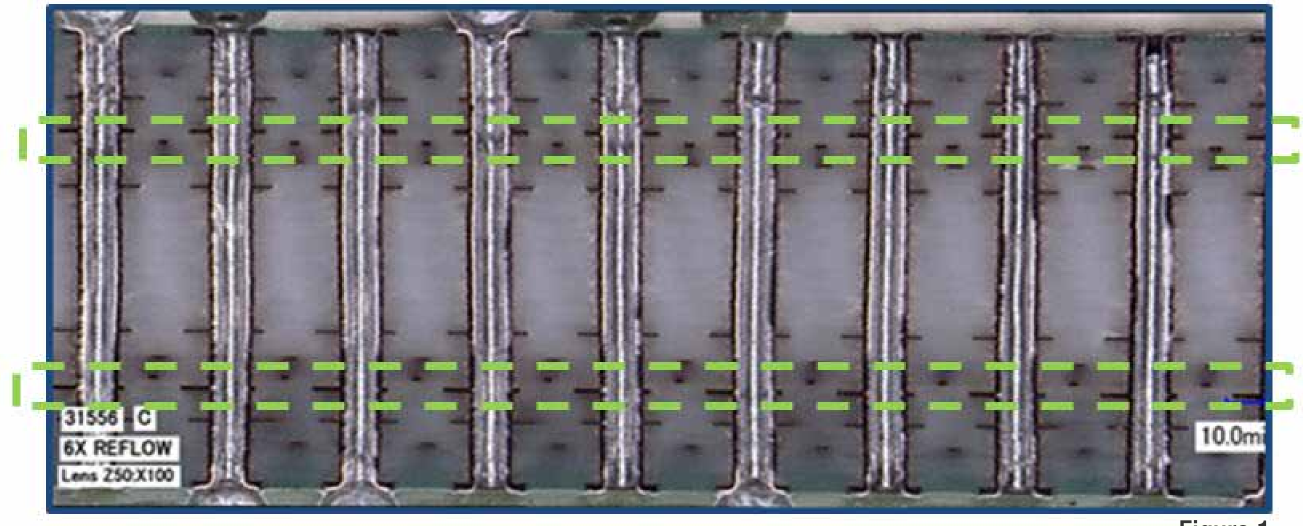


Figure 1

Dimensional Stability and Moisture Absorption

In addition to robust thermal properties, dimensional stability is critical to printed circuit board fabrication (**Figure 2**). The ability for design engineers to size artwork appropriately is critical to ensure that features between interlayers line up at drilling and in any subsequent lamination process. Being able to design around predictable movement of materials in the X and Y directions to compensate for shrinkage and growth is in itself a science and must be taken into consideration when designing laminate. Isola's reinforced Ultra-EC25 has demonstrated that its overall shrinkage and growth is considerably less and more consistent than film-based dielectrics. When comparing the overall movement of film-based materials to that of reinforced Ultra-EC25, the material attained more than a 50 percent reduction in overall movement and a greater degree of predictability of the material.

