

MATERIALS SCIENCE AND TECHNOLOGY NEWSLETTER

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Dr. Robert H. Lacombe
Chairman
Materials Science and Technology
CONFERENCES, LLC
3 Hammer Drive
Hopewell Junction, NY 12533-6124
Tel. 845-897-1654, 845-227-7026
FAX 212-656-1016
E-mail: rhlacombe@compuserve.com

FOCUSING ON HIGH TEMPERATURE POLYMERS, THIN FILMS AND ADHESION

IN THIS ISSUE

EDITORIAL COMMENTS 2

TALES OF THE DEVELOPMENT LABORATORY:

THE CASE OF THE WRONG OVEN 2

Fracture Mechanics 101 3

The Mystery Unwrapped 5

**Solving the Riddle of Excessive
Stress in the Polyimide 5**

Statistical Physics of Polymer Liquids 6

Epilog:

**More Statistical Physics and the Value
of Stress Modeling 7**

Statistical physics of rigid rods

**Value of stress modeling and
fracture mechanics (8)**

COURSES AND CONSULTING ON ADHESION AND ADHESION MEASUREMENT 9

Adhesion Courses 9

Consulting 9

SYMPOSIA ON HIGH TEMPERATURE POLYMERS AND ADHESION ASPECTS OF THIN FILMS 10

CALL FOR PAPERS:

**FIFTH INTERNATIONAL SYMPOSIUM
ON POLYIMIDES AND OTHER
HIGH TEMPERATURE POLYMERS
AND THE**

**THIRD INTERNATIONAL SYMPOSIUM
ON ADHESION ASPECTS OF THIN
FILMS INCLUDING ADHESION
MEASUREMENT AND METALLIZED
PLASTICS 10**

EDITORIAL COMMENTS

This issue of the Newsletter will introduce the upcoming **FIFTH INTERNATIONAL SYMPOSIUM ON POLYIMIDES AND OTHER HIGH TEMPERATURE POLYMERS** and **THE THIRD INTERNATIONAL SYMPOSIUM ON ADHESION ASPECTS OF THIN FILMS (INCLUDING ADHESION MEASUREMENT AND METALLIZED PLASTICS)**. These two topics are of particular interest to the conference Director Dr. Mittal and myself as we spent many years together in the development laboratory of the IBM Corporation wrestling with the problem of using the polyimide materials as dielectric layers in microelectronic structures. This application of the polyimide materials was quite challenging in that it involved a whole gamut of materials related questions including:

- ▶ Chemical stability of polyimides
- ▶ Thermal stability of polyimides
- ▶ Electrical properties of polyimides
- ▶ Mechanical stability of polyimides
- ▶ Adhesion of polyimides to metals, semiconductors and ceramics

What better list of challenges could a materials scientist want? Furthermore, in addition to the highlights just mentioned there were further pressing questions concerning the thermodynamic behavior of the polyimides with regard to the solubility of moisture and their barrier properties with regard to a whole rogues list of nasty corrosives such as sulphur dioxide, nitrous oxide and a host of other contaminants commonly found in the air we breathe. At low concentrations these gases are relatively innocuous to humans but can easily destroy a metal line on the order of one micron in width. All of this gave rise to exciting times in the development of polyimides as thin film materials for electrical insulation and out of this work, both within the IBM company and elsewhere, arose the very first international symposium on polyimide materials which was held in Ellenville, New York in November 1982. The meeting was held under the auspices of the Mid-Hudson Section of the Society of Plastics Engineers and featured 60 papers from 130 authors worldwide. A quick perusal of the Proceedings Volumes¹ shows that already by 1982 the polyimide materials had found a wide range of applications outside the microelectronics industry including high performance adhesives for aerospace applications,

protective coatings for service up to 700 F and insulating layers for implantable electrodes. The upcoming Fall 2007 symposium to be held in Orlando Florida will cover these and many other topics dealing with this most interesting and useful class of materials.

Of all the problem areas listed above, the one that most bedeviled the microelectronic applications was the question of adhesion of the polyimides to metals, semiconductors and ceramics. This question was touched upon in a previous issue of the Newsletter

www.mstconf.com/Vol2No2-2005.pdf and is one of the central themes of the companion symposium on Adhesion Aspects of Thin Films being held back to back with the polyimide symposium. The two symposia thus mutually reinforce each other and many participants will have a keen interest in both.

By way of introducing the topic of adhesion problems with polyimide coatings I present the following personal reminiscence typical of the type of problem commonly faced by the development laboratory especially when introducing new materials to the manufacturing line. The events depicted are true but names have been withheld or changed to protect the guilty.

TALES OF THE DEVELOPMENT LABORATORY: THE CASE OF THE WRONG OVEN

I believe it was an afternoon in late Summer or early Fall during the lunch hour and I was at my desk gazing at the turkey vultures wheeling in languid circles high above the Southern hills and contemplating the best way to use up some unspent vacation time when a knock came at the door. Upon signaling the caller to enter one of the technicians from the manufacturing line approached holding a plastic box commonly used for transporting ceramic substrates. Even from a distance of several feet I could see through the clear plastic cover that these parts had a coating which was badly delaminated. Since I was one of the Lab's resident experts on delamination and cracking problems it was immediately clear that here was big trouble and thoughts of vacation time rapidly evaporated. Closer examination indeed confirmed what a quick glance at a distance foreboded. Here was a collection of ceramic substrates coated with a polyimide material that had delaminated on an impressive scale. Figure 1 gives a schematic view of the nature of these parts.

