Accelerated Humidity Durability Testing of Adhesiveless Polyimide Laminates

Bergstresser, T.R., Bergkessel, N.E., and Poutasse, C.A.
Gould Electronics Inc.
34929 Curtis Blvd., Eastlake, Ohio 44095

Abstract
An important performance requirement for flexible laminate material is adhesion of copper to the substrate. Excellent initial adhesion between copper and polyimide can be achieved by performing a suitable plasma pre-treatment of the film followed by vacuum depositing a thin metal tiecoat layer prior to copper build-up. However, adhesion is reduced when laminates are exposed to humid environments, particularly when the temperature is high. In this study, adhesiveless polyimide laminates were exposed to a highly aggressive humidity durability test, and adhesion performance was evaluated. Test conditions were 121 °C, two atmospheres of pressure, and 100% relative humidity for up to 168 hours. Practical adhesion was determined using the 90° peel test. The effects of polyimide substrate material type and chromium tiecoat metal thickness are compared. Peelback specimens were examined by surface analytical techniques to determine failure loci and physical and chemical changes within the interphase regions. Peel retention behavior is explained in terms of the surface analytical results.

Introduction
Polyimide (PI) film based laminates are used extensively for flexible and high density electronic interconnection applications. Advanced products that incorporate these materials include chip scale packages (CSPs), notebook computers, hard disc drives, and printers, as well as many medical devices and consumer products. PI based substrates, particularly adhesiveless constructions made using direct metallization processing, have a number of advantages including (i) ultra-thin substrates, (ii) fine-line processing capability, (iii) ease of metallizing both sides of the substrate, and (iv) inherent advantages of reel-to-reel processing.

Polyimide is the substrate material of choice for advanced interconnection applications for a number of reasons. It has excellent mechanical properties and is able to withstand the elevated temperatures and harsh chemical environments used during processing. It has good dimensional stability and CTE close to that of copper over a fairly wide temperature range. PI material options include Kapton*-E from DuPont as well as Upilex**-SGA and Upilex-S from Ube Industries.

A key performance requirement for laminate material is adhesion of metal to the base film. Excellent initial adhesion can be achieved by plasma pre-treating the film followed by vacuum depositing a thin metal tiecoat layer prior to copper build-up[1]. However, exposure to processing or environmental stresses can reduce adhesion and adversely affect yields or finished product reliability. The combination of moisture and elevated temperature is a particularly severe environment to which laminate may be exposed. It is also an environment of particular interest to the industry. For example, CSP reliability tests have included the 85/85 stress test (exposure to 85 °C / 85% RH for up to 1000 hours) and the pressure cooker test (exposure to 121 °C and 2 atm pressure at 100% RH for up to 168 hours)[8]. While CSP reliability tests are typically performed on finished packages, the affect of test conditions on laminate adhesion is of interest as well.

Kapton-E based laminates lose adhesion when exposed to elevated temperature in air[2]. Adhesion losses are significantly reduced when chromium, or to a lesser degree, nickel alloy tiecoats are used. The tiecoat metal improves adhesion by acting as a copper diffusion barrier. Peel strength decreases with time when Kapton-E[3] or Kapton-H[4,5] laminate is exposed to 85 °C and 85 % relative humidity. Laminate with a chromium tiecoat retains adhesion more effectively than laminate with a monel tiecoat[3]. After 85/85 exposure, laminate with a chromium tiecoat exhibits cohesive failure in Kapton after peel testing[3-5]. Degradation of PI mechanical properties caused by hydrolysis is a possible adhesion loss mechanism. Moisture induced oxidation of chromium, leading to interfacial failure and catastrophic peel strength loss, has been observed for Kapton type materials after higher temperature exposure conditions[6,7].

* Kapton is a registered trademark of DuPont
** Upilex is a registered trademark of Ube Industries

In this study, adhesion of PI laminates after exposure to 121 °C and 2 atm pressure at 100% RH for up to 168 hours was determined. Materials made using standard commercial processing were used in order to maximize relevance to industry. The effect of substrate material was determined by comparing results for Kapton-E and Upilex-SGA polyimides. The effects of chromium tiecoat thickness were also evaluated. Practical adhesion was measured using the 90° peel strength test. X-ray photoelectron spectroscopy (XPS) was used to characterize fracture surfaces of peeled samples, and the results were used to help explain adhesion performance.

