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Advanced Mechanical Surface Testing

APPLICATIONS BULLETIN

Special Issue: Micro-Electronic Applications

Nano-Scratch Tester (NST) for characterising anti-stiction coatings for microsystems

Introduction

Due to their extremely low working force range, mechanical microsystems are sensitive to phenomena which can usually be ignored in macroscopic mechanical systems. Stiction refers to the adhesion originating from the tribological contact of moving parts, which can result in immobilisation of the device. In a typical microscopic contact, stiction forces in the nano- and micro-Newton range can prove severely detrimental to the microsystem functionality. Different force types can be responsible for stiction, although capillary forces are believed to be predominant in mechanical microsystems.

This application note describes the use of the Nano-Scratch Tester (NST) for investigating the tribological functionality of a microsystem known as a *microshutter*. This micromachined system consists of a shutter blade, a suspension beam, two fixed electrodes and two stoppers at either side of each electrode to prevent short circuits. The hole under the blade is positioned so that it is either open or closed, depending on where the blade is positioned. A typical microshutter is shown in Fig. 1. With this kind of microsystem, stiction can occur between the sides of the blade and their respective stopper surfaces. Recent efforts have been made to lower the surface energy of polysilicon microstructures by depositing extremely thin coatings by plasma polymerisation. However, it is very difficult to deposit sufficient material on vertical sidewall structures.

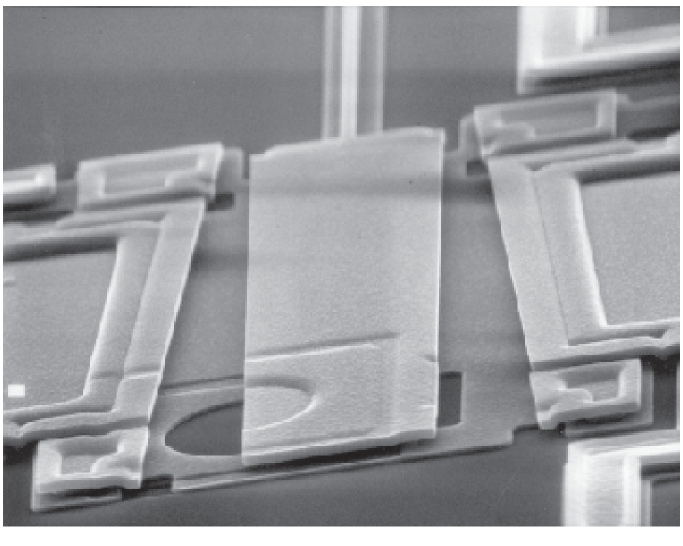

Figure 1 : SEM micrograph of a typical polysilicon microshutter.

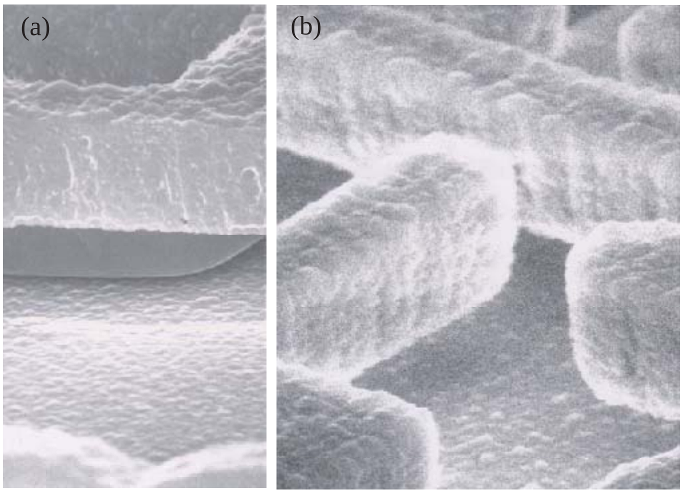

Figure 2 : SEM micrographs showing the original polysilicon surface texture (a) of the microshutter sidewall and the Teflon-like coated microstructure (b) which can significantly reduce stiction in this type of microsystem.