Dimensional Stability Analysis
Ultra-EC25 vs. Leading Film-Based Material

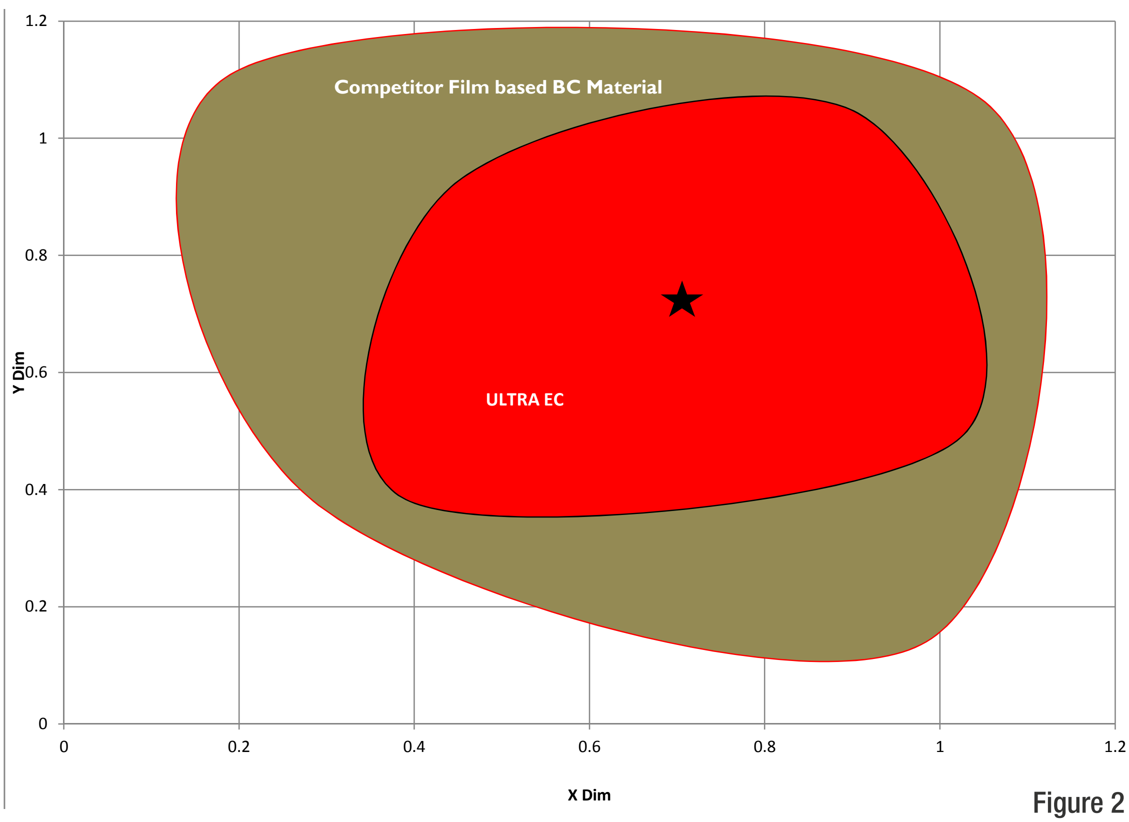


Figure 2

Another product characteristic critical to PCB is a material's resistance to moisture absorption. Isola's ultrathin reinforced Ultra-EC25 was tested with respect to a leading film-based embedded capacitance material and was found to have better than one and a half times lower moisture absorption (**Figure 3**). Testing was done per IPC-TM-650 2.6.2.1, 24 hours at 23°C. Additionally, samples were also immersed for 24 hours at 100°C. The benefits of low moisture absorption become evident in characteristics critical to PCBs related to a material's ability to withstand propensity for blistering, delamination, cracks or fracture. In addition, low-moisture absorption materials retain electrical properties such as their dielectric constant (Dk) and loss tangent (Df), as well as resist potential degradation that can result in conductive anodic filament (CAF) growth (Figure 4). Environmental- or process-related moisture can be a challenge. However, formulating a material that can minimize or eliminate the concerns associated with these conditions is a differentiating characteristic. Moisture in a PCB has the potential to change the quality, functionality, thermal behavior and thermomechanical properties that affect overall performance. Ultra-EC25 was designed with low moisture absorbing characteristics, thereby providing the electrical and thermal properties critical to the reliability of PCBs.

