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SI – A Multifunctional Polyimide for Use in Flex Circuitry

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Abstract
Polyimides have proven their performance in electronic applications demanding high strength, increased durability, broader temperature ranges and exceptional chemical resistance. They serve as the material of choice for fabricating flex circuitry due to their excellent properties and demonstrated capabilities. Typical polyimides require the use of an adhesive to assemble multilayer circuits, which results in additional material thickness for the overall package. Several concerns related to the adhesives currently used involve CTE mismatch, wrinkling, voids and delamination of the layers that can ultimately lead to circuit failure. The recent trend is toward adhesiveless materials; reducing the total package thickness without compromising the performance, capacity or cost of the final product.

One material, which has been investigated in an effort to meet the demands of the electronics industry, is an advanced polyimide developed by researchers at NASA Langley Research Center. SI (Soluble Imide) is a thermoplastic that extends the possibilities for polyimides in flex circuits. SI can be used as a substrate material by laminating or casting directly onto metal foil such as copper or aluminum yet is versatile enough to be used as the adhesive in fabricating flex circuits thereby producing an ultra-thin adhesiveless, monolithic flex circuit. Eliminating the adhesive results in a reduction in materials and processing costs, lighter end weight circuits, increased flexibility, and circuits with smaller z-axis expansion.

Introduction
Polyimides have been used in the flex circuit industry for a number of years with moderate to high success. Some of the initial drawbacks have been the requirements of additional adhesives to bond these materials to substrates. Adhesiveless flex polyimide materials have become a new wave emerging in this field in an effort to resolve the issues associated with the use of adhesives.

An amorphous, thermoplastic soluble imide (SI) developed by NASA Langley Research Center has attempted to overcome the obstacles of the conventional polyimides currently available. The thermoplastic nature of this material has provided some unique capabilities while retaining the desirable characteristics inherent in polyimides.

SI has exhibited excellent adhesive properties when laminated to a variety of materials including polyimides, copper and aluminum foils and, of particular interest, is its affinity to bond to itself.

The objective of this study is to investigate the properties associated with SI and review its capability as an alternative adhesive or substrate for use in flex circuit applications.

Basic SI Film Properties
Material properties have been determined on 25µm thick SI polyimide film. The values for physical and thermal data are listed in Table 1.

Table 1 - Physical and Thermal Properties for 25mm SI Film

Property	Units	Method	Result
Glass Transition Temperature	C	DSC	250
Density @ 23C	g/cm3	Density Column	1.376
CTE 23-150C 150-200C	$10^{-6}C^{-1}$	TMA	46 60
Thermal Conductivity	$Wm^{-1}K^{-1}$	ASTM-C-518	0.244
Flammability		UL 94	VTM-O
Solder Float		IPC2.4.13 Method B	Pass

As expected, the values for the physical and thermal properties are typical for polyimide materials.[1] The electrical properties of SI film are identified in Table 2.

Table 2 - Electrical Properties* of 25mm SI Film

Property	Units	Method	Result
Dielectric Breakdown	V/mil	ASTM D-149	7230
Dielectric Constant		IPC 2.5.5.3	3.1 @ 10GHz
Dissipation Factor		IPC 2.5.5.3	0.004 @ 10 GHz
Volume Resistivity	Ω•cm	IPC 2.5.17	1.4×10^{16}
Surface Resistivity	Ω	IPC 2.5.17	6.2×10^{13}

*Data From Penn State University

The dielectric constant remains relatively constant over a wide range from 10kHz through 2MHz as illustrated in Figure 1. In a separate test, conducted by Penn State University, the dielectric constant was measured on 25µm thick film at 10Ghz and found to be 3.1. This further illustrates the trend towards a constant dielectric value through a very broad range of frequencies.

