

Copper on Polyimide Flexible Substrate For Ultra-Thin, High Performance Applications

Bergstresser, T.R., and Sallo, J.S.
Gould Electronics Inc., Electronic Materials
34929 Curtis Blvd., Eastlake, Ohio 44095

Abstract

Adhesiveless copper on polyimide substrate materials are now widely used in the production of flexible circuits, rigid-flex boards, chip scale packages and HDI products. A typical construction includes a polyimide base film, a thin metal tiecoat, a copper seedcoat, and a layer of electrodeposited copper. The manufacture of these materials makes use of continuous vacuum techniques for tiecoat and seedcoat, and special roll to roll electrodeposition methods for copper build-up. In this paper, properties and performance of adhesiveless copper on polyimide substrate will be discussed. The elimination of the adhesive layer substantially reduces weight and thickness, offering advantages in portable applications. In addition, copper thinner than 5 μm is routinely provided, with copper layers as thin as 0.2 μm available for semi-additive approaches. The availability of very thin copper facilitates manufacture of fine-line circuit features, and traces narrower than 25 μm have been produced. A smooth copper-polyimide interface is ideal for high speed applications and for fine line etching. Selection of an appropriate tiecoat material provides good copper adhesion to the base film, even after exposure to harsh environmental and processing conditions. Polyimide base films offer good thermal and chemical stability and a low dielectric constant. Small copper grain size and good tensile strength, ductility, and flexural endurance in the electrodeposited copper offer advantages in both flexible circuit and chip scale packaging applications. This paper also discusses manufacturing methods and availability of material types for this important class of substrate material.

Introduction

Polyimide film based substrates are widely used for flexible and high-density electronic interconnection applications. One approach that is used to apply copper is to laminate copper foil to the base film using an adhesive. This approach is used for conventional flex circuit and TAB applications, but it does suffer some drawbacks. Examples include increased thickness and weight of the circuit, thermal stability and other issues with the adhesive itself, and a minimum copper thickness limitation based on the availability of commercial copper foils.

A second approach is to directly deposit metallization layers on to the polyimide surface. A vacuum technique, such as sputter deposition, is a common method for direct metallization. This class of adhesiveless copper on polyimide substrates addresses key requirements for new generations of portable commercial products, hard disk drive interconnections, chip scale packages, and other advanced applications. Adhesiveless materials are thin and lightweight, and they facilitate fine-line feature formation because of the availability of very thin copper. In this paper, technical attributes of vacuum metallized adhesiveless copper on polyimide substrates are discussed.

Overview and Manufacturing

Adhesiveless copper on polyimide substrates typically include the polyimide base film, a thin metal tiecoat, a copper seedcoat, and a layer of electrodeposited copper, as shown in Figure 1. They can have single or double-sided metallization, and are often provided in roll format to streamline subsequent processing.

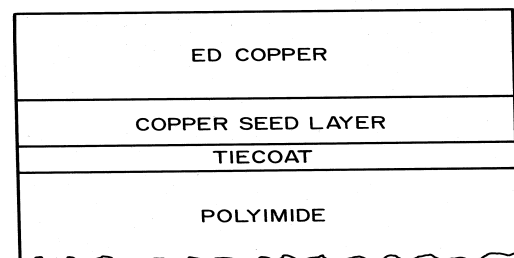


Figure 1: Typical Construction of Adhesiveless Flexible Laminate

Two roll-to-roll manufacturing processes are used to apply the metallization layers. Tiecoat and seedcoat layers are applied using vacuum deposition techniques. The process begins with a plasma pretreatment of the polyimide. The pretreatment cleans and chemically modifies the surface to enhance adhesion. After the pretreatment, tiecoat and seedcoat metals are sputter deposited. The tiecoat metal is either chromium or a nickel based alloy, and the seedcoat metal is copper. The tiecoat serves to enhance adhesion, particularly after materials are exposed to severe processing or environmental conditions. The purpose of the copper seedcoat is to provide sufficient electrical conductivity to permit electroplating to final copper thickness.

The second process is electrodeposition of copper. The process is highly versatile, and copper thickness can be tailored to the application need. Copper on

either side of the substrate can differ in thickness. In some instances, electrodeposited copper on the laminate can be eliminated altogether, and only the ultra-thin, vacuum deposited copper is provided.

Polyimide Base Film

Polyimide base film is commercially available from three manufacturers: E.I. DuPont de Nemours & Co., Ube Industries, Ltd., and Kaneka Corporation. Film thicknesses range from 12.5 μm to 125 μm , although 25 μm and 50 μm films are most common.

