MEMS Reliability Alliance
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UNRELEASED POLYSILICON BEAM FAILURE

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The MEMS Reliability Alliance is composed of three core institutions:

(1) MEMScaP S.A., a MEMS software company who provides the MEMS-Pro design software.
(2) Cronos Integrated Microsystems, a wholly-owned subsidiary of JDS Uniphase. Cronos provides a polysilicon surface micromachining process (MUMPs™) to the international MEMS community.
(3) Jet Propulsion Laboratory, which provides the MEMS test structure design, release etching, testing, and characterization.

An array of polysilicon beams were fabricated on the MUMPs37 run. An example array is shown in Figure 1. These beam arrays, designed by Mr. Gary O'Brien at the University of Michigan, contain cantilever beams of various lengths and widths in both vertical and lateral configurations. These beams were designed to study stiction phenomena after release etching.

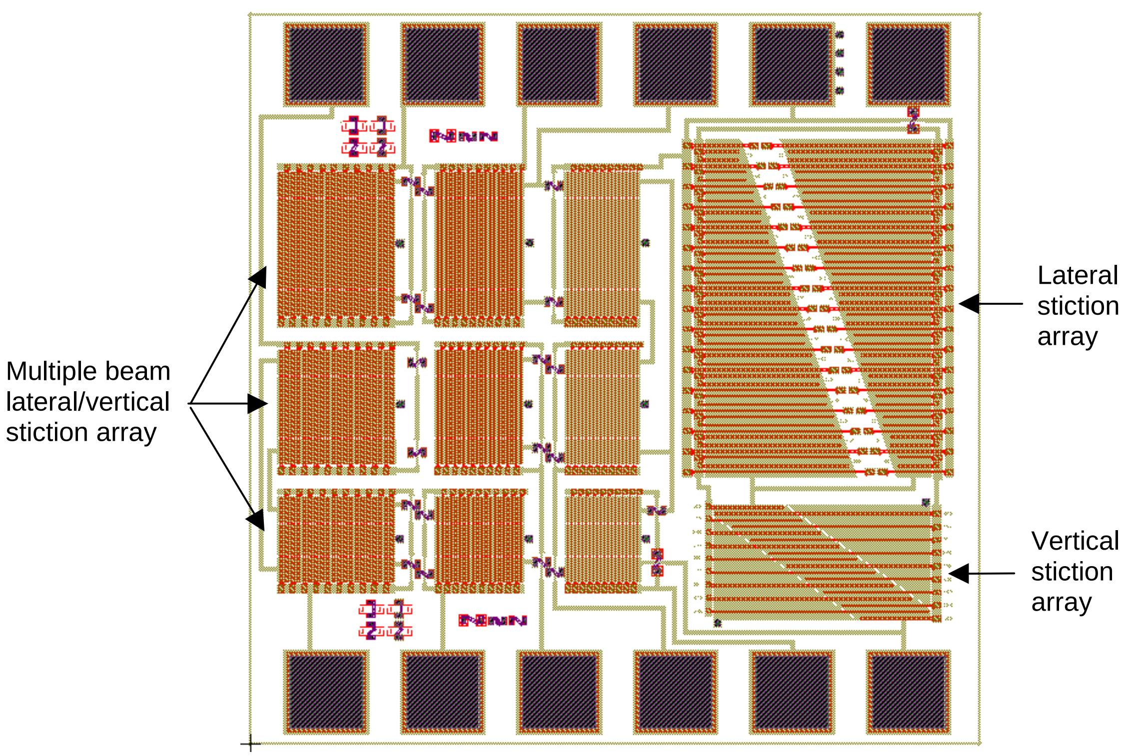

Figure 1. Example beam array on MUMPs37 run.

Both poly1 beam arrays and poly2/poly1 beam arrays were fabricated. The cross section of the poly2/poly1 beams is shown in Figure 2. The poly1 beams have a similar cross section, but without the poly2 layer. Also, the poly1 beam arrays are covered with 0.75µm of oxide (oxide #2 in the MUMPs layer sequence).

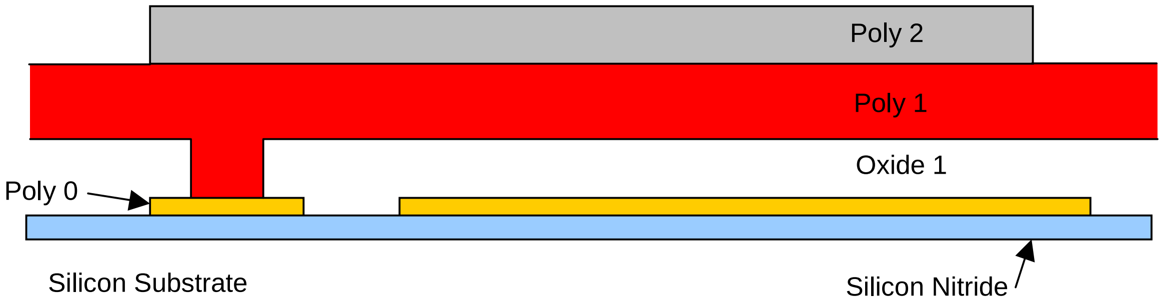

Figure 2. Cross section of poly2/poly1 beam. Poly2 is 1.5µm thick, poly1 is 2.0µm thick, oxide1 is 2.0µm thick, poly0 is 0.5µm thick, and the silicon nitride is 0.6µm thick. Poly1 is a continuous, anchored sheet.

