Kapton®
polyimide film

Advanced Flexible Dielectric Substrates for FPC/TAB Applications

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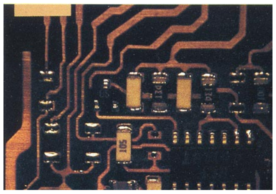
Introduction and Background

Kapton® polyimide film is a substrate used in flexible printed circuits (FPC), that provides significant advantages for both processing of circuitry and functionality of circuitry. Processing advantages include the capability to fabricate from roll to roll, high mechanical strength, and unique distortional resistance to harsh environments such as high temperature bonding stations and corrosive aqueous etchants.



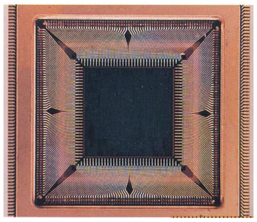
Fine Line Flexible Printed Circuit

Historically, functionality advantages have included several areas. Circuitry is dielectrically very reliable with excellent adhesion of the conductors.

Its thinness and flexibility allow it to be installed into small volumes, requiring intricate and severe folding. These time-tested advantages have led to numerous applications. Examples are FPCs for electronic cameras, calculators, computers, communications equipment, distance detectors, aircraft harnesses, solar panels, space vehicles, missiles, etc. (Ref. 1). Additionally, a very specialized use in FPCs, where polyimide film has been utilized predominantly, is in Tape Automated Bonding (TAB). Kapton® polyimide film was in fact a component of the original TAB product when it was introduced by GE as the Minimod process in the early 1970s (Ref. 2&3). Still another form of FPCs is multilayer FPCs, which place additional demands on substrate mechanical and chemical properties.

Performance demands of polyimide film as a dielectric substrate for FPC applications have intensified greatly since its commercial introduction in 1965. These greater demands have stemmed from the design impetus for all circuitry, which is the progression to ultra-miniaturization of solid state memory and logic devices with increasingly greater lead counts. Continually higher circuit density is required to permit bonding to these various devices. As technology progresses, the design engineer, in desire for more reliable substrates, seeks thinner dielectrics, which will not distort under mechanical stresses of processing, and also dimensionally inert materials that defy exposure to heat and chemicals of processing. Along with greater functionality, there is the attendant quest for higher production yields.

Assessments of those properties of dielectric substrates which need improvements have been the subject of several recent papers, and of market studies by DuPont. Holzinger (Ref. 4&5) has considered TAB substrate materials from the aspects of their functionality. Monisinger (Ref. 6) has further defined the properties needed. Even though most literature addresses the needs of the TAB substrate, the properties of an ideal FPC substrate, including multilayer flex, are probably about equivalent. The incentive for emphasis on TAB is that it offers an inexpensive route to gang bonding IC chips, and appears to be a commercially stable technology, given its 20 year age.



Tab Circuit

The general conclusion is that low CTE, low shrinkage to heat, low moisture absorption, high tensile modulus, and good chemical etchability are critical to advanced functionality. Additionally, the new substrates must not be inferior in electrical properties, nor in adhesiveless plating behavior, as compared to existing aromatic polyimide films. Indeed, we concur that these are the key properties requiring improvement. Accordingly, the most important *quantitative* property levels that have represented our product goals are summarized in Table 1.

Table 1

Properties of an Ideal TAB and High Performance FPC Substrate

Property	**Goal Level**
Shrinkage, 200^{o}C, mils/in.	0.1
CTE, 50^o-200^{o}C, ppm/^{o}C	17
Modulus, 23^{o}C, kpsi	750
H_2O Absorption, %	1.5
Chemically Etchable	Yes

Rationale for the properties of an ideal TAB/FPC substrate, shown in Table 1, are often dependent on subjective criteria, but some explanation for the quantitative values is in order. Shrinkage was established at 0.1 mil/in., because it affords excellent ability to precisely and repetitively align personality windows for the TAB process. It also affords precise registration of through-holes for multilayer applications, and of installation holes for large circuits. Further, low shrinkage provides consistent registration of the artwork pattern in circuitry connections. The CTE of 17 ppm was chosen because of its match to copper from room temperature to solder bath temperatures (Ref. 7), for without such a match the stresses during a thermal change of several hundred degrees Celsius would cause excessive distortions. A modulus of 750 Kpsi is believed to be an economic incentive, because it allows the design engineer to obtain adequate stiffness with 2-3 mil film as an alternative to 5 mil substrate with a modulus of 400 kpsi. A stiffer material is also easier to process into laminate.

Water absorption is a subjective goal to some extent, but the specific value of 1.5% is about at the limit of aromatic polyimides; another step forward to other polymeric structures is believed to be required to dramatically lower moisture absorption. Furthermore, moisture content of about 2% is about the limit of tolerance of most polyimide copper clads to sudden excursions to 250-300^{o}C during TAB bonding without blistering.

