Piezoresistive cantilevers and measurement system for characterizing low force electrical contacts

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Abstract

The continued miniaturization of integrated circuits (ICs), interconnects, relays, and packaging critically depends on the electrical properties of low force electrical contacts. This paper presents the design, fabrication, and characterization a micro-mechanical force sensor integrated with a four-wire electrical contact characterization capability to evaluate low force and small area electrical contacts comprised of thin films. The sensor consists of a silicon cantilever beam with a piezoresistive force sensor suitable for high-accuracy force measurements in the nanoNewton to milliNewton range. The work presented expands the characterization capabilities for the electromechanical properties of such contacts over what is currently available, using instrumented micro-electromechanical system (MEMS) force sensors. The effects of varied contact tip dimensions and different gold films manufactured using standard semiconductor processing techniques are studied. The cantilevers are evaluated for force sensitivity, range, noise and sensitivity of four-wire contact resistance measurements. The piezoresistors have a gage factor of about 35 and noise of $<1 \mu V/Hz^{1/2}$ or $1 \text{nN/Hz}^{1/2}$ at 1 Hz (the lowest frequency of intended measurements). Measurements of a typical cantilever design indicate sensitivity of 56 mV/N when the cantilever spring constant is about 1 N/m and a corresponding force resolution of about 3 nN. Force measurements are noise limited and 2 Hz sampling rates were used. Four-wire contact resistance measurements are made synchronously with piezoresistor bridge output voltage measurements. Thin film gold contact behavior below 1 mN is influenced by film manufacture method and the resulting differences in microstructure and hardness.

Keywords: Contact resistance; MEMS relays; MEMS force sensor; Interconnects; Piezoresistive cantilevers

1. Introduction

To carry out measurements of contact force in the milliNewton to nanoNewton regime, new instrumentation is required. Conventional load cells operate down to tens of milliNewtons, but not below. Conventional atomic force microscopy (AFM) or scanning tunneling microscopy (STM) operates up to tens of nanoNewtons, but not above. To operate between 10 nN and 10 µN, we have designed and developed a new micro-electromechanical system (MEMS) cantilever of intermediate thickness. This paper reports on the design, fabrication and characterization, and includes some preliminary materials test data.

Piezoresistive force sensing cantilevers (Fig. 1) are utilized with a piezoelectric actuator, signal conditioning, and position control to measure contact resistance of low force thin film electrical contacts. Characterization of thin film electrical contacts is of interest for the design of MEMS relays, low force probes and interconnects. 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 wire bonding or solder flip-chip techniques. One approach involves the use of flexible interconnect structures that are integrated with the package or the testing apparatus. These spring interconnect contacts allow the device to be fully contacted by simply placing and pressing the interconnect array into contact. Examples of flexible interconnects include miniature spring contacts used for probing and packaging [1–5] such as FormFactor MicroSprings™ for pressure mated contact applications as shown in Fig. 2a and b. Initial work on the design of prototype sensors and measurements to characterize the gold films used in separable contacts such as these was presented earlier [6,7]; this paper provides a comprehensive overview of the sensors and system and reviews representative data.

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
Nomenclature

\( E \)  
Young’s modulus (Pa)

\( H \)  
hardness (Pa)

\( K \)  
effective spring constant (N/m)

\( L \)  
cantilever length (m)

\( P \)  
load (N)

\( t \)  
cantilever thickness (m)

\( w \)  
cantilever width (m)

Greek letters

\( \delta \)  
deflection (m)

\( \varepsilon \)  
strain at piezoresistor surface

\( \theta \)  
angle of deflected cantilever (rad)

packages, to minimize the number of redistribution layer, and to reduce the area required for transition to external or off-chip connections. Contacts of small area and low force have been studied previously for very specific applications and material systems. Previous results reported for thin film contacts have been limited to the metals and geometries used in specific microrelays, etc. [8–13]. These and other work show that the properties of thin films can vary substantially from bulk properties [14–16]. Hannoe and Hosaka reported limited results for thin film manufacture method variation on contact resistance behavior using steel pins on thin film flat specimens [17]. Beale and Pease used AFM cantilevers to study low force contacts with a two-wire measurement to evaluate the nature of contaminant films [18,19]. Most low force contact data in the literature was obtained from force balance systems without continuous and synchronous data collection to characterize bulk materials [9,15,20–23]. Force balance systems provide the necessary range but the data obtained are generally single point measurements because they are not easily instrumented for continuous force and in situ contact resistance measurements. In situ testing more closely replicates the conditions of the contact applications for probes, switches, and relays. Continuous monitoring allows spurious resistance spikes and contact slippage to be detected.