The substrates in question were destined to support an advanced line of microchips to be used

¹ "Polyimides: Synthesis, Characterization and Applications, Volumes I and II", Ed. K. L. Mittal (Plenum Press, New York, 1984).

in the fabrication of a state of the art supercomputer. The underlying ceramic provided mechanical support and an insulating matrix for the basic power requirements of the chip. On top of the ceramic was a much thinner layer of polyimide which supported a dense mesh of thin film copper wiring for transmitting fast digital signals. The high electrical conductivity of the copper and the low dielectric constant of the polyimide made this combination ideal for meeting the stringent requirements of digital signals. One unusual feature of the design shown in figure 1 is the large thickness of the polyimide layer. At 175 microns the thickness of the polyimide was indeed exceptionally large according to prevailing standards since in the past the laboratory had many problems with delamination and cracking of films only 10 to 15 microns in thickness. The basic problem arose from the fact that the polyimide had a thermal expansion coefficient nearly 10 times larger than the ceramic. This coupled with the fact that the polyimide material had to be cured at temperatures ranging up to 400 C gave rise to very high thermal strains when the coated substrate laminate was cooled back to room temperature. However, the substrates in question used a newer variety polyimide with a very low thermal expansion coefficient closely matching that of the underlying ceramic so only relatively minor thermal strains should develop on curing. In fact a number of calculations were performed based on fracture mechanics studies of Suo and Hutchinson² which indicated that the polyimide coating in question should be stable in layers from 4 to 8 millimeters in thickness?!

At this stage it was time to form a task force and start rounding up the usual suspects. In addition to the polyimide layer there were also several levels of copper thin film wiring imbedded in the polyimide. The case against the copper strengthened when the analytical laboratory reported X-ray measurements which showed that the stress in the copper was something like 100MPa. This is some 3 times higher than what one would ever expect in even the most highly stressed polyimide. If the copper were indeed the

² "Steady State Cracking in a Brittle Substrate Beneath Adherent Films", Z. Suo and J. Hutchinson, *International Journal of Solids Structures*, **25**, 1337 (1989). An adaptation of this paper more friendly for purposes of engineering calculations may be found in ADHESION MEASUREMENT METHODS: THEORY AND PRACTICE, Robert Lacombe (CRC, Taylor and Francis, Boca Raton, Florida, 2006). See in particular chapter 4 section 4.2.2.

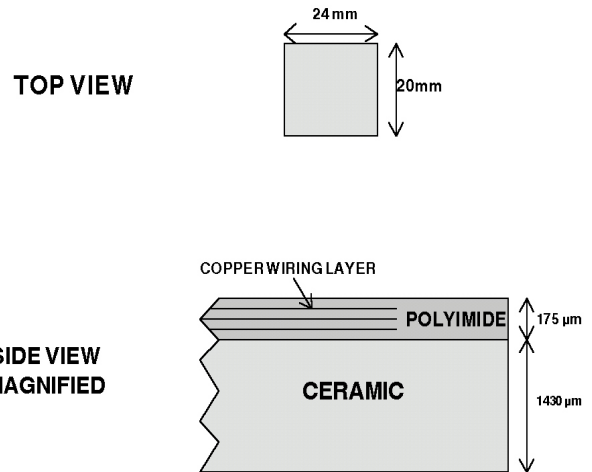


Figure 1 Schematic of ceramic substrate coated with polyimide and containing several layers of copper wiring.

culprit then significant adjustments would have to be made to the copper deposition process which would not have been a very appealing prospect. I, in fact had serious doubts that the copper wiring was the problem since even though the stress was high there was not that much of it in the thin film wiring layers compared to the volume of the polyimide. The precise reasoning for this reservation will be made clear later. Rather, my first impulse was to doubt the initial Suo-Hutchinson calculations which indicated that the expected stress in the polyimide was not enough to cause delamination or fracture. These calculations were basically back of the envelope type estimates based on the relatively simple formulae developed by Suo and Hutchinson and perforce harbored a number of simplifications which might not be valid for a full blown wired substrate. Now the Suo-Hutchinson formulae may be relatively simple and allow for straight forward hand calculations but they are by no means trivial and to get a better estimate means solving the full set of continuum mechanics field equations for the structure in question. This means rolling out the big guns and performing detailed numerical evaluations of the stress/strain equations using finite element methods.

Fracture Mechanics 101

Luckily I happened to be prepared for just such an eventuality since I had spent a number of years upgrading the computational capabilities of the laboratory using high powered workstations. In addition, I had also developed a number of fracture