The plasma polymerisation process is in this case applied with hexafluoropropene as a precursor molecule in order to grow a Teflon-like coating. The samples are placed under a Faraday cage (i.e., a field free zone) within the reactor in order to promote a conformal growth of the polymer film, this being necessary in order to cover all faces of the microstructures. The Scanning Electron Microscope (SEM) images shown in Fig. 2 confirm that the deposition process is sufficiently isotropic to coat the lateral surfaces of the electrodes, stoppers and blade over their whole height.

Quality control of such thin films is very difficult *in-situ* owing to the complexity of the micro-machined structure and the difficulties in positioning a probe tip onto a sidewall. For this reason, different types of Teflon-like coatings are deposited onto wafers of mono- and polysilicon material similar to that of the microshutter itself. Subsequent NST measurements are then performed in order to characterise the adhesion and frictional properties of the coatings.

To give an idea of the dimensional limitations involved with the microshutter, some explanation of its operation are needed: electrostatic forces are only used to keep the shutter in the open or closed position, whilst the driving force to switch the shutter from one state to the other is only delivered by the spring energy stored in the suspension beam. The electrostatic voltage is only active over the narrow gap (0.5 - 1 µm) between the shutter blade and one of the electrodes. The shutters are brought to resonance by applying an alternating excitation voltage on one electrode and a direct attraction voltage on the other.

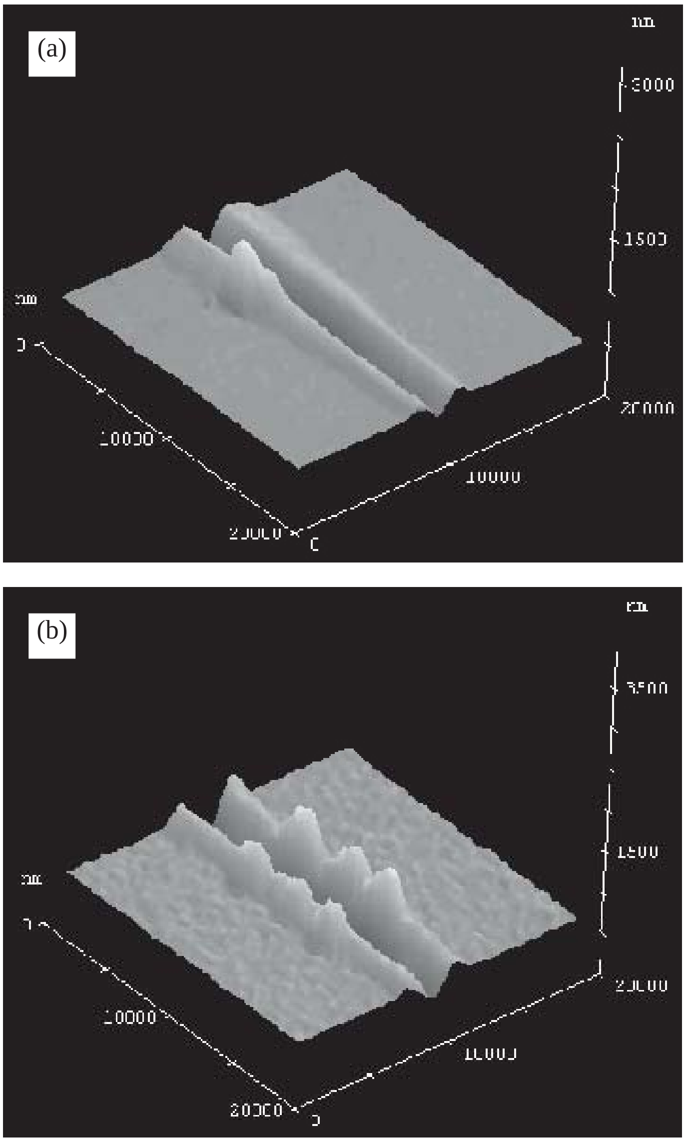

Figure 3 : Scanning Force Microscopy (SFM) images showing the difference in plastic deformation of the deposited polymer coating for a standard polished Si substrate (a) and a polysilicon substrate (b). The images were taken at the main critical point along the scratch path where delamination begins. Note the difference in surface roughness between the two types of sample.

