**Mechanical Reliability of Metal-Polymer Thin Film Systems**

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The four metal-polymer thin film systems tested were:

- Kapton with Gold
- Polyethylene with Gold

Two systems were prepared by plasma etching and sputter deposition at WSU.

### Fatigue

Fatigue: The thin film system (Polyethylene-Gold) undergoes creep each time it cycles to high pressure and back. If this were continued indefinitely, fatigue would eventually fracture the system at a relatively low stress level.

### Conclusions:

Characterization of metal-polymer thin film systems is possible with bulge testing, but care must be taken to select a hole size appropriate to the film's thickness so as not to induce circumferential compressive stresses. The thickness of the metal on the polymer does affect the biaxial modulus and residual stress in the system, but whether the polymer was plasma etched prior to sputtering does not. Further testing is necessary. Given enough strain or cyclical stresses, all of the metal-polymer systems can be made to fail, either by peeling and flaking of the metal film or by loss of conductivity based on fiber delamination and/or alignment during strain. However, more damage is done by abrasion than fatigue.

### For future study

Calculate the amount of strain during testing, the relaxation modulus and the adhesion energy between the polymer substrate and metal layers. The effects of interlayers such as TiW to improve adhesion should be tested.

### References

2. Acknowledgments: Financial support was provided by the National Science Foundation under Grant No. INT-125925. Additional support was provided by the National Science Foundation under Grant No. INT-125925.

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**Goal:** To explore the mechanical and fracture properties of metal-polymer thin film systems

**Metal-polymer thin film systems** are made up of thin polymer and metal films bonded together. They are used in many new applications, such as flexible electronics and satellites.

In order for a metal-polymer thin film system to serve its purpose, it must be flexible, strong, and light. Bulge tests highlight these characteristics for different types of metal-polymer thin film systems, as well as show what happens when they finally fail.

**Bulge testing** is a mechanical test technique where the sample is deflected upward by applying pressure on one side. This deflection is measured against the applied pressure and multiple mechanical properties of the material can be extracted from the curve formed. Two properties which greatly affect the reliability are the residual stress (a stress that persists in a material that is free of external forces or temperature gradients) and the biaxial modulus.

The bulge testing setup starts by clamping the thin film in a plexiglass clamp in one of three hole sizes (3.84, 9.02, 13.6 mm diameters). Pressure is applied below using bellows, and is measured by a pressure transducer. The deflection of the system is read using a laser vibrometer, and the pressure and deflection data is graphed in real-time by a computer. This data can then be exported and analyzed according to the following equation [1]:

\[ P(h) = \frac{C_1 \sigma R e}{a} h + \frac{C_2 E B e}{a^4} h^3 \]

where:
- \( P(h) \) is the pressure applied to the film
- \( \sigma \) is the residual stress in the system
- \( E \) is the biaxial modulus of the system

Since every value but \( a \) and \( E \), are known, using curve fitting software, an equation to the form \( P(h) = A + Bh \) fits to the data received from the bulge test, allows solving for both the residual stress \( \sigma \) and the biaxial modulus \( E \).

### Fatigue

Fatigue: Kapton plastically deforms under stress, and the gold which has formed micro-cracks under the tensile load, goes into compressive stress when the pressure is released, fracturing the gold.

### Conclusions:

Characterization of metal-polymer thin film systems is possible with bulge testing, but care must be taken to select a hole size appropriate to the film’s thickness so as not to induce circumferential compressive stresses. The thickness of the metal on the polymer does affect the biaxial modulus and residual stress in the system, but whether the polymer was plasma etched prior to sputtering does not. Further testing is necessary. Given enough strain or cyclical stresses, all of the metal-polymer systems can be made to fail, either by peeling and flaking of the metal film or by loss of conductivity based on fiber delamination and/or alignment during strain. However, more damage is done by abrasion than fatigue.

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