mechanics routines based on the finite element method as implemented using the commercially available ANSYS® program. An example of a typical model is displayed in Fig. (2) which shows a small section of a larger model near the edge of a coated substrate where a small crack has initiated. The module shown in Fig.(1) was in fact cut out of a larger brick using a dicing saw. The saw can leave small nicks in the edge of the module which serve as ideal weak spots for a delamination or a fracture to initiate. In the case under consideration the crack always propagate just below the true interface and was therefore a decohesive failure as opposed to a true interfacial delamination. The finite element routines I developed allowed one to simulate the propagation of a crack anywhere desired and thereby also determine the driving force propelling the crack. The ultimate source of the driving force is of course the residual stress in the thin film wiring layer which would like to relax itself by any mechanism available. Propagating a crack is one such mechanism that is available if the material is sufficiently weak. The driving force is measured as an energy per unit area or effectively the energy required to create a unit increment of new surface area by propagating the crack length by some small distance. The cohesive forces holding the material together of course try to resist the propagation of the crack since they demand that a minimum amount of energy be supplied in order break the cohesive bonds. If the driving force is too weak, insufficient energy is available and the crack cannot form. The driving force available to propagate a crack or delamination is called the Strain Energy Release Rate and given the symbol G . It is measured in units of energy per unit area or Joules/meter² (J/m²). Thus if $G=5$ (J/m²) the driving force can supply 5 joules of energy to create one square meter of new surface area. On the other hand, every material can be assigned what is known as a Surface Fracture Energy signified by the symbol γ . This is the energy required to create one square meter of new surface by breaking the cohesive bonds which hold the material together. Thus if $\gamma = 5$ (J/m²) then the driving force for crack propagation must be at least this large to drive a crack. With all these tools in hand it was fairly straight forward to pull together a model similar to the one shown in Fig.(2) and test the original Suo-Hutchinson calculations mentioned above. The result shown in Fig.(3) essentially confirmed that the original hand calculations were correct. There should have been no way for the thin film layers to delaminate from the ceramic substrate. Figure (3) plots the crack driving force vs crack length for a crack propagating 50 micro-meters below the true thin film/ceramic interface. The calculations

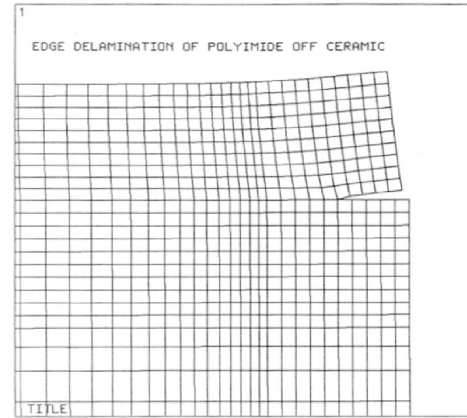


Figure 2 Typical section of a finite element model depicting delamination of a polyimide coating off a ceramic substrate. Such models are quite general and can simulate not only a clean delamination at the polyimide/ceramic interface but also the unexpectedly common case where the crack actually propagates in the ceramic slightly below the true interface. This type of failure mode is called a decohesion though it can easily be confused with a true delamination since the crack can propagate quite close to the true interface.

determined that the maximum driving force occurred for a crack propagating at that depth. Thus the failure mode was decohesive in the ceramic. Figure (3) shows that the maximum driving force for this crack is roughly 2.4 (J/m²). It was known from experiment that the surface fracture energy of the ceramic was about 15 (J/m²). Thus the data in Fig.(3) clearly indicates that the crack should not propagate. About the only sinister aspect of the data in Fig.(3) is that the driving force is increasing with crack length making

70 MICRON LENGTH CRACK 50 MICRONS BELOW PI/GC INTERFACE

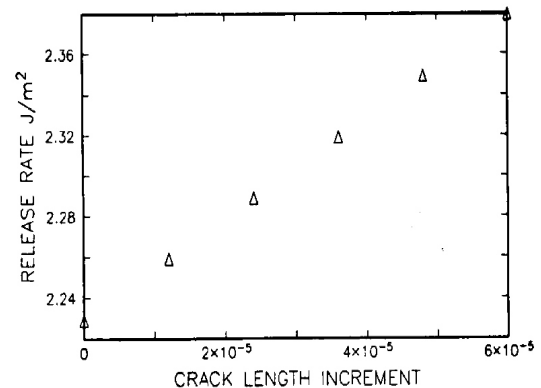


Figure 3 Driving force for decohesive failure of a thin film wiring layer of a low stress polyimide on a ceramic substrate. The horizontal axis is measured in meters.

this an example of an unstable but definitely arrested crack. At this stage any thoughts of using up unspent vacation time had completely evaporated. The best calculations we could perform were saying that the thin film wiring layers definitely could not decohere. The only remaining theory was that the high stress in the copper was somehow at fault, an idea which was not readily compatible with any fracture mechanics argument that we could plausibly think of. In the famous words of Winston Churchill we were faced with a "riddle wrapped in a mystery inside an enigma"³. Subsequent events would unwrap the mystery and reveal that the riddle was really rather more mundane than we could have imagined at the time.

The Mystery Unwrapped

In this sort of situation one is reminded of the sagacious words of Sherlock Holmes that it "is a fundamental error to try and theorize in the absence of data"⁴. Thus we recommended that more data be gathered, and in particular the stress level in the thin film wiring layer be measured. Since this layer was predominantly polyimide we needed to gather more data on the stress in the polyimide material. At length this task was accomplished and the result was not what was expected. The measured stress in the polyimide material was some 6 times higher than it should have been. This data, though unexpected, clearly explained why the substrates were decohering as shown in Fig.(4). The driving force for a 70 micron crack was very close to the measured surface fracture energy of the ceramic material and since the driving force was unstable in that it increased with increasing crack length the prediction was clear. At this point we had unwrapped the enigma of why the substrates decohered but the riddle of why the polyimide stress was so much higher than expected remained unsolved. Since it was now clear that excessive stress in the polyimide was the real culprit destroying the parts and not the stress in the copper thin film wiring the task force could now focus attention on why the stress level in the polyimide was so high.