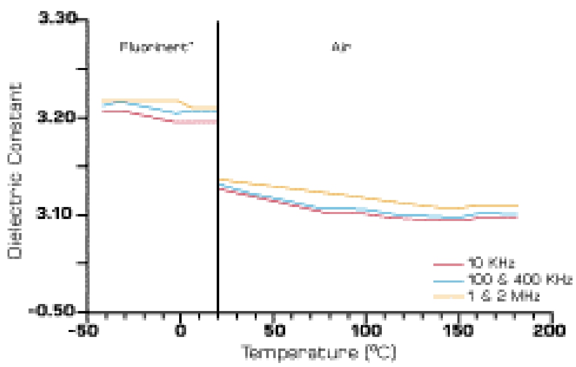

Figure 1 - Dielectric Constant of SI

Mechanical properties for SI have been determined as outlined in Table 3. The peel strength is noticeably high at 8 pounds per linear inch and the initiation tear strength indicates the relative toughness of the material as a thin film.

Table - Mechanical Properties of 25mm SI Film

Property	Units	Method	Result
Tensile Strength	ksi	ASTM D638	18
Tensile Modulus	Ksi	ASTM D638	451
Elongation	%	ASTM D638	20
Peel Strength	lb/in	IPC 2.4.9	8
Initiation Tear Strength	g	ASTM D1004	1016

As with most polyimides, SI exhibits good chemical resistance as noted in Table 4. Another unique feature is that SI is no longer soluble in NMP (the solvent it is manufactured from) after it has been processed beyond its glass transition temperature of 250°C.

Table 4 - Chemical Resistance* of 25mm SI Film

Property	Units	Method	Result
Jet Fuel	%	Weight change	< 0.1
Toluene	%	Weight change	< 0.1
MEK	%	Weight change	< 0.1
Methyl Chloride	%	Weight change	< 0.1
Hydraulic Fluid (TCP based)	%	Weight change	< 0.1
THF	%	Weight change	< 0.1
Ethylene Glycol	%	Weight change	< 0.1
HCl (conc.)	%	Weight change	< 0.1

*Tested for 10 days at room temperature on 25µm films twisted around a tight radius

SI film has an overall low permeability of oxygen and is more selective to oxygen versus nitrogen (Table 5). The moisture absorption of SI was determined using IPC –TM-650, Method 2.6.2 and has been found to be 1.6% (Table 5). Biological tests performed thus far have shown no fungus growth on SI films (Table 6). SI, having excellent solvent and biological resistance, along with low gas permeability, makes it a choice material as an environmental barrier.

Table 5 - Gas Permeability* Of SI Thin Film

Gas Permeability	Units	Test	Result
Permeability	Barrers	@ 27C	$P(O_2)$ = 0.09
Selectivity		@ 27C	α (O_2/N_2) = 8.90
Moisture Absorption	%	IPC-TM-650-2.6.2	1.6

*Data from AIR Products and Chemicals Inc., Allentown, PA

Table 6 - Fungus Resistance* Of A Melt Extruded SI Film

Biological	Test	Result
Aspargillus niger	IPC-TM-650-2.6.1	No Growth
Aureobasidium pullulams	IPC-TM-650-2.6.1	No Growth
Gliocladium virans	IPC-TM-650-2.6.1	No Growth
Penicillium funiculosum	IPC-TM-650-2.6.1	No Growth
Chaetomium globosum	IPC-TM-650-2.6.1	No Growth

*Data From Trace Labs, Linthicum, MD

Manufacturing Methods of SI

Due to the thermoplastic nature of the SI polyimide, it can be melt processed to form a thin film by extrusion. Melt viscosity parameters for different molecular weights is illustrated in Figure 2.

