Multilayer Material Technology for Improved Signal Integrity in the Region Above 5 GHz

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Substrate materials that provide low Dk and low loss properties have become an essential element of high-speed digital and analog systems. In some sense, achieving a solution for providing excellent signal integrity within a high layer count design has become "The Holy Grail" in the OEM community. Traditional epoxy/glass materials fail to meet the electrical performance required of many new designs.

OEMs that produce high-speed optical routers, switches, networks, servers, etc., all require materials with lower dielectric constants (Dk) and dissipation factors (Df) to further improve the performance of their products. The lower Dk allows them to run faster signal speeds and higher packaging densities by retaining nominal impedances with thinner dielectrics. The lower Df enables them to run longer traces, use less incident power, and improve the overall integrity of the signal.

Although low Dk and low Df properties have already been produced in RF/microwave materials, existing material systems do not have the ability to produce ultra-thin dielectrics and subsequent multilayer structures with higher layer counts.

Table 1 summarizes the key properties of some of the materials used today in digital broadband and RF/microwave applications. The impact of this new technology can best be realized by comparing the standard N6000-21 to the new N6000-21 SI™. The Dk is lowered by ~0.3 and the Df is lowered by ~ 0.003. This allows the N6000-21 resin to be used as a bridge between RF/microwave and digital broadband applications, while providing end users with some key advantages.

BACKGROUND DISCUSSION

After extensive discussions with various OEMs, a product performance sheet was generated that outlined a balance of properties that would enhance multilayer designs, processing, and reliability. The resin technology chosen was APPE chemistry from Asahi-Kasei. The APPE (Nelco's N6000-21) resin was ideal because it had a combination of good electrical, thermal, and mechanical properties. It also had the important side benefit of being able to be processed similar to a high Tg FR-4 epoxy system. The material is also available in

Properties	Getek	N4000-13	N4000-13SI	N6000-21	N6000-21 SI	N9348	Rogers RO 4350	Taconic RF 35
Resin Type	Epoxy/PPO	Modified Epoxy	Modified Epoxy	APPE	APPE	PTFE with glass/ ceramic	Thermoset with glass & ceramic	PTFE with glass/ ceramic
Dk @ 10 GHz	3.8	3.6	3.4	3.5	3.0	3.48	3.5	3.5
Df @ 10 GHz	0.012	0.014	0.010	0.009	0.006	0.003	0.004	0.0025
Tg By TMA (¡C)	160	180	180	160	160	NA	>280	NA
Z-CTE (%)	4.6	4.0	4.0	4.2	4.2	~1.3-1.4	~1.2-1.3	~1.4-1.5
UL Rating	94 V-0	94 V-0	94 V-0	94 V-0	94 V-0	94 V-0	94 V-0 (cores only)	94 V-0
Peel Strength (lbs/in)	7.5	7.5	7.5	7.0	8-10	12-13	4-6	10.0
CAF Resistant	N/A	YES	YES	YES	YES	NA	N/A	N/A

Table 1. Key Properties of Digital Broadband and RF/Microwave Materials.

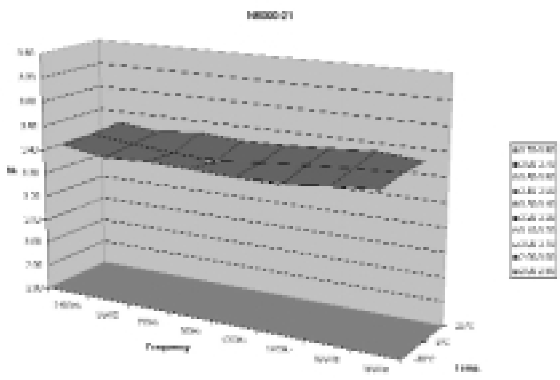

Figure 1a. Dielectric Constant vs. Temperature and Frequency N6000-21.

