Ultra-Thin, Highly Flexible Cables and Interconnections for Low and High Frequencies

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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.
Integration of various components into HiCoFlex are possible, thin film sputtered NiCr resistors are under test, capacitors and embedded silicon chips will be studied later. Integrated RF structures and RF lines are the topic of this paper.

1.2 Thin Film on Foils

This technology makes use of commercial polymer foils completed by thin film metallisations. Polymer foil material useful for RF applications are polyimides, e.g.

Kapton (DuPont trade mark), liquid crystalline polymer (LCP) and other polymers with suitable RF properties, like HyRelex (Taconic trade mark).
Methods for temporary attachment of the foils on rigid carriers during the thin film coating and their detachment afterwards have been studied. The use of the thermal Release Sheet Realpha (product of NITTO DENKO Corp.), e.g. No. 3195V (Release 170°C), allowed lowest release forces.

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 enabled by the thin film technology and conductors enforced by Cu/Ni/Au electroplating ensure a remarkable high frequency performance. This allows 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. A microstrip design with benzocyclobutene (BCB) was realized and measured until 40 GHz.

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.

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.
- A further option would be PTFE based polymer foils, like HyRelex (a product of Taconic).

LCP, BCB and HyRelex 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.

Physical data of Polyimides, Kapton, LCP, BCB		Polyimide PI 9161	Polyimide PI 9141	Polyimide PI 2611	Cyclotene 3022 (BCB)	Kapton Type 100 HN	LCP R/flex 3600)	PTFE HyRelex TF-260
Supplier		ALTANA	ALTANA	HD Micro-systems	Dow Chemical	DuPont	Rogers	Taconic
Coeff. of Therm. Expans. (CTE)	ppm/K	3	51	3	52	20	17 (x,y)	12 (x,y)
Dielectric Constant @ 50% RH		3.1 0% RH	3.1 0% RH	2.9 1 kHz	2.65 1MHz	3.4 1 kHz	2.9 1-10 GHz	2.6 1-10 GHz
Dissipation Factor (tg δ)		0.002 1 kHz	0.006 1 kHz	0.002 1kHz	0.015 GHz	0.002 1 kHz	0.002	0.002 10 GHz
Volume Resistivity	Ohm*cm	10^{16}	10^{17}	> 10^{16}	10^{19}	$1.5*10^{15}$	$5*10^{15}$	
Breakdown Voltage	V/µm	> 250	> 250	> 200	300	118	160	50
Decomposition Temperature	°C	620	520	620				400
Youngs Modulus	GPa	7.8	3.0	8.5	2.0	2.5	4.8	11.2
Tensile Strength	MPa	310	110	350	85	230	103	
Elongation	%	27	31	25	6	25	16	
Water Absortion @ 85°C 50%RH	%	1.5 23°C, 95%	1.0 23°C, 95%	< 0.5	< 0.13	1.8 23°C	0.04 24h, 23°C	0.02 24h, 23°C

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

2.2 Coplanar waveguide test structures

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

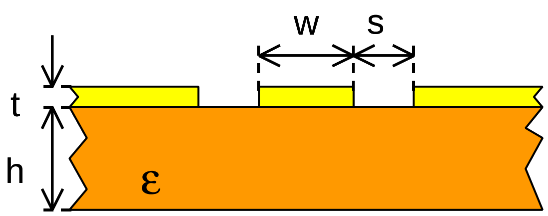

Fig. 2. Coplanar waveguide structure

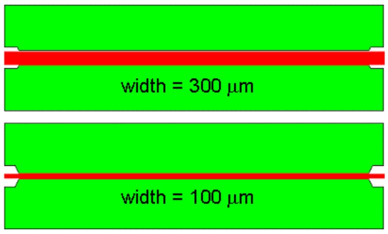

Fig. 3. Section of photomask for CPW

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 metallisation 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.

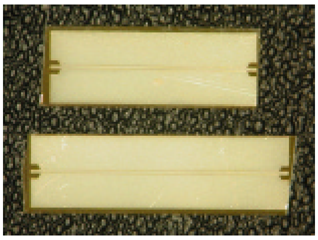

Fig. 4. Realized flexible coplanar wave-guide test samples

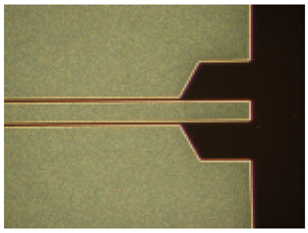

Fig. 5. Contact part of a realized coplanar waveguide with 100 µm conductor width.

2.3 Measured RF properties of polyimide films and LCP

The measurements of the RF properties (losses etc) of the test samples were performed in the RF laboratories of AVANEX. The terminations of the line had to be cut to avoid harmful impedance changes. For accurate results a careful contacting of the test structures needed much attention.

The measured S-Parameters are plotted in figures 6 and 7 for each of the polymers. The RF performance of PI9161 (fig. 6) is acceptable, at least to 20 GHz with a return loss of better than -20 dB. This indicates that the line is well matched to 50O. The results for PI2611 and LCP Rogers R/flex 3600 (fig. 6) are similar.