Moisture Absorption Comparative Chart

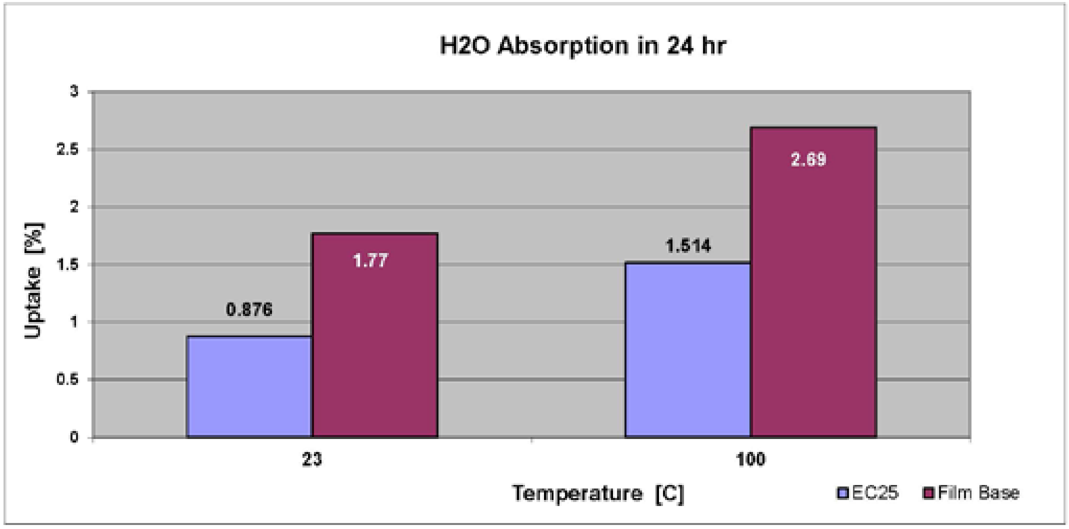


Figure 3

Conductive Anodic Filament Growth Chart

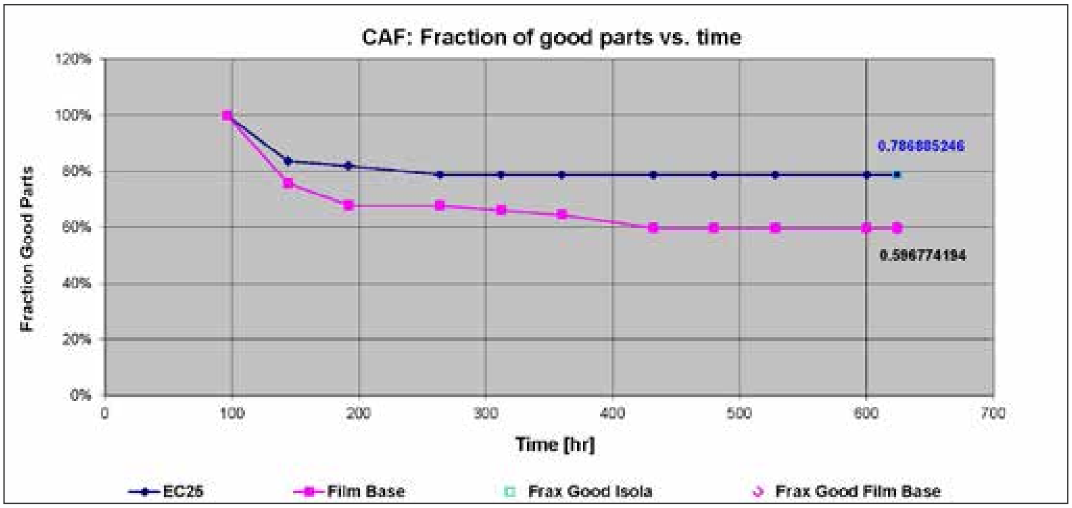


Figure 4

Electrical Characteristics and Performance

Embedded capacitance in PCBs is a modern alternative to the use of discrete decoupling capacitors that are typically connected between the power and ground layers to mitigate ground-bounce effects. The embedded approach utilizes closely spaced power and ground layers as the source of capacitance and offers advantages such as reduced board size, reduction of number of solder joints and improved high-frequency performance. Demands for smaller form-factors and higher speeds make the use of embedded capacitors increasingly advantageous.

While the concept of embedded capacitance in PCBs can be realized with standard laminate materials, thinner materials provide increased capacitance (inversely proportional the thickness). Isola's Ultra-EC25, specifically developed for this purpose, offers exceptional electrical and processing performance over competing products.

To understand the electrical performance impact of Ultra-EC25, a series of simulations were done using ANSYS® SIwave, an industry-standard signal integrity tool. The simulation was performed on the PCB stack-up illustrated in Figure 5, which shows an eight-layer board structure with the power and ground layers located in the center. This construct utilizes embedded capacitance of the closely coupled power and ground planes and offers reduced impedance. Lower impedance results in lower induced voltage during current draws and reduced EMI. First, analysis was performed on baseline designs having nominal ground /power plane separation and compared to one that utilizes Isola's Ultra-EC25 material. Next, analysis was performed comparing Ultra-EC25 to two competitive film-based materials. The metric for comparison is the self-impedance between the power and ground planes and the transimpedance between two ports defined between the power and ground planes.

The performance of the PCB embedded capacitance structure with a nominal 4-mil separation distance between the ground and power planes is shown in **Figure 6**. Here, the magnitude of input impedance is plotted versus frequency at each of two ports on the board. Also shown is the transimpedance between the two ports. For this nominal thickness of 4 mils, the impedance is seen to be above 1.0 for the majority of the frequency range considered (1 to 10 GHz) and between 0.1 and 1.0 for the case of |Z12|. These two quantities should be as low as possible, ideally zero.