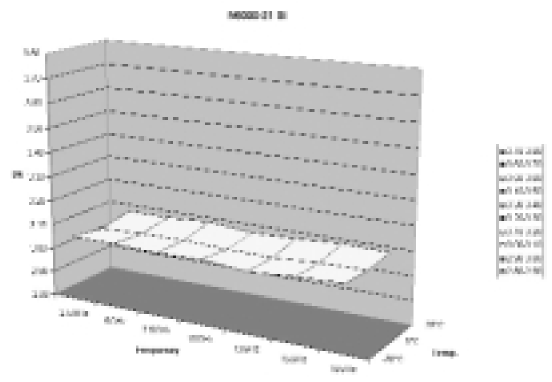

Figure 1b. Dielectric Constant vs. Temperature and Frequency N6000-21 SI™.

a wide variety of prepreg and core configurations, and has a UL 94V-0 rating.

Park Nelco elected to offer this system in an SI™ version (utilizing Nittobo's NE glass fabric reinforcement) because it improved both the electrical and mechanical performance characteristics. Nittobo discovered that, by modifying the ratio of the components used to make standard E-glass, they could lower the Dk and Df of the glass.[2] They found, for instance, that they could lower the Dk by decreasing the calcium oxide and increasing the boron oxide contents. They finally settled on the ratios shown in Table 2 because it provided the best balance of properties.

Table 3 provides a comparison of the glass properties. The Dk and the Df of the SI glass was reduced by 33% and by 50%, respectively. Since the Dk and Df of the final product is directly proportional to the volume fractions of the resin and glass components, these changes were very significant. The SI glass also has a significantly lowered X/Y axis expansion. This translates into less dimensional movement during fabrication and more reliability in high mechanical stress applications.

Although the electrical properties are exciting in ambient conditions, a number of OEMs needed data on the temperature stability of Dk and Df over frequency. Materials that are not stable or show large changes in dielectric properties at varying temperatures pose problems in certain applications.

The stability of the APPE system regarding temperature was characterized using the IPC Stripline method TM 2.5.5.5. Both N6000-21 and N6000-21SI™ were cycled a number of times (for repeatability) between –30˚C and 25˚C. Figures 1a and 1b illustrate the excellent Dk stability of this technology. The use of the SI glass technology lowers the Dk and produces a flatter Dk curve. We are currently performing additional testing to chart repeatable Df values using this same technique.

Figures 2a and 2b show the Dk change at varying frequencies and different resin contents. The slope of the Dk with respect to resin content is flatter for the N6000-21 SI system when compared to non-SI materials because the difference between the Dk of the SI glass and the APPE resin is less than that with standard E-glass. This makes N6000-21 SI superior for high-frequency and digital applications that require tight impedance requirements.

RELIABILITY TESTING

A number of tests were run to validate the reliability and performance of the combined N6000-21 resin and SI technology. The first test was a conductive anodic filament (CAF) resistance test.[3] More and more OEMs (Sun, Tellabs, Alcatel, Cisco, etc.) are requiring CAF-resistant materials. Sun believes that the new designs are stretching the reliability capabilities of standard FR-4 epoxies.[4] These OEMs have designed test vehicles that test the propensity of materials to have CAF failures and are using the test to screen materials. Sun has made its design available for use by the IPC, hoping that it will be adopted as a standard.

The N6000-21 and N6000-21 SI has been tested on two designs so far. The results have been very favorable. These tests both had similar environmental test parameters. The test vehicle from OEM #1 was a 10-layer design whereas the one from OEM #2 was a 6-layer design. See Table 4 that summarizes the other key parameters.

Components	E-Glass (Wt%)	SI Glass (Wt%)
SiO_2	52-56	52-56
CaO	16-25	0-10
AlO_3	12-16	10-15
B_2O_3	5-10	15-20
MgO	0-5	0-5
Na_2O, K_2O	0-1	0-1
TiO_2	0	0.5-5

Table 2. Glass Compositions.

Property	Units	SI Glass	E-Glass	Delta
Coefficient of Expansion	ppm / ¡C	3.4	5.5	-38%
Heat Conductivity	Kcal / mhr¡C	0.86	0.89	Negligible
Specific Heat	cal /¡C	0.206	0.197	Negligible
Dielectric Constant	1 MHz	4.4	6.6	-33%
Dissipation Factor	1 MHz	0.006	0.0012	-50%

Table 3. Comparison of Glass Properties.

