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A Standard Method for Measuring Wafer Bond Strength for MEMS Applications

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A round robin, to provide precision and bias data for SEMI standard MS5-1107, Test Method for Wafer Bond Strength Measurements Using Micro-Chevron Test Structures, is underway. The precision and bias data, combined with experience in applying the test instructions included in MS5-1107, will provide the basis for an updated version of MS5. Measurements at the pilot lab have been completed, and the round robin is on-going at six additional laboratories.

Background

Chevron structures have been commonly used for measuring fracture toughness by providing a structure with a pre-defined point from which a crack will propagate (1). Typically, a chevron is ground into the long axis of a rectangular block of material, such as shown in Figure 1; the structure is tested in a materials testing machine by applying force at the points shown.

The micro-chevron test structure (2) is fabricated by patterning a chevron notch into a wafer; this patterned wafer is then bonded to an unpatterned wafer, and the 10 mm by 10 mm structure is removed by dicing the wafer. The micro-chevron structure, as defined in MS5, is shown in Figure 2. Since each of the bonded wafers is thin, the long axis of the chevron structure shown in Figure 1 is not present; therefore a different approach must be taken for applying the forces needed to measure the bond strength. The method required to measure such a geometry and bonded structure is described in MS5-1107 (3).

One advantage to using the chevron and micro-chevron method is that there are characteristic curves associated both with successful and unsuccessful tests. This gives immediate feedback indicating whether the results from a particular test should be further analyzed.

SEMI MS5-1107

SEMI MS5-1107 is concerned with measurement of the fracture strength of a bonded wafer pair. Figure 2 shows the details of the design of the micro-chevron test structure. A wafer is patterned to leave one or more plateaus in the shape of a chevron. This patterned wafer is bonded to an unpatterned wafer or an unpatterned region of a patterned wafer. [Note that the actual bonding method is beyond the scope of the standard.] After bonding, the micro-chevron test structure is diced from the wafer. Since the patterned features may not be visible on the now-bonded wafer pair – unless one of the wafers is transparent – the location of the chip may need to be identified via infrared transmission. Alternately, sawing guides may be etched into the patterned wafer before bonding. This technique requires double-sided patterning capability. The specific method for identifying the location of the micro-chevron chip is also beyond the scope of MS5-1107.

Although the dimensions of the micro-chevron are not specified, the recommended dimensions of W and B are 10 mm for each. Note that each unique chevron geometry requires finite element modeling (FEM) and that, at this time, FEM modeling for only the 10 mm by 10 mm geometry (2, 4) is included in MS5-1107.

A key aspect of the micro-chevron test is attachment of the specimen to the materials testing machine. MS5-1107 specifies the dimensions of the contact points between the mounting studs and the micro-chevron, as well as the locations where the studs are to be mounted to the micro-chevron; the contact method and the method of interfacing the studs with the material testing machine are considered beyond the scope of the standard, since several methods may be used which are expected to give satisfactory results.

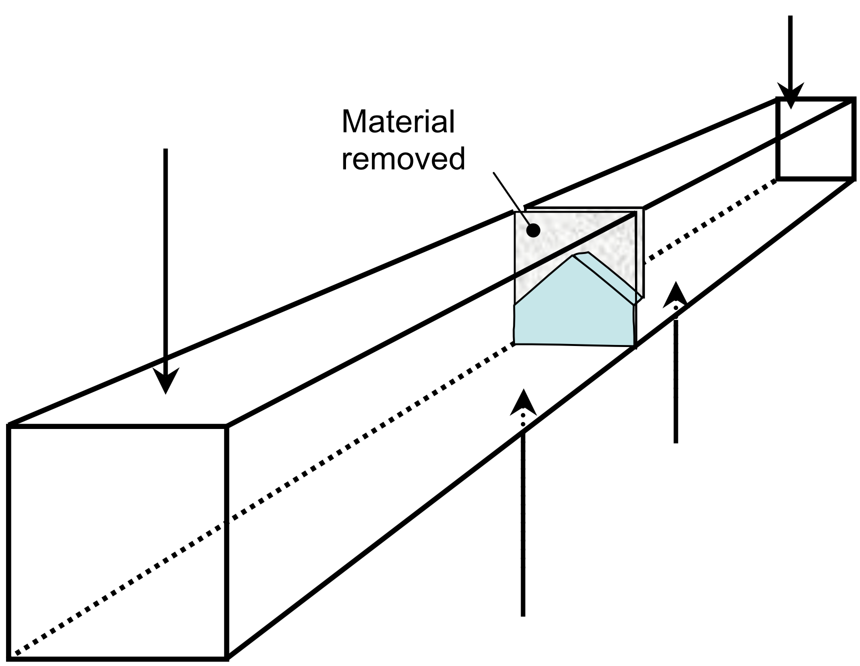


Figure 1. Conventional chevron-notch test structure. The forces are applied at the four points shown.

