

Newly Developed low-transmission-loss multilayer materials for PWBs applied to high GHz bands

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Abstract

The frequencies used to communication and process information have been extended beyond the GHz band to the microwave band to handle the growing volume of data. Signals on printed wiring boards (PWBs) used in these applications have come to adopt higher frequencies. At higher frequencies signal will attenuate more easily. It is getting important in high-frequency circuits to reduce the transmission loss on PWBs.

We have newly developed low-transmission-loss multilayer materials suitable for PWBs applied to high GHz bands. The new laminates made with new resin system have good dielectric properties and show the same level of low dissipation factor as the PTFE laminates. The transmission loss of the new laminate with our original profile-free copper foil is lower than that with VLP foils. These new laminates have proved to be reliable materials for good transmission. Moreover, they have high Tg, low moisture absorption, and good heat resistance suited for the lead-free soldering process.

Key word: multilayer materials, high frequency, low-transmission-loss, low Dk,

Introduction

The adoption of higher frequency signals in information processing is accelerating in recent years with the development of the overall information communication technology. For the base material for PWBs used in these fields, the improvements in the dielectric characteristics, that is, the reduction of the delay and loss of signal propagation are required. Moreover, high heat resistance suited for lead-free soldering process is increasingly required for the environmental protection.

Development Concept

The base resin having polar groups causes polarization of its dipoles. The dipoles repeat alternate polarization at extremely high speeds depending on the frequency used. Here, the friction in molecular motion generates heat and increases the dissipation factor. Since higher frequency result greater heat, the base materials for high frequency use are required to have higher glass transition temperature (Tg) and better heat resistance.

The dielectric property of resin depends on its molecular structure. To attain lower dielectric constant, we examined several methods: introductions of atoms of low polarizability and bulky structure and the reduction of water absorption. When there is a polar group like a hydroxyl group in the structure, Dk and Df increase notably. The dielectric property of olefin materials have been proved to give rise to low Dk and Df.

On the basis of these knowledge, we have designed new resins having excellent heat resistance

(high Tg) and dielectric properties (low Dk and Df)

(1) Molecular Design of the New Resin System

We selected a low-Dk and -Df thermosetting resin, low-polar and rigid linear polymer, and low-Df inorganic filler. As the thermosetting resin, the resin which has low polarity and stable Dk and Df to temperature and humidity change was selected. The linear polymer which has a low Dk and Df, a high Tg, excellent heat resistance and low water absorption property was also selected. We combined two types of polymers based on our original polymer alloy technology to achieve the targeted properties.

(2) Filler Interphase Control System (FICS)

PWB substrates can contain various inorganic fillers besides glass fibers mainly to attain a lower coefficient of thermal expansion, a higher modulus and better processability. In conventional substrates, a higher content of inorganic filler usually causes the aggregation of fillers as illustrated in Figure 1. This is the main factor which causes various disadvantages such as the increase in water absorption, and the poor heat resistance, electrical insulation and CAF restraining properties.

We have solved this aggregation problem by applying a new system named FICS which is very effective in improving the dispersion of filler.

FICS is a filler treating system that will efficiently afford a unique function at the filler surfaces ⁽¹⁾⁻⁽³⁾. As this system considerably improves the dispersion of filler, the substrate based

on FICS can achieve low water absorption, excellent heat resistance and insulation reliabilities.

Figure 2 shows the relationship between water absorption and Df. When we did not treat filler,

water absorption and Df were very high. It was proved that the application of optimal treating (FICS) decrease water absorption and Df at the same time.