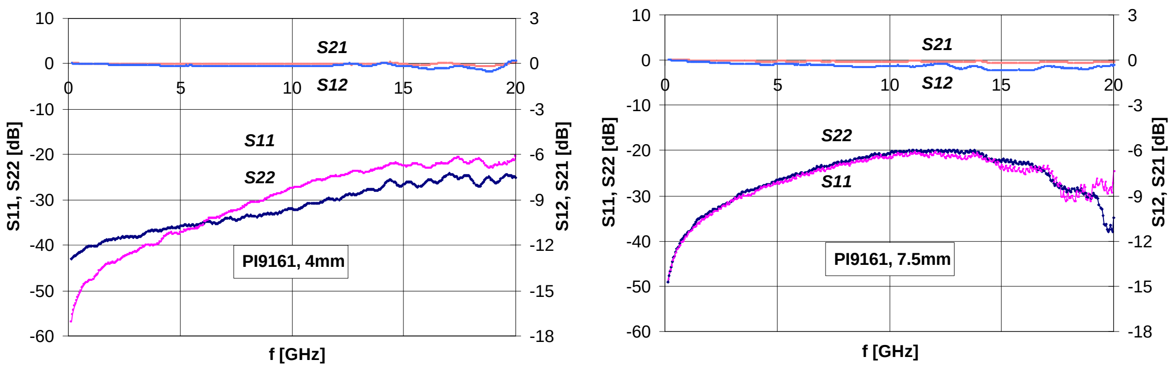

Fig. 6. S-Parameters measured at 25°C for waveguides with the polyimide PI 9161, sample length 4 (left) and 7.5 mm (right)

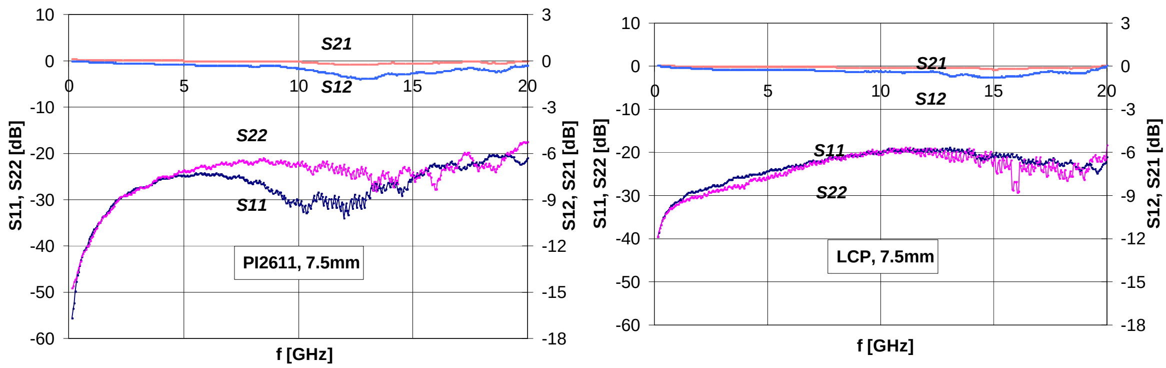

Fig. 7. S-Parameters measured at 25°C for waveguides with the polyimide PI2611 (left), and with LCP Rogers R/flex 3600 (right), sample length each 7.5 mm

2.4 Microstrip test structures

For the analysis of the RF properties of PI-BCB-PI multilayer sandwiches, a second test pattern was used. Figures 8 and 9 illustrate the profile and the layout of these pattern.

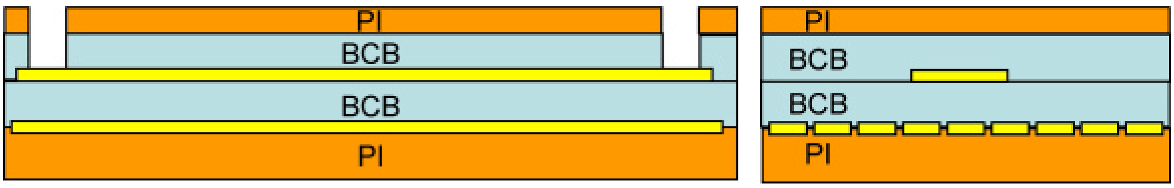

Fig. 8. Multilayer sandwich PI-BCB-PI. Section along (left side) and across (right side) transmission line

Fig. 9. Multilayer sandwich test pattern

The test structure had transmission line length of 22, 12, 5 and 0 mm, shorts and opens. Transmission lines width was designed as 47 µm. The ground layer was meshed for increased adhesion. Except below the transmission lines where the ground is not meshed. The design values of the lower BCB layer thickness was 20 µm and the upper 10 µm. The same design was used for different structures: PI-BCB, PI-BCB-BCB and PI-BCB-BCB-PI sandwiches. In the case of PI-BCB the electric field lines will enter into the air on one side of the transmission line. The dimensions of the practical samples were very close to the designed values, the thicknesses and the transmission line widths were within 1 μm of the designed values.