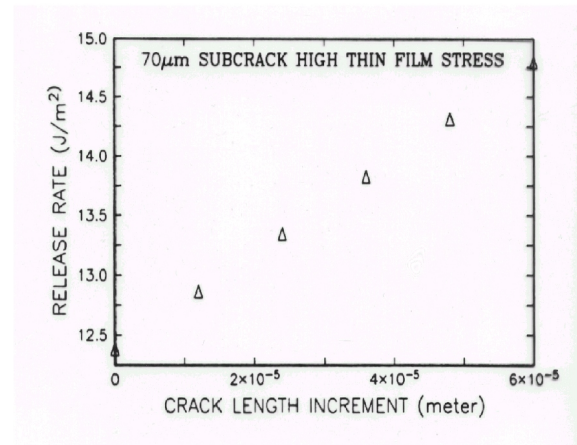


Figure 4 Repeat of analysis shown in Fig.(3) but now using actual stress level measured in polyimide coated on real parts. The driving force for a 70 micron crack is now very close to the surface fracture energy of the ceramic material which was measured to be 15 (J/m²).

Solving the Riddle of Excessive Stress in the Polyimide

A bit of detective work was now required to track down to cause of the high stress in the polyimide insulator layers. At length one of the task force members was quietly monitoring the curing ovens and observed a line worker approach with a cart loaded with parts to be cured. These parts had just been coated and were about to go through the first curing step which was what is called a "soft bake". This is essentially a low temperature heating at roughly 80 C which was required to drive off excess solvent and allow the film to settle. On approaching the ovens our worker noted much to his annoyance that the oven he was supposed to use was tied up curing other parts. This was not good since management needed to get a large volume of parts through the line in order to meet early user requirements such as electrical test procedures, machine test bed needs, quality assurance demands and a host of other pressing necessities. Because of this all line workers received bonus rewards based on the number of parts processed and this busy oven was clearly standing in the way of such rewards. Not to be thwarted at this critical juncture our enterprising worker quickly noted that a neighboring oven was not in use and from his point of view an oven was an oven and the need to press on critical so into the idle oven go the parts. Now if were in the business of baking bread or cookies the consequences of this change in ovens would have quite likely been of little consequence. However,

³ Winston S. Churchill, Radio broadcast (October 1, 1939). Commenting most likely on Stalin's peace pact with Hitler on the eve of WWII.

⁴ Sherlock Holmes in "Hound of the Baskervilles"

as anyone familiar with curing polyimide films will tell you, the curing process highly critical and extremely finicky. The oven in question essentially carried out the "soft bake" at too high a temperature for too short a time giving rise to a film stress cure cycle similar to the one shown in Fig.(5). From this figure we see that at the end of the cure cycle when the sample is returned to room temperature the stress in the polyimide coating is a very substantial 30MPa.

Figure (6) shows a sample which has received the proper soft bake cycle of 80 C for 30 minutes. What jumps out you immediately is that the stress in the finally cured coating is somewhat less than 5MPa which immediately explains the unexpected factor of 6 increase in the polyimide stress in the failed parts. So the riddle of the decohering parts came down to a case of too few ovens to meet the volume demands of the development cycle or too big a rush to get out parts which placed an excessive strain on the capabilities of the development line. A rather more commonplace occurrence in the fast paced world of microelectronics than one would like to imagine.

Statistical Physics of Polymer Liquids

An interesting aspect of this episode in the trials and tribulations of the development laboratory is the nature of the polyimide material that was being used for the thin film wiring structure. Most of what one might call "standard polyimides" exhibit stress/temperature behavior similar to what is shown in Fig.(5). These materials are applied to rigid substrates as a highly viscous polyamic acid precursor liquid using a spin coater. After drying the polyamic acid is converted to polyimide via a number of intermediate cure steps. The final cure step is typically a high temperature bake somewhere near 400 C in order to develop the full physical properties of the final coating. The stress in the coating comes from a variety of sources including shrinkage due to chemical reactions and solvent loss. However, the predominant factor contributing to stress buildup tends to be the thermal expansion mismatch between the polyimide and the substrate which can be as much as a factor of 10 depending on the materials involved. The polyimide we were using at the time was of a special variety known as a low thermal coefficient of expansion (low TCE) material. Whereas your standard garden variety polyimide has a thermal expansion coefficient somewhere in the range of 30-40 ppm/C the low TCE materials are on the order of 6 ppm/C or roughly 5 times smaller. This low TCE matches nicely with substrate materials such as silicon (3 ppm/C) and

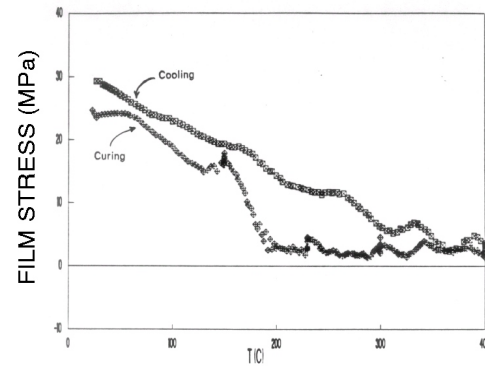


Figure 5 Film stress vs cure temperature for polyimide coating with a high temperature/short time soft bake. Note that on cooling back to room temperature this film is in a high stress state close to 30MPa.

ceramic (3-6 ppm/C) and accounts for the very low residual post cure stress shown in Fig.(6). What makes the low TCE materials different from the standard polyimides is the long and stiff chain units which make up the polymer chain. The effect of this chain architecture difference is exhibited in Fig.(7). The top half of the figure depicts a standard flexible chain in solution showing essentially random chain orientation. On drying