To evaluate these thin gold films in an “as-deposited” condition, force sensors are fabricated with the contact materials using standard micro-fabrication techniques such as sputtering, evaporating, and plating of gold. The structures are used to identify the differences in contact characteristics introduced by the deposition method of the contact materials. Different material systems, film thickness, and contact interactions can also be evaluated by varying the metallization or geometry of these structures.

2. Cantilever design

The cantilever spring constant is optimized for the experimental setup (piezoelectric, signal conditioning, and A/D
converter resolutions) to provide the desired force range for the measurements (10 nN to 10 mN) while maximizing force resolution. The cantilevers and piezoresistors are optimized within constraints to maintain linear elastic beam bending behavior and piezoresistor linearity. The system is displacement controlled; input displacement of the cantilever results in a contact force proportional to displacement times the cantilever spring constant. Best resolution over the largest range is obtained by driving the cantilever with the smallest increments possible and using cantilevers of minimum spring constant, i.e., the longest, softest cantilevers. The design tradeoff is achieving minimum spring constant and best resolution for the equipment available with dimensions suitable for the electrical contacts.

The cantilevers are designed to allow full travel of the actuator within the design limits to maximize the force resolution over the piezoactuator travel. The Polytec PI closed loop piezoactuator has a maximum range of 100 μm, nominally repeatable within 2 nm increments. Cantilever dimensions are sized to remain in the linear range of the elastic beam equations and linear strain limits for piezoactuators for the deflection range. The cantilever dimensions must allow for a contact pad much larger than the contact sphere to facilitate alignment of the contact pair, and the beams must provide enough structure to withstand the thin film residual stress of the metal traces and contact pad with minimal deformation.

The angle of deflection of the beam, \( \theta \), is constrained to ensure that the deflection is linearly proportional to displacement of the end.

\[
\theta = \frac{6PL^2}{Etw^3} \leq 0.1
\]

Piezoresistor strain, \( \varepsilon \), is limited to <0.001 to ensure linear resistance change with applied strain [24].

\[
\varepsilon = \frac{6LP}{Et^3w} \leq 0.001
\]

When (1) and (2) are satisfied, the beam bending behavior can be approximated by the spring constant,

\[
K = \frac{Et^3w}{4L^3}
\]

The cantilever load displacement behavior is then described by the effective spring constant, \( K \), as

\[
P = K\delta
\]

The thin gold films studied vary in thickness from 1000 Å to 1 μm with an underlying passivation oxide on the silicon cantilever. The beam thickness should be at least an order of magnitude thicker than the gold and oxide for their stiffness and residual stresses to have negligible effect on the beam mechanics. With worst case stresses of 300 MPa in the films on a composite beam cross-section, a minimum thickness of 25 μm is set to ensure the worst case strain at the root of the beam is <0.01 or 1% of the maximum strain allowed by (2).

Microbeam bending tests with a nanoindentation confirmed that the additional thin films at the surface do not substantially affect the theoretical beam spring constant. Natural frequencies of the beams also shifted <1% when resonated before and after stripping the metallization, confirming negligible gold film effect on the beam behavior.

The width is constrained by the necessity for sufficient area of the gold contact pad and independent metal leads for the four-wire resistance measurement; these leads do not overlap the piezoresistive region to avoid cross talk between the signals. The leads are patterned 0.5 μm thick aluminum for ease of fabrication (i.e. compatibility with CMOS processing in the Stanford facilities), their resistance is constrained by the resistance tolerance of the sense leads to the Keithley 236 current source measure unit (SMU). To minimize the path resistance, the minimum line width of the aluminum is 25 μm. For the longest cantilevers of 6 mm the predicted path resistance at this width is about 10 Ω; less than 1 Ω of additional resistance in the path comes from the Al/Ti/Pt/Au interface. The piezoresistors are a single “U” shaped loop 20 μm wide with a 20 μm gap between the traces. The minimum cantilever width including isolation of at least 5 μm between features is 140 μm, but this provides a contact pad width of only 60 μm. The largest contact tip structures tested are 100 μm in diameter and the minimum pad width chosen is much larger, e.g., 250 μm, to provide area for multiple tests on the same pad.