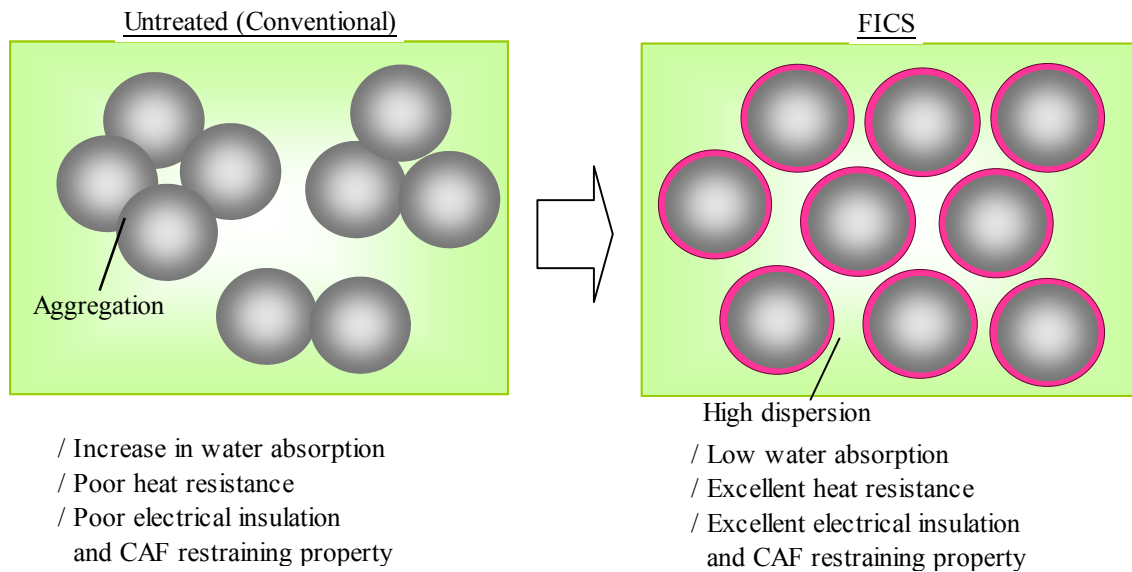


Figure 1 Technical concept of FICS

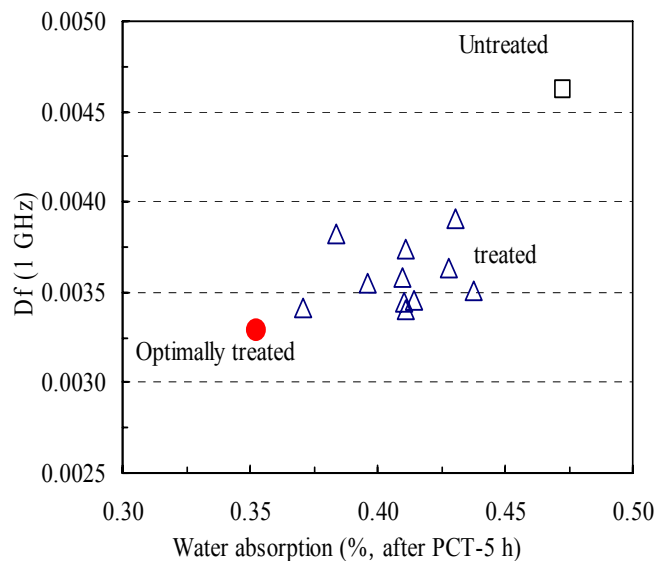


Figure 2 Relationship between water absorption and dissipation factor (Df)

The laminate features the Tg as high as 180°C. The

Characteristics of New Material

A novel low-transmission-loss multilayer material was developed with the new resin system. Table 1 shows the general properties of the laminate using E-glass fabrics. The Dk and Df of the laminate were calculated from the transmission loss. The laminate achieved Dk of 3.40 and Df of 0.0028 at 1 GHz; Df is about one-seventh that of the conventional FR-4, and nearly the same as that of the PTFE laminate. The laminate can also meet the requirement of high frequency specification of JPCA-HCL01/IEC 61249 -2-32(TBD).

copper peel strength is satisfactory for the practical use. Moreover, the laminate was proved to have better solder resistance and lower water absorption than that of FR-4. It withstands the T-288 test (IPC-TM650 2.4.24.1) for more than 60 min. In addition, no abnormality was detected in the new laminate after 5 h moisture treatment (121°C/0.22 MPa) followed by 20 s dipping in 288°C solder. The water absorption value was about one-fifth that of the conventional FR-4.

We concluded that the laminate can meet the requirement of high performance, lead-free specification of IPC4101B/126, and the high temperature soldering process using lead-free solder.