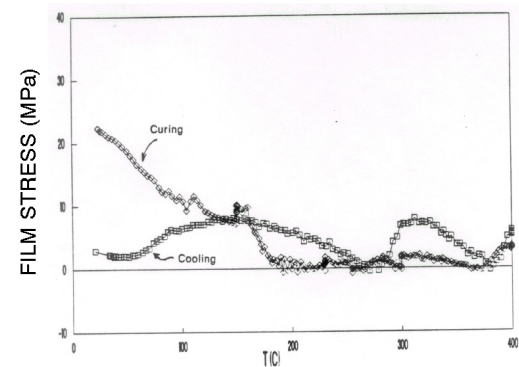


Figure 6 Stress vs temperature cure cycle for polyimide coating which has undergone the required 80 C/30 minutes soft bake cure step. Note that final stress after cooling to room temperature is somewhat less than 5 MPa which is dramatically lower than the 30MPa achieved by the sample shown in Fig.(5).

the material shrinks down to a solid film which more or less maintains the same random chain orientations as existed in the solution state. One consequence of this is that in-plane inter-chain interactions are governed mainly by relatively weak van der Waals interactions and this gives rise to high thermal expansion behavior in consequence of the weak chain to chain coupling. The bottom half of Fig.(7) shows the corresponding case of polymer chains containing long stiff chain segments. In dilute solution the chain orientations are again random since there is plenty of room for the chains to spread out and there is minimal interference between neighboring chains. As solvent is lost due to drying, however, the chain density increases and the chains begin to be packed together more closely. In particular the segments of chains close to the substrate surface begin to feel the presence of this barrier and due to their length and stiffness are forced to adopt an orientation closely parallel to the surface. Anyone can easily simulate this effect by holding a pencil in the air and noticing how it can take on any orientation. However, as you bring the pencil close to a flat surface such as a table you quickly note that due to the rigidity of the pencil it of necessity must assume configurations which are parallel to the obstructing surface. This all implies that in the finally dried polymer coating the chains now have a preponderant tendency to be aligned parallel to the substrate surface. In consequence the thermal expansion behavior is now governed more by the intra-chain carbon-carbon bonds as opposed to the much weaker inter-chain van der Waals interactions. The net result is a much lower in plane thermal expansion behavior.

So what happened when the wrong oven was used to cure the coatings? Here we must remember that these are viscous coatings and as solvent is removed through drying it takes time for the chains to assume their preferred packing order. In effect the high temperature in the wrong oven drove the solvent off faster than the chains could reorient and worse the imidization reaction also set in at the much higher drying temperature. After the imidization reaction occurs the polyimide material freezes up making any further chain relaxation processes impossible. Thus if dried in the wrong oven the polyimide essentially froze into the random chain configuration typical of the standard materials giving it the same kind of post cure thermal expansion behavior. This of course lead to the high curing stresses which so nicely destroyed the parts the development line was trying to put out.

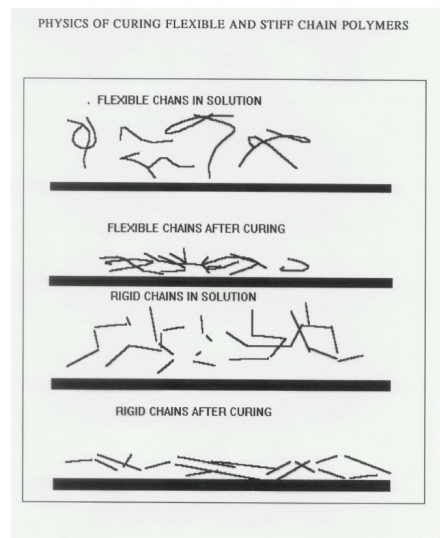


Figure 7 Schematic comparison of the curing behavior of flexible and rigid chain polymers. Flexible chain systems assume random orientations in solution and more or less maintain this configuration on drying. Rigid chain systems are also random in solution at low chain densities, however, upon drying the rigid chain segments force the chains to align parallel to the substrate surface due to simple steric interference effects.

Epilog: More Statistical Physics and the Value of Stress Modeling

Statistical physics of rigid rods

All of these problems with stiff chain polymer systems brought back memories of my previous life as a post doctoral student at the University of Massachusetts. I'm not going to reveal how long ago that was but in those days there were two burning issues in polymer physics, one relating to the problem of short range order in amorphous polymers and the other the problem of polymer-polymer compatibility. The short range order problem was definitely the more glamorous one since there was a raging controversy between two schools of thought one which contended that short range order was essentially nonexistent in amorphous polymers and the other which contended that even in amorphous systems interchain interactions would bring about a certain amount of order on the scale of a nanometer or so. On the no short range order side was no less a light than Paul Flory who I believe was one of only 2 Nobel laureates in the polymer field, the other being Carruthers for the discovery of NYLON. On the other side were no less impressive investigators such as Philip Geil then at Case Western Reserve University who had done considerable work on the morphology of polyethylene and a variety of biopolymers polymers

such as collagen and elastin. My thinking at the time was that if I could bring off a rigorous statistical mechanical calculation that would resolve the issue one way or the other that would be a definite coup after which I would be able to write my own ticket to further fame and fortune. However, I was not so naive as to think that such a calculation was going to be easy since I had been toiling in the vineyards of polymer statistical mechanics for some 5 years up to that point and was well aware of the difficulties. Nonetheless it would be worth a try, so step one was to investigate the existing literature to see what had already been done which turned out to be not much. Prof. Flory himself had published an article dealing with the problem but there was an essential difficulty with his paper in that he used mean field theory to compute the free energy of the system. Now mean field theory is a very handy computational method for working out the thermodynamic properties of liquids but is nonetheless an approximation which does not take into account the subtleties of the correlations which are involved in more rigorous approaches. In fact mean field theory can be shown to be completely wrong as one approaches critical points where the long range correlations become not only important but actually dominate the problem. Thus if I were to resort to the use of mean field theory any result derived would immediately be open to the criticism that an approximate computational method was used and thus the results should be considered suspect.