Experimental

Two commercially obtained PI substrates were used in this study: (1) 2 mil Kapton-E manufactured by DuPont, and (2) 2 mil Upilex-SGA from Ube Industries. All laminates studied were single-sided. They were prepared by first plasma pre-treating the substrate in an oxygen-containing environment at low pressure. A chromium tiecoat and copper seedcoat were then sputter deposited. Sputtering targets were 99.99+ % pure copper and 99.9 % pure chromium. Chromium tiecoat thickness ranged between 0 Å and 300 Å, and the copper seedcoat thickness was 2000 Å. Tiecoat and seedcoat thickness were determined based on dissolving layers in acid solution and analyzing the solution using Inductively-Coupled Plasma Spectroscopy. Final laminate copper thickness was built-up to 18 μm by electrodeposition. All processing was conducted in a roll-to-roll fashion using production equipment.

Samples were prepared for testing by mounting laminate on a backing support, then print and etch processing 1/8 inch line and space patterns. Patterned samples were removed from the backing support prior to placing them in the pressure cooker. The pressure cooker was an Electric Pressure Steam Sterilizer, model number 25X, and was obtained from VWR Scientific. Samples were suspended in the cavity to avoid pooling of water during exposure. Samples were exposed to 121 ± 2 °C, 15 psig, and 100% relative humidity (PC) conditions for up to 168 hours.

Practical adhesion was determined using the 90° peel strength technique. Measurements were conducted on as-plated samples, without additional build-up of copper. Upon removal from the pressure cooker, samples were mounted on a rigid substrate by passing through a nip roller set at 230 °F running at 1 foot per minute. Peel testing normally was completed within 1 hour after exposure. The equipment used was a Model # MC 4100 Instron with a Sintech upgrade and running Testworks V2.11f software. A 10 lb loadcell and 2 in min^{-1} cross-head speed were used. Average peel strength was determined for each condition by peeling three 1/8 inch lines per sample. In some instances, multiple tests of a single condition were accomplished and the results averaged.

Trace-side and substrate-side fracture surfaces of peeled samples were analyzed by XPS. Samples used for the analyses were 1/2 inch traces. The Instron was used to initiate fracture, and the resulting peelback samples were mounted and loaded into ultra-high vacuum immediately thereafter. The XPS unit was a Physical Electronics PHI 560 ESCA/SAM System equipped with a double-pass CMA. The work was carried out using a Mg x-ray source operating at 15 kV and 300 watts power. Depth profiling was accomplished using a 4 keV Ar ion beam rastered over a 7 x 7 mm area. A sputter rate of 24 Å min^{-1} was calibrated against a 350 Å SiO_2/Si standard. Depth profiling was accomplished using alternating sputter intervals of 20 seconds.

Adhesion Results

Peel strength for Kapton-E laminate is shown in Figure 1 as a function of PC exposure time. No tiecoat (copper only) and 70 Å, 170 Å, and 300 Å chromium tiecoat sample data are included. Initial peel strength (0 hours exposure time) for the samples with tiecoat ranged between 5.3 lb/in and 5.6 lb/in. While initial peel strength is not affected by chromium thickness, earlier work has shown peel is dependent on copper thickness[1]. Higher peel strength, around 7 lb/in, might be expected had copper thickness been 35 μm. Initial peel strengths were 5.0 lb/in and 3.4 lb/in (4.2 lb/in average) for samples without tiecoat. The higher measurement is close to those observed for samples with chromium tiecoat. However, the lower measurement indicates variability for samples without tiecoat. Hence, in general, (1) application of a chromium tiecoat does not greatly enhance initial peel strength on Kapton-E, but (2) increased scatter is possible for samples without tiecoat. Similar results were observed in earlier studies[1].