2.5 Measured RF properties of PI-BCB sandwiches

The measured S-Parameters of the PI-BCB samples with line length 5mm, 12mm and 22 mm, respectively are plotted in figure 10. Return loss values below -18dB for low frequencies and values below -25dB for frequencies above 10GHz were measured. The insertion loss values, S12- and S21-Parameter, show an attenuation of 0.84dB/cm at 20GHz and 1.5dB/cm at 40GHz. Additional insertion losses can be observed at about 6GHz. These losses are proportional to the line length, indicating an increased absorption.

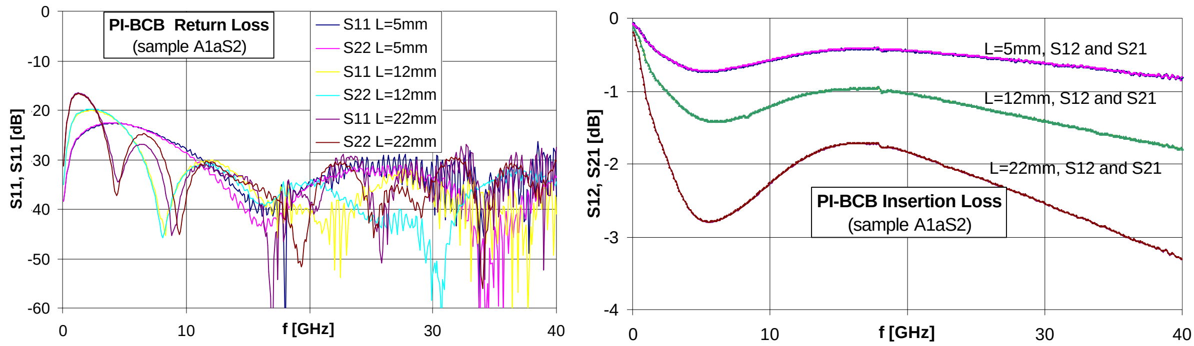

Fig. 10. S-Parameters measured at 25°C for microstrips on PI-BCB sandwiches, line lengths 5, 12 and 22 mm.

Figure 11 shows the measured S-Parameters for PI-BCB-BCB samples with a line length 5mm and 12mm, respectively. The insertion loss values show resonance effects, depending on the sample length. They are caused by an impedance mismatch and thus resulting reflections at the interface between probe and line. The insertion loss values, for the same line length, are increased by a factor of 2 to 3 compared to the measurements in figure 10.

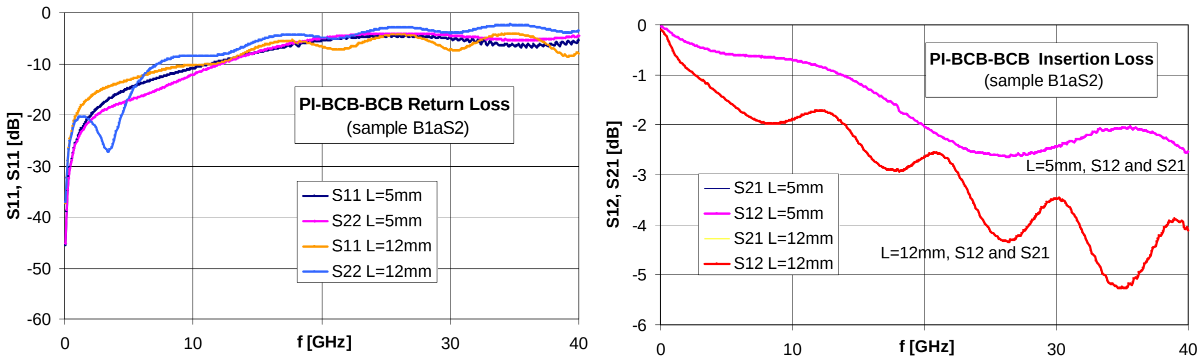

Fig. 11. S-Parameters measured at 25°C for microstrips on PI-BCB-BCB sandwiches, line lengths 5 and 12 mm.

For the PI-BCB-BCB samples no additional insertion losses at 6GHz, as has been observed for the PI-BCB samples, occurred. One possible reason might be that the release process or the environment harms the RF properties of the microstrips, since for the PI-BCB-BCB samples the lines are covered with the BCB. Whereas in case of the PI-BCB, the lines are exposed. First tests with dehydration, to remove eventually adsorbed water, showed no effect. Another possible reason is a not completely cured lower BCB layer. Since the lower BCB layer in the PI-BCB-BCB sandwich is cured a second time while processing the upper BCB layer. Further investigations, like measuring the samples before releasing and additional BCB curing steps, are required. Also work is ongoing on PI-BCB-BCB-PI samples.

3 Applications

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

4 Conclusions

Loss measurements on coplanar waveguides clearly show that the tested 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 an attenuation of 1.3dB/cm at 20GHz. Microstrips on PI-BCB and PI-BCB-BCB sandwiches as dielectric material have been measured up to 40 GHz. The results indicate a good RF performance for this material combination which is not susceptible to moisture and still very flexible.

The described methods with the analysed polymers allow highly flexible RF cables, interconnections and other RF structures.

5 Acknowledgements

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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