Table 1 General properties of the new laminate

Item	Condition	Unit	JPCA-HCL01 /IEC 61249 -2-32(TBD)	IPC 4101B 126 *****	New laminate	PTFE/E-Glass substrate	Conventional FR-4
Dielectric Constant (Dk)	1 GHz *	-	-	-	3.50 - 3.55	2.65 - 2.70	4.10 - 4.20
	1 GHz **	-	≤ 3.7	-	3.40 - 3.45	2.60 - 2.65	4.00 - 4.10
	3 GHz **	-	-	-	3.40 - 3.45	2.60 - 2.65	3.95 - 4.05
Dissipation factor (Df)	1 GHz *	-	-	-	0.0014 - 0.0018	0.0005 - 0.0010	0.0160 - 0.0180
	1 GHz **	-	≤ 0.007	-	0.0024 - 0.0028	0.0024 - 0.0028	0.0180 - 0.0200
	3 GHz **	-	-	-	0.0034 - 0.0038	0.0030 - 0.0034	0.0200 - 0.0220
Copper peel strength (18 μ m)	Standard (Rz: 5-7 μ m)	kN/m	≥ 0.6	-	0.7 - 0.9	1.3 - 1.4	1.4 - 1.6
	VLP (Rz: 3-4 μ m)		≥ 0.3	-	0.6 - 0.7	-	-
	PF (Rz: 1 μ m)		≥ 0.3	-	0.7 - 0.8	-	-
Glass transition temperature (Tg)	TMA	°C	≥ 150	≥ 170	175 - 185	20 - 25	120 - 130
CTE	α_{xy}	ppm/°C	-	-	14 - 15	17	
	α_{z1}		-	≤ 60	48 - 55	100 - 110	50 - 70
	α_{z2}		-	≤ 300	100 - 130	290 - 320	240 - 310
T260	IPC-TM-650 2.4.24.1	min	-	≥ 30			
T288			-	≥ 15	> 60	-	< 3
T300			-	≥ 2	> 60	-	< 3
Heat resistance (288 °C/20 s dipping)	PCT *** -3 h	-	-	-	Good	Good	NG
	PCT *** -5 h	-	-	-	Good	Good	NG
Water absorption	PCT *** -5 h	%	-	-	0.20 - 0.30	0.01 - 0.02	1.0 - 1.2
CAF restraining property ****	-	h	-	-	> 1000	-	> 1000
Flammability	UL-94	-	V-0	V-0	V-0	V-0	V-0

* IPC-TM-650 2.5.5.9: Capacitance method with RF Impedance/Material Analyzer (25 °C)

** JPCA-TM00 A test method for copper-clad laminates for printed wiring boards dielectric constant and dissipation factor.

IPC-TM-650 2.5.5.5.1: Triplate-line resonator method with Network Analyzer (25 °C)

*** Moisture treatment condition: PCT (121°C/0.22 MPa)

**** TH/TH wall thickness: 0.3 mm, Condition: 85°C/85%RH, 100 V dc applied

***** IPC4101B slash sheet 126 is for high Tg, high performance laminate for lead free application.

IPC4101B does not have slash sheet for high frequency application.

Figure 3 and 4 are the calculation results of Dk and Df. The new laminate was proved to have slightly less frequency dependent. The ability to withstand ionic migration, or the resistance against conductive anodic filaments (CAF), was evaluated by monitoring the insulation resistance between through-holes with 0.3 mm TH/TH distance under 100 V DC applications in 85°C/85%RH atmosphere. Figure 5 shows the results of CAF evaluation for the new laminate and FR-4. The new laminate did not breakdown even after 1000 h, exhibiting good endurance against ionic migration.