Additional constraints come from the equipment used in the measurement. The first actuator used in the experiments was a Melles–Griot two-axis open loop piezoelectric stage. The repeatability and linearity under monotonically increasing input voltages is excellent, but the hysteresis in open loop conditions precluded analysis during unloading. The stage was driven with a 12-bit analog voltage signal (0–10 V) from a National Instruments data acquisition card DAQ-1200 commanded through LabVIEW on a PC laptop. The displacement at 10 V was 37.5 μm and resolution was limited by the step size or bit resolution of the analog output from the DAQ card—12-bit is the best output resolution available with a PC interface. The resolution was subsequently improved by using a Polytec P-731 piezoactuator with ES09.C2 capacitive feedback and E-515 GPIB position controller for theoretical displacements of 1 nm. However, the on-board sensor monitor output and 16-bit input resolution limits the measurement to a few nanometers. Also, the maximum GPIB bus speed for this controller is several Hertz, which limits the stepping rate and implies proportionally longer test times for increased resolution.

Change in piezoactuator is measured by the voltage change on a Wheatstone bridge, where the other legs are comprised of a 1% metal film resistor and two halves of 1 kΩ and 10 kΩ Bourns™ balance potentiometers in series for fine and coarse balance adjustment. The piezoresistors are typically 5–6 kΩ. Sensitivity is maximized when the resistance on the legs is equal and the bridge voltage is nulled to zero before each measurement. The first measurement system
Nanoindentation, surface roughness is evaluated by atomic force microscopy, and microstructure is studied with focused ion beam (FIB) cross-sections and images, and scanning electronic microscopy (SEM) images.

The measurements are made by driving the cantilever a known distance with a piezoactuator. A metal electrical contact pad is brought into physical contact with a mating metal contact tip or surface and electrical contact resistance, displacement, and piezoresistance (indirectly force) are monitored. Fig. 3a shows a schematic of the test setup for simultaneous force and electrical contact measurements. Note that the structure provides independent current and voltage paths everywhere but through the contact interface to minimize the effect of path resistance in the measurement. Fig. 3b is an image of a 100 μm glass calibration sphere embedded in photoresist and metallized with the gold film under test. The flakes in the image are from dicing the samples and are blown off with nitrogen before contact testing. These tips are used as the spherical half of the contact pairs while the flat half of the pair is the gold contact pad at the end of the cantilever.

Displacement resolution of the piezoactuator and the spring constant of the cantilever determine the smallest force increments and resolution for the cantilevers. The width and length for the cantilevers are then optimized for maximum force resolution over the range of 10 nN to 10 mN, within the constraints given by (1) and (2) as well as the minimum beam thickness requirement. Cantilever design dimensions are found for nominal beam thicknesses of 25 and 40 μm to provide maximum sensitivity and resolution for the system setup and given the constraints of the piezoactuator. The design space is depicted graphically in Fig. 4 for a maximum measurable force of 10 mN and a beam thickness of 40 μm. The minimum spring constant (K), and corresponding maximum length as given by (3), allowed by the linearity constraints for a maximum force of 10 mN are 85 N/m and 3 mm, respectively. The

![Diagram](image)

**Fig. 3.** (a) Schematic of a piezoresistive cantilever and metallized spherical contact tip as used for mechanical and electrical measurements. (b) SEM calibration spheres are potted in photoresist and metallized for use as the spherical half of the contact pairs.

utilized a Keithley 2000 digital multimeter in four-wire resistance (Kelvin) measurement mode. However, the current and voltage used in the measurement are not controllable with this device. A second revised system uses a Keithley 236 SMU and the current and voltage can be adjusted and compliance limited. As per ASTM B 539 [25], the dry contact measurements do not exceed 20 mV or 100 mA to prevent artificially lowered contact resistance by fritting of surface films and oxides. However, the standard is written for large-scale electrical contacts and lower currents are likely to be more appropriate for MEMS switches, microrelays, and probes. For example, Hyman and Mehrregany [10] observed asperity softening and material transfer with 10 mA of current under 0.5 mN loads for contact areas with radii of several microns.

The measurement system presented here is appropriate for loading and unloading measurements of force and contact resistance of thin films deposited in the semiconductor fabrication process. Contact resistance and adhesion as a function of normal force and current are continuously recorded. Observations of the surfaces before and after contact tests are captured. Hardness measurements of the films of varied thickness and manufacture are made by

![Graph](image)

**Fig. 4.** Graphical representation of design space for maximum force resolution for a 40 μm thick cantilever, spring constant, K (N/m), is minimized when length, L (μm), is maximized within the limits of linear piezoresistor and beam behavior.
dimensions for cantilevers designed to measure different force ranges are given in Table 1.