Exposure of Kapton-E laminate to PC conditions reduces peel strength. For samples without tiecoat, peel strength decreased rapidly to just over 1 lb/in within 24 hours of exposure to PC conditions. Peel strength subsequently continued to decrease with time, but at a reduced rate. After 168 hours exposure, nearly 100% loss was observed. For samples with a chromium tiecoat, peel strength also decreases with exposure time, but the rate of loss is less dramatic. After 24 hours exposure, at least 2.7 lb/in peel strength was observed. Peel strength

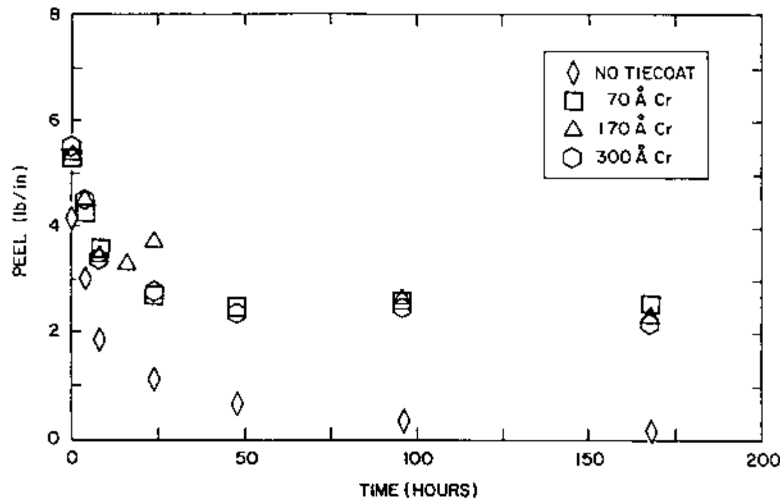

Figure 1: Peel Strength as a function of PC exposure time for Kapton-E laminate with 170 Å Chromium Tiecoat and 18 μm Copper

remained fairly constant thereafter, and, after 168 hours of exposure, peel strength exceeded 2 lb/in in all cases. The data show that the presence of a chromium tiecoat effectively reduces adhesion loss for Kapton-E based laminates exposed to PC conditions. Furthermore, chromium thickness has no appreciable affect on peel strength losses.

Peel strength for Upilex-SGA laminate is shown in Figure 2 as a function of PC exposure time. Initial peel strengths for Upilex-SGA laminates without tiecoat were 1.8 and 1.5 lb/in. Initial peel strength ranged between 5.7 and 6.3 lb/in for samples with a tiecoat. Chromium tiecoat appears to significantly enhance initial adhesion for Upilex-SGA based materials. Peel strengths with tiecoat are marginally higher for Upilex-SGA laminate than for Kapton-E laminate. Normally, Upilex-S laminate has lower peel strength than Kapton-E laminate of similar construction. It appears the "GA" treatment successfully enhances Upilex-S initial adhesion when chromium tiecoat is present.

As with Kapton-E laminate, exposing Upilex-SGA laminate to PC conditions reduces peel strength. The peel strength of copper only samples decreased to

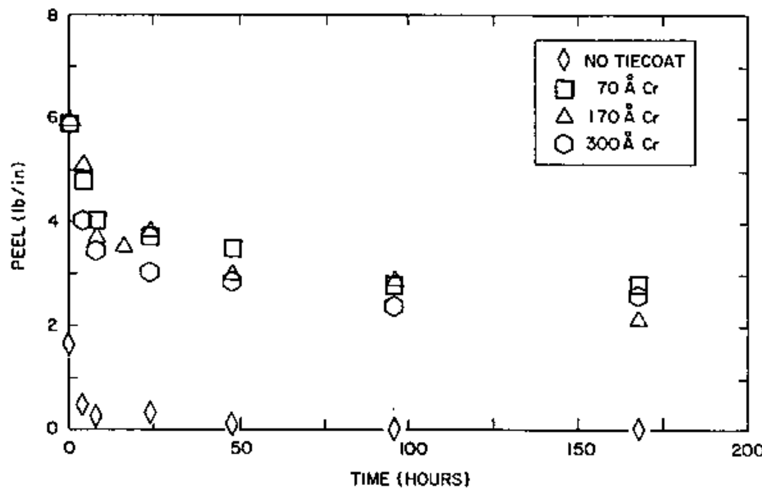

Figure 2: Peel Strength as a function of PC exposure time for Upilex-SGA laminate with 170 Å Chromium Tiecoat and 18 μm Copper

less than 1/2 lb/in after 4 hours of PC exposure. Thereafter, peel strength was essentially zero. Peel strength of samples with chromium decreased from about 6 lb/in to between 2.5 - 3 lb/in within 24 hours exposure. Subsequently, peel strength leveled off. After 168 hours of exposure, peel strength values between 2 and 2.5 lb/in were obtained.

