Investigating Micro-scale Surface Change of an Ohmic MEMS Switch Contact between Switching Cycles

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Abstract. The leading cause of failure of the Ohmic (metal-metal contact) MEMS switch is through micro-scale wear of the contact surface. The wear is caused by both dynamic mechanical forces and the electrical signal. Characterisation of these contact surfaces has importance in understanding how the surfaces change as a result of wear, as well as the dominant mechanisms of wear for given switching conditions. Measurement of these surfaces has previously limited to measurement at the conclusion of switching. The following describes a novel apparatus for the investigation of the Ohmic MEMS switch contact surface inbetween individual switching cycles, and its use in investigating the early stages of micro-wear during low force (<1 mN) switching of a thin-film Au contact.

Introduction

Ohmic MEMS switches are micrometre-scale electrical components designed to complete, or interrupt, an electrical signal path through making or breaking a conductive pathway. They offer potential for low cost, low insertion-loss and high-isolation switching, of particular value for high frequency signals where the performance of solid-state alternatives falls off. The devices are manufactured using microfabrication techniques, with the conductive contact surfaces formed of metallic thin-films. Practical surface roughness ensures the true contact area is much smaller than the apparent contact area, and limited to locations where surface asperities on opposing contacts touch, or 'a'-spots. A circuit may only be completed where there is a metallic pathway between contacts at an 'a'-spot, thus they cause a constriction of current flow lines and the surface texture gives rise to a constriction resistance. As a consequence, micro-scale wear can have a profound influence on device performance, with the majority of Ohmic MEMS switch failures attributed to the contact surface interface itself **[1,2].**

Several difficulties exist in analytically predicting switching performance. Simplifications that allow macro switch behaviour to be accurately predicted, such as diffusive conduction dominating, materials behaving according to their bulk properties and well distributed 'a'-spots do not hold for the MEMS contact. Several improvements to micro-contact theory have been made; however the distribution and size of the 'a'-spots remain a parameter that can usually only be determined by empirical measurement of the surface **[3,4].** As well as the mechanical effects, the influence of carrying power when operated (hot switching) must also be evaluated on the surface wear process. When hot switching below the arcing threshold this is best described with reference to the Voltage-Temperature relationship that predicts the formation of a molten-metal bridge as contacting asperities undergo separation that driving a fine transfer wear process **[5]**.

The contact wear process is exceptionally complex and not fully described by current literature. Investigating the contact surface in-situ requires the resolution of a-spot features at the micro-scale. The following describes an apparatus to measure the contact surface at the micro-scale, between individual switching cycles and its use to investigate the dry switched wear of a thin film Au contact surface undergoing switching at low force conditions.

Ohmic MEMS Switch Contact Testing Apparatus

An overview of the apparatus is presented in Figure 1. The system allows the precision control of

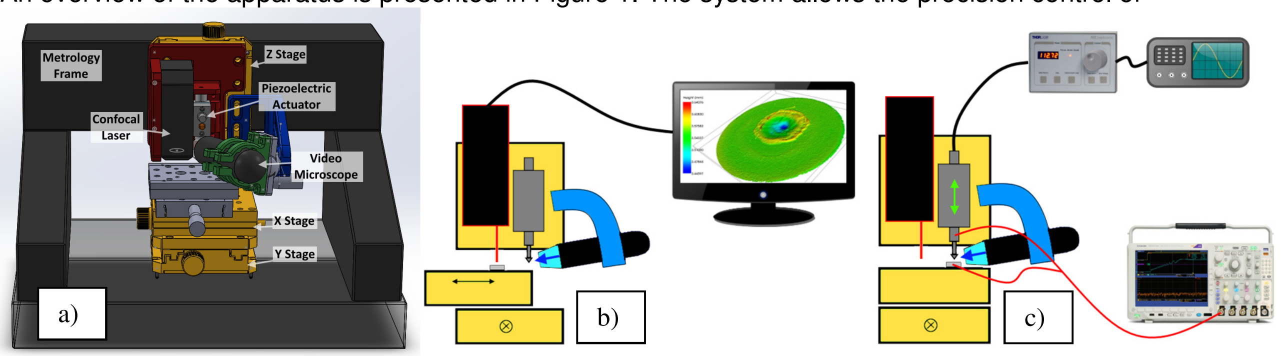

Figure 1. a) the apparatus design and major components, b) schematic of apparatus measuring contact surface with displacement laser and c) schematic of apparatus switching contact