3. Fabrication process

The cantilever fabrication process flow is depicted in Fig. 5, the cross-section of the process is shown in the left column and a top down wafer view is in the right column. The cantilevers are fabricated from (1 0 0) n-type silicon-on-insulator (SOI) wafers of approximately 25 and 40 μm silicon device layer thickness. The standard prime grade wafers are background doped with phosphorus at 5–20 Ω·cm. The piezoresistors are doped with a $10^{15}$ cm$^{-2}$ boron implant through a 250 Å thermal oxide and annealed to a concentration of about $6 \times 10^{18}$ cm$^{-3}$. The doping levels and annealing cycle are determined from piezoresistor design recommendations of Harley and Kanda [26–28]. Conductive traces are implanted from the piezoresistor terminations to the aluminum contacts with a dose of $10^{10}$ cm$^{-2}$ and annealed to a concentration of about $2 \times 10^{19}$ cm$^{-3}$. The damaged oxide is stripped and a 2500 Å thermal passivation oxide is grown for electrical isolation of the metal leads and substrate. The structures are defined and released using a deep reactive ion etch (DRIE) process from both sides of the SOI wafer. Because of equipment cleanliness constraints, the gold is deposited after the front side DRIE. The resulting trenches, which define the cantilever structures, reduce the yield of subsequent liftoff processing and instead the evaporated and sputtered gold pads are deposited through a beryllium–copper etched shadow mask. The shadow mask is aligned and clamped in a custom fixture for an Electronic Visions 620 alignment system.

The evaporated and sputtered gold targets are 99.999% pure and are deposited after reaching vacuum of about $10^{-7}$ Torr with chamber temperatures of about 100 °C during deposition. For evaporation, deposition power is controlled to maintain a deposition rate of about 3 Å/s. The evaporated gold is deposited in one vacuum cycle over an evaporated 250 Å titanium adhesion layer and 250 Å platinum barrier layer; the sputtered gold is deposited over the same evaporated adhesion and barrier layers in a second pumpdown cycle immediately upon transfer to the sputtering system and no adhesion problems were observed. Argon sputtering gas is flowed at 5 sccm with a chamber pressure of

![Fig. 5. Fabrication process for cantilevers. Details are shown for evaporated or sputtered gold samples. Start with SOI n-type (1 0 0) wafer. Mask #1: etch (4000 Å), alignment marks. Grow protective oxide ~250 Å. Mask #2: 50 keV boron implant piezoresistors, dose = 1e15 ions/cm². Mask #3: 40 keV B implant conductors, dose = 5e15 ions/cm². Strip and re-grow oxide to ~2500 Å, this activates dopant with a junction depth of ~1.5 μm. Mask #4: open oxide for metal contacts to conductive regions with wet etch, back side is now oxide free. Sputter 0.5 μm aluminum. Mask #5: etch back aluminum to define interconnects and contacts. Mask #6: pattern 7 μm Shipley SPR220 resist for front etch of cantilevers. BOE etch to open oxide and DRIE silicon etch to buried oxide. Mask #7: shadow mask for Ti/Pt/Au metallization. Mask #8: back side align and pattern 18 μm SPR220 for back side etch. DRIE anisotropic silicon etch through wafer. H₂ forming gas anneal for contacts at 400 °C for 2 h.](Image)
\( \sim 10^{-3} \) Torr during sputtering at 50 W and deposition rates of about 2 Å/s on a single wafer. The wafers with plated gold contact pads are fabricated similarly with a patterned 250 Å titanium and 250 Å platinum underlayer and a blanket seed layer of 1000 Å of evaporated gold followed by electroplating with a cyanide based “soft” gold deposited at 3ASF or nickel hardened plated gold deposited at 8ASF. The electroplating uses patterned photoresist as a mold to control the coverage and exposed plating area. For these wafers, the back side DRIE is done after the electroplating. The microstructure, hardness, and surface roughness of all thin film variations are characterized to determine the effect of different deposition conditions and thickness.