Overall, the peel strength behaviors of Upilex-SGA and Kapton-E laminates with tiecoats were not significantly different. Initial peel strengths were about the same, peel strength losses after exposure were comparable, and chromium thickness had no appreciable affect. However, the relative performances of samples with and without tiecoat differ. In the case of Kapton, tiecoat has little effect on initial peel and clearly reduces the rate of peel loss relative to copper only material. In the case of Upilex-SGA, the presence of tiecoat clearly increases initial peel strength. Furthermore, it is difficult to determine whether the chromium tiecoat reduces the rate of loss due to PC exposure because the no tiecoat sample reaches zero peel so quickly.

Both laminate materials performed remarkably well given the severity of the test conditions. As indicated earlier, the PC test has been used for CSP reliability testing. Reliability could be impacted by blistering or delamination, but inspection of exposed samples before peel testing revealed no trace of either. Both substrates exhibited reasonable adhesion, more than 2 lb/in peel strength after 168 hours. Furthermore, this value may understate adhesion performance in a CSP. Previous work demonstrated that a double-sided laminate construction significantly reduces peel strength losses after exposure to 85 °C and 85 %RH[3]. CSP components similarly encapsulate the underlying substrate material. Since reliability testing is accomplished on finished CSPs, one might expect package components to attenuate laminate peel strength losses when the package is exposed to PC conditions.

Discussion

Determining the locus of peel failure relative to substrate, tiecoat and copper layers is important to help understand operative failure mechanisms and adhesion losses. Interfacial fracture halves, or peelbacks, were analyzed by XPS to determine chemical compositions of peel fracture surfaces. Depth profiles as well as high resolution elemental scans were obtained. Elemental scans provide atomic concentrations at the fracture surface, while depth profiles provide composition as a function of distance into the surface. In some instances, information on failure location could be obtained by visual inspection of peeled samples.

Peel failure is cohesive in Kapton-E for unexposed samples, as has been observed previously[1]. The XPS depth profile of a trace side peelback for as-received Kapton-E with 170 Å tiecoat is given in Figure 3. Carbon is predominant at low sputter time. As sputter time increases, carbon concentration declines. Chromium increases rapidly after 2-3 minutes and peaks at about 12 minutes. Carbon persists well into the region where chromium is present. The predominance of carbon during the initial stages of the profile and its persistence into the chromium region confirm Kapton is present on the trace-side peelback. It is difficult to precisely determine the depth of the interphase region because it is governed

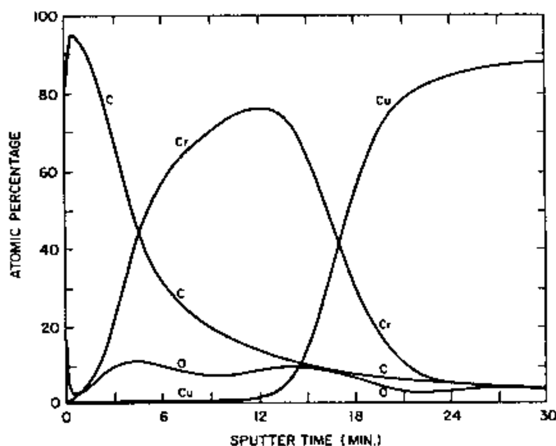

Figure 3: XPS depth profile of trace-side peelback of Kapton-E laminate with 170 Å chromium tiecoat and 18 μm copper. As-received sample.

Element	Kapton-E Substrate[1]	Peelbacks - 96 hrs PC	
		Trace	Substrate
Copper	ND	0.19	0.06
Chromium	ND	0.77	ND
Carbon	73.4	72.80	72.67
Oxygen	18.3	18.85	18.77
Nitrogen	8.4	7.39	8.50

Table 1: Atomic percentages of peelback surfaces of Kapton-E with 170 Å chromium tiecoat and 18 μm copper after PC exposure

by a number of physical and instrumental factors. As such, the profiles are best used as relative indications of depth between similar materials. However, it appears that there is a lack of a sharp demarcation between polyimide and chromium layers. If significant, this contributes to good interfacial bonding and cohesive failure within the polyimide.

