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Metal-armouring for shock protection of MEMS☆

A.K. Delahunty*, W.T. Pike

Optical and Semiconductor Devices Group, Imperial College London, United Kingdom

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ABSTRACT

This paper demonstrates a novel concept for the shock protection of MEMS suspensions: solder is incorporated within the sidewalls of the suspension to produce protective metal armouring. This provides solder–solder contact at the extremes of the suspension travel, greatly increasing the shock resistance. Model suspension systems were fabricated using deep reactive ion etching (DRIE) and shock tested in a drop-test rig at acceleration levels up to 6000 × g. The solder armour proved to absorb ~90% of the collision kinetic energy and double the shock resistance of the MEMS suspension.

1. Introduction

With MEMS becoming increasingly commonplace in many different industries, the need for more robust microstructures that can withstand high shock environments is now more important than ever. Consumer electronics need to be able to reliably withstand accidental drops, sensors used in the automotive industry as well as MEMS being considered for Military applications [1] need to cope with severe in-use conditions and because of their easy integration with IC circuitry and their reduced mass and power consumption, MEMS are now being used for space applications where they are required to survive significant shock and vibration forces during both the launch and separation stages as well as during deployment and operation [2].

Current shock protection methods for MEMS include *external protection methods*: mechanical latching [3], electrostatic clamping [4], electromagnetic clamping [5] and encapsulating the devices in a wax which sublimes in the vacuum of space [6], or *internal protection methods*: optimising dimensions to withstand a known force [7] or using squeeze film damping [8], compliant non-linear springs [9,10], hard shock-stops [11], metal armouring [9], parylene coatings [10] or microglass beads [12] to dissipate energy. A shock absorber which is suitable for both space and terrestrial applications and which can absorb significant amounts of energy without needing a power source or without adversely affecting the performance of the device does not currently exist. This work presents a novel shock-protection method for MEMS which successfully satisfies these requirements.

2. Design concept

Providing a shock absorber which can absorb the energy of an impact is an effective method of increasing the robustness of a MEMS device. When designing shock protection the aim is to absorb the maximum amount of energy within a minimum amount of time, with energy generally being absorbed through the deformation of solids, either through plastic flow or controlled brittle fracture [13]. We propose using solder as a form of metal armouring to protect the silicon suspension during a shock event; replacing brittle silicon–silicon impact with ductile solder–solder impact. The solder should deform upon impact, absorbing large amounts of energy in the process and eliminating the risk of brittle silicon fractures.

Metal armouring was first proposed to mitigate shock damage by Yoon et al. [9]. Using softer materials at the point of impact, the number of collisions as well as the post-shock settling time is reduced. However the sidewall deposition of gold which they propose should reduce the impact forces, but such metallisation is not straightforward, and the limited thickness of metal constrains the protective potential. We have previously used solder reflow on metal pads to produce more substantial bumpers able to undergo significant plastic deformation. These are fabricated to overhang the collision points of the suspension (Fig. 1a). However although

* Corresponding author. Tel.: +44 (0)20 7594 6242.
E-mail addresses: a.delahunty09@imperial.ac.uk, aifricd@gmail.com (A.K. Delahunty).

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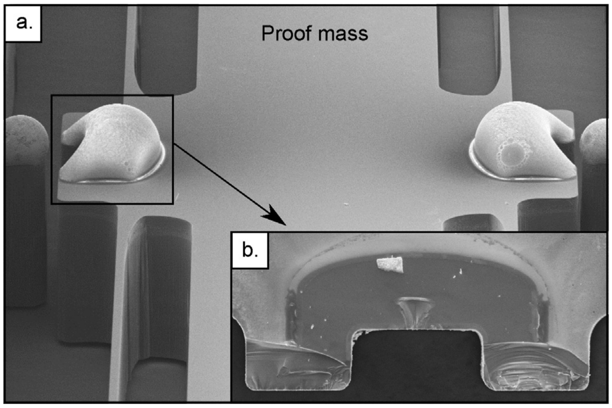

Fig. 1. (a) Bumpers created through the reflow of solder on metal pads (before shock testing), (b) solder bumper failed at the pad–wafer interface during a shock event. The damage at the silicon bumper tips occurred during rebound after the solder bumper de-adhered and was no longer available to protect the silicon.

enhancing the robustness, upon collision these bumpers can fail due to de-adhesion at the pad–wafer interface (Fig. 1b).

