Investigation of Dry Chemical Actuators Using Palladium 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 Tools, Plasma-Therm Takachi HDP-CVD, SC4500 Odd-Hour Evaporator, PT770 Etcher (Left Side), OEM Endeavor Aluminum Nitride Sputtering System, Leica CPD300 Critical Point Dryer, DISCO Dicing Saw

Abstract:

The goal of this work is to design microscale systems that enable the conversion from chemical to mechanical energy via chemomechanical transduction. Previously, by making use of the surface chemistry of platinum, we have demonstrated that a platinum-titanium bimorph can respond to changes in its environment and actuate [1]. In contrast to platinum's surface reactions with gaseous hydrogen and oxygen, palladium is a material known to absorb atomic hydrogen in bulk. In this work, we demonstrate that we can use both surface and bulk properties of palladium to drive actuation.

Summary of Research:

Palladium is well-known for its ability to absorb hydrogen in bulk, thus enabling it to be a material of choice for sensing [2-4], hydrogen purification [2], and storing hydrogen [2,5].

While hydrogen is diffusing into bulk palladium, the material can undergo a phase transition from a hydrogen-poor α phase to a hydrogen-rich β phase depending on the concentration of hydrogen that the palladium is exposed to. The α→β phase transition causes a lattice expansion which can induce a large amount of strain. This is normally undesirable for sensing and storage purposes, however, in this project we present a novel way to utilize this strain to drive microscopic actuators, enabling the development of mechanisms such as small mechanical switches that can not only sense the presence of hydrogen, but also control the amount of hydrogen present by closing and opening a valve.

Figure 1A shows an array of fabricated hinges post release, and Figure 1B shows an individual hinge. To

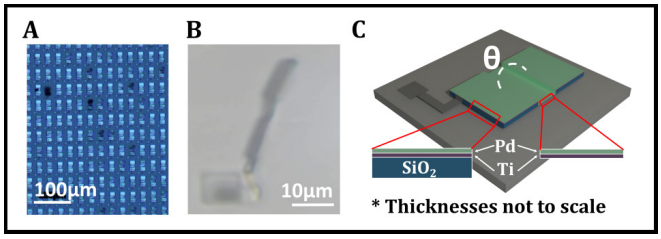

Figure 1: Optical micrographs and 3D rendering of individual hinges.

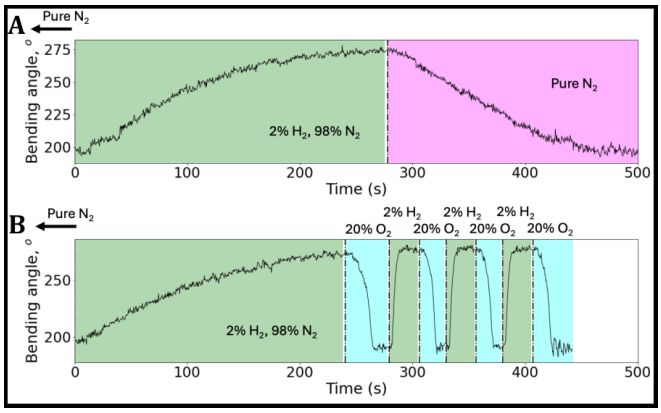

Figure 2: Actuation data upon exposing a hinge to cycling between A) 2 v% H_2 and 20 v% O_2 (All counterbalanced to 1 atm with N_2) and B) 2 v% H_2 and ultra high purity N_2.

fabricate these hinges, a sacrificial layer of aluminum nitride is used, and rigid 600 nm think silicon dioxide panels are deposited on top of the aluminum nitride via chemical vapor deposition. After the rigid panels are patterned, a thin layer of titanium is sputtered to act as a tether, after which the bimorph consisting of 20 nm of sputtered titanium and 20 nm of sputtered palladium is deposited, completing the fabrication process. A 3D

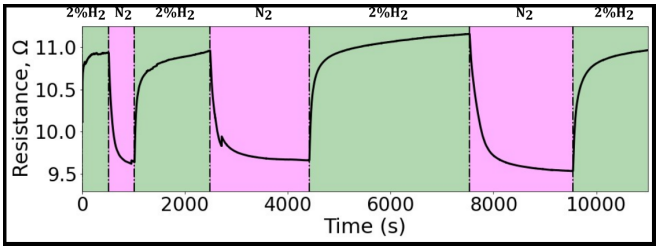

Figure 3: Resistance data upon exposing a palladium film to cycling between 2 v% H2 and ultra high purity N2.

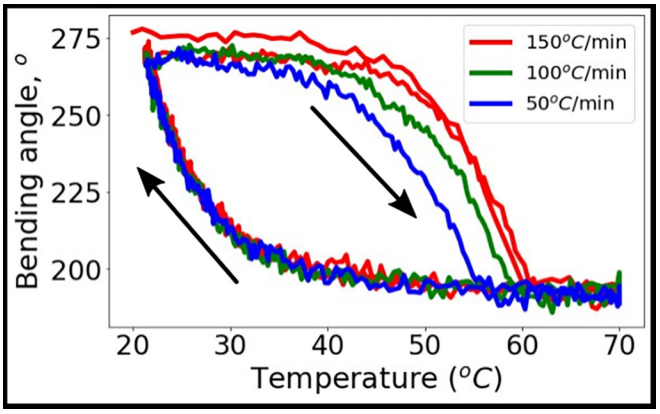

Figure 4: Temperature driven actuation of the palladium hinge under different temperature ramp rates.

rendering of an individual hinge with all the layers is shown in Figure 1C. The chips are then diced, released, dried in the critical point drier, and brought to the lab for experimentation.

Upon exposing the devices to 2 v% H2, 20 v% O2, or ultra pure nitrogen (all at 1 atm, H2 and O2 counter-balanced with N2), we observe an actuation of around 100 .on our 3 μm long hinges, as shown in Figure 2.

We also notice that the application of oxygen instead of nitrogen drives faster actuation not only while oxygen is turned on, but also the oxygen affects the rate of actuation while hydrogen is applied.

We think that actuation in 2 v% H2 and ultra pure nitrogen is driven by the formation of palladium hydride as atomic hydrogen is diffusing into the palladium lattice. Upon the application of oxygen gas to the palladium hydride system, oxygen molecules can dissociate and react with atomic hydrogen in the palladium lattice to form OH. and eventually water. This provides an additional chemical pathway for atomic hydrogen to be removed from the palladium lattice.

To test the formation of palladium hydride, we have conducted additional experiments via the measurement of electrical resistance, as shown in Figure 3.

In addition, because the formation of palladium hydride is known to be a temperature-dependent process, we were able to show that we can drive a similar actuation by cycling the temperature in a 2 v% H2 environment.

Conclusions and Future Steps:

Through numerous analyses and fabrication runs, we have shown that the devices actuate reliably and reproducibly. We are currently in the process of understanding the material science and chemistry behind these actuators and running experiments to test our theoretical models and hypotheses.

References:

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