Adhesion Measurements of Thin-Film Polymer/Metal Interfaces Used in LIGA Fabrication

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Failure of the interface between polymer micromolds and metallized substrate surfaces has been identified as an important limitation in LIGA fabrication yield. Failure is likely governed by the polymer glue-layer/metal-surface interface. Interface failure depends on two variables: the applied driving force for interface separation and the inherent interface strength. Driving forces for interface separation during LIGA processing can arise from residual stress that evolves during bonding of the polymer micromold sheet to the substrate as well as applied stress during procedures such as development. Interface strength depends on properties of the metallized substrate (e.g., surface roughness, surface composition) and properties of the polymer glue layer (e.g., chemistry, molecular weight). In addition, interface strength may be altered by radiation exposure and environmental effects such as water vapor and developer. The objective of this study is to establish a technique for quantifying the inherent adhesion between thin polymer films and metallized substrate surfaces. Quantifying adhesion facilitates understanding of the material and processing variables that affect the interface.

Adhesion of the glue-layer/metal-surface interface is measured using a fracture-mechanics approach applied to notched-beam specimens. Initial fabrication steps for the beams follow LIGA processing procedures; i.e., Si wafers with sputtered Ti/Cu/Ti films are coated with micrometer-thick, spin-cast layers of PMMA (M_W=2.2x10^6). Two 40 mm X 40 mm squares are cleaved from each wafer and are diffusion bonded (170^{o}C/30 min at 10 MPa) together through the thin-film PMMA layers. Notched beams having dimensions of 40 mm length X 4 mm width X 1 mm thickness are produced from the bonded squares using a dicing saw. In this way, the beam specimens have two thin-film PMMA/Ti interfaces normal to the notch, as shown schematically in Figure 1. The beams are displaced in four-point bending, which causes crack initiation from the Si notch root followed by crack propagation along the PMMA/Ti interface (Figure 1). The mechanics of the four-point bend configuration dictate that interface cracks ideally propagate at constant load. The driving force for interface separation, applied strain energy release rate (G), is calculated from this plateau load. An image of the beam specimen and loading fixtures is shown in Figure 2.

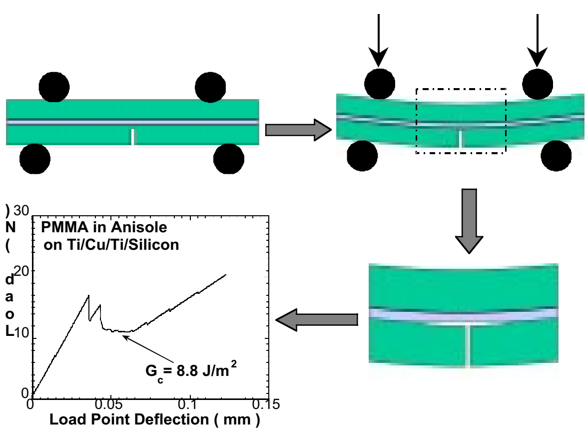

Figure 1. Schematic representation of four-point bend technique. Actual data for PMMA in anisole is shown at the lower left.

Results demonstrate that the four-point bend technique reveals effects of LIGA processing variables on the glue-layer/metal-surface interface. Two processing variables are initially emphasized: solvents used for applying the spin-cast PMMA and surface treatments of the metallized Si wafers. Figure 3 shows typical applied load *vs* load-point displacement data for a beam specimen that was fabricated using PMMA in chlorobenzene and without any treatment of the Ti surface. The data exhibit a load plateau corresponding to stable crack propagation along the PMMA glue-layer/Ti interface.