This work, originally reported here [14], avoids the limitations of both sidewall metallisation and pad-mounted bumpers: the solder is incorporated directly into the sidewall by reflow of solder balls in through-wafer conduits. The resulting bumpers collide at the centre of percussion of the suspension, and should absorb maximum energy from the fundamental mode of the suspension, and minimise the excitation of cross-axis modes.

3. Fabrication

3.1. Silicon suspension systems

Model suspensions, consisting of folded cantilevers either side of a proof mass, were fabricated using through-wafer deep reactive ion etching (DRIE) (Fig. 2a). High quality vertical sidewalls are achieved by using a Halo mask [15,16] to minimise the effects of both microloading [17] and etch lag [18] and a thin sacrificial aluminium layer is deposited on the back side of the wafer using a thermal evaporator to prevent notching at the foot of the microstructure [19]. The aluminium provides a conductive layer which eliminates charge build up towards the end of the etch, otherwise a positively charged insulator surface will deflect the ions towards the sidewall resulting in a lateral etch. Once etching is complete the aluminium layer is stripped.

3.2. Solder bumpers

The collision points at the centre of the suspension incorporate conduits that can accommodate two solder balls (Fig. 2b) which reflow to form the bumpers which are mechanically keyed in place (Fig. 2c): two 300 μm-diameter $Sn_{3.0}Ag_{0.5}Cu$ solder balls reflow to form bumpers in a 500 μm-thick wafer. The solder balls are lightly dipped in flux before being placed in the through-wafer conduits. The flux helps (a) to keep the solder balls in place before reflow and (b) to promote reflow between the two balls. A solder rig with a conductive heating stage and a sealed chamber is used for reflow. Nitrogen gas is used to purge air in the sealed chamber prior to heating, and the stage is heated to a peak temperature of 260 °C, remaining above the melting temperature of the solder (220 °C) for a minimum of 5 min.

4. Bumper design

4.1. Conduit geometry

The final reflow profile of the solder was simulated using Surface Evolver [20], which uses finite element analysis (FEA) to calculate the equilibrium shape of the molten solder subject to relevant constraints and forces; namely surface tension, gravity, the geometric

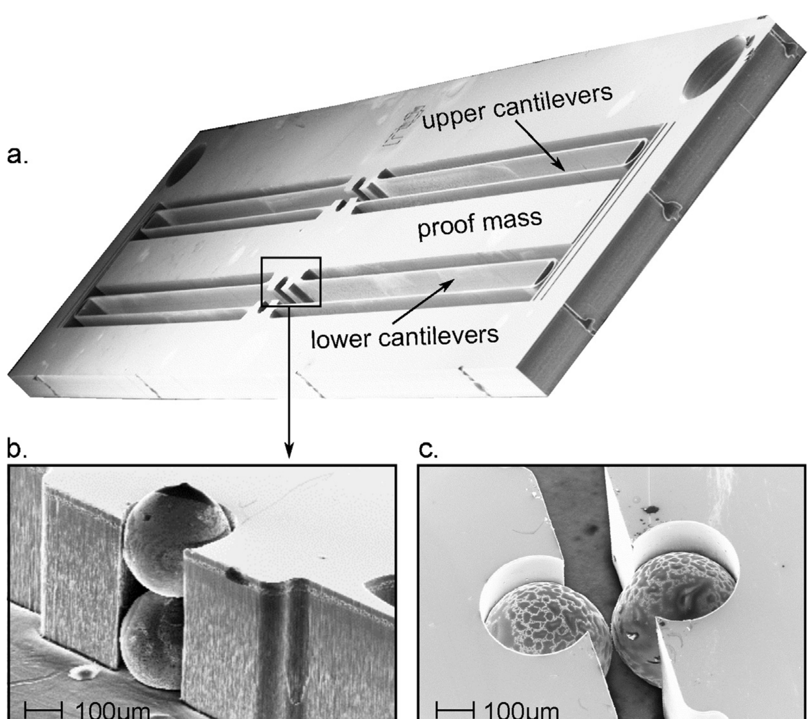

Fig. 2. (a) Model suspension system, (b) solder balls before reflow, and (c) solder bumper after reflow.