Results

The results presented in Fig. 3 show three-dimensional SFM images of nano-scratches made on the polymer coating deposited on two different substrates. The plastic deformation seems to be more marked for the polysilicon substrate than for the polished Si. The surface roughness is also higher in the case of the former. This factor could well influence the tribological characteristics of the microshutter contacts and so needs to be optimised.

Nano scratch tests were performed on the different sample types with an applied load in the range 0 to 1 mN, using a standard diamond tip of radius 2 µm. A typical result is shown in Fig. 4 for the case of the polysilicon substrate and a distinct change in both the penetration depth and frictional force signals corresponds to the measured critical point. A standard cantilever was used, having a maximum load of 100 mN and a resolution of 1.5 µN. The maximum measured penetration depth was around 0.9 µm and scratch speed was maintained at 2 mm/min.

Conclusions

The Micro Electro Mechanical Systems (MEMS) industry already accounts for over a billion dollars a year and is growing rapidly. Much of the research and development effort is presently concentrated on improving the fabrication processes for various devices. However, there are still many serious issues related to tribology, mechanics, surface chemistry and materials science in the operation and manufacture of MEMS devices. Such issues are currently preventing rapid commercialisation of MEMS systems from taking place.

The solutions lie in a fundamental understanding of friction/stiction, wear and the role of surface contamination and environmental debris in microscale devices. Very little is understood about the tribology of bulk silicon and polysilicon films used in the construction of these devices. Additional problems lie in the characterisation of components *in-situ* within their normal operating environment. Dimensional limitations make it very difficult to place a measuring probe exactly at the interface where tribological modifications take place in service.

The Nano Scratch Tester is a pioneering instrument in the field of surface mechanical properties characterisation. Combined with a scanning force microscope it becomes a very powerful tool for investigating scratch resistance, adhesion, wear, roughness and deformation modes (both elastic and plastic) in both bulk and coated materials.

The example featured in this application note is only one of many systems which can be better understood by adequate characterisation methods. Microelectronic devices no longer consist only of silicon. The recent development of lithography and precision engineering techniques has allowed the use of a large variety of materials, e.g., metals, ceramics, glasses and polymers. Stiction problems need to be solved in all types of devices, e.g., relay contacts, motion-stopping structures, valves, etc. Currently, the friction in bearings is the main requirement for tribology research in non-silicon micro actuators. There is still very little known about the effect of processing parameters (such as doping level, annealing temp. and deposition time), microstructure and specimen size on the micro/nano-mechanical behaviour of MEMS and similar device materials. The Nano Scratch Tester, with its versatile operation modes and high resolution, should prove to be a useful tool in the investigation of many such parameters and their effects on service operation and lifetime.

P. Voumard from CSEM Microsystems and H. F. Knapp from the Nanotechnology Group at ETH Zurich are acknowledged for providing the samples featured in this application note.

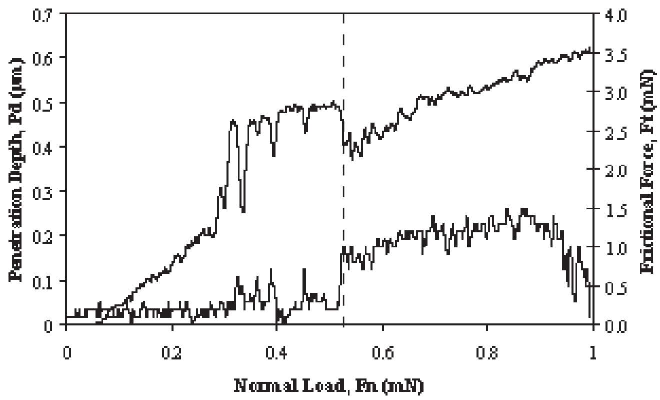

Figure 4 : Typical NST results showing the critical point at which the indenter reaches the Si substrate. The upper curve corresponds to the penetration depth and the lower curve to the frictional force, for the measurement shown in Fig. 3 (b).

In-situ Integrated Circuit (IC) characterisation with the Nano Hardness Tester (NHT)

Introduction

Adequate quality control of integrated circuit (IC) components is fundamental during the development phase, allowing design and process engineers to evaluate the functionality of a new device before it reaches the final package test, where the late realisation of design flaws can be extremely costly in terms of time-to-market issues. Production line control is also important to maintain quality standards and check the properties of materials arriving from outside suppliers.