There was, however, one other paper by Lars Onsager, also a Nobel Laureate for his work on irreversible thermodynamics, which was entirely rigorous in that it involved a term by term evaluation of the virial series for the liquid. This essentially amounts to estimating the pressure, volume, temperature (PVT) behavior of the liquid as an expansion in the density. At any stage one can look at the higher order terms and estimate the residual error. Thus this approach was rigorous in the sense that you could always know what error you were committing which was not the case for mean field theory where the error was unknown but assumed to be small at least away from critical points. Using this approach Onsager was able to compute the PVT the behavior of a collection of rigid rods thus modeling the behavior of liquid crystal materials which are known to undergo a variety of interesting phase transitions due to the restrictions on their packing behavior as the density of the fluid increases. I believe he carried out the series to third order and at that stage was able to conclude that the liquid underwent a packing alignment transformation which he concluded was a second order phase

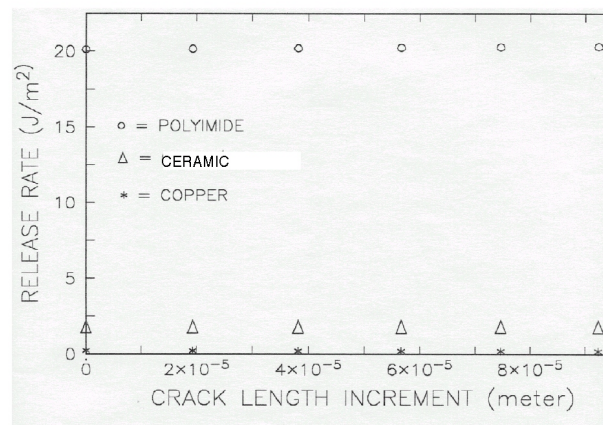


Figure 8 Plot exhibiting separate contributions of each material to the overall driving force for decohesion of copper/thin film wiring off a ceramic carrier.

transition. This was quite an accomplishment and relevant to the problem I was considering since it dealt directly with the problem of ordering in liquids due to short range steric effects. However, Prof. Robert Zwanzig, then at the University of Maryland, felt that this was not enough. With the aid of a succession of graduate students, Zwanzig was able to push the expansion out to seventh order, with each successive term in the virial expansion being a PhD thesis for some hardy graduate student. At the end of the day Zwanzig basically concluded that Onsager was in fact right, the rigid rod solution does undergo a second order phase transition as you increase the density to a certain critical value. Such a heroic effort was certainly impressive, but as a post doctoral fellow with 2 maybe 3 years to show some accomplishment I did not feel that I would have enough time to go the virial expansion route. Thus constraints of time and energy forced me to fall back on the polymer-polymer compatibility problem which turned out quite nicely if not so gloriously as the short range order problem would have could I have solved it. Nonetheless, the case of stiff chain polyimide materials brought back memories of that problem which might be approachable today via computer simulation given the tremendous advances in available compute power that have occurred in the intervening decades.

Value of stress modeling and fracture mechanics

As pointed out above the ability to perform a detailed stress analysis on the module along with the associated fracture mechanics simulation greatly expedited the progress of the task force in

solving the problem of the decohering thin film wiring structures. Figure (8) exhibits a plot of the driving force for decohesion vs crack length for a fully developed steady state decohesion which has progressed from the edge of the substrate well into the copper/polyimide thin film wiring layers. One nice feature of this type of plot is that it allows one to look separately at the contribution each material makes to the overall driving force for decohesion. Recall from the discussion above that early on in the investigation it was thought that the copper wiring should be a prime suspect due to the relatively high stress level in this material as measured by X-ray techniques. Figure (8) shows that, to the contrary, the contribution of the copper to the overall driving force is negligible and that the true culprit is the polyimide material. Having this data in hand therefore put the task force on the correct track as opposed to wasting a lot of time going down a blind alley. The explanation as to why the much lower stress polyimide material dominates the decohesion process as opposed to the much higher stress copper is quite straightforward once one is aware of the basic mechanism driving the decohesion process. Recall that it is the residual stress in the thin film layer that is the source of strain energy driving decohesion. The units of stress are force per unit area, however simply multiplying numerator and denominator by length we see that the stress can also be thought of as an energy per unit volume i.e. $\text{force} \times \text{length} / \text{volume}$. Thus the pent up stress in the structure can also be thought of as a reservoir of pent up elastic energy which puts the structure in a thermodynamically unstable state. It would somehow like to release all this energy and go into a lower energy state and one way of doing this is by propagating a decohesion crack. Thus the system drives the decohesion crack by drawing on energy pent up in the thin film structure and since the volume of this structure is overwhelming dominated by the polyimide material it is the stress in the polyimide that dominates the decohesion process. Thus some fairly elementary fracture mechanics analysis greatly expedited the work of the task force and allowed me to return to the pressing problem of how best to use up my remaining vacation time.