Polyimide is a high performance polymer that has a number of desirable properties for advanced electronic applications. Selected properties of three commonly used films are given in Table 1. Polyimide films have a high degree of thermal stability, permitting them to withstand processing at elevated temperatures. They have low shrinkage and a

Property	Kapton^a-E	Upilex^b-S/SGA	Apical^c-HP
I. Thermal			
Tg	High	High	High
CTE, ppm/°C, 50-200°C	16	12	12 (100-200°C)
Heat Shrinkage, %	0.05 (200 °C 1hr)	0.07 (250 °C 2hr)	0.06 (200 °C 2hr)
II. Mechanical (1 mil)			
Tensile Strength, ksi, @ 25 °C	45	57	52
Tensile Modulus, ksi, @ 25 °C	700	1280	884
Elongation, %, @ 25 °C	55	30	50
III. Electrical (1 mil)			
Dielectric Constant, @ 1 kHz	3.2	3.5	3.2
Dissipation Factor, @ 1 kHz	0.0015	0.0013	0.001
Dielectric Strength, V/mil	7200	6800	8000
IV. Chemical			
Water Abs., 24 hrs. 23 °C, %	1.8	1.2	1.2
Chemical Etch	Yes	No	Yes
V. Other			
Laser Ablation	Yes	Yes	Yes

Notes

- a Kapton is a registered trademark of the E.I. DuPont de Nemours & Co.
- b Upilex is a registered trademark of Ube Industries, Ltd.
- c Apical is a registered trademark of Kaneka Corporation
- d All property data based on information from suppliers

coefficient of thermal expansion (CTE) close to copper over a fairly wide temperature range. Because polyimide CTE is close to copper, mechanical stresses induced in copper during thermal excursions are minimized. While polyimides are flexible, they have reasonably high strength and modulus. This enhances handling during board processing, especially for very thin materials. The dielectric constant for polyimide is as low as 3.2, which is less than that of a typical adhesive material. They also have low dissipation factor and good dielectric strength. Consequently, polyimides provide advantages in electrical performance for high speed applications relative to adhesive based systems. Polyimides are chemically stable, and withstand harsh chemical environments associated with circuit board processing. At the same time, Kapton and Apical polyimides are chemically etchable in hot potassium hydroxide, and all three polyimides are laser ablatable. These features allow windows or vias to be produced in the final circuit.

Polyimides are also available to address specific application requirements. DuPont offers two specialty polyimides called Kapton-XC and Kapton-MT. Kapton-XC has enhanced electrical conductivity compared to their standard product. Sheet resistance can be in the range 50 to 10^{12} ohms per square. This product can be useful for shielding or anti-static applications. Kapton-MT has enhanced thermal conductivity, which is about three times that of their standard product. This material can be useful for circuits requiring enhanced heat dissipation. Both films maintain the good thermal and chemical characteristics of standard Kapton polyimide.

Tiecoat

Tiecoat materials include chromium and monel, a nickel based alloy. The tiecoat can be as thick as several hundreds of angstroms, and as thin as a few angstroms. Chromium has advantages in that it provides superior adhesion performance, as will be discussed in more detail below. However, a second etching step, typically potassium permanganate, is required for removal. Monel is etchable in industry standard etchants such as cupric chloride, and hence, circuitization can be accomplished in a single etch process. Monel also has fewer environmental concerns than chromium.

Excellent initial peel strength of copper on polyimide can be achieved by plasma pre-treating the polyimide film prior to metallization. The peel strength of 35 μm copper on 2 mil Kapton-E substrate is typically 7 lb/in with a chromium tiecoat. However, process and application environment conditions to which materials are exposed can degrade adhesion of copper to a base

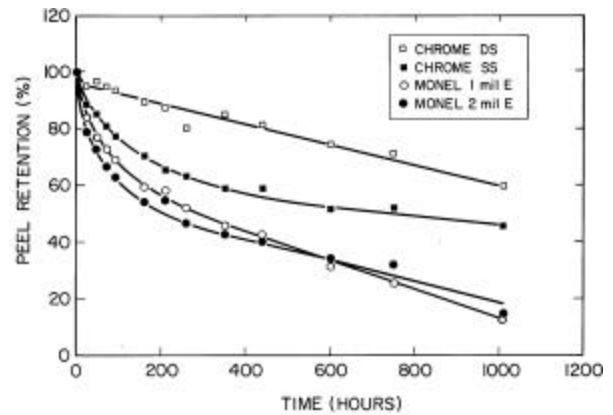


Figure 2: Peel Strength Retention for Adhesiveless Substrates with Monel and Chromium Tiecoats after Exposure to 85°C / 85% RH

film. Selection of an appropriate tiecoat can reduce adhesion losses under such circumstances.

A chromium tiecoat enhances adhesion retention after exposure to various environments. Peel strength of 18 μm copper on 50 μm Kapton-E is about 2.5 to 3 lb/in after 168 hours in a pressure cooker at 121 °C and 2 atmosphere pressure at 100% relative humidity¹. Peel strength drops to nearly zero in about 12 hours without the chromium tiecoat. A chromium tiecoat is superior to monel tiecoat in reducing peel strength losses after exposure to 85 °C and 85% relative humidity, as shown in Figure 2. Both monel and chromium tiecoats reduce adhesion losses after exposure to elevated temperature conditions and to neutral potassium gold cyanide electroplating baths². However, under such conditions, the chromium tiecoat provides better protection against adhesion losses than does monel.