Chemical etchability, with common polyimide etchants such as NaOH, or KOH, is advantageous, because some processes use etchants to make various holes in substrates. Caustic etching of holes is often used on two layer TAB, which consists of only polyimide/metal, and which is processed by forming holes in the substrate after the conductive layer (copper usually) is applied. If the product were not caustic etchable, its use would either be limited to three layer TAB (where the adhesive coated substrate is punched before the copper is laminated), or exotic etchants would be required with the attendant environmental problems.

Approaches to Attain Properties

All approaches to fabricate an advanced TAB/FPC substrate have emphasized alteration of the polyimide backbone structure. Out of these studies have come two new production films, which we believe have definite processing advantages, that are a direct consequence of the specific properties built into the films. These two films are designated as Kapton® KN and Kapton® E, and they will be sold into both FPC and TAB end uses. The type KN is targeted at one- and two-sided circuitry via roll cladding. It is also intended for 3-layer TAB applications (use of adhesives) of medium complexity; e.g., 40-200 leads. The type E is targeted at multilayer and fine line circuitry where the conductor is bonded adhesivelessly. TAB applications are believed to lie in higher complexity systems with greater than 200 leads, as well as two conductor TAB.

Developmental Work to Achieve New Films

In order to acquire a high modulus and low CTE, random copolymerization of stiff diamine segments into the pyromellitic dianhydride/4,4'-oxydianiline polyimide was demonstrated. Polymerization of these stiff segments is under continued study, where the stiff polyimide segments are introduced into the chain as blocks rather than as random units. The advantage of such a method is that it is likely to enhance the effect of stiff segments at much lower concentrations than if the segments were introduced in a random fashion. The main difficulty with the block copolymer approach is the one of authentically maintaining the block throughout the course of polymerizations/processing, and doing such a feat on a reproducible basis. In this regard, investigation in this area of polyimide chemistry, in addition to continuing, will be reported elsewhere at a later date.

Since the moisture absorption of copolymer formulations is not predictable, several empirical attempts were made to lower the moisture absorption as well as the dielectric constant, which is affected by moisture and is a recurring concern to circuit designers.

Specific effects of stiff codiamine segments were demonstrated by investigation of paraphenylene-diamine (PPD), introduced into the chain in a random fashion. A gradual increase in modulus with a corresponding decrease in CTE was found to be dependent on the PPD content. Figures 1 and 2 clearly define the behavior of these mechanical properties as a function of the mole percentage of PPD. In effect, this film has become known as type K.

Figure 1. Moduli of Experimental Copolyimide Films

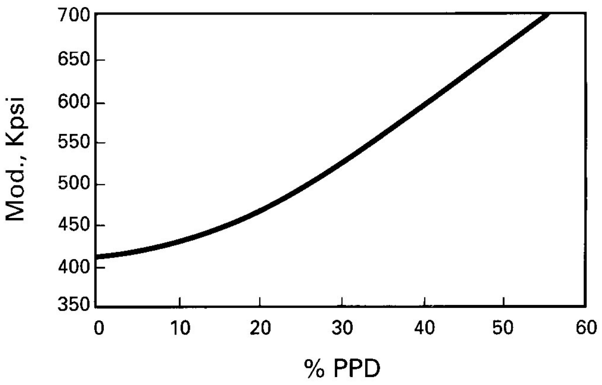
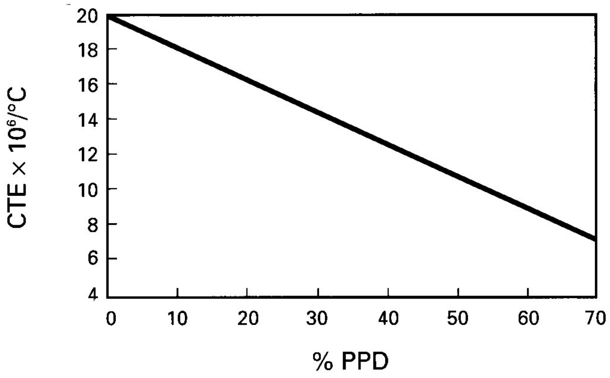


Figure 2. Coefficients of Thermal Expansion Experimental Copolyimide Films



In much the same fashion by which the formulation of type K was achieved, the systematic introduction of co-segments into the polymer chain was done to arrive at type E. Statistical design of the various compositions was utilized in order to reduce the total number of compositions that were investigated. At the same time, attention was given to alteration of promising compositions so that film manufacture was possible.

Typical Property Results

Selected typical properties of the goal level properties given in Table 1 are shown in Table 2. Table 3 provides additional properties of the two new films, which are believed to be significant for both processability and for functionality. As indicated previously, type K is believed to be more functional than Kapton® type V for FPC roll to roll processing and for TAB, since it will provide greater stiffness at equivalent gage and even allow probable reduction in gage for many applications. The CTE match to copper is evident, and this too will afford greater utility without distortion in thermal excursions. The water absorption is actually higher than Kapton®, but when this fact is coupled with the surprising result that the film will expand and contract less than Kapton® during relative humidity changes (CHE), the trade-off appears to lean toward the type KN. The caustic etchability of the film is actually more than Kapton®, whereas the electrical properties are about equivalent.