COURSES AND CONSULTING ON ADHESION AND ADHESION MEASUREMENT

Adhesion Courses

Since the theme of this issue of the Newsletter is devoted to Adhesion Aspects of Thin films and High Temperature Polymers this is a good opportunity to bring to everyone's attention that in

addition to organizing International Symposia, the Conference Director Dr. Mittal and I also give a joint course on Adhesion and Adhesion Measurement Methods. The Adhesion Measurement course lasts for 1 day and is given in conjunction with all of the MST Symposia. The next scheduled class will be on June 16, 2007 in Cincinnati, Ohio in conjunction with the SIXTH INTERNATIONAL SYMPOSIUM ON POLYMER SURFACE MODIFICATION: RELEVANCE TO ADHESION www.mstconf.com/surfmod6.htm and the SIXTH INTERNATIONAL SYMPOSIUM ON SILANES AND OTHER COUPLING AGENTS www.mstconf.com/silanes6.htm. Actually, both of these symposia are closely related to the two Fall 2007 symposia on POLYIMIDES and ADHESION ASPECTS OF THIN FILMS and a number of readers may want to participate in both of these conferences. However, for those who have neither the time nor the wherewithal to go to conferences there is another option in that MST can come to you. Dr. Mittal and I can come to your location and give a full 3 day course covering all aspects of adhesion science and adhesion measurement. The first 2 days are given by Dr. Mittal and present an overview of the science of adhesion covering everything from surface analytical methods to adhesion improvement strategies. Day 3 is devoted to the critical topic of adhesion measurement since this is a universal tool in improving the adhesion of existing processes and developing adhesion strategies for new ones. The basic philosophy comes down to the fact if you cannot appropriately measure what you are trying to develop you will have no idea where you are at any point much less whether you are making progress or not. Also for large classes of 10 or more students the on site 3 day course is very cost effective on a per student basis since there are no student travel expenses involved and there is a significant discount for every student above 10 that joins the course. The course schedule is quite flexible and we strive to adapt it to the needs of our clients. The course length can be abbreviated or lengthened as required and since the adhesion measurement course stands alone it can be given back to back with the 2 day overview or if more convenient given at later date as a follow up course. Full details of the course syllabus are available on the conference website at (www.mstconf.com/MSTCourses.htm).

Consulting

If it should happen that you find yourself faced with a real nasty adhesion related problem that is either thwarting your development program or, heaven forbid, threatening to shut down your production line then with our 40 some odd years

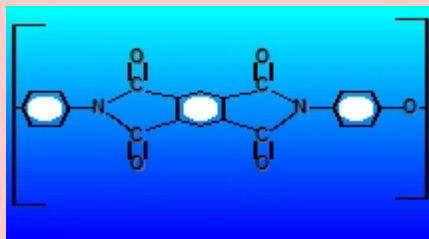
collective experience with adhesion related problems, we can be of direct assistance in getting you on track again. The MST staff have addressed all manner of adhesion and surface related problems for companies both large and small. From large Fortune 500 corporations to small start up enterprises with only a dozen or more employees. Further details are available on the Conference Website at www.mstconf.com/MSTconsult.htm .

SYMPOSIA ON HIGH TEMPERATURE POLYMERS AND ADHESION ASPECTS OF THIN FILMS

CALL FOR PAPERS: FIFTH INTERNATIONAL SYMPOSIUM ON POLYIMIDES AND OTHER HIGH TEMPERATURE POLYMERS AND THE THIRD INTERNATIONAL SYMPOSIUM ON ADHESION ASPECTS OF THIN FILMS INCLUDING ADHESION MEASUREMENT AND

METALLIZED PLASTICS

It has been my pleasure in these pages to give a brief reminiscence of my own experiences in dealing with the polyimide materials and their adhesion to ceramic substrates. As their tends to be a certain universal nature to these types of problems I'm sure many readers have come across similar situations whereby the specific details may differ widely but nonetheless the underlying physical processes that tend to make or break any given development or manufacturing enterprise tend to follow nearly parallel tracks. Thus we would like to most cordially invite all readers to join us in Orlando Florida this coming Fall for what promise to be stimulating and rewarding symposia on these topics. This offers an opportunity to not only catch up on the latest developments but to also personally interact with the investigators involved and learn first hand where things are headed in the future both in terms of fundamental investigations and novel applications.



CALL FOR PAPERS

FIFTH INTERNATIONAL SYMPOSIUM ON POLYIMIDES AND OTHER HIGH TEMPERATURE POLYMERS

**SYNTHESIS, CHARACTERIZATION AND APPLICATIONS
To be held November 5-7, 2007 in Orlando Florida, USA**

This symposium is the fifth in a series the first of which was held in Newark, NJ in 1999. As with its predecessors, this symposium will be concerned with all aspects of polyimides and other high temperature polymers. These materials have found applications in such diverse areas as the aerospace industry and microelectronic components. A unique combination of physical and chemical properties make these materials highly attractive for demanding applications where chemical inertness, high temperature stability, low dielectric constant, mechanical toughness and processability are primary concerns. This symposium is organized to bring together scientists, technologists and engineers

TOPICS OF INTEREST INCLUDE:

- ▶ Chemistry, synthesis and characterization of polyimides and other high temperature polymers.
- ▶ Surface chemistry and surface modification

PHYSICO-CHEMICAL PROPERTIES

- ▶ Thermal-mechanical properties
- ▶ Electrical properties
- ▶ Adhesion properties and adhesion improvement
- ▶ Encapsulation and barrier properties
- ▶ Effects of aging and environment on long term stability, reliability and durability

APPLICATIONS

- ▶ Polyimides as adhesives and insulators.
- ▶ Polyimides as dielectrics, photoresists and encapsulants in microelectronic and biomedical structures
- ▶ Metallization of polyimide and investigation of interfaces.