The Nano Hardness Tester (NHT) has already shown its value in being able to accurately measure the mechanical properties of IC aluminium bonding pads [1]. However, its combination of high positioning accuracy (< 1 µm) and automated measurement of hardness and elastic modulus at a nanometer scale, make it ideally suited to characterisation of many different kinds of IC structure. For example, a modern IC may consist of many circuit tracks which are of deposited gold, copper or aluminium. These are usually thin films of thickness 0.5 - 3.0 µm and the track width may be as small as 10 µm. The substrate may be a relatively hard substrate (e.g., silicon) but in other cases may be a much softer material (e.g., polymer) such as those used for printing heads. The adhesion of the film to the substrate is an important consideration, as is the hardness and elastic modulus.

Nanoindentation can reveal significant information regarding the structural integrity of a certain coating. For the case of aluminium bonding pads, which must serve the dual function of a probe-testing and bonding platform, mechanical properties need to be accurately controlled. Insufficient hardness of the film results in deep scrub marks (during probe-testing) which then prevent a good bonding between the pad and the gold connecting wire. In addition, if the pad is too soft then substantial debris may be produced when the probe tip comes into contact with it, this being a very important consideration in such a particle sensitive environment. Surface topographical observation (e.g., scanning force microscopy (SFM)) is also useful in measuring the surface roughness of IC contacting parts as a high roughness may induce premature wear, or prove detrimental to the functionality of the specific device.

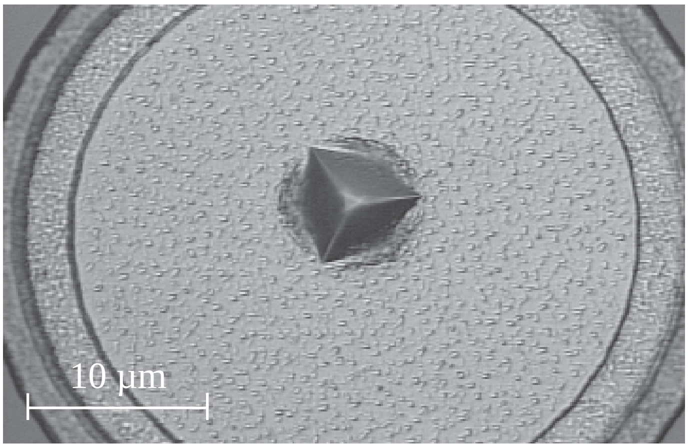

Figure 1 : Optical micrograph of a 200 mN nanoindentation performed on a circular bonding pad consisting of a 1 µm aluminium film deposited onto a Si substrate.

Application

The optical micrograph shown in Fig. 1 shows a 200 mN indentation placed in the centre of a circular bonding pad (pad diameter = 40 µm). In this case, the indentation depth is slightly greater than the pad thickness in order to investigate the deformation which is produced. This can be used to simulate the effect of a probe tip contacting the pad during the device testing procedure. Indenting through the coating can also cause cracking or delamination of certain coatings from the substrate. This allows fracture toughness to be investigated in addition to hardness and modulus. Fig. 2 shows a typical gold conducting track onto which a nanoindentation has been placed. Highly precise position control is required in order to measure the properties of the gold independently to those of the surrounding Si structure. The size of the indentation is also important because if it is too large then the measured mechanical properties may not be representative of the track material alone.

[1] N. X. Randall, E. Holländer and C. Julia-Schmutz, *Characterisation of integrated circuit aluminium bonding pads by nanoindentation and scanning force microscopy*, Surface and Coatings Technology 99 (1998) 111-117

