Ultra-thin, highly flexible RF cables and interconnections

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1 Very thin, flexible cables and interconnections

Two technologies for very thin, flexible cables and interconnections, HiCoFlex and 'Thin Film on Foils', are discussed in this paper as a basis for RF applications.

1.1 HiCoFlex Technology

HiCoFlex is a new technology for the production of flexible multilayer substrates [1]. The HiCoFlex multilayer technology uses rigid substrates, alumina or glass plates as a carrier during the multilayer build-up process and the assembly of components. First, a thin 'release layer' is applied on these substrates. The multilayer is built up by repetitive application of polyimide layers (by a spin-on process and by curing liquid solution) and metal layers (by sputtering and, if needed, enforced by galvanic deposition). Vias between conductor levels are opened by laser or plasma processing. Assembling and bonding of the components and tests of the circuits are possible while the film is still sticking on the rigid carrier substrate, avoiding handling problems. After that, the flex multilayer can be released from the carrier. This technology allows narrow and well-defined lines and gaps (down to 10 … 20 μm) and vias of 30 μm. Actually, circuits with up to 4 metal layers have been realized. The total thickness of such a film is about 50 μm. The minimum bending radius is smaller than 0.5 mm. It is even possible to fold the material without prejudice to the electrical properties. The results are highly flexible, film-like circuits with excellent mechanical and electrical properties.

1.2 Thin Film on Foils

This technology makes use of commercial polymer foils completed by thin film metallizations. Methods for temporary attachment of the foils on rigid carriers during the thin film coating and their detachment afterwards have been studied.

2 RF Cables and Interconnections

The use of HiCoFlex and 'Thin Film on Foils' has now been extended to high frequency applications. Narrow and well-defined lines and gaps potentiated by the thin film technology and conductors enforced by Cu/Ni/Au electroplating ensure a perfect high frequency performance. This enables the realization of very thin, highly flexible microstrips, stripeline and waveguide structures for RF cables and interconnections.
The aim of this work was to evaluate and qualify different polymers for RF applications. HiCoFlex coplanar waveguides based on different polyimides and thin film on liquid crystalline polymer (LCP) foils were compared. Losses were measured to verify the performance until 20 GHz. Further tests with benzocyclobutene (BCB) are in process.

2.1 Polymer materials

On the one hand the evaluated polymers were applied by spin-on technique:

- The polyimide PI9161 (a product of ALTANA), which normally is used for HiCoFlex, was selected for its low thermal expansion coefficient.
- The polyimide PI2611 (a product of HD Microsystems) had the same low thermal expansion, but lower water uptake and otherwise similar properties,
- Benzocyclobutene 3022 (BCB, a product of Dow Chemical), well-known for its excellent RF properties, but due to the brittleness was not of use for detachable films. Only PI-BCB multilayers and PI-BCB-PI sandwiches make flexible films possible.

Physical data of Polyimides, Kapton, LCP, BCB		Polyimide PI 9161	Polyimide PI 9141	Polyimide PI 2611	Kapton Type 100 HN	LCP R/flex 3600)	Cyclotene 3022 (BCB)
Supplier		ALTANA	ALTANA	HD Micro-systems	DuPont	Rogers	Dow Chemical
Coeff. of Therm. Expans. (CTE)	ppm/K	3	51	3	20	17 (x,y)	52
Dielectric Constant @ 50% RH		3.1 0% RH	3.1 0% RH	2.9 1 kHz	3.4 1 kHz	2.9 1-10 GHz	2.65 1MHz
Dissipation Factor (tg δ)		0.002 1 kHz	0.006 1 kHz	0.002 1kHz	0.002 1 kHz	0.002	0.015 GHz
Volume Resistivity	Ohm*cm	10^{16}	10^{17}	> 10^{16}	$1.5*10^{15}$	$5*10^{15}$	10^{19}
Breakdown Voltage	V/µm	> 250	> 250	> 200	118	160	300
Decomposition Temperature	°C	620	520	620			
Youngs Modulus	GPa	7.8	3.0	8.5	2.5	4.8	2.0
Tensile Strength	MPa	310	110	350	230	103	85
Elongation	%	27	31	25	25	16	6
Water Absortion @ 85°C 50%RH	%	1.5 23°C, 95%	1.0 23°C, 95%	< 0.5	1.8 23°C	0.04 24h, 23°C	< 0.13