NOVEL AND ADVANCED FORMULATIONS

- ▶ Ultralow dielectric materials, low thermal expansion liquid crystals, polyimide blends, nanocomposites, copolymers, foams,... etc.

interested in all aspects of high temperature polymers, to review and assess the current state of knowledge, to provide a forum for exchange and cross-fertilization of ideas, and to define problem areas which need intensified efforts. The invited speakers have been selected so as to represent widely differing disciplines and interests, and they hail from academic, governmental and industrial research laboratories. This meeting is planned to be a truly international event both in geographic coverage as well as in spirit. The technical program will contain both invited overviews and contributed original research papers. It is planned to chronicle the transactions in a hard-bound volume of archival quality (to match or exceed the standards of the journal literature) which will serve as a reference work for future generations of investigators.

This symposium is being organized by MST Conferences, LLC under the direction of Dr. K. L. Mittal, Editor, Journal of Adhesion Science and Technology. A proceedings volume is planned for this symposium and further details will be provided in due course. Please notify the conference chairman of your intentions to present a paper as early as possible. An abstract of about 200 words should be sent by **June 15, 2007** to the conference chairman by any of the following methods:

E-mail: rhl@mstconf.com

FAX: 212-656-1016

Regular mail:

Dr. Robert H. Lacombe
Conference Chairman
3 Hammer Drive
Hopewell Junction, NY 12533

Contact by phone: 845-897-1654

Full conference details and registration via the Internet will be maintained on our web site:

<http://mstconf.com/polyimd5.htm>

Or mail response form below to the conference chairman at the address above.



CALL FOR PAPERS

THIRD INTERNATIONAL SYMPOSIUM ON ADHESION ASPECTS OF THIN FILMS (INCLUDING ADHESION MEASUREMENT AND METALLIZED PLASTICS)

To be held November 7-9, 2007 in Orlando, Florida, USA

This symposium is the third in a series dealing with adhesion aspects of thin films, adhesion measurement and metallized plastics. The first symposium with this title was held in Orlando, FL in 2003 with the intent of integrating key aspects of three separate symposia which treated these topics singly in the past. The main idea was to provide a broader venue for the discussion and exploration of these three closely related fields of endeavor. The main part of the symposium focuses on those aspects of thin film technology that have a direct bearing on film adhesion to the substrate. This is a topic of both fundamental interest to all aspects of thin film technology and of great practical concern in applications where films of high stress are involved. The coating of diamond films onto machine tools is one of many applications where thin film adhesion is a critical factor in coating durability. The second part of the symposium will deal with the ability to accurately measure the adhesion of coatings to surfaces. This is always a crucial part of development and manufacturing processes dealing with coatings and films. Finally, metallized plastics are a burgeoning technology

heavily dependent on thin film adhesion with applications ranging from decorative design to optical coatings to advanced thin film wiring schemes in the microelectronics industry. Metallized plastic films allow the technologist to capitalize on the favorable properties of two disparate classes of materials to create new and unique products which transcend the performance and usefulness that can be obtained by either class alone.

The invited speakers have been selected so as to represent widely differing disciplines and interests, and they hail from academic, governmental and industrial research laboratories. This meeting is planned to be a truly international event both in geographic coverage as well as in spirit. The technical program will contain both invited overviews and contributed original research papers.

TOPICS OF INTEREST INCLUDE:

Adhesion Aspects of Thin Films

- ▶ Factors influencing adhesion - Residual stress, mechanical properties, contamination ... etc.
- ▶ Long term bond durability, corrosion prevention
- ▶ Adhesion promoters

Fundamental Issues

- ▶ Role of surface chemistry, wettability and morphology
- ▶ Fundamental adhesion mechanisms including role of surface roughness/morphology and film/substrate interactions

Applications of Adhesion Measurement

- ▶ Adhesion measurements in quality control and manufacturing
- ▶ Adhesion measurements in support of coating process research and development
- ▶ Adhesion measurement instrumentation for laboratory and manufacturing environments

Fundamental Aspects of Adhesion Measurement

- ▶ Mechanics of adhesion testing, the role of film stresses
- ▶ Fracture mechanics of adhesion testing
- ▶ Physico-chemical aspects of adhesion testing, the role of film morphology and chemistry

Metallized Plastics

- ▶ Metallization techniques and properties of metal deposits
- ▶ Metal diffusion during deposition
- ▶ Morphology and properties of metal deposits

Investigation of Interfacial Interactions

- ▶ Influence of polymer surface functional groups
- ▶ Metal-polymer interactions
- ▶ Fundamental adhesion mechanisms including coating-substrate interactions at nanoscale

This symposium is being organized by MST Conferences, LLC under the direction of Dr. K. L. Mittal, Editor, Journal of Adhesion Science and Technology. An archival volume is planned for this symposium and further details will be provided in due course. Please notify the conference chairman of your intention to present a paper as early as possible. An abstract of about 200 words should be sent by **June 15, 2007** to the conference chairman by any of the following methods:

E-mail: rhl@mstconf.com

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3 Hammer Drive
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845-227-7026

Full conference details and registration via the Internet will be maintained on our web site:

www.mstconf.com/adhfilm2007.htm

Or mail response form below to the conference chairman at the address above.