LOW FORCE ELECTRICAL CONTACT MEASUREMENTS USING PIEZORESISTIVE MEMS CANTILEVERS TO CHARACTERIZE THIN-FILM METALLIZATION

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SUMMARY

The continued miniaturization of ICs, interconnects, relays, and packaging critically depends on the electrical properties of low-force electrical contacts. We have designed, fabricated, and characterized a micromechanical force sensor integrated with a 4-wire electrical contact characterization capability, as shown in Figure 1 to evaluate low force electrical contact pairs. This sensor consists of a silicon cantilever beam with a piezoresistive force sensor suitable for high-accuracy force measurements in the mN-nN range. This work expands the characterization of the electromechanical properties of such contacts, using instrumented MEMS force sensors

Keywords: Contact resistance, MEMS force sensor, Interconnects

BACKGROUND

The electronics packaging and testing industry is interested in the development of new methods for making contacts to electronic chips to improve or replace conventional wirebonding or solder flip-chip techniques. One approach involves the use of flexible contact structures that are integrated with the package or the testing apparatus and allow the device to be fully contacted by simply placing and pressing the interconnect array into contact, e.g. Formfactor microsprings used for probing and packaging as shown in Figure 1.

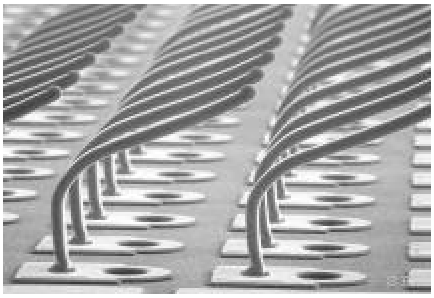

Fig. 1: Formfactor microsprings™ make electrical contact with pads by aligning and pressing in place.

As the line width and pitch for interconnects and packaging pads shrink, the size of electrical contacts for packaging and test must also decrease to accommodate smaller packages and minimize the number of redistribution layers and the area required to transition to external or off-chip connections. Contacts of small area and low force have been studied previously for very specific applications and materials systems. Previous results reported for thin film contacts have been limited to the specific metals and geometries used in microrelays etc. [1-4] From these and other work, it is well accepted that the properties of thin films can vary substantially from bulk properties [5-7]. Hannoe reported limited results of the effect of thin film manufacture on contact resistance using steel pins on thin-film flat specimens [8]. Beale used AFM cantilevers to study low force contacts with a 2-wire measurement to evaluate the nature of contaminant films [9]. Most low force contact data available utilized force balance systems without continuous and synchronous data collection and bulk materials [5, 10-12].

To evaluate these metal films as manufactured, force sensors are fabricated with the contact materials in place using standard micro-fabrication techniques such as sputtering, evaporating, and plating of metal [13]. The structures are used to identify the differences in contact characteristics introduced through manufacture of the contact materials. Different materials systems, film thickness, and contact interactions can also be evaluated by varying the metallization or geometry of these structures.

EXPERIMENT

Sensor Design

The force sensors are piezoresistive cantilevers fabricated from thick SOI wafers (25 to 100μm Si thickness) with separate metallization traces for a 4-wire measurment patterened out to the tip of the cantilever. A gold pad of varied properties is located at the tip of the cantilever. The cantilevers are mounted on a displacement controlled piezoactuator. They are stepped into contact and further deflected on a gold tip with corresponding wiring pairs for the 4-wire measurement of contact resistance. The contact force is inferred from the beam stiffness and the calibrated piezoresistive voltage change. The position of contact is detemined from the step change in the piezoresistance signal and, for gold contacts, this typically corresponds with a change to a finite contact resistance measurement. Cantilever beam stiffness is optimized for the experimental setup (piezoactuator, signal conditioning, and A/D converter resolutions) to provide the desired force range for the measurements (10 nN to 10 mN) and while maximizing force resolution. The cantilevers and piezoresistors are optimized within the contraints of maintaining elastic beam bending and piezoresistor linearity. Microbeam bending testing, utilizing a nano-indenter, of sample cantilevers confirmed that the theoretical beam stiffness is not substantially affected by the additional thin films at the surface. Figure 1 depicts the cantilever measurment setup and SEMs of the cantilevers and tips. The fabrication and design are discussed in more detail elsewhere [13].