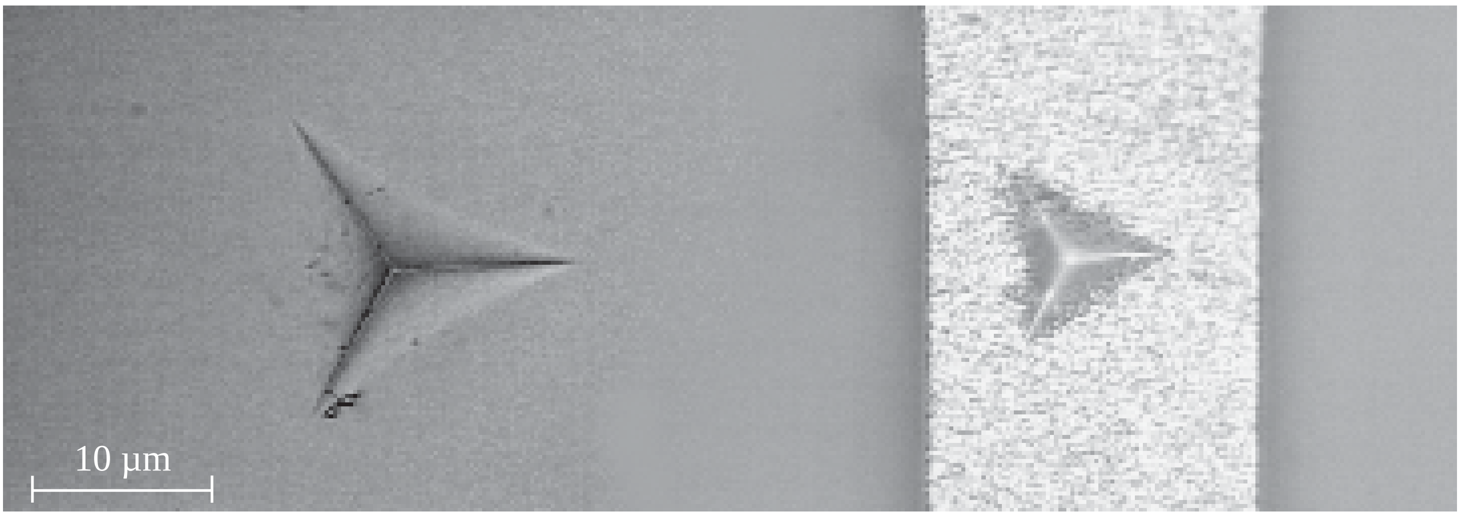

Figure 2 : Optical micrograph of nanoindentations placed in the Si structure of an IC device (left) and on a gold conducting track (right). Note that the positioning accuracy of the NHT allows the indent to be accurately positioned within a track of width 15 µm. The track is produced by lithographic etching, after which gold is deposited by sputtering into the prefabricated channel.

Quality control of Micro-Slit reflective coating with the Nano-Scratch Tester (NST)

The variable-entrance slit system (or *Micro-slit*) is now commonly used as a critical diaphragm component in many spectrophotometers whose principal function is to analyse the molecular fingerprint of liquid samples. This micromachined structure (Fig. 1) consists of a central aperture plate supported by a pair of flexible beams which allow light of different wavelengths to pass through the slit. The aperture plate is coated with a thin (500 nm) aluminium coating which serves the function of masking any light around the aperture.

Characterisation of the adhesion of this Al coating to its Si substrate is difficult owing to the small size of the aperture plate. The Nano-Scratch Tester (NST) has been used to accurately measure the scratch resistance by making progressive load scratches over the load range 0 - 10 mN with a 5 µm diamond tip. Fig. 1 shows two such scratches made on each side of the central slit. Subsequent optical microscopy along the scratch paths allows the critical failure points to be observed: first failure consists of cracking at the sides of the path (Fig. 2(a)), whereas final failure is seen as delamination of the coating from the substrate (Fig. 2(b)). Such measurements confirm the use of the NST as a useful tool for characterising coatings *in-situ* on ultra-small devices where low loads and high positioning accuracy are indispensible.