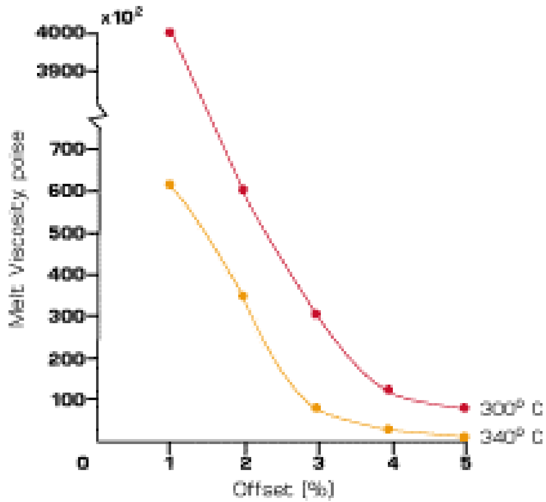

Figure 2 - Melt Viscosity for Different Molecular Weights of SI

Thin film, tubing and rods have been manufactured using a single screw Brabender extruder. Typical processing conditions range from 280°C – 340°C depending on the number of heating zones and barrel size. The polyimide powder was converted to pellets with subsequent processing of the pellets to produce the final product.

Processing of Adhesiveless Copper Clad

SI was solution cast onto 18µm copper and dried to form a 12µm and 25µm thick film on the copper foil (Figure 3). The samples were post baked and the volatile retention was measured to be <0.1% using a Seiko Model 220 thermogravimetric analyzer (TGA) in air. The single sided laminate material can be used to form single layer or multi-layer flexible circuits. Some material properties were tested for a 12µm thick SI polyimide cast onto 18µm copper and are listed in Table 7.

Figure 3 - SI Polyimide Solution Cast onto Copper

Table 7 - Properties for 12mm SI Film Solution Cast onto 18mm Copper

Property	Units	Method	Result
Solder Float		IPC 2.4.13 Method B	Pass
Peel	pli	IPC 2.4.9	4.5
Tensile Strength	psi	IPC 2.4.19	13,900
Elongation	%	IPC 2.4.19	78
**Dimensional Stability	%	IPC 2.2.4	0.012 (FD) 0.013(WD)

**Data taken from 12µm polyimide film

Single sided samples were laminated together using an autoclave with processing conditions of 285°C, 200psi, and a 1 hour hold to form a double sided copper clad of 18µm copper with a 25µm thick polyimide core.

Multi-layer Flex Circuit Production

Multi-layer flex circuits have been fabricated up to three layers using SI as the adhesive in combination with a commercially available polyimide. An image of the circuit can be found in Figure 4.

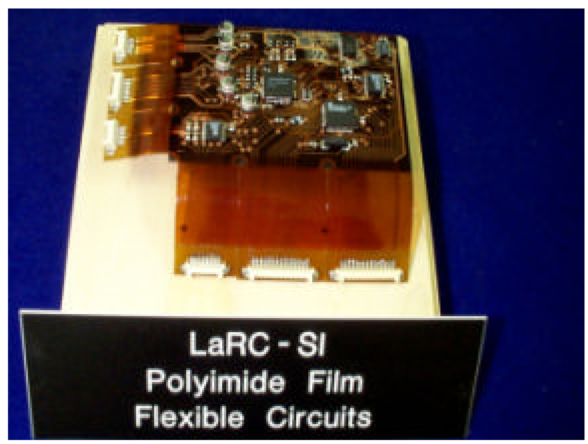

Figure 4 - Three Layer Flexible Circuit Designed for NASA GIFTS* Program

The polyimide substrate was used as received from the manufacturer; no adhesion promoters were employed. The circuits were produced by laminating 35µm copper foil with 25µm thick SI to a 25µm polyimide substrate using an autoclave and processing conditions of 300°C, 100psi, and a 1 hour hold. The artwork was patterned, etched and mechanically drilled for each layer using conventional techniques. The three layers of artwork were then stacked according to Figure 5 and processed in an autoclave at 300°C, 100psi, and a 1 hour hold to produce the multi-layer circuit. The coverlay was predrilled and laminated to the circuit. Total package thickness including the coverlay was measured to be on average 375µm thick.