a stationary contact relative to a mobile contact. Separation and reposition of contacts is achieved in an X,Y & Z coordinate reference frame using three motorised linear translation stages (Figure 1a, b & c – shown in yellow). A piezoelectric nano actuator provides fine Z control (10 nm) of the mobile contact and high speed cycling (> 1.25 kHz) for enhanced-rate contact lifetime-testing.

The lower, planar contact is held on the XY stages such that it can be located in the XY reference coordinates. A granite structure supports the Z translation stage above the XY stages. The Z stage also carries, a video microscope, for visually showing the contact positions) and a laser displacement meter. The fixed contact surface is mapped by translating the XY reference frame below the laser displacement meter (shown in Figure 1b) such that a raster scanning displacement mapping of the contact surface is recorded.

The electrical characterisation of the contact resistance at closure is recorded using a 4-wire Kelvin probe method and micro Ohmmeter (Keithley, USA). While the voltage transient at opening, corresponding to the molten-metal bridge rupture is recording using a high speed digital storage oscilloscope (Tektronix, USA). Visualisation of the contact approaching the surface is achieved using a 400x video microscope integrated to the system.

Evolution of the Surface of a Dry Switched Au Thin Film Contact

The evolution of a thin film Au contact is presented in colour maps of the measured surface height (Figure 2.a,b &c). The transfer of contact material back and forth between contacts as a result of individual switching cycles is demonstrated. The transfer pattern is validated by examination of the surface after switching using conventional microscopy (Figure 2d).

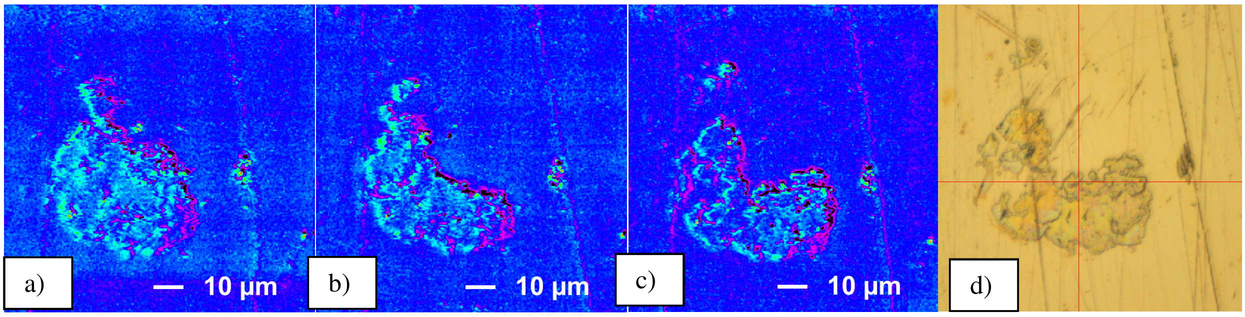

Figure 2. Contact surface mapping showing film delamination and transfer between contacts after a) 3 switching cycles, b) 4 switching cycles, c) 10 switching cycles and d) same region under 500x conventional microscopy after switching

Conclusion

A novel apparatus for investigating the contact evolution of an Ohmic MEMS switch contact is described and demonstrated detecting wear on a thin film Au contact at MEMS scale forces. The apparatus is capable of resolving the microscopic change in contact morphology as the result of individual switching operations. The wear process of a simple Au film contact is then investigated between individual switching events during initial contact "bedding in". The surface damage process is revealed to be a complex wear arising from plastic contact separation linked to film delamination wear, as well as molten metal bridge events, responsible for more subtle surface wear. The wear process is shown not to be a simple cumulative process; rather the process is highly complex with seemingly catastrophic damage arising very early from a low number of switching cycles. This damage is shown to be partially or fully repaired by subsequent switching events and provides insight to the unpredictable and catastrophic failure mode previous observed in Au films where they are employed as MEMS contacts.

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