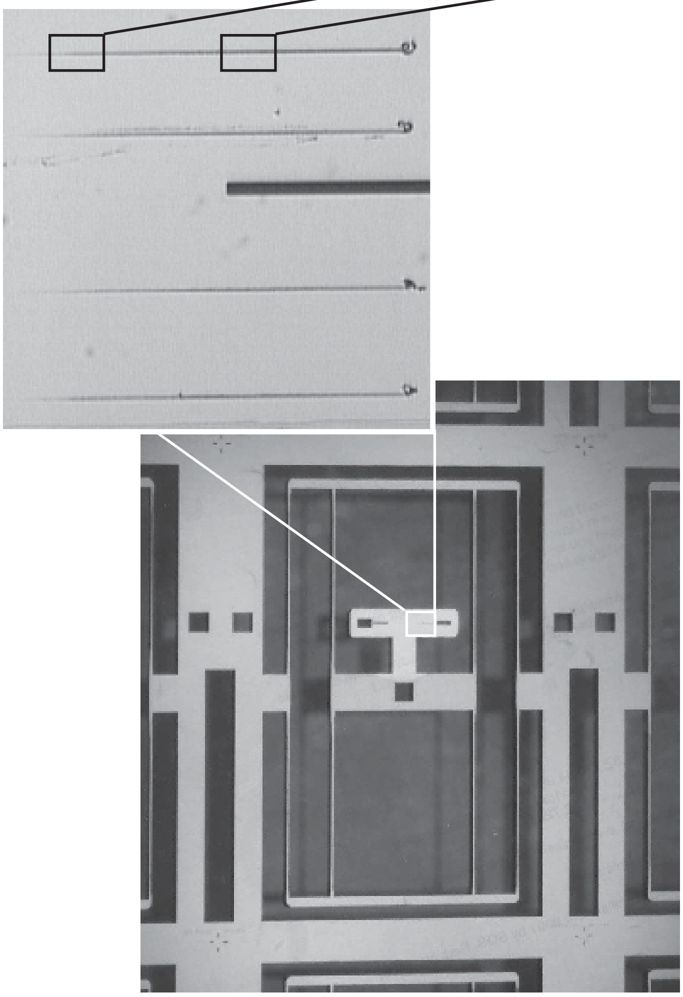

Figure 1 : Optical micrograph of a typical Microslit structure showing the central aperture plate supported by a pair of flexible beams of thickness 80 µm. The zoomed image shows two scratches made on each side of the central slit (scratch direction from left to right).

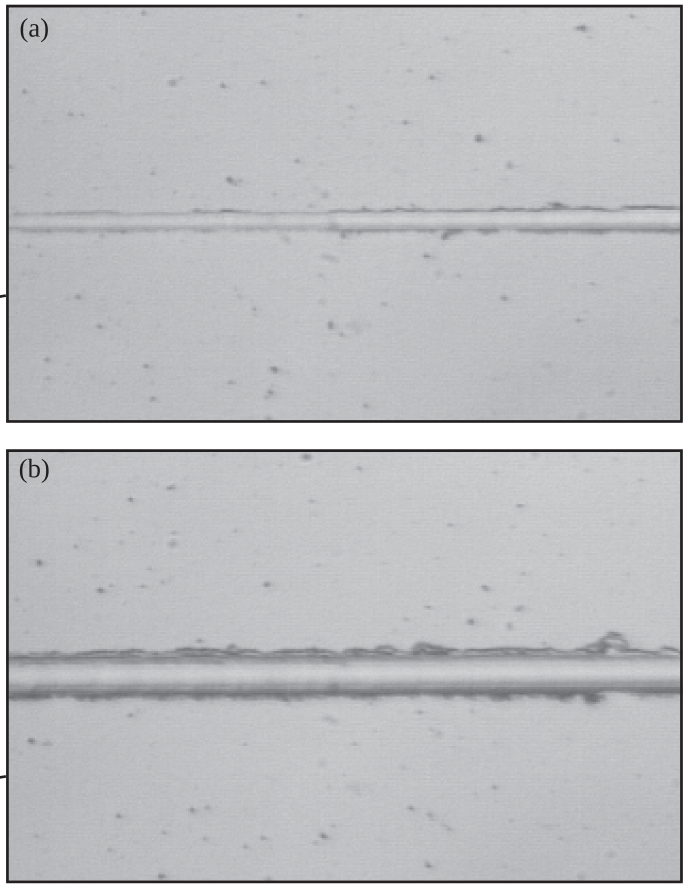

Figure 2 : Optical micrographs of first failure (a) where initial cracking occurs and final failure (b) where the aluminium coating completely delaminates from the Si substrate. These images correspond to one of the scratches shown in Fig. 1.

Instruments

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