Of particular interest are the poly2/poly1 beams in the lateral/vertical stiction array. A close-up of one set of beams in this array is shown in Figure 3. Beams varied from 2 - 6µm in width, and 120 - 200µm in length. The gap between beams was 2µm (for the 6µm and 4µm beam widths) and 3µm for the 2µm wide beams.

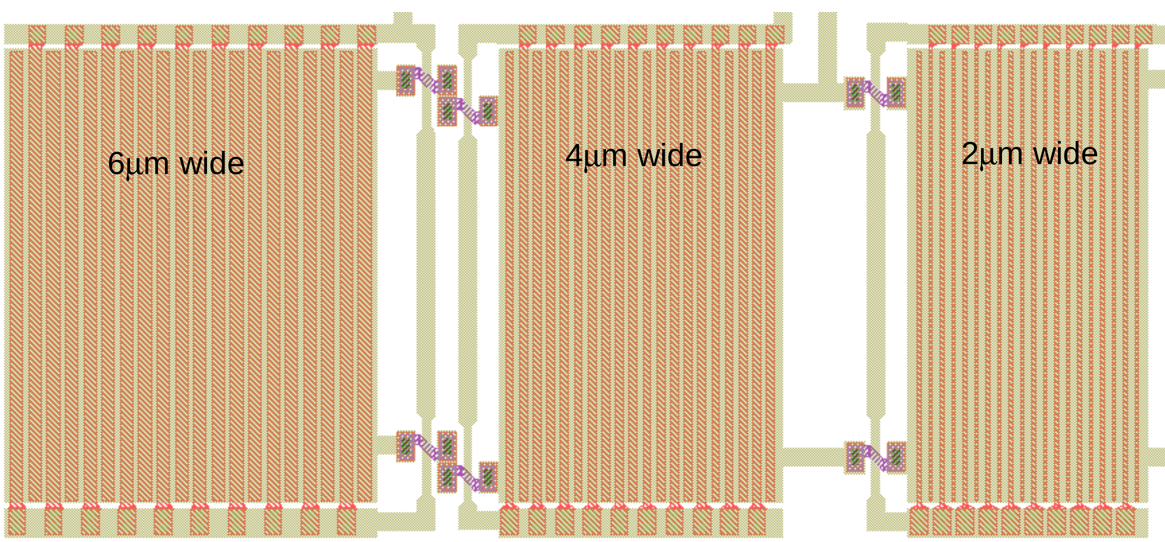

Figure 3. Close-up of the top view of a lateral/vertical stiction beam array.

It was found that the poly2/poly1 2µm wide beams did not survive wafer dicing. As shown in Figures 4 - 7, the damage was extensive to this array. The cause of failure is presumably the pressure of the water jets in the dicing saw. The dicing cuts were made perpendicular to the beams. Thus, the force due to the water jets is perpendicular to the beam as affects the entire length of the beam. Damage occurred only on the 2μm wide poly2/poly1 beams. As shown in Figure 4, 4μm wide beams survived in tact. All poly1 beams survived due to the protective oxide 2 layer that covered them (these die were not released, so all oxides were still present).