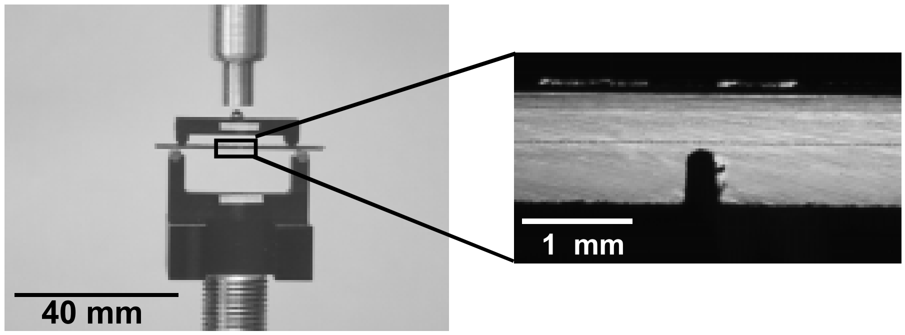

Figure 2. Specimen and loading fixtures. To the right is an enlarged image of the machined notch in the beam prior to testing.

The strain energy release rate to propagate the interface crack is calculated from an analytical solution for the four-point bend geometry. Figure 4 compares G values for specimens fabricated using PMMA in cholorobenzene *vs* PMMA in anisole and for Ti surfaces subjected to an oxygen plasma treatment. These results show that interface adhesion energy is higher for PMMA in chlorobenzene *vs* PMMA in anisole and is mildly lowered by oxygen plasma exposure of the Ti surface.

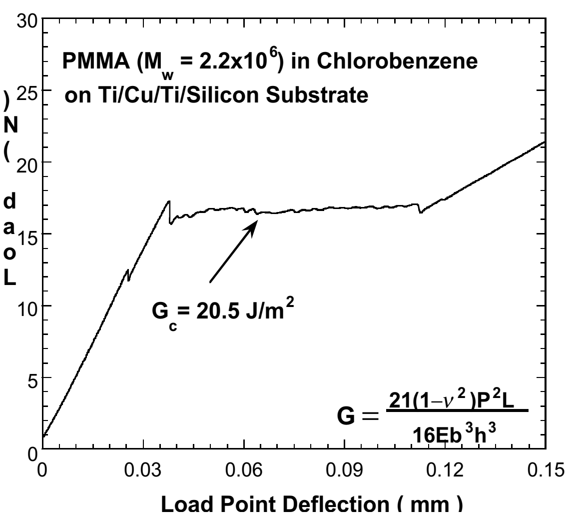

Figure 3. Stable crack growth along the PMMA glue-layer/Ti interface in a beam fabricated using PMMA in chlorobenzene applied to the as-received Ti surface.

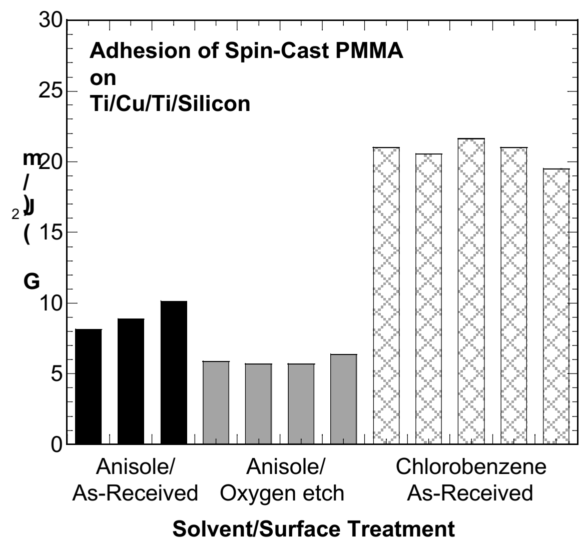

Figure 4. Summary of adhesion results for three different fabrication processes.

The ultimate objective is to use the four-point bend technique as a tool in understanding the governing processing variables and adhesion mechanisms of polymer glue-layer/metal-surface interfaces. For example, Auger analysis of wafers that are subjected to current oxygen plasma-treatment procedures reveals elevated concentrations of contaminants on the Ti surface. This result coupled with the data in Figure 4 suggests that increased concentration of contaminants may degrade inherent interface adhesion. Other variables to be examined include water vapor and developer effects on the PMMA glue-layer/metal-surface interface as well as exposure of the interface to radiation. In addition, experiments on solvent-bonded beams will be compared to those fabricated using diffusion bonding.

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