PCB Board and Stack-up
(Closely spaced power and ground layers)

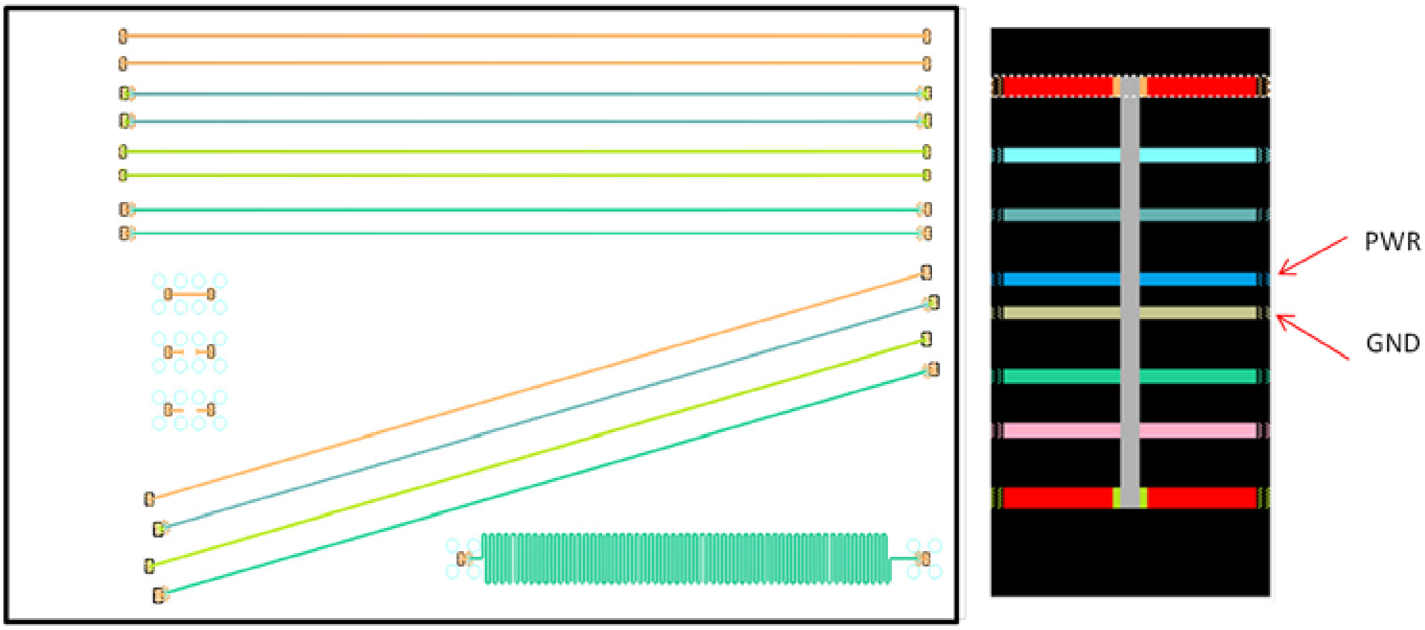


Figure 5

Impedance Magnitude versus Frequency for a 4 mil Embedded Capacitance Layer

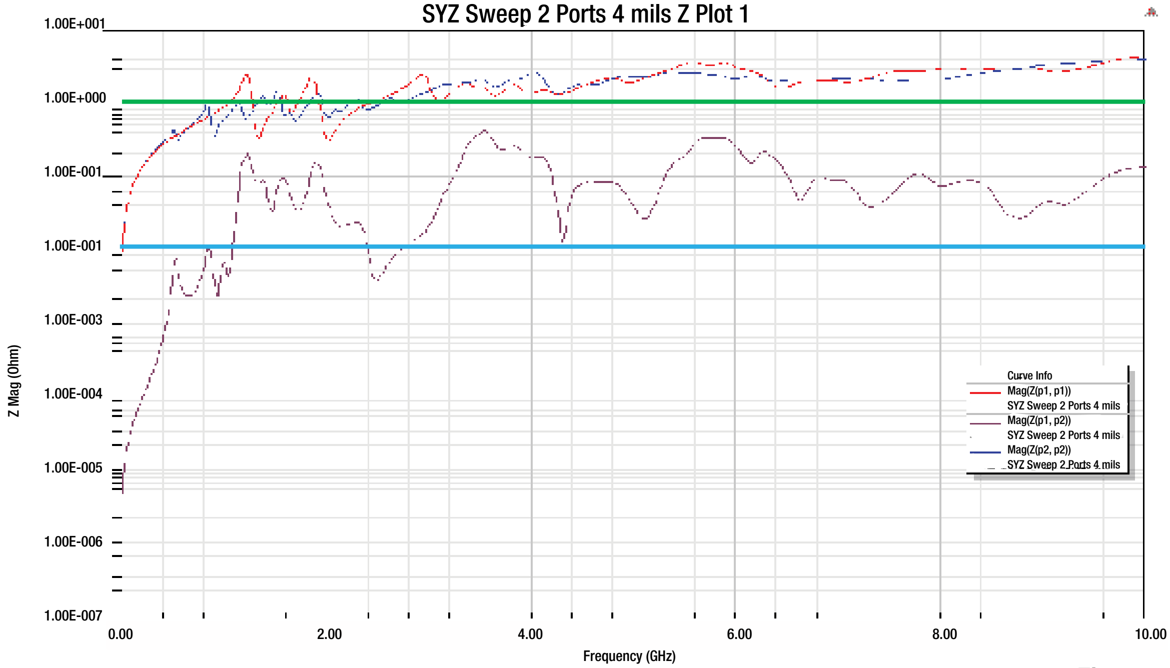


Figure 6

Figure 7 illustrates the performance of the PCB of **Figure 5** utilizing Ultra-EC25 with a thickness of 1 mil and a Dk of 4.0. Here, the impedance versus frequency is shown to stay below 1.0 over the full frequency range considered. Additionally, |Z12| is approximately 0.01 with some oscillation across the band.

Impedance Magnitudes vs. Frequency for 25μ Ultra-EC25 Layer vs. Frequency

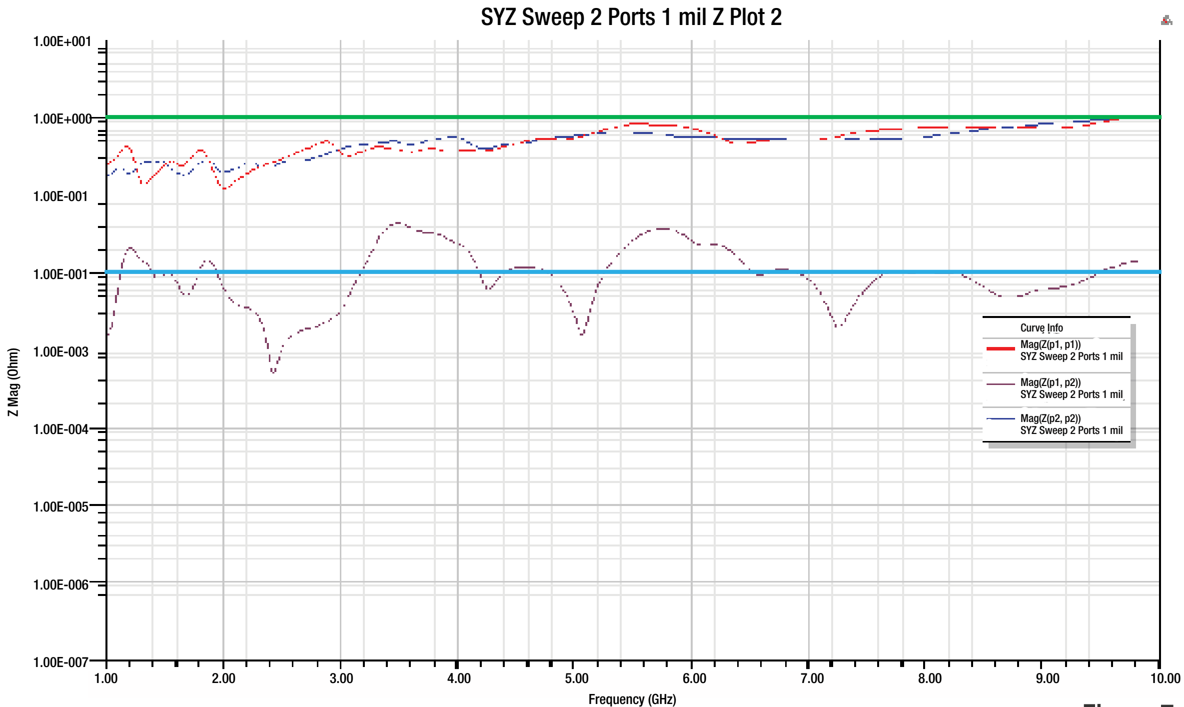


Figure 7

The performance of Isola Ultra-EC25 versus two veteran film-based dielectric materials for embedded capacitance is illustrated in **Figure 8**. The data shows a decreased performance of Film-based #1 versus Ultra-EC25 for both self-impedance (lZ11l, lZ22l) and transimpedance (lZ12l). Results for Film-baed #2 at a thickness of 22 micron are shown in **Figure 9**. Here the performance is seen to be slightly lower than that of Isola Ultra-EC25, even though one of the leading film materials is thinner. The higher Dk of Ultra-EC25 provided a higher capacitance, thus reducing the impedance of the ground plane more effectively.