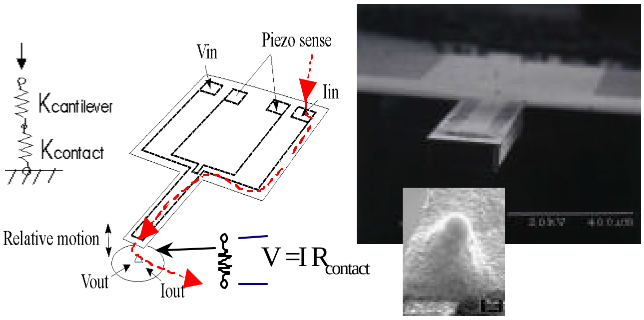

***Fig. 2:** Schematic shows a 4-wire contact resistance measurement setup, SEM images on right of a cantilever and metallized calibration sphere used as a contact tip.*

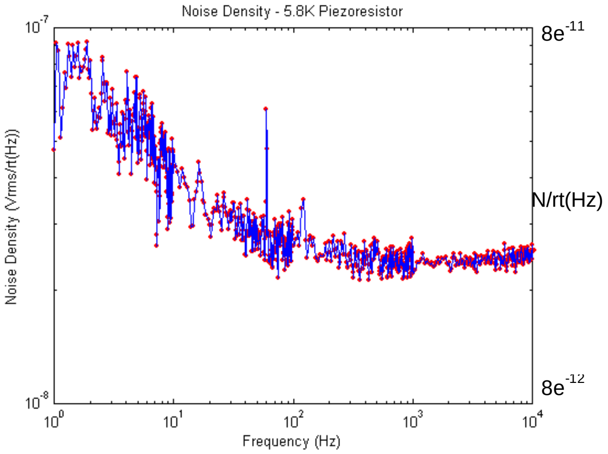

***Fig. 3:** Noise data for the piezoresistors are collected on an HP89410A vector signal analyzer. The noise over the frequency range 10^{-1} to 10^{5} is dominated by 1/f noise below 1kHz. Noise at 1Hz is less than 0.1mV/ÖHz or 80pN/ÖHz.*

Figure 2 is a frequency domain plot of the piezoresistor noise separate from the experimental setup and circuitry noise; the theoretical best force resolution corresponds to about 80pN for measurements made at 1Hz.

Contact Resistance Measurements

The gold contacts tested for this paper are evaporated 0.5µm or 1µm gold (99.999% pure) over an adhesion layer of Ti and a barrier layer of Pt, 250Å each. Further characterization of sputtered and plated gold contacts is underway. Thus far only spherical tips, which are metallized similar to the cantilever pad, have been evaluated for comparison to Hertzian contact theory of a sphere on flat contact. The contact tips consist of a metal-coated glass sphere (for well-known contact geometry) or a solid gold "ball" (for highly-compliant contact structure); each of these is also coated with varying thickness of metals, deposited by evaporation, sputtering, or plating.

Measurements made with a typical cantilever and metallized glass spheres with 0.5µm gold thickness over a 5mN force range are shown in Figure 4. The traces demonstrate the repeatability of the contact behavior, though as expected a lateral wiping motion/scrub during contact and an oxygen plasma clean improve the contact resistance over the case of the nominal tests with no pre-treatment of the surfaces.

