Investigation of Dry Chemical Actuators using Palladium and Palladium-Gold Thin Films

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Primary CNF Tools Used: Heidelberg DWL2000 Mask Writer, ABM Contact Aligner, Oxford 81/82/100 Etchers, AJA Sputter Deposition Tool, Oxford PECVD, Plasma-Therm Takachi HDP-CVD, SC4500 Odd-Hour Evaporator, Plasma-Therm 770 Etcher (Left Side), OEM Endeavor Aluminum Nitride Sputtering System, Leica CPD300, DISCO Dicing Saw

Abstract:

This project is focused on the fabrication of chemical actuators from palladium or palladium-gold thin films and characterization of their actuation using hydrogen gas. Previously, we reported on the design of chemical actuators using surface reactions on platinum thin films [1]. In contrast to platinum, atomic hydrogen can diffuse into palladium and palladium-gold thin films, thus generating strains and stresses that are larger than those that can be realized using surface reactions of platinum. In this report, we describe our results with palladium actuators, as well as present some initial results with the palladium-gold bimetallic system.

Summary of Research:

We are exploring how palladium can be used in microscopic bimorph structures that function as chemically-driven hinges. The work is motivated by prior studies of the dissociation of hydrogen on the surface of palladium and diffusion of atomic hydrogen into the palladium lattice to trigger a phase transition [2].

The goal of this project is to harness the bulk absorption of atomic hydrogen into palladium and the subsequent phase transition to drive actuation on the microscale. By fabricating bilayers of palladium and titanium (equal in thickness), we have shown that it is possible to selectively strain one half of the device relative to the other half thus generating a bending of the bimorph. Preliminary results hint that the actuation dynamics are influenced by a first-order phase transition upon exposure to hydrogen gas.

In addition to palladium, we have also started fabricating actuators using a palladium-gold bimetallic system due to its ability to surpass the first order phase transition and undergo a second-order phase transition beyond a certain gold concentration in the alloy. We predict that the order of the phase transition will be reflected in the dynamics of the actuator response [3].

To accomplish this goal, we purchased palladium sputtering targets for CNF and are co-sputtering palladium and gold. Pure sputtered palladium grains were first characterized with a scanning electron microscope as seen in Figure 1, and the smallest possible grain size (obtained by sputtering at 3mTorr) was chosen to build actuators.

To fabricate these devices, a sacrificial layer of aluminum nitride is sputtered onto a fused silica wafer with the OEM Endeavor sputtering system and a layer of aluminum oxide is grown with the Oxford FlexAl on top of the aluminum nitride. Both layers are then patterned and etched in the PT770. After the aluminum nitride is etched, a layer of silicon dioxide is grown with plasma enhanced chemical vapor deposition (PECVD) or high density plasma chemical vapor deposition (HPD-CVD) techniques and patterned. Finally, the bimorph microactuator consisting of titanium and either palladium or palladium-gold is sputtered onto the chip and patterned via lift-off. After the devices are fully fabricated, the chip is soaked in MIF 726 overnight to etch away the aluminum nitride and aluminum oxide layers. It is then dried in the Leica critical point dryer. The chips are then moved to a custom-built exposure chamber for testing in different gaseous environments.

Conclusions and Future Steps:

We have fabricated hinges that show a repeatable actuation upon the application of hydrogen, as shown in Figure 2.

In addition, initial results with palladium-gold show that the alloy responds faster than the pure metal under hydrogen exposure, as shown in Figure 3.

In the future, we aim to characterize further the phase transitions that occurs when palladium is exposed to hydrogen and the influence of the phase transitions on actuation dynamics. Additionally, we will characterize a wider range of compositions of palladium-gold to develop an understanding of how changes in the order of the phase transitions impacts actuator performance.

References:

[1] Nanqi Bao, et al. Gas-phase microactuation using kinetically controlled surface states of ultra-thin catalytic sheets. PNAS, 120(19), 2023.

[2] Noah J. J. Johnson, et al. Facets and vertices regulate hydrogen uptake and release in palladium nanocrystals. Nature materials, 18(5), 2019.

[3] A. Maeland, and T.B Flanagan. X-ray and thermodynamic studies of the absorption of hydrogen by gold-palladium alloys. The Journal of Physical Chemistry, 69(10), 1965.

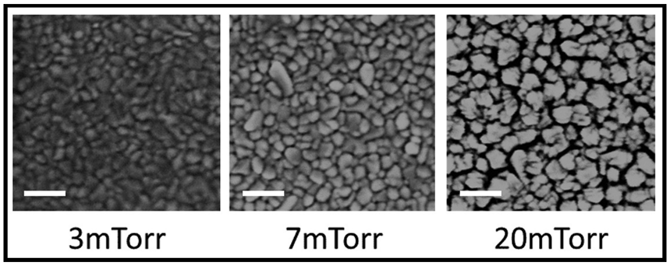

Figure 1: SEM images of grain structures of palladium films sputtered at 3, 7, and 20 mTorr. Scale bars are 100 nm.

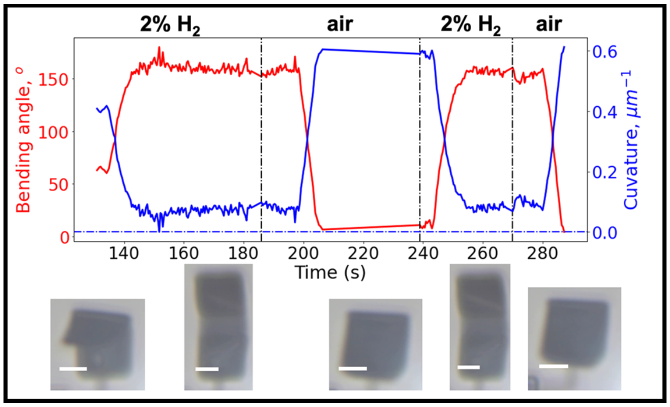

Figure 2: Single palladium hinge (bimorph) responding to hydrogen and air. Scale bars are 5 µm.

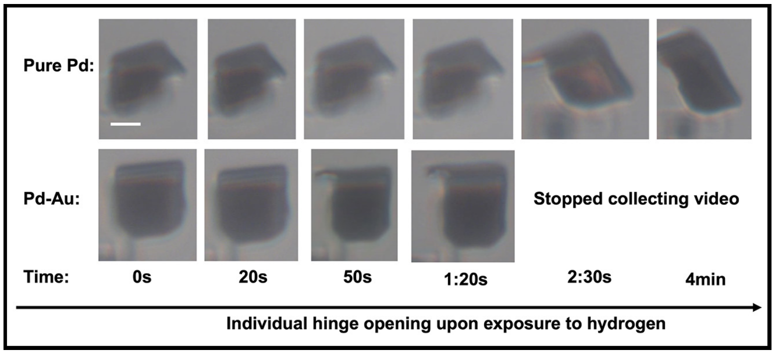

Figure 3: Comparison of responses of actuators fabricated from palladium versus a 24% palladium-gold alloy. Scale bar is 5 µm.