Failure of PC exposed Kapton-E laminate appears to be more complex. The visual appearances of exposed and unexposed peelbacks were mostly similar. However, inspection revealed that some exposed peelbacks exhibited a small degree of failure at the chromium-copper interface. Not all peelbacks exposed to the same conditions in duplicate trials exhibited the phenomenon. Also, occurrence was spotty and did not occur over the whole length of all traces. Where present, chromium-copper failure was confined to the trace edge. Less than 10% to 20% penetration was observed. Exposure to PC conditions apparently introduces some weakness to the chromium-copper interface and could contribute to data scatter. However, other factors are more critical to the observed peel strength losses since (1) the small degree of penetration was not proportional to the magnitude of peel loss, (2) traces without chromium-copper failure did not exhibit consistently higher peel strength, and (3) there was no compelling trend with exposure time.

The primary locus of failure does not change when Kapton-E is exposed to PC conditions. Surface atomic concentrations for a 170 Å chromium, Kapton-E peelback after 96 hours PC exposure are given in Table 1. As-received Kapton-E substrate concentrations are included in the table for comparison. Carbon, oxygen and nitrogen ratios for both peelback surfaces are nearly identical to those observed for as-received Kapton-E. A small concentration of chromium was measured on the

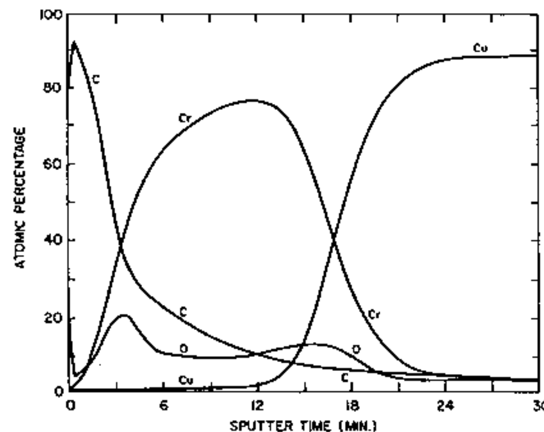

Figure 4: XPS depth profile of trace-side peelback of Kapton-E laminate with 170 Å chromium tiecoat and 18 μm copper. 96 hour PC sample.

trace-side surface, but chromium was not detected on the substrate side. The substrate-side copper concentration is negligible. The depth profile for the 96 hour sample is given in Figure 4. Carbon and chromium profiles are nearly identical to those observed for the unexposed sample shown in Figure 3. Based on the XPS data, Kapton is retained on the trace-side peelback surface, and failure occurs cohesively in the PI after PC exposure.

The chromium and copper concentrations for the trace side peelback provide some evidence for highly localized interfacial failures, or pullouts. The presence of the pullouts is most likely a result of chromium oxidation. Evidence for oxide formation is found by comparing oxygen profiles for exposed and unexposed samples. In Figure 4, a strong peak in oxygen concentration is evident within the chromium-Kapton interphase region. An examination was made of the chromium elemental region for acquisition cycles corresponding to peak oxygen concentration. Broadening of the peak envelope indicates that the increase in oxygen above baseline is due to chromium oxidation. In Figure 3, it is possible there is a similar oxygen concentration peak, but the magnitude is significantly less pronounced than for the exposed sample. It appears PC exposure oxidizes the chromium, weakens the interface, and causes highly localized interfacial failure to some degree.

Chromium oxidation and interfacial weakening do not explain adhesion losses arising from PC exposure. The small chromium surface concentration indicates the total area comprised of pullouts is insufficient to account for the drop in peel strength. Furthermore, it is unlikely that small pullouts can be removed from a mechanically intact polymer layer even if the interface is weakened. Finally, the peel strength of exposed samples must relate to Kapton mechanical properties (after exposure), since failure occurred there. For these reasons, degradation of polyimide mechanical properties is the most likely reason Kapton-E materials lose peel strength when exposed to PC conditions.