4. Measurement system

The measurement system schematic is shown in Fig. 6, the electronics are rack mounted and the microscope and stages are on a vibration isolation table. The cantilevers are mounted on a Polytec PI 500 two-axis piezoelectric stage with capacitive feedback and are displacement controlled via the E515 GPIB. GPIB position commands issued by LabVIEW and a GPIB card provide better resolution (~1 nm) than driving with an analog signal. The cantilever contact pad is aligned to the sphere under a Nikon Optiphot 150 microscope with CCD camera and monitor which are then switched off before the cantilever is stepped into contact and further deflected through the full range of the actuator. The tests are performed in a copper-clad box that acts as a Faraday cage and provides isolation from light and air flows. The contact resistance is derived from four-wire measurement of the contact current, measured as the voltage drop across a 1 Ω resistor, and the voltage across the contact; both signals are buffered and amplified by AD624 instrumentation amplifiers and monitored with the National Instruments DAQCard-AI-16XE-50. The contact force is derived from the beam spring constant and the calibrated piezoresistive voltage change. Both the cantilever and the contact tip are cleaned for 1 min with a 150 W oxygen plasma to remove organic films that may have formed. Initial studies found that the contact resistance of the gold films improved with oxygen plasma cleaning or a lateral “wiping” motion during contact. The oxygen plasma clean is less destructive to the surface. Consequently, an oxygen plasma clean is performed within immediately prior to all tests, the elapsed time from clean to test start is <1 h. The tests are conducted in ambient air maintained at 20 °C and about 50% relative humidity, therefore at least a monolayer of water must be assumed to exist.

5. Results

Noise data for the piezoresistors are collected on an HP89410A vector signal analyzer. The noise over the frequency range \( 10^0 \) to \( 10^5 \) is plotted in Fig. 7 for a 5.8 kΩ piezoresistor and is dominated by 1/f noise below 1 kHz; the noise at 1 Hz is \( <1 \text{nV/Hz}^{1/2} \) (1 nN at 1 Hz), therefore the resolution of the low speed measurements is most limited. The resistance of the piezoresistors is nominally 5.8 kΩ; the change in resistance over the deflection range of the piezocantilever on this cantilever is about 60 mΩ and the gage factor is about 35.

The cantilevers are calibrated to find the effective spring constant and the force sensitivity of the piezoresistor and they are driven with white noise to find the resonant frequency and derive the spring constant. Sensitivity is determined from frequency spectra of the cantilevers driven at resonance. The velocity of the end of cantilever is measured with a Polytec PI

![Fig. 6. Schematic experimental setup. Cantilever position and contact current/voltage are controlled via a LabVIEW program through GPIB commands. Voltage signals are conditioned and collected with a data acquisition card and LabVIEW.](image1)

![Fig. 7. Noise density of 5.8 kΩ piezoresistor. The noise floor for DC measurements is less than a nanoNewton and is dominated by 1/f noise up to about 1 kHz. The Johnson noise level is well below the noise of the additional signal conditioning and data acquisition electronics.](image2)
OFV-3001 controller and OFV-303 optics head laser vibrometer. The vibrometer signal and the bridge output voltage are captured with an HP89410A signal analyzer. The setup for this calibration measurement is shown in Fig. 8.

The evaporated, sputtered, and electroplated gold contact films tested are approximately 1500 Å, 0.5 or 1 μm thick with a 250 Å titanium (Ti) adhesion layer and a 250 Å platinum (Pt) barrier layer. The contact spheres are 50

and 100 μm diameter borosilicate glass or polystyrene and are metallized similar to the cantilever pad. This geometry is evaluated experimentally for ease of comparison to Hertzian contact theory [29] of a sphere on flat contact. The contacts utilize metallized calibration spheres for well

known contact geometry and different sphere materials to provide substrates of differing hardness and compliance.

Loading and unloading contact force and resistance measurements made with a typical cantilever and 50 μm diameter metallized glass spheres with 0.5 μm gold thicknesses are shown in Fig. 9a. The force range of each test varies and depends on the effective spring constant of the cantilever sensor and actual range of displacement traveled after contact. The softest cantilevers allow a linear measurement range from ~10 nN to ~1 mN, while the stiffest cantilevers cover a range from ~100 nN to ~10 mN. However, a “good contact” with contact resistance <10 Ω is typically obtained with several μN of force. The contact resistance measurement is made over the range of milliohms to kilohms and saturates for values >1 kΩ. The contacts appear to “snap in” to contact resistance values much lower than 1 kΩ as seen in Fig. 9b. The contacts behave nominally like Hertzian elastic (5) contacts but with much higher resistance than theory would predict. The resistance values also flatten out and do not continue to decrease with increasing force as rapidly as Hertz theory predicts, this is noticeable in both Fig. 9a and b. We believe the behavior deviates from a Hertzian model for several reasons which require further simulation. First, deformation of the gold films and material transfer is evident after the test. Plastic deformation is likely the dominant cause at larger loads while electromigration is expected to occur at smaller loads and contact areas. Second, the material properties and mechanical behavior of the films is a function of the microstructure and thickness, best characterized by the hardness. The purely elastic model does not address this variation. Finally, the surface roughness of the films dominates the initial contact behavior and the largest asperities may be on the order of the film thickness. The behavior of these “nano-contacts” then largely influences the whole contact behavior. Still for reference, we compare the behavior to a Hertzian contact. The “a-spot” contact area radius, \(a\), for a Hertz elastic contact between materials 1 and 2, where \(P\) is the load, \(E\) the Young’s modulus, \(v\) the Poisson’s ratio and \(r\) the radius of curvature of the contact sphere, is [29]:

\[
a = \sqrt[3]{\frac{3P}{4E_1(1-v_1^2) + E_2(1-v_2^2)}}r
\]

Fig. 8. Calibration schematic for determining the effective spring constant of the cantilever and the force sensitivity of the piezoresistor. The cantilevers are driven with white noise to find the resonant frequency and derive the spring constant. Sensitivity is derived from the frequency spectra of the cantilever driven at resonance.

Fig. 9. Loading and unloading data are plotted for gold films, nominally 0.5 μm thick, on 50 μm diameter glass spheres. The correspondingly lower stable contact resistance behavior correlates with differences in hardness values. (a) Plotted on a semi-log scale, the adhesion forces are apparent. (b) Plotted on a log-log scale, the initial contact behavior and snap in to a “good” contact (<10 Ω) are seen to depend on film type as well. The contact resistance predicted from Hertz theory (5) and (6) is also plotted.
where

\[ E_1 = E_{\text{Si}} = 1.79 \times 10^{11} \]
\[ E_2 = E_{\text{Gl}} = 7.03 \times 10^{10} \]
\[ v_1 = v_{\text{Si}} = 0.23 \]
\[ v_2 = v_{\text{Gl}} = 0.22. \]

The substrate properties for silicon and glass are taken to have the dominant effect on the contact behavior.

The corresponding Maxwell spreading resistance is [9]

\[ R = \frac{1}{2} \rho \tag{6} \]

where

\[ \rho_{\text{gold}} = 2.30 \times 10^{-8} \, \Omega \text{m} \]

As expected, the contact resistance behavior is correlated with the gold film manufacture method and the various films were characterized by surface scan with an atomic force microscope, by nanoindentation, and microstructure analysis using focused ion beam section images and scanning electron microscopy images. The correspondingly lower stable contact resistance of an evaporated gold contact is in large part due to differences in hardness. For instance, the measurements are correlated with data from nanoindentation of the films as shown in Fig. 10. The hardness measurements are determined using the Oliver and Pharr method at 10% of relative indentation depth where there is a small plateau in the data [30]. For <10% relative depth, surface effects dominate the measurement and for >10% relative depths the substrate effect becomes substantial. For comparison, evaporated gold, sputtered gold, and nickel hardened electroplated gold at approximately 1 μm film thickness have hardness values of about 1.2, 2.1 GPa, respectively, these are all greater than a typical bulk gold hardness of about 0.6 GPa [31].

Separate tests were conducted on the effect of surface cleaning by mechanical wiping action during contact, similar to probe needle operation, and oxygen plasma cleaning of the surface prior to testing. The lateral wiping motion/scrub during contact and a preliminary oxygen plasma clean both improve the contact resistance over the case of the nominal tests with no pre-treatment of the surfaces. Oxygen plasma cleaning provides the best improvement in both initial and overall contact resistance behavior.

Contact force and resistance measurements and characterization of a series of gold films with differing thickness, manufacture method, and varying load and bias conditions were conducted and will be presented in a more comprehensive review elsewhere.

6. Conclusions

Custom piezoresistive MEMS cantilevers incorporating four-wire measurement capability have been designed, fabricated, and evaluated. They are suitable for evaluation of continuous force and contact resistance measurements in the range of nanoNewtons to milliNewtons and milliohms to kiloohms resistance ranges. This system expands the characterization capabilities for the electromechanical properties of microcontacts beyond those of commercially available systems, using instrumented MEMS force sensors. The deposition method and resulting microstructure and hardness variation are found to influence the contact resistance behavior of thin film gold microcontacts in this force range. Thin film gold contact behavior below 1 mN is found to be correlated with hardness measured by nanoindentation.
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References


Biographies

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