Aging of Anti-Stiction, Anti-Friction Self-Assembled Monolayers (SAMs) for Microsystem Interfaces

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Motivation—Excessive interfacial interactions can lock parts together (stiction) or cause high levels of friction in micro-machines (MEMS devices). The current strategy for minimizing friction and stiction involves coating surfaces with thin organic coatings called self-assembled monolayers (SAMS). Unfortunately, desired coating properties are known to degrade with time, particularly if parts are stored in humid environments. The goals of this research are to determine the rate at which film properties change in aggressive environments, probe mechanisms for these "dormancy effects", and identify strategies for developing coatings that are optimized to provide long-term stability.

Accomplishment—SAMS deteriorate in humid environments due to: 1) attack by water of the bonds between the coating and substrate, and 2) rearrangement of molecules within the coating to uncover sticky components (either functional groups used to anchor the SAM to the surface or bare patches in the coating). We are currently evaluating the stability of a range of SAM coatings in which surface anchors, hydrocarbon structures, and processing conditions are varied. Accelerated aging tests have been conducted in which SAMS are exposed for various times to high relative humidities (RH) and elevated temperatures. Changes in coating morphologies have been monitored using atomic force microscopy (AFM). Changes in the adhesive properties of the SAM surfaces have been monitored using a scanning probe system developed at Sandia called the interfacial force microscope (IFM). Results obtained to date indicate that most coatings are unstable in humid environments. AFM results (Fig. 1) suggest that water penetrates the SAMS and disrupts the bonding at the SAM-substrate interface to form spherical blisters (Fig. 1a) or interconnected networks (Fig. 1b). The IFM results confirm that restructuring in humid environments also leads to dramatic increases in the adhesive character of the SAM surfaces (Fig. 2).

Significance—Many SAM coatings used to coat micromachine surfaces are more susceptible to damage in humid environments than initially expected. Some coatings are compromised after only two weeks at 50^{o}C and high humidity. While aging is accelerated at high temperatures and humidities, the dependence of degradation on temperature and humidity is complex. For example, at 100% RH, coatings tend to deteriorate more rapidly at 50^{o}C than at 80^{o}C. Aging effects do not necessarily follow expectations as a function of film composition and processing conditions. For example, films that have been annealed to promote formation of covalent Si-O-Si bonds can degrade faster than unannealed films that are only attached to the surface with hydrogen bonds. More research will be required to unravel the key parameters, such as the kinetics of water diffusion into and out of the films, water concentrations within the films and at the SAM-substrate interface, and interfacial reaction rates in order to develop new coatings to promote long-term stability.

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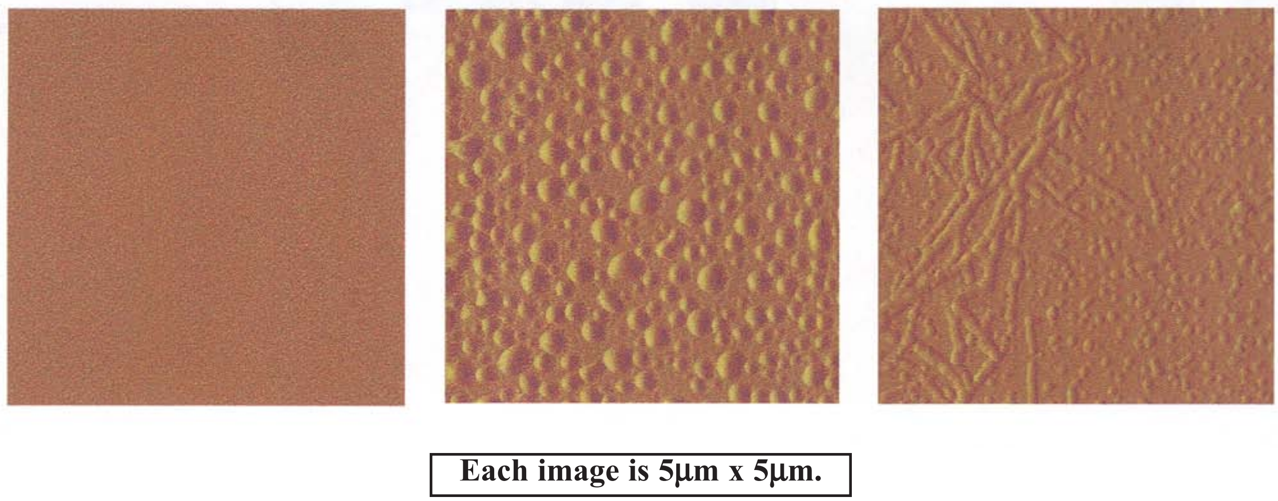

Figure 1. AFM Images of SAM Coatings: (Left) As-fabricated dimethyldichlorosilane (DDMS) coating showing ideal monolayer structure. (Center) DDMS coating after two weeks at 50°C, 100%RH showing formation of spherical blisters. (Right) Octadecene coating after 50 days at 50°C, 80% RH showing formation of interconnected blisters.

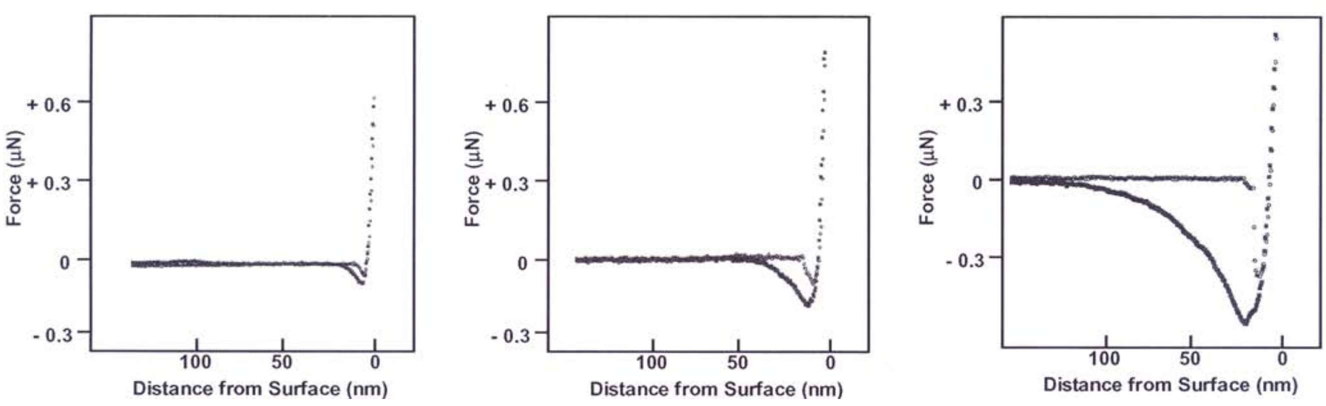

Figure 2. Interfacial force microscope (IFM) normal force vs. distance profiles for octadecene films as a function of exposure conditions. The IFM tip approaches the surface from the left (top trace in each figure) and is then retracted (bottom trace in each figure). Deflections in a negative direction represent attractive, adhesive interactions. The strong positive (repulsive) deflection at the right of each profile is due to mechanical deformations of the tip and substrate when the tip contacts the surface. (Left) Initial film prior to humidity testing. (Center) Film exposed for 50 days, T = 50°C, RH = 80%. (Right) Film exposed for 180 days, T = 80°C, RH = 100%.