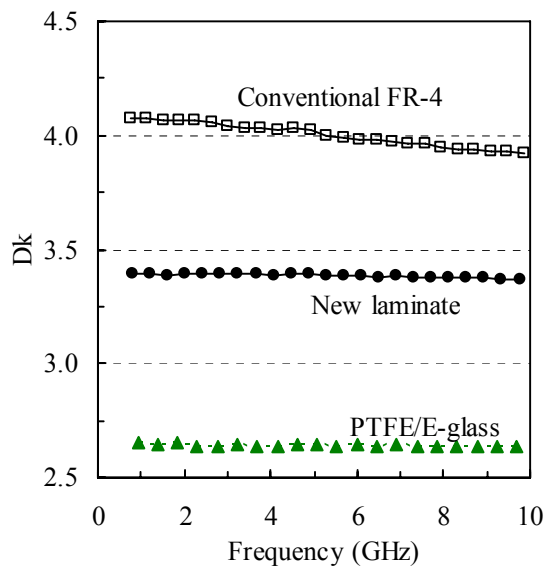


Figure 3 Dielectric constant of the laminate

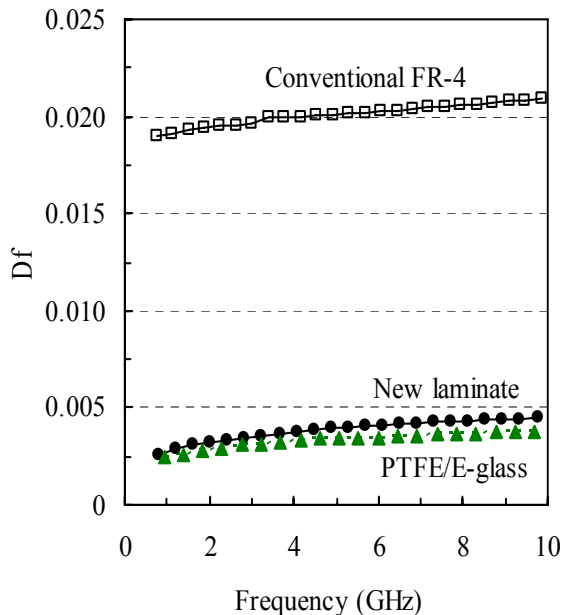


Figure 4 Dissipation factor of the laminate at high frequencies up to 10 GHz

< Conditions >

- 85°C/85%RH, 100 V
- t0.8mm (Cu: 18 μ m)

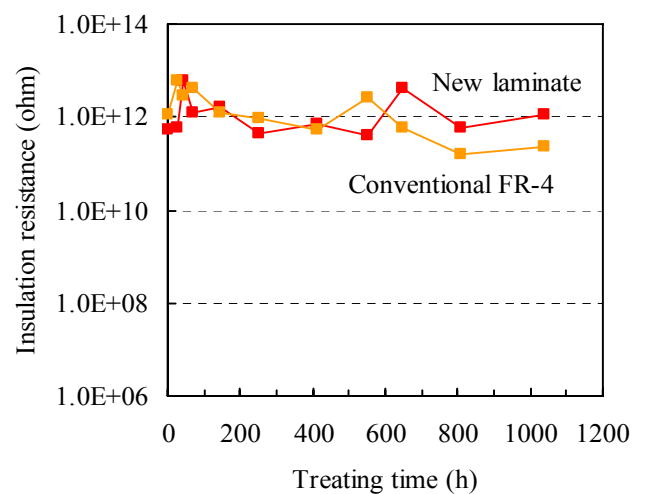
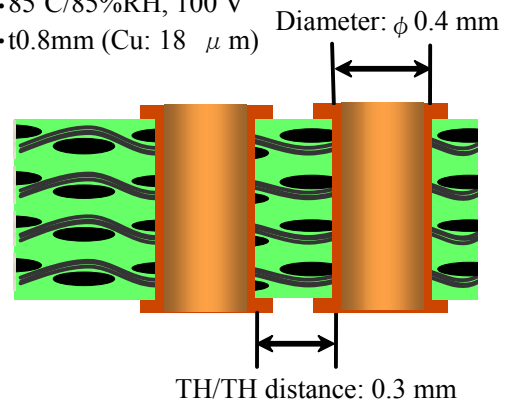


Figure 5 Results of CAF evaluation

The connection reliability of through-hole was evaluated by the thermal shock test (-65°C/30 min - 125°C/30 min) of the multilayered board of thickness 3.0 mm. Figure 6 shows the results of the test for the new laminate and FR-4. The new laminate showed few change in electric resistance at 1,000 cycles, exhibiting good through-hole connection reliability.

Properties at High Frequency

We prepared 8-layer boards and measured the transmission loss of the laminates with a network analyzer. Measurement was carried out on the strip-line structure of PWBs in 25°C/60%RH atmosphere with a characteristic impedance of 50 ohm. The strip-line parameters are as follows: copper foil thickness, 18 μ m; signal line width, 124-138 μ m; dielectric thickness, 0.26 mm; and line length, 500 mm. The copper foils used were VLP foil (Rz: 3-4 μ m) or our original profile-free foil (Rz: 1 μ m).

Figure 7 shows the transmission loss of the laminates at high frequencies up to 6 GHz. The new laminates were proved to have far lower losses than the conventional one. The effect of profile-free foil is also shown in the table.