Film Type E is a very high performance film that will serve the high technology demands of exceptional stiffness at thinner gages, and yet maintain a CTE match to copper. The lower water absorption will ensure use of the film at high humidities in solder baths without blistering and the very low CHE will maintain excellent dimensional stability under a wide range of humidity conditions. Caustic etchability of the film will open its use to designers who wish to chemically mill holes in their circuits during processing. It will ensure development and fabrication of two-conductor FPC/TAB with very high lead counts. Electrical properties are maintained to provide a very high level of circuitry performance. Laser ablatability has been a proven attribute with type E.

Table 2
Typical Properties vs. Goal Properties of Advanced Polyimide Substrates for FPC/TAB/Multilayer Flex Applications*

Property	Goal	Type V	Type KN	Type E
Shrink., 200^{o}C Mils/in.	0.1	0.3	0.3	0.3
CTE, ppm/oC 50o-200oC	17	26	15	14.5
Modulus, 23oC Kpsi	750	400	630	775
H2O Absorb, %	1.5	3.0	3.7	2.0
Etchable, OH	Yes	Yes	Yes	Yes

***All are 50mm (20 mil) films**

Table 3
Unique Properties of New Polyimide Films Types KN and E for FPC/TAB/Multilayer Flex Applications*

Property	Type V	Type KN	Type E
CHE,ppm/% RH	17	14	9
H_2O Permeability, g/m2/day	22	28	4
Oxygen, Permeability, cc/m2/day	114	105	4

***All are 50mm (2.0 mil) films**

Additional typical properties are shown in Table 4 to gain a better perspective on the behavior of these films relative to Kapton® type V. Characterization is continuing and available results show the hydrolytic stability of the type E films, as measured by change in elongation after 1000 hours exposure to 85% RH and 85^{o}C, to be essentially equivalent after the aging period and under the conditions imposed. Thermal durability testing indicates that the new films have the same order of thermal life as does conventional Kapton® type V. Retentions of greater than 10% elongation after 100,000 hours at 200^{o}C in an air atmosphere are anticipated.

Conclusions

New polyimide films based on different polymer backbones have been developed for use in FPC and TAB applications. Kapton® type KN offers increased modulus, a thermal coefficient match with copper, low shrinkage, and chemical etchability for one and two sided circuits via roll cladding and three layer TAB applications of medium complexity. Kapton® type E offers the same advantages with a higher modulus and reduced water absorption and hygroscopic expansion for multilayer and fine line circuitry, as well as laser ablatability.

Table 4
Additional Typical Properties of New Polyimide Films 2 mil types KN and E for FPC/TAB/Multilayer Flex Applications*

Property	Type V	Type KN	Type E
Tenacity, kpsi	34	40	40
Elongation, %	80	80	40
Initial Tear (Graves), lb/mil	2.4	2.6	2.4
Propagating Tear (Elm.), g/mil	12	17	10
Density, g/cc	1.42	1.45	1.46
Diel. Str., V/mil	4500	5000	6000
Diel. Const.,			
100 kHz, 10% RH	3.1	3.1	3.1
100 kHz, 50% RH	3.5	3.6	3.4
Diss. Factor,			
100 kHz, 10% RH	0.0012	0.0022	0.0022
200 kHz, 50% RH	0.0065	0.0082	0.0064
Volume Resistivity, Ohm-cm			
10% RH	3.6xE17	2.4xE17	3.1xE17
50% RH	1.8xE17	1.6xE17	1.3xE17
Surface Resistivity, Ohm			
10% RH	9.3xE17	8.9xE17	13.0xE17
50% RH	0.1xE17	3.1xE17	1.3xE17

***All are 50 µm (2.0 mil) films**

References

1) Marketing Bulletin, “Flexible Circuitry,” E.I. du Pont de Nemours & Co., Inc., Electronics Department, H-05332.

2) Marketing Bulletin, General Electric, Integrated Circuit Product Department, Electronic Components Division, March, 1971.

3) T.J. Matcovich, “Microcircuit Interconnection Techniques and Applications,” Am. Ceram. Soc. Bull. (USA), Vol. 51, #4, 359 (1972).

4) S.T. Holzinger, “TAB Types and Material Choices,” EXPO SMT ’88 Technical Proceedings, 247, (1988).

5) S.T. Holzinger, “TAB: Mechanical, Chemical, and Thermal Considerations for Three Layer TAB Materials,” EXPO SMT International ’89 Technical Proceedings, 149 (1989).

6) M. Monisinger, “Advantages of Polyimide Film in TAB Packaging,” Surface Mount Technology, 61, October (1989).

7) L.R. Williams, J.D. Young, and E.H. Schmidt, “Design and Development Engineering Handbook of Thermal Expansion Properties Aerospace Materials at Cryogenic and Elevated Temperatures,” Rocketdyne Division Contract No. NAS-8-19, March 30, 1967.