Upilex-SGA analytical results are given in Table 2. XPS surface atomic concentrations of the initial substrate, as-received peelbacks, and 96-hour exposed peelbacks are included for comparison. The tiecoat thickness of each peelback specimen was 170 Å. Carbon, oxygen, and nitrogen concentrations do not differ a great deal for Upilex-SGA and Kapton-E substrates. One difference is the presence of a small amount of silicon at the Upilex-SGA surface. As indicated earlier, the "GA" modification, which includes the presence of a form of silicon, appears to successfully enhance peel strength.

Carbon, oxygen, and nitrogen concentrations of as-received Upilex-SGA peelbacks are virtually identical to those determined for the as-received substrate. No chromium and only a trace of copper were detected on the trace side peelback. The observed surface concentrations demonstrate that there is no interface exposure, and failure is cohesive in the Upilex.

A comparison of depth profiles of the two material systems reveals subtle differences within the interphase regions. A trace-side peelback depth profile of Upilex-SGA laminate with 170 Å chromium tiecoat is shown in Figure 5. The silicon (and nitrogen) region was left out of the profile for ease of comparison, and the remaining atomic concentrations are normalized. As with Kapton-E, carbon predominates at low sputter times. Also, carbon decreases with sputter time, and chromium emerges after 2 - 3 minutes. However, the carbon concentration decreases much more gradually for the Upilex peelback than for the Kapton peelback. Indeed, for the Upilex sample, carbon persists through the chromium layer into the region where copper emerges. Since concentrations are

Element	Upilex-SGA Substrate	Peelbacks - As Received		Peelbacks - 96 hrs PC	
		Trace	Substrate	Trace	Substrate
Copper	ND	0.10	0.10	0.17	0.07
Chromium	ND	ND	ND	ND	ND
Carbon	73.32	74.46	72.99	73.81	73.59
Oxygen	17.90	17.39	18.29	17.34	17.40
Nitrogen	7.31	6.92	7.94	7.53	8.02
Silicon	1.48	1.13	0.68	1.16	0.91

Table 2: Atomic percentages of peelback surfaces of Upilex-SGA with 170 Å chromium tiecoat and 18 μm copper before and after PC exposure

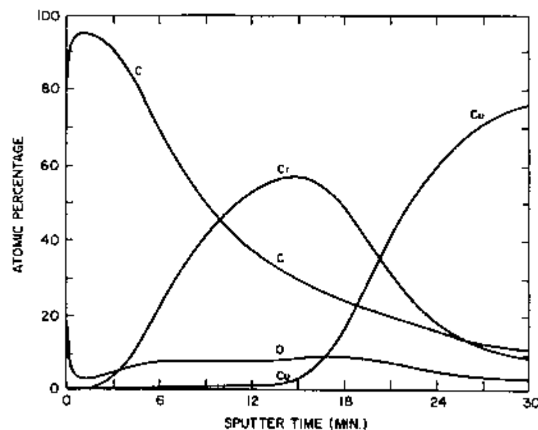

Figure 5: XPS depth profile of trace-side peelback of Upilex-SGA laminate with 170 Å chromium tiecoat and 18 μm copper. As-received sample.

normalized, the maximum chromium concentration is lower as well. Based on the depth profiles, the chromium-polyimide interphase region appears to be broader for the Upilex peelback. One might expect greater interfacial bonding between metal and polymer given a less distinct interphase region. However, when failure is cohesive in the polymer, polymer mechanical properties have more to do with peel strength. This may explain the similarities in initial peel strengths.

After Upilex-SGA samples are exposed to PC conditions, visual inspection of peelbacks reveal a small degree of chromium-copper failure. The occurrences were not appreciably different from those found for Kapton-E. Like Kapton-E, Upilex-SGA laminate fails primarily within the polymer after PC exposure. Referring again to Table 2, trace and substrate side atomic concentrations obtained for samples exposed for 96 hours were almost identical to those for unexposed samples. The carbon, oxygen, and nitrogen concentrations and the absence of a chromium signal on the trace-side peelback demonstrate polymer is present on the trace-side surface. A trace-side depth profile for a PC exposed Upilex peelback is shown in Figure 6. Computer difficulties were experienced during the latter stages of the analysis, and a complete profile was not obtained. Nevertheless, since carbon is prevalent at low sputtering times, the profile supports the idea that failure occurs in the polymer. Based on reasoning similar to that used for Kapton-E samples, mechanical weakening of polymer is the most likely cause of adhesion loss occurring from PC exposure of Upilex-SGA based samples.