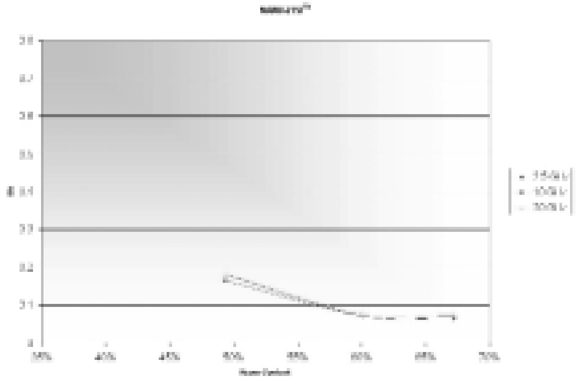

Figure 2a. Dielectric Constant vs. Resin Content—N6000-21 (APPE).

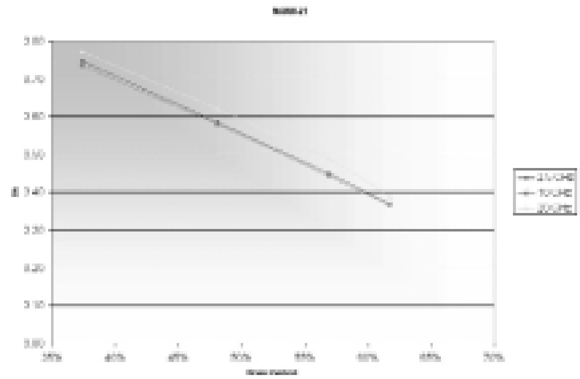

Figure 2b. Dielectric Constant vs. Resin Content—N6000-21SI (APPE-SI).

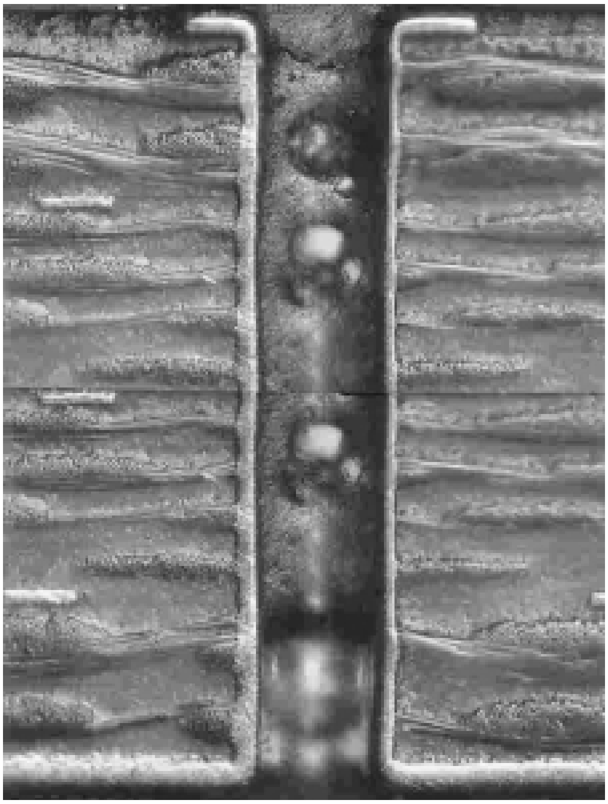

Figure 3. 6-Layer Board. (0.038" in thickness and 0.010" hole in diameter. Appearance after 60 X 10 seconds solder float at 550˚F).

N6000-21 SI CAF Tests	Temperature (¡C)	Humidity (%Rh)	Time (Hours)	Bias (Volts)	Minimum (Mils) Hole - Hole Spacing	Results
OEM #1	65	85	500	10	10.4	Pass
OEM #2	65	85	500	10	15	Pass

Table 4. Parameters of CAF Test.

In both tests, the CAF coupons were wired as specified and were allowed to stabilize in the chamber for 96 hours at 65˚C and 85% Rh with no voltage. They were then connected to a power supply with 1MW current limiting resistor-in-circuit, and then 10V DC was supplied for the rest of the duration of the test. Every 125 hours the power supply was disconnected and resistance measurements were done. This was done until 500 hours of the test were completed. The criteria of passing this test were not to have a resistance drop greater than a decade.