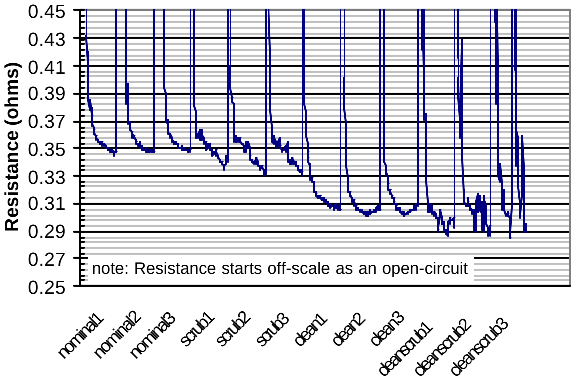

***Fig. 4:** Contact Resistance decreases with lateral scrubbing motion and with O2 plasma cleaning. Variation with repeated contact under the same load and tip conditions is insignificant.*

In the results presented here, the gold pads are patterned over an underlying aluminum layer on the cantilevers; aluminum has similar hardness to gold. Future designs will have no aluminum underlayer and thus will provide data for evaluation of its effect. Figure 5 shows micrographs and SEM images of a typical pad, glass core tip, and gold core tip after several contact tests. The gold core tip underwent substantial deformation during the lateral scrub test while the glass core tip maintained its geometry with only minor scratches on the surface gold. These photos indicate that significant wear and material transfer are possible in the range of tens of milli-Newton contact forces—i.e. the highest forces these surfaces were subjected to.

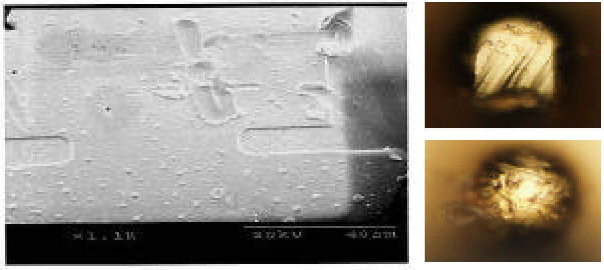

Fig. 5: *Left: normal contact and lateral scrub marks on 1um gold over 0.5um Al film. Several test were done with gold film on gold (top right) and glass (bottom right) spheres, the gold spheres scrape and deform while the glass film shows signs of material transfer and scrubbing.*

Figure 6 shows a set of contact resistance measurements as a function of applied force during the applied loading. The tests utilized antilevers of different stiffnesses, resulting in varied force ranges between the tests, with gold films of 0.5µm and 1µm thickness. Contact geometery was a sphere on flat in all the tests, but the sphere size was varied; results are plotted with an ideal Hertzian elastic sphere on flat contact model. Clearly, contact compliance, geometry, and a cleaned surface are important, but futher investigation is necessary to determine why all of the contacts measured, fall short of the predicted conductance. These experimental results are similar to low-force contacts reported in the literature and the cause is suspected to be thin film effects and variation in evaporated film thickness deposited over a spherical geometry. The measured thin film resistivity is slightly higher than the bulk property but does not alone account for the higher contact resistance.

Finally, Figure 7 shows simultaneous measurements of resistance, force, and gold contact deformation during a loading cycle. The displacment applied to the cantilever is known and most of this is taken up by the cantilever deflection. Though some small component is due to the compliance of the gold-gold contact interface. Since contact force can be derived as a function of cantilever stiffness and applied displacement, from F=Kx, and the force in the cantilever can also be derived from the measured piezoresistance change, the difference can be used to estimate what portion of the total deflection which is comprised of contact yielding.