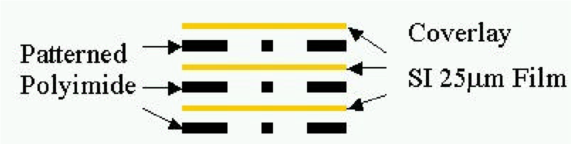

Figure 5 - Lay-up of Multi-layer Circuit Using SI as the Adhesive for Polyimide

To illustrate the overall reduction in package thickness, and the unique capability to laminate SI directly to itself, the same circuit was produced using SI as the substrate and the adhesive. Three layers were patterned using 35µm copper clad with a layer of 50µm thick SI. The artwork was patterned, etched and mechanically drilled for each layer using conventional techniques. The three layers of artwork were then stacked as illustrated in Figure 6 and processed in an autoclave at 300°C, 100psi, and a 1 hour hold to produce a monolithic multi-layer circuit. The coverlay was predrilled and laminated to the circuit. Total package thickness including the coverlay was measured to be on average 250µm thick. A total package reduction of approximately 125µm resulted from the use of SI as the substrate and the adhesive.

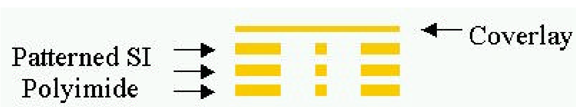

Figure 6 - Lay-up of Multi-layer Circuit Using SI as the Substrate and Adhesive

Multi-layer circuits have also been successfully fabricated using a standard thermal press. Typical processing conditions are similar to the autoclave process described above. The lay-up is placed in a cold press and ramped to 300°C. Once the lay-up has reached the processing temperature, a pressure of 200psi is applied and held for 30-60 minutes. The press is cooled and the lay-up is removed after the temperature is well below the glass transition temperature of SI, 250°C.

A build up technique for multi-layer flexible circuits on high performance rigid boards has been performed using the thermal press with good success. In Figure 7, this method was used to laminate a four layer circuit to a rigid board.

Figure 7 - Lay-up of Multi-layer Circuit Using SI as the Substrate and Adhesive Via the Build Up Method

The rigid board had a maximum temperature limitation of 280°C. In order to achieve adequate flow, 25µm thick SI on 35µm thick copper clad was laminated to the rigid board at 280°C with a pressure of 300psi for 45 minutes. The lay-up was removed and the artwork was pattern and etched. A second layer of 25µm thick SI on 35µm thick copper clad was laminated to the rigid board using the same processing conditions. These steps were repeated until all four layers were adhered to the rigid board.

Conformal circuits can be easily fabricated using SI film as illustrated in Figure 8. The multi-layer circuit was patterned using conventional techniques and attached to a carbon composite structure using an autoclave process. The circuit showed excellent adherence and conformed to the curved structure without distortion of the artwork.

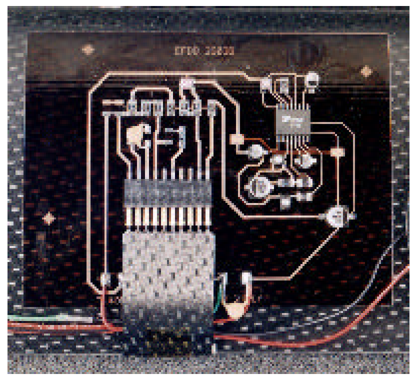

Figure 8 - Multi-layer Circuit Laminated to Carbon Composite Structure

Conclusions

The thermoplastic nature of SI has demonstrated some very unique properties while retaining the desirable characteristics associated with polyimides. The adhesive capabilities of SI will offer a new solution for the flexible circuit manufacturer. The ability to process SI as a cast solution onto copper or other metals as well as melt extrude the powder has rendered this a very versatile material to manufacture.

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*NASA GIFTS Program: The Geo-Synchronous Imaging Fourier Transform Spectrometer satellite instrument or GIFTS, is set for launch in 2004. Weather information provided by GIFTS will be equivalent to launching 100,000 weather balloons every minute at intervals of two miles.