Fig. 1 Physical data of polymers (source data sheets and literature)

On the other hand some commercial foils, after coating with thin films, were used:

- LCP foils, R/flex 3600 (supplied by ROGERS Corporation), known to have excellent RF properties, e.g. a dielectric constant of 2.65 over a wide frequency range,
- Polyimide foil, like KAPTON type 100 HN (a product of DuPont), a typical base material for flexible printed circuit boards.

LCP and BCB have the advantage of a low water uptake, an important point for high frequencies. The physical data of the evaluated polymers have been collected and tabulated in figure 1.

2.2 Realized RF test structures

For the analysis coplanar waveguide (CWG) test patterns are used. Figures 2 and 3 illustrate the profile and the layout of these patterns.

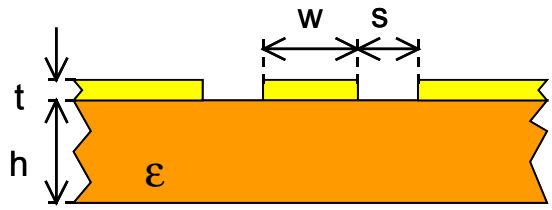

Fig. 2. Coplanar waveguide structure

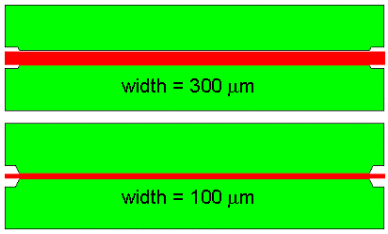

Fig. 3. Section of photomask for CPW

The polyimides PI9161 and PI2611 are applied by spin-on, drying and curing. The final layers have a low frequency dielectric constant of 3.1. For the LCP foils, R/flex 3600, the backside Cu has to be removed to get reasonable results. Before the thin film process the foils have been temporarily attached to ceramic substrates.
The dielectric thickness used in the samples is 20 µm for the polyimide and 50 µm for the LCP. A thin seed layer of 100 nm Ti and 300 nm Cu is deposited by sputtering. The conductor and ground metallization is a 7 µm plated layer of Cu/Ni/Au. The test patterns (fig. 2 and 3) have conductor widths of w = 100 µm and 300 µm, the space between conductor and ground s is 20 µm. Figures 4 and 5 show pictures of the final flexible coplanar waveguide test samples. Similar microstrips in PI-BCB-PI sandwiches are under way.

Fig. 4. Realized flexible coplanar waveguide test samples

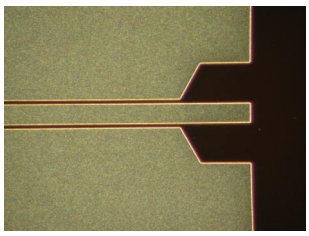

Fig. 5. Contact part of a realized coplanar waveguide with 100 µm conductor width.

2.3 Results of RF measurements

The measurements of the RF properties (losses etc) of the test samples were performed in the RF laboratories of AVANEX. The terminations of the cables had to be cut to avoid harmful impedance changes. For serious results a careful contacting of the test structures needed much attention.
The measured S-Parameters are plotted in figures 6 and 7 for each kind of polymers. The RF performance of PI9161 (fig. 6) is acceptable, at least to 20 GHz with a bandwidth ≥ 20 dB. The results for PI2611 and LCP Rogers R/flex 3600 (fig. 6) are similar.