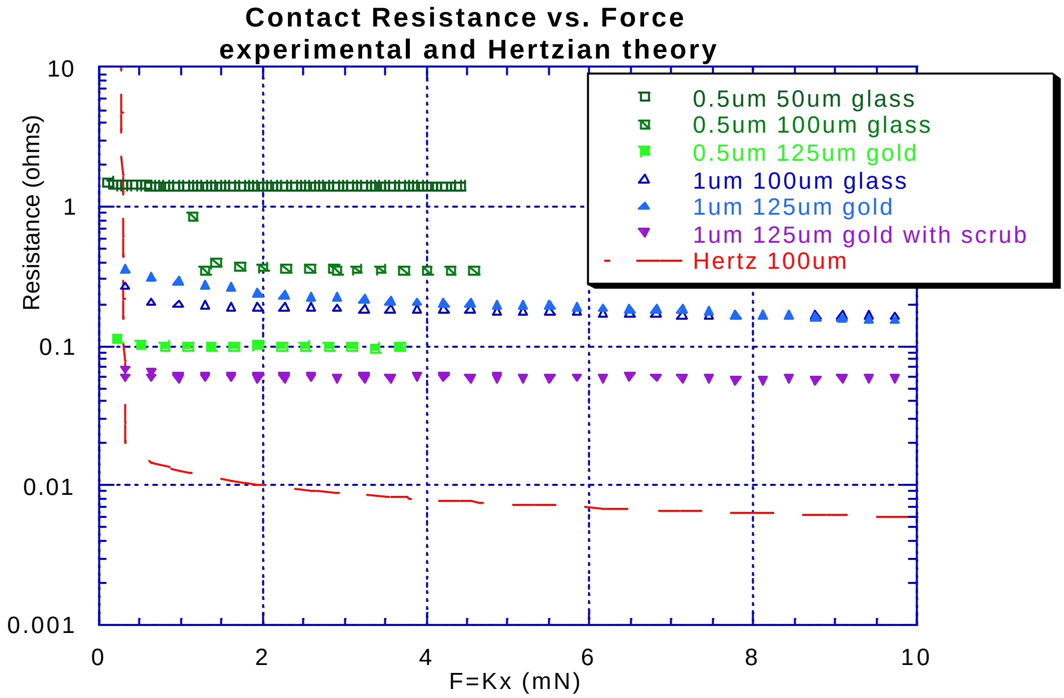

Fig. 6: *Experimental and ideal Hertzian elastic (R=r/2a) contact resistance vs. force are derived from the displacement for several cantilevers and tip sizes. Resistance decreases with increasing Au film thickness, lateral scrub, gold vs. glass tip cores, and larger tips. Filled plot markers indicate gold cores and outlines indicate glass.*

The measurements in Figure 6 were not precise enough to isolate the contact compliance with certainty, but further improvements in the experimental apparatus should facilitate this measurement.

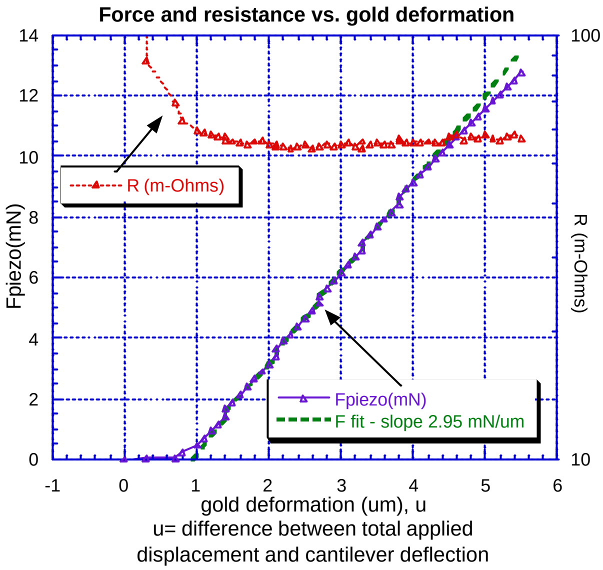

Fig. 7: *Contact deformation derived from the applied displacement, sensed force, and stiffness, K=865N/m, is plotted with contact resistance.*

CONCLUSIONS AND FUTURE WORK

The sensors and experimental setup discussed here provides the capability to make the first simultaneous measurement of electrical resistance and contact compliance in this force range. When combined with nanoindentation force measurements on the same materials and geometries, we can extract precise measurements of contact mechanics with simultaneous resistance measurements over an array of geometries, film thickness, and compositions. Further characterization of thin film electrical contacts of varied manufacture is underway and the research will identify the key parameters that affect thin film contact resistance in this force regime, and provide guidelines for researchers seeking to develop low-force electrical contacts for packaging and testing applications.

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