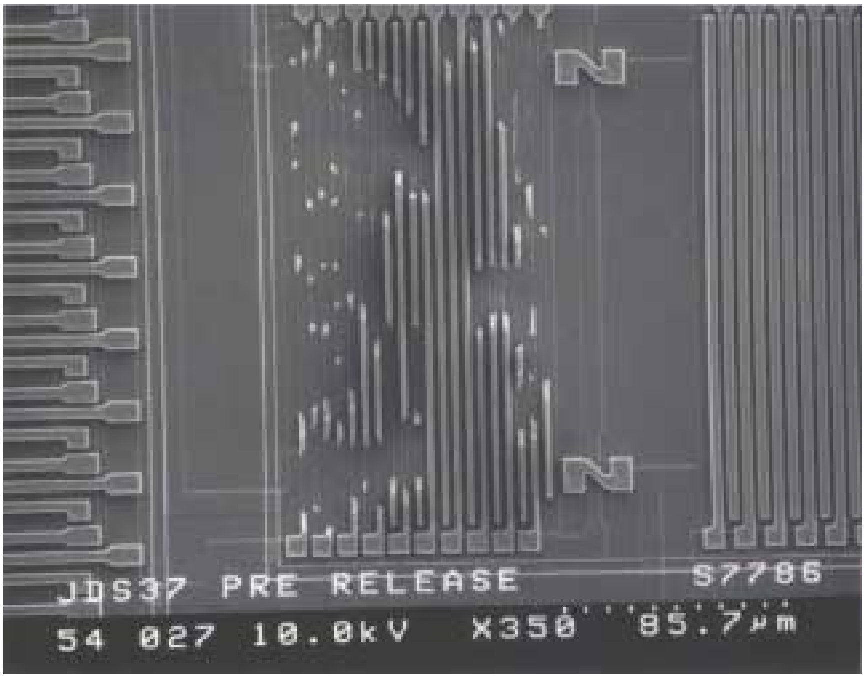

Figure 4. SEM photo of beam array, top view. As shown, 2μm wide poly2/poly1 beams (center) were damaged during wafer dicing. 4μm wide poly2/poly1 beams (right) were not damaged.

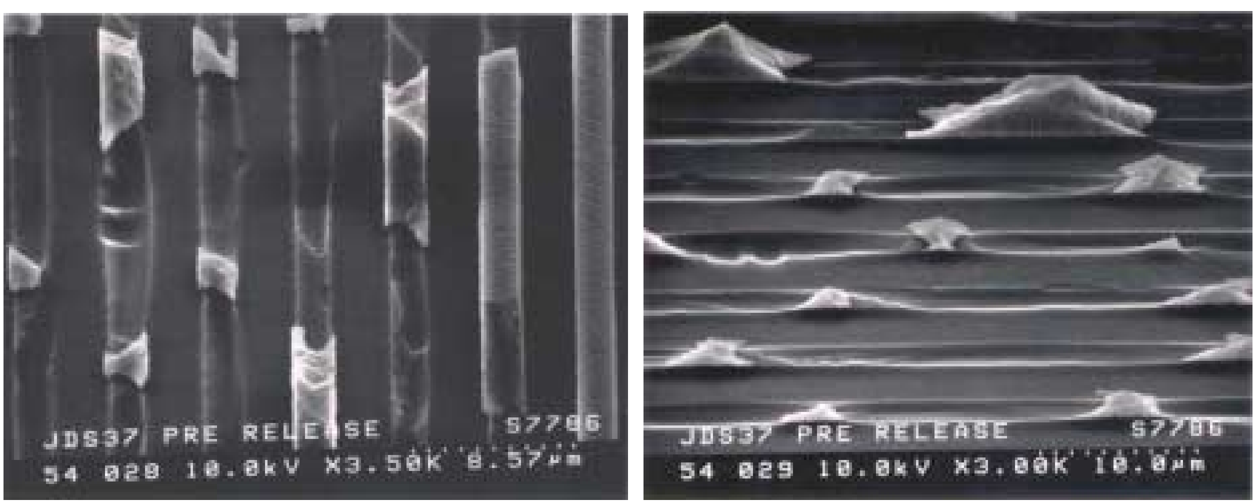

Figure 5. Perspective views of the damaged area. During wafer dicing the poly2 broke off from the poly1 sheet beneath, leaving behind an indentation. The remaining poly2 appears brighter in color.

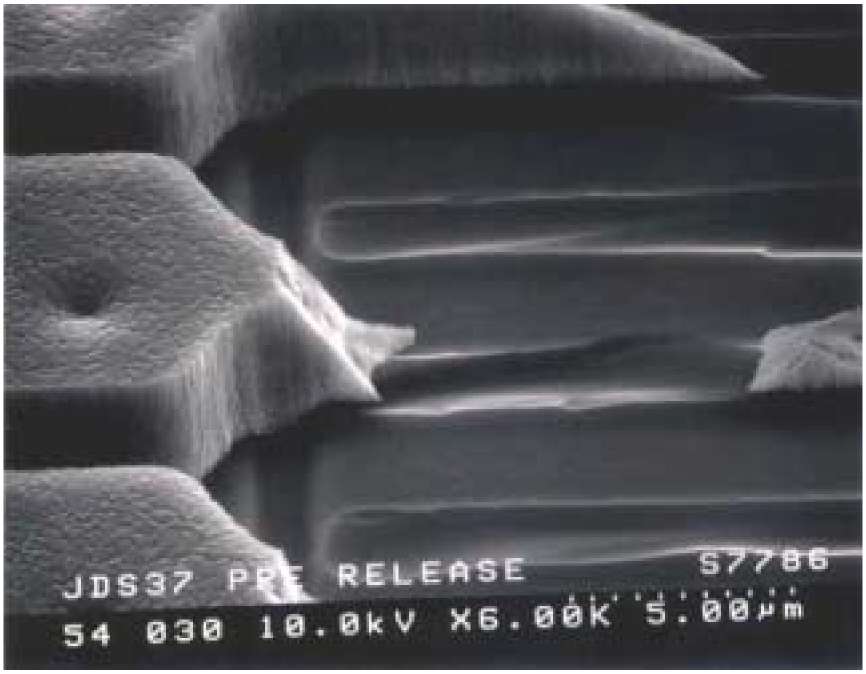

Figure 6. Close-up perspective view of the poly2 portion of the beam anchor, and indentations after beam damage. The indentations appear smooth and well defined.