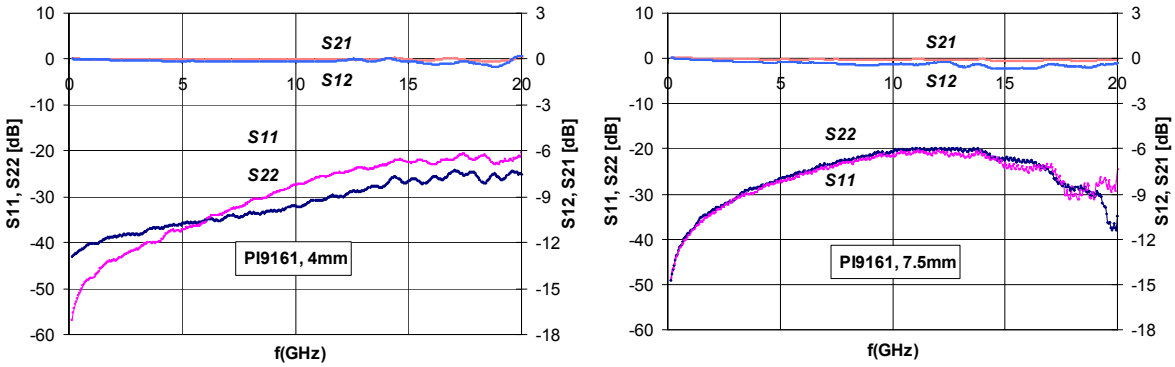

Fig. 6. S-Parameters measured for waveguides with the polyimide PI 9161, sample length 4 (left) and 7.5 mm (right), measured at 25°C

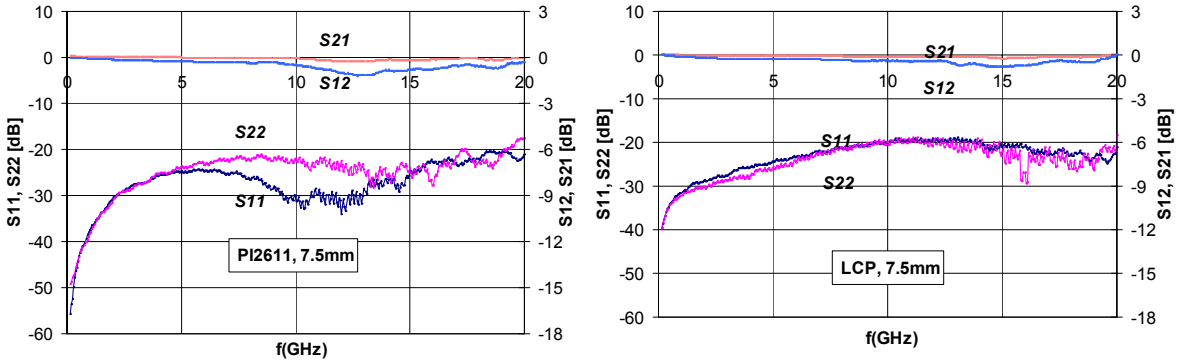

Fig. 7. S-Parameters measured for waveguides with the polyimide PI2611 (left), and with LCP Rogers R/flex 3600 (right), sample length each 7.5 mm, measured at 25°C.

3 Applications

Fields of applications are high density interconnect (HDI) technologies for sensors, industrial and medical microsystems, and newly also high frequency inter-connections, e.g. between submodules for telecommunication and opto-electronics.

4 Conclusions

Loss measurements on coplanar waveguides clearly show that the tested materials, the polyimides PI9161 and PI2611 and the Liquid Crystal Polymer LCP Rogers R/flex 3600, are appropriate for RF applications and exhibit a good performance, at least up to 20 GHz with a bandwidth > 20 dB, i.e. S11, S22 < -20 dB and S12, S21 > -1 dB. RF structures with PI-BCB-PI sandwich as dielectric material will follow later.
The analysed polymers produced by the described methods allow highly flexible RF cables.

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6 Reference

[1] A. Fach, Y. Athanassov, U. Brunner, D. Hablützel, B. Ketterer, J. Link, „Multilayer polyimide film substrate for interconnections in microsystems“, Microsystem Technologies, Volume 5, pp. 166-168, 1999