There are other tests available that use variations of the same theme. For instance, one OEM has a test that requires temperature and humidity conditioning at 85˚C and 85% Rh, respectively. The samples are then subjected to a bias of 100V for 1,000 hours. Failure occurs if the resistance of the samples is less than 10^{10} ohms. The N6000 SI has not yet been tested under these criteria.

Another test performed was a pressure cooker solder dip (PCSD) test. In this test the laminate is subjected to high-humidity conditions followed by extensive thermal excursions. The conditions include placing the samples in a pressure cooker (acts as a humidity chamber) under a pressure of 15 psi for ~2 hours. After the pressure cooker cycle, the samples are thermal shocked within 30 minutes by floating on a solder bath for 600 seconds at 288˚C. The criterion for passing this test is that the samples do not delaminate before 600 seconds.[5] The test was run on a laminate 0.031" in thickness for both N6000 and N6000-21 SI, and both the products passed the test.

Actual parts built by two fabricators were also subjected to the thermal shock test. The multilayer boards are prebaked for 5 hours at 155˚C to remove any absorbed moisture. They are then thermal shocked (solder floated) 60 times for 10 seconds at 550˚F. After this test, the samples are examined for delamination.

This test is very severe and is difficult to pass when microvias and small diameter holes are present. However, N6000-21 SI was able to pass this test up to 600 seconds without any delamination or copper cracking of the PTH, which confirms the robustness of this APPE-SI™ technology. Figure 3 shows a cross section of the board subjected to the test.

FIELD APPLICATIONS

There are a number of major programs that are incorporating or considering this technology. The largest program already using N6000-21 SI is for an OEM that manufactures high-speed, high-capacity optical switches for smarter, faster optical networks. These switches are installed in the core of telecommunication networks to manage the flow of optical signals, which are beams of light carrying voice, video, and data traffic, transmitted over fiberoptic cables. They chose N6000-21 SI because of its high-speed and low-loss characteristics. This program uses N6000-21 SI both in the motherboards and backplanes. The backplane is a 12-layer board that is run on a 24" x 36" format.

The N6000-21 SI is also being considered for a wireless local area network (LAN) application. It allows mobile users to access information from remote locations, using digital cellular technology, for instant access to networks and the Internet. It is fast and needs no plugs, cables, or connectors. The PC card works in a notebook computer and receives and transmits digital information over a radio frequency of 2.4 GHz. This OEM selected the product because of its low loss characteristics and its superior reliability. They also wanted a material that would be easy to fabricate and be available globally.

Another OEM is qualifying N6000-21SI for a highly scalable memory solution to support quality of service and Advanced Network Services (ANS) functions at full wire speed for high-end routers and switches. N6000SI is also being tested by another OEM for high-speed, high-performance routers.

CONCLUSIONS

The N6000-21 is a unique low-loss, high-speed APPE system that, when used in combination with SI™ glass, can improve and extend the use of high-speed, high-frequency, and high-density interconnects for digital broadband and RF/microwave applications. This technology allows the fabricator and OEMs to benefit in a number of ways.

First, the system has very good electrical characteristics. It has stable Dk and Df values across a wide range of different frequencies and temperatures. Since the Dk of the SI glass is ~33% lower than standard E-glass, the N6000-21 SI™ is less sensitive to changes in resin content. These attributes make it an ideal product for high frequency applications.

Second, it is a 94V-0 product that is available in a wide range of laminates and prepregs. Therefore, it can be tailored to a specific Dk for critical RF applications or can be used like a conventional material for dense high speed interconnects. The competitive RF products either have a limited selection of building blocks or must be run as a hybrid. The latter can be costly because it requires a separate UL qualification.

Finally, the N6000-21 SI™ can be processed in a conventional PCB fabrication process. It is compatible with most coppers and can be oxidized with the alternative oxide baths available. The lamination cycle is similar to standard high Tg FR-4 products and it can be drilled and desmeared using similar parameters. ■

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