Localized interfacial failures, or pullouts, did not appear to be present on the Upilex peelback. Chromium was not detected on the trace-side peelback of the exposed sample. Further examination of the depth profile in Figure 6 reveals (1) the broad interphase region characteristic of the as-received Upilex-SGA sample and (2) the absence of a significant increase of chromium oxidation within the polymer-chromium interphase region. It is possible these two features indicate a greater degree of intrinsic interfacial adhesion for the Upilex material and explain the apparent lack of pullouts. However, as indicated above, the apparent incidence of pullouts for the Kapton sample is quite small. In either case, it is unlikely that they contribute to peel loss after PC exposure.

Polymer mechanical property degradation has been advanced as the main reason both material systems lose peel strength after exposure to PC conditions. The question remains as to why mechanical strength degrades.

In previous work, it was hypothesized that hydrolysis degraded mechanical properties and reduced peel strength for Kapton-E laminate that was exposed to 85 °C and 85% RH for up to 1000 hours[3]. Peel strength and XPS results for Kapton-E are remarkably similar for the pressure cooker and 85/85 tests. The shapes of adhesion retention curves, as well as the absolute peel strength values, nearly coincide when the 1000 hour 85/85 time scale is compressed to the 168 hours utilized by the PC test. Peelback surface concentrations and depth profiles of exposed samples were almost identical for the two tests. It appears that the pressure cooker test is in many ways an accelerated version of the 85/85 test. If hydrolysis is responsible for degradation after the 85/85 test, it appears likely a similar mechanism is operative for the PC test.

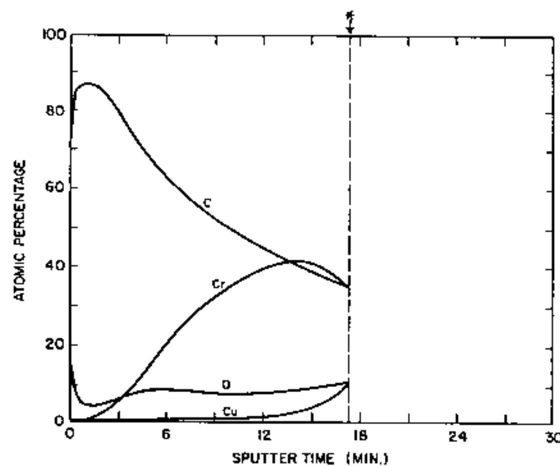

Figure 6: XPS depth profile of trace-side peelback of Upilex-SGA laminate with 170 Å chromium tiecoat and 18 μm copper. 96 hour PC sample.
* Data acquisition terminated prematurely

Evidence for hydrolysis presented in the previous work was indirect. To further address the issue, Kapton-E and Upilex-SGA samples before and after pressure cooker exposure were submitted to an outside laboratory for FTIR analysis. For both materials, the spectra after exposure showed a slight absorbance increase in the OH stretch region near 3600 cm^{-1}. All exposed Kapton-E and Upilex-SGA samples tested (2 for Kapton-E, 1 for Upilex-SGA) exhibited the increase, but in each case the effect was small. While an increase in OH stretch absorbance might be expected if hydrolysis were to occur, the FTIR results are not conclusive enough to unequivocally substantiate the hydrolysis hypothesis. Hydrolysis remains a distinct possibility, and further work in this area should be pursued.

The earlier work with the 85/85 test advanced the possibility that copper accelerates hydrolysis and led to greater peel strength losses for exposed Kapton-E with monel tiecoat as compared to chromium tiecoat[3]. Chromium was thought to act as a diffusion barrier. Similarly, it might be expected that the chromium tiecoat minimizes copper contact with the substrate, reduces hydrolysis, and improves peel strength retention after PC exposure. This mechanism would not completely explain the behavior of Upilex-SGA materials since initial peels without tiecoat were low. Further work is needed to characterize the Upilex-SGA system and to characterize the influence of copper on PI hydrolysis.