Copper

Copper can range in thickness from 2000 Å, when there is no electroplating, up to 35 μm after plating. Thickness between 5 μm and 18 μm is more typical. Copper thickness is very uniform; tolerances are less than 10%. Copper thickness can differ on either side of the laminate, which adds options for the flexible circuit designer.

A unique feature of the adhesiveless copper on polyimide substrate is the availability of thin copper. Thin copper not only reduces thickness and weight of the final circuit, but also facilitates the formation of very fine lines. The smooth interface between copper and polyimide also facilitates fine-line feature formation. Lines 25 μm wide are readily formed using adhesiveless copper on polyimide substrates. Semi-

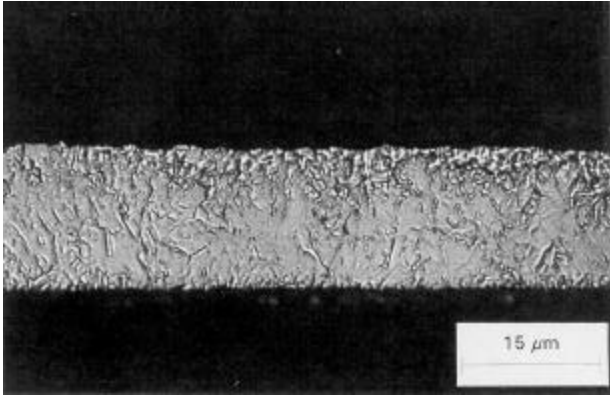


Figure 3: Cross-Section of Copper from Adhesiveless Flexible Laminate

additive fabrication methods, using copper as thin as $0.2\ \mu\text{m}$ as a base, have led to the best fine-line results. Thin copper also has the advantage of facilitating some types of laser via fabrication techniques.

A cross-section of an example of copper plate-up from an adhesiveless substrate is shown in Fig. 3.

True columnar morphology, which can be present with some electrodeposited coppers, is not present³. Grain size depends on the thickness of the copper and orientation of view. Average grain size in $5\ \mu\text{m}$ copper is $0.8\ \mu\text{m}$ and $1.3\ \mu\text{m}$ in the planar and cross-sectional orientations, respectively³. In planar view, individual grains are equiaxed. In cross-sectional view, some individual grains are equiaxed, while others exhibit some extension in the growth direction. The incidence of grain extension apparently increases with the thickness of copper³.

Mechanical properties for adhesiveless plate-up copper are comparable to the same properties for some types of electrodeposited foils. Tensile strength for $18\ \mu\text{m}$ copper plate-up is about 54 ksi, while elongation is 12%. The good combination of strength and elongation helps to withstand stresses that are induced during flex-to-install, and high strain, low cycle, bending operations. Adhesiveless plate-up copper also exhibits excellent flex fatigue performance. Strain accommodation due to good adhesion between polyimide and copper promotes greater cycles to failure in low strain, high cycle regime³. Thin copper also promotes greater cycles to failure⁴.

Conclusions

Technical attributes of adhesiveless copper on polyimide substrates were reviewed. Commercially available polyimide base films exhibit good thermal, mechanical, electrical, and chemical properties. The selection of a chromium or nickel alloy tiecoat can enhance adhesion performance after exposure to severe environmental conditions. Of the two, chromium offers better adhesion performance. However, monel has the advantage of being etchable in a single process step. Thin copper and a smooth copper to substrate interface facilitate fine-line etching. A good combination of copper strength and elongation reduces the possibility of cracking during high strain, low cycle and flex-to-install applications. Small grain size and thin copper contribute to good fatigue life during repetitive flexing.

Acknowledgements

The authors wish to acknowledge the contributions of their many colleagues at Gould Electronics in Eastlake, Ohio and Phoenix, Arizona.

References

1. Bergstresser, T.R., Bergkessel, N.E., and Poutasse, C.A., in Proceedings of the Fifth International Conference on Flexible Circuits, September 15-16, 1998, San Jose, CA, STC, 1998.
2. Bergstresser, T.R., Bergkessel, N.E., Chiang, S.K., Poutasse, C.A., and Russell, D.B., in Proceedings of the Fourth International Conference on Flexible Circuits, October 19-20, 1997, San Jose, CA, Semiconductor Technology Center, 1997.
3. Merchant, H.D. et al., *Circuit World*, **26**(4), pp. 7-14, 2000.
4. Merchant, H.D., Chiang, S.K., and Minor, M.G., in proceedings of the Third International Conference on Flex Circuits, October 23-25, 1996, Sunnyvale, CA, STC, 1996.