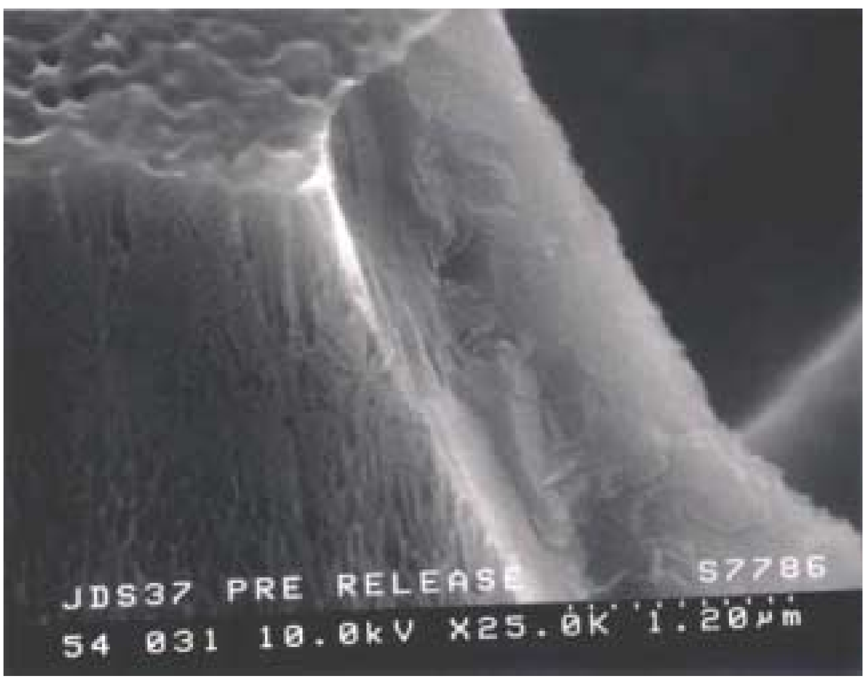

Figure 7. Close-up of the anchor portion of the center beam in Figure 6. The remaining poly2 portion of this beam shows relatively smooth surfaces and microcracking.

Based on the data gathered from Figures 4 - 7, it appears that the adhesion of poly2 to poly1 is strong, such that when the poly2 portion of the beam is exposed to excessive force, a portion of the poly1 is broken off with it (hence the indentation). The amount of force that caused the failure can be estimated by the following equation:

$$F_{\max} = \frac{2\varepsilon_{\max} EI}{bL}$$

where ε_{max} = fracture strain of polysilicon (0.01), E = Young's modulus for polysilicon (10^{11} Pa), I = moment of inertia for the poly2 portion of the beam, b = beam width, and L = beam length. The moment of inertia for the poly2 portion of the beam can be described by:

$$I = \frac{ab^3}{12}$$

where a = beam thickness. To establish an upper limit on fracture force, we use the longest beams (200μm × 2μm × 1.5μm). In this case, since the direction of applied force is perpendicular to the beam, a = 200μm, b = 2μm, and L = 1.5μm. Using these values in the above equations, $F_{max} \approx$ 90mN. Thus, the applied force on the beams was **at least 90mN** to cause fracture.

It should be noted that prior to the wafer dicing, all beams underwent a 20 minute ultrasound bath to clean any photoresist residue off the chips. Although under the optical microscope, the beams looked intact afterwards, none of the beams were inspected for microcracks. It is possible that microcracks may have been initiated in the 2μm wide poly2/poly1 beams during the ultrasound bath, which propagated during wafer dicing until failure. Further studies will need to be performed to confirm whether microcracks were formed.

Conclusions

- The poly2 portion of 2μm wide poly2/poly1 beams was damaged during wafer dicing, presumably due to the pressure exerted by the water jet, perpendicular to the beams, during wafer dicing. The applied force on the beams was at least 90mN, causing fracture in the beams.

- All other beams remained intact after wafer dicing.

- Poly2 adhesion to poly1 appears to be strong, since the poly1 under the poly2 beams is also missing, resulting in indentations in the poly1.

- Microcracks may have been initiated in the 2μm wide poly2/poly1 beams during a 20min ultrasound bath prior to wafer dicing, which propagated during wafer dicing until failure.