Summary and Conclusions

Peel strengths were determined for Kapton-E and Upilex-SGA adhesiveless flex laminates that were exposed to 121 °C and 2 atm pressure at 100% RH for up to 168 hours. Prior to exposure, peel strength was comparable for Kapton-E and Upilex-SGA laminate when a chromium tiecoat was present. In each case, peel exceeded 5 lb/in for 18 μm copper, with the Upilex-SGA being marginally higher. Both laminate materials performed remarkably well after exposure given the severity of the test conditions. Peel strength decreased with exposure time, but after about 24 hours further losses were minimal. In each case, peel strength exceeded 2 lb/in after 168 hours of exposure. Chromium tiecoat thickness had no appreciable effect on performance for either substrate. However, in each case, the presence of tiecoat was required for good peel strength after PC exposure. For Upilex-SGA, chromium was also required to achieve good initial peels.

Peelback samples were examined visually and analyzed by XPS in order to determine failure location and provide insight into adhesion behavior. Before PC exposure, peel failure occurs within the polymer for both substrates. Since the weak link is within the PI, peel strength depends as much on PI mechanical properties as it does on interfacial adhesion between PI and chromium tiecoat. After PC exposure peel failure also occurs primarily within the polymer for both substrates. Hence, degradation of polyimide mechanical properties is the most likely reason Kapton-E and Upilex-SGA materials lose peel strength when exposed to PC conditions.

Visual evidence was obtained for a small degree of sporadic, non-uniform failure between copper and chromium at trace edges after PC exposure. The effect was seen on both substrates. PC exposure of

Kapton-E also appeared to (1) oxidize chromium at the chromium-Kapton interface, and (2) create a small quantity of highly localized areas of interfacial failure, or pullouts. Similar results were not observed with the Upilex-SGA substrate. Interfacial adhesion between substrate and chromium may be slightly greater for Upilex-SGA systems based on the lack of observed pullouts and an apparent broadening of the interphase region revealed by XPS depth profiles. The incidences of chromium-copper failures and/or pullouts are minimal and appear to be secondary with respect to overall adhesion performance. They do underscore the severity of test conditions and could contribute to data scatter. However, neither contributes significantly to peel strength losses.

Degradation of polyimide mechanical properties, and hence peel strength losses from PC exposure, could be caused by hydrolysis. Copper may accelerate hydrolysis and chromium tiecoat may improve peel retention by acting as a diffusion barrier. Further work is needed to confirm hydrolysis and the influence of copper.

Acknowledgement
The authors gratefully acknowledge the assistance of S. Phillips for sample preparation, environmental conditioning, and peel testing.

References

1. Bergkessel, N., Bergstresser, T., Chiang, S.K., and Russell, D., in Proceedings of the IPC 3rd Annual Flexible Circuits National Conference, May 19-20, 1997, Phoenix, AZ, IPC, 1997.
2. Bergstresser, T.R., Bergkessel, N.E., Chiang, S.K., Poutasse, C.A., and Russell, D.B., in Proceedings of Flexcon, October 19-20, 1997, San Jose, CA, Semiconductor Technology Center, 1997.
3. Bergstresser, T.R.., Bergkessel, N.E., and Poutasse, C.A.., in Proceedings of the IPC 4th Annual Flexible Circuits National Conference, March 18-19, 1998, San Jose, CA, IPC, 1998.
4. Ahn, E.C., Jin, Yu, and Park, I.S., J. Mat. Sci.: Materials in Electronics, 1996, **7**, pp. 175-179.
5. Kim, D.G., Molis, S.E., Oh, T.S. Kowalczyk, S.P., and Kim, J., J. Adhesion Sci. Technol., 1991, **5**(7), pp. 509-521.
6. Furman, B.K., Childs, K.D., Clearfield, H., and Purushothaman, S., J. Vac. Sci. Technol. A, Jul/Aug 1992, **10**(4), pp. 2913-2920.
7. Furman, B.K., Neurogroschl, D., and Purushothaman, S., in Metallized Plastics 2, ed. By Mittal, K.L., Plenum Press, 1991, pp. 437-447.
8. Ewell, Gary J. and Speece, Dana J. paper presented at Chip Scale International '98, Santa Clara, CA, May 5-7, 1998.