Ultra-EC25 vs. Veteran Film-base Dielectric Materials #1

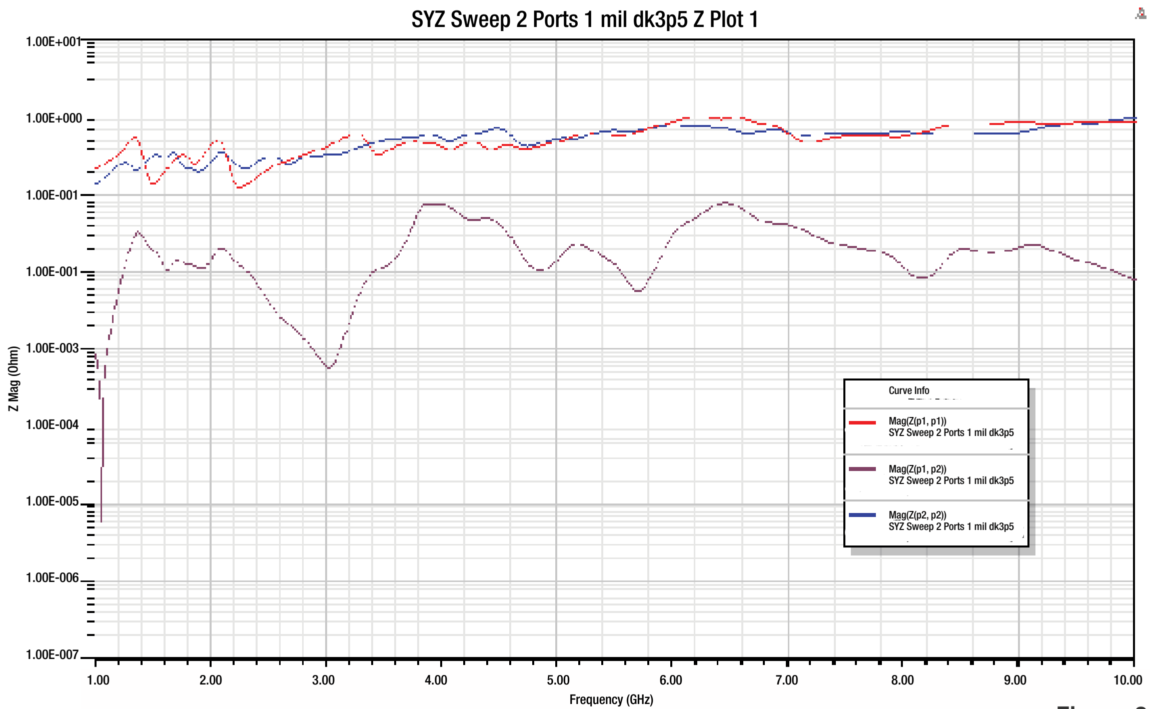


Figure 8

Ultra-EC™25 vs. Veteran Film-base Dielectric Materials #2

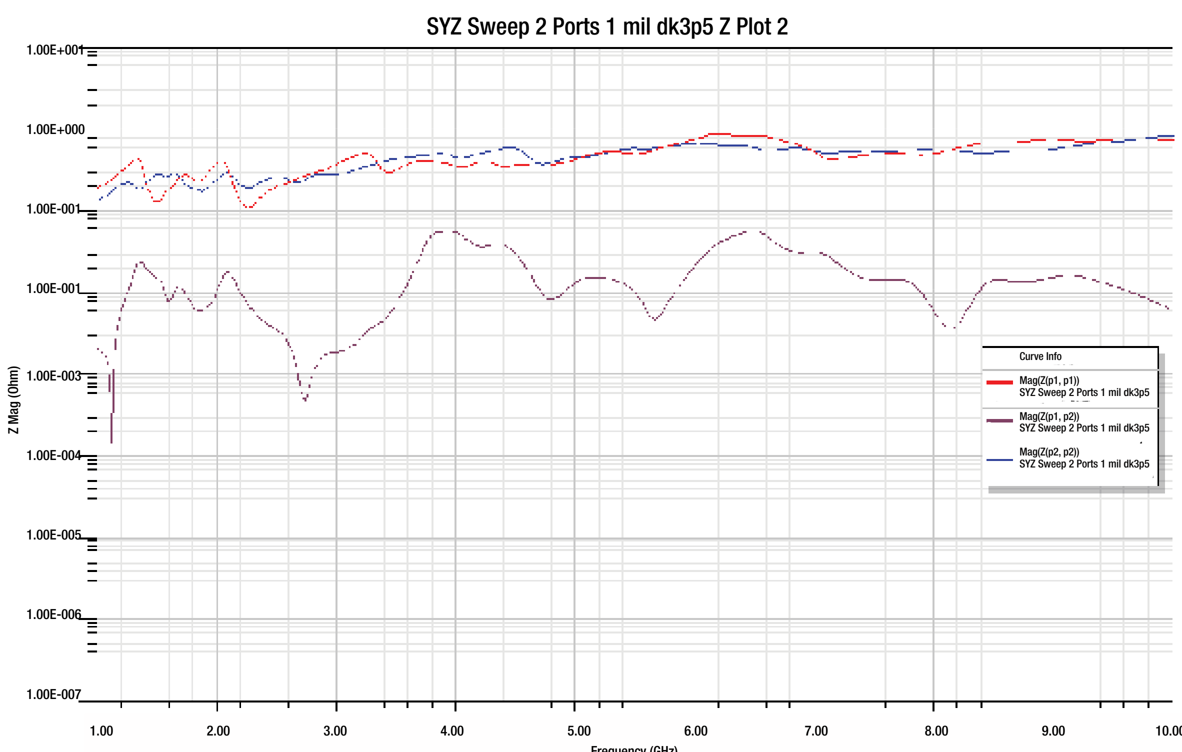


Figure 9

To complement the above-mentioned impedance analysis, the capacitance of Ultra-EC25 measured at 1 MHz on a clad sample of known surface area, which has had its thickness determined by cross section. From this data, the Dk and capacitance density (CP) can be calculated (**Figure 10**). The capacitance is typically 1900 pF from this test, which yields values of 4.0 for Dk and 94 pF/CM² for CP. Using the same model from which Dk and CP are calculated, along with the model for Dk versus thickness, other values of Dk and CP can be estimated for the full thickness specification range. The result of these estimations is summarized in **Figure 10**. The loss tangent (Df) cannot be obtained from the capacitance test. Therefore, a thicker laminate is made from the same composite and measured in the normal method. Values for Df thus obtained are typically 0.022.

Ultra-EC25 PCB Processability

A dielectric material that offers electromechanical solutions needed for today's technology is only as good as its ability to be successively processed into a complex multilayer printed circuit board. As with any ultrathin material, extreme care must be taken during processing. It is not unusual to require a leader edge, frames or copper edge borders to promote a higher-yielding inner layer when processing ultrathin material through conveyor systems such as pre-clean or develop/etch/strip (DES) lines.

Ultra-EC25 has an advantage over film-based products that while delicate, its reinforced 25µ structure has the rigidity and resilience that prevents it to from folding or wrinkling unto itself. Feedback from industry leading PCB manufacturers has been very encouraging and positive. Etching, drilling, desmearing, plating, lay-up and laminating Ultra-EC25 has resulted in minimal challenges and yield loss. Its dimensional stability, while still requiring careful sizing and compensation factors depending on the circuit features, has demonstrated two times better results than film-based products.

The ability to build complex circuits with buried via, tight lines and spacing, in addition to challenging pads with extremely tight pitch requirements is possible with Ultra-EC25. This new material revolutionizes ultrathin dielectrics designed for reduced feature designs and embedded capacitance applications.