< Conditions >

- / Laminate: t3.0 mm/18D (Plated Cu: 20 μ m)
- / Test pattern: Daisy-Chain (320-Hole)
- / Pre-treatment: E-3/130 $\rightarrow$ C-192/30/60
 $\rightarrow$ 260°Cmax reflow, 3cycle
- / Test condition: -65°C/30 min $\leftrightarrow$ 125°C/30 min

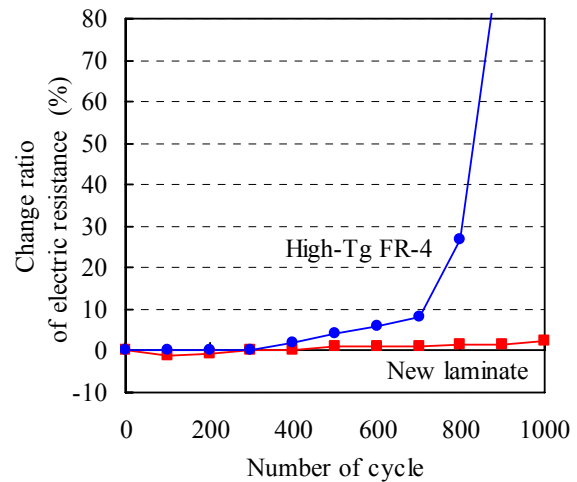
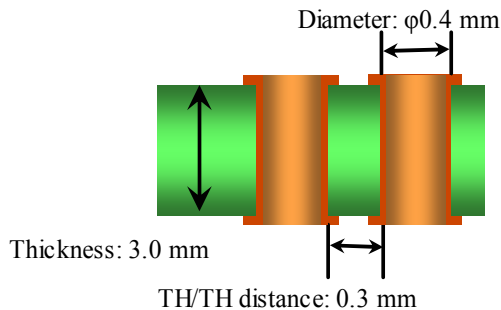
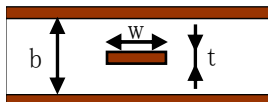


Figure 6 Results of thermal shock test

< Measurement conditions >

- Evaluation PWB: Strip-line structure
- Temperature and humidity: 25°C/60%RH
- Characteristic impedance: 50 ohm

< Dimensional parameters >



- Line width (w): 0.124-0.138 mm
- Dielectric thickness (b): 0.26 mm
- Copper thickness (t): 18 μ m
- Line length: 500 mm

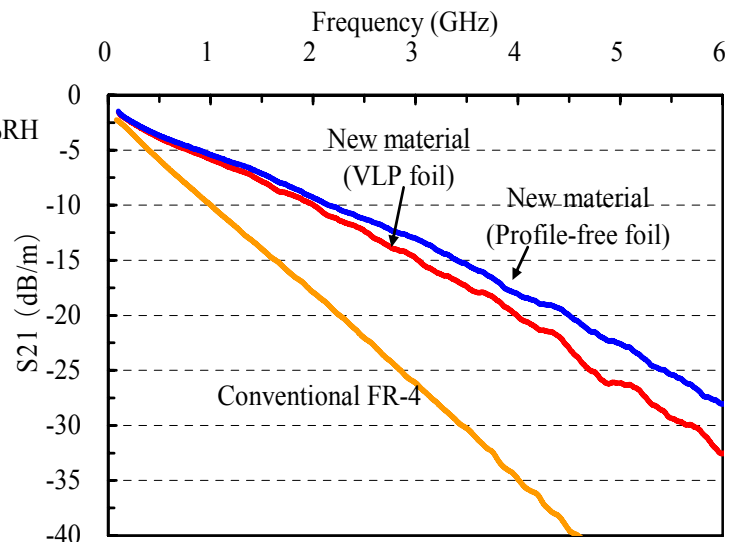


Figure 7 Transmission loss of the laminates at high frequencies up to 6 GHz

Conclusion

- (1) We have developed the filler dispersion technology and the resin whose dielectric properties and heat resistance are excellent. The laminate with these technologies showed almost the same level of low dissipation factor (Df) as the PTFE laminate at high frequency signal (3GHz).
- (2) The laminate also showed the excellent properties such as low moisture absorption, high CAF resistance and high Tg enough to obtain the heat resistance for lead-free soldering process.
- (3) The newly developed laminate is suitable for application in the PWBs for various high speed and high frequency uses, such as high-end server, router, measuring equipment, super computer, RF module and antenna.

Note: The contents of this report are based on the results of experiments and do not represent a guarantee of the values for each property.

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