25µ Ultra-EC25 Capacitance Value

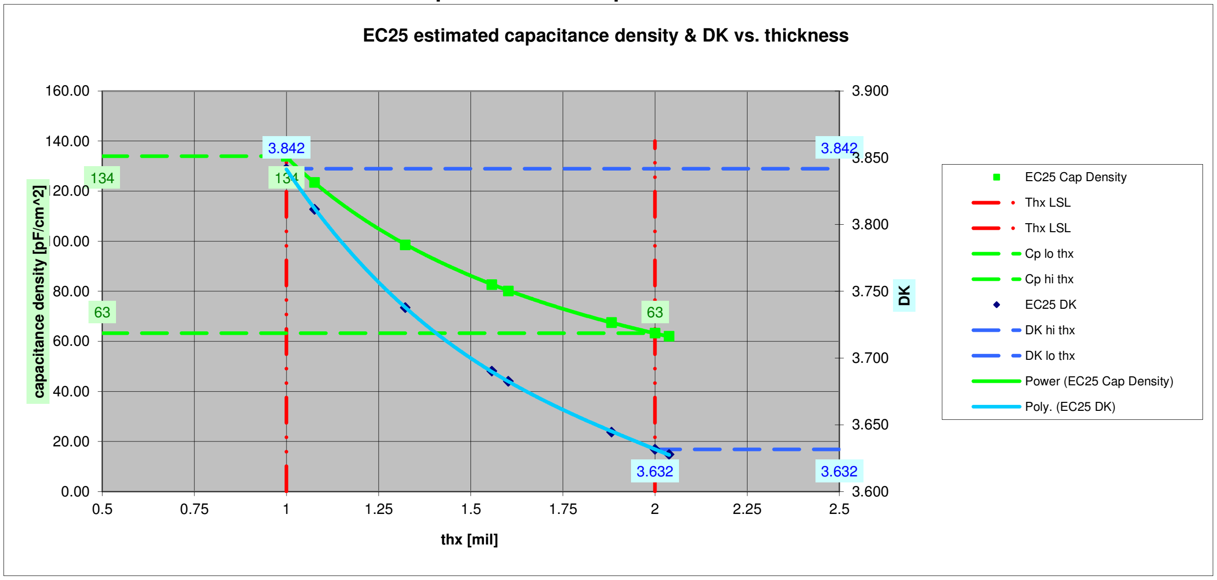
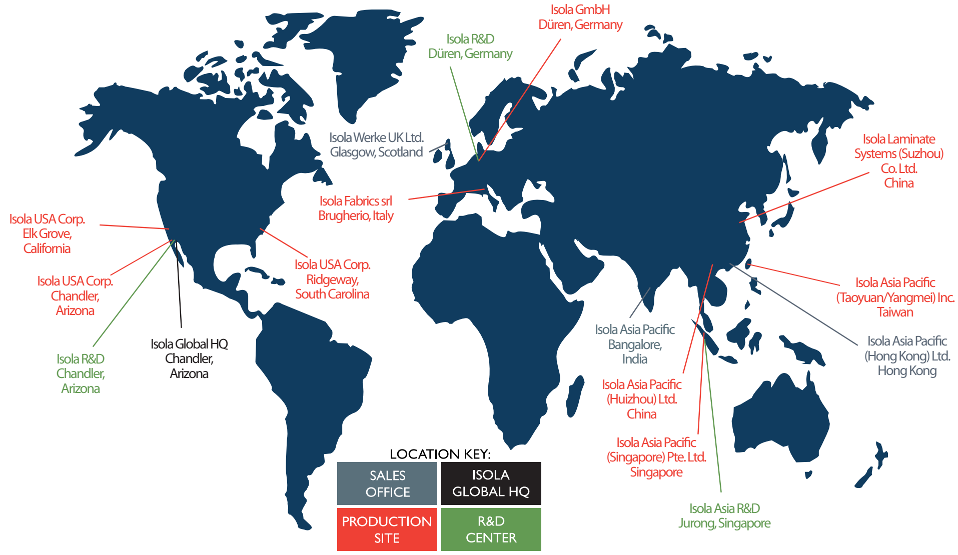


Figure 10

Summary

The industry is now able to incorporate a material into PCB designs where the PCB thickness is crucial to the application and physical constraints, primarily thickness is a necessity. These applications can be cell phones, touch pads, network routers and servers as well as other futuristic applications.

Designers now have the option to apply an innovative alternative to film-based products, which have been unable to provide the electromechanical solutions outlined in this paper. Isola's ultrathin reinforced Ultra-EC25 has been designed to provide electrical properties in areas where embedded capacitance is needed or the ability to provide thin dielectric solutions where overall board thickness is a challenge, tight lines and spacing or tight pitch for PCB designs present an advantage. Ultra-EC25 has a Tg of 180°C, a typical peel strength of 6 to 7 pli, a Dk 4.0, a Df of 0.022, a Cp of 94 pF/CM² and offers improved dimensional stability and resilient handling.



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