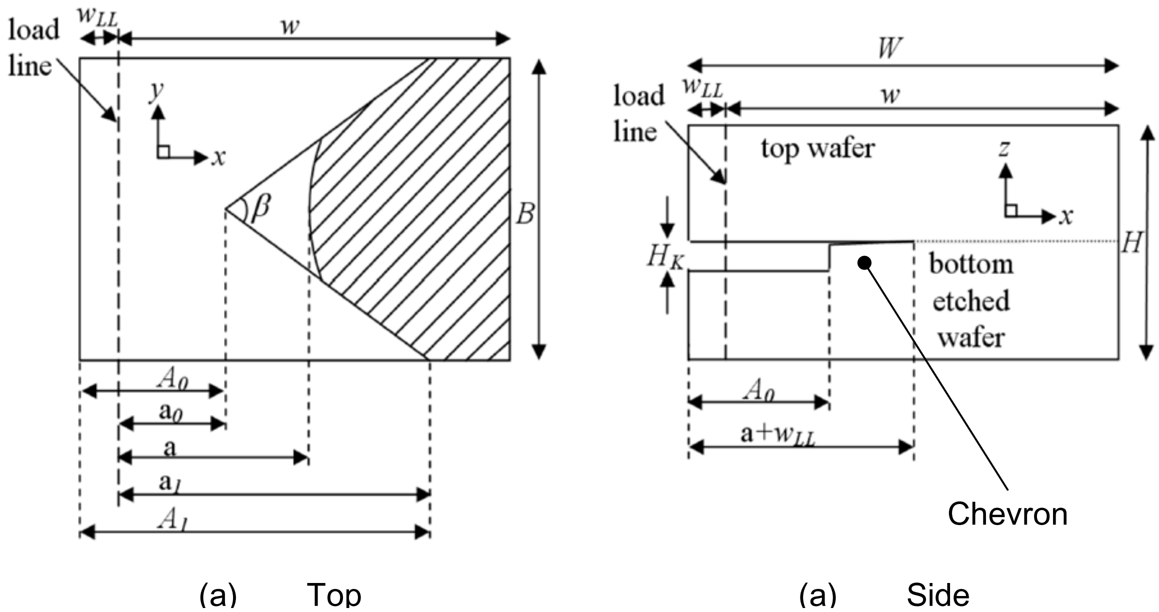


Figure 2. Key dimensions of the micro-chevron test structure described in MS5-1107. The recommended values of W and B are 10 mm each.

Pilot Lab Study

One of the seven researchers who had volunteered as a participant in the round robin was asked to serve as a pilot for the round robin. Twenty-five micro-chevron samples as well as a copy of MS5-1107 were delivered to this researcher. Further, this researcher was asked not to seek additional clarification to the experimental procedure described in MS5-1107 from any source other than the experiment coordinator. This was done to allow for the clarification of any instructions in MS5-1107 that are unclear.

The twenty-five samples were divided into three groups, T, R, and S, designated as follows: the five T samples were identified for test purposes, to allow for checking the system and setup; the fifteen R samples were identified as the Round Robin samples; and the five S samples are for retention by the lab for any future work.

During the pilot process, several steps in MS5-1107 were deemed to be not fully clear. The team used this feedback to modify section 10 of MS5-1107.

The first issues noted were related to the alignment of the sample and stud during the gluing process. Whereas the interface dimensions of the stud are specified by MS5-1107, the actual gluing process is not specified as part of the standard. The standard specifies that the studs must be aligned to the end of the sample to within a small distance and rotation. The intended placement is specified in the standard, but not a method for verifying that the target placement is achieved, beyond visual inspection of the placement of the studs relative to the target location. The gluing process chosen by the pilot lab used a gel-type cyanoacrylate. One issue identified by the pilot laboratory was that the glue must be kept out of the mouth of the sample. There appeared to be a correlation between cases where the glue entered the mouth of the chevron and the force versus displacement did not follow the expected characteristic curve (see Preliminary Results, below). It is planned that an appendix describing one or more gluing process(es) will be added to future versions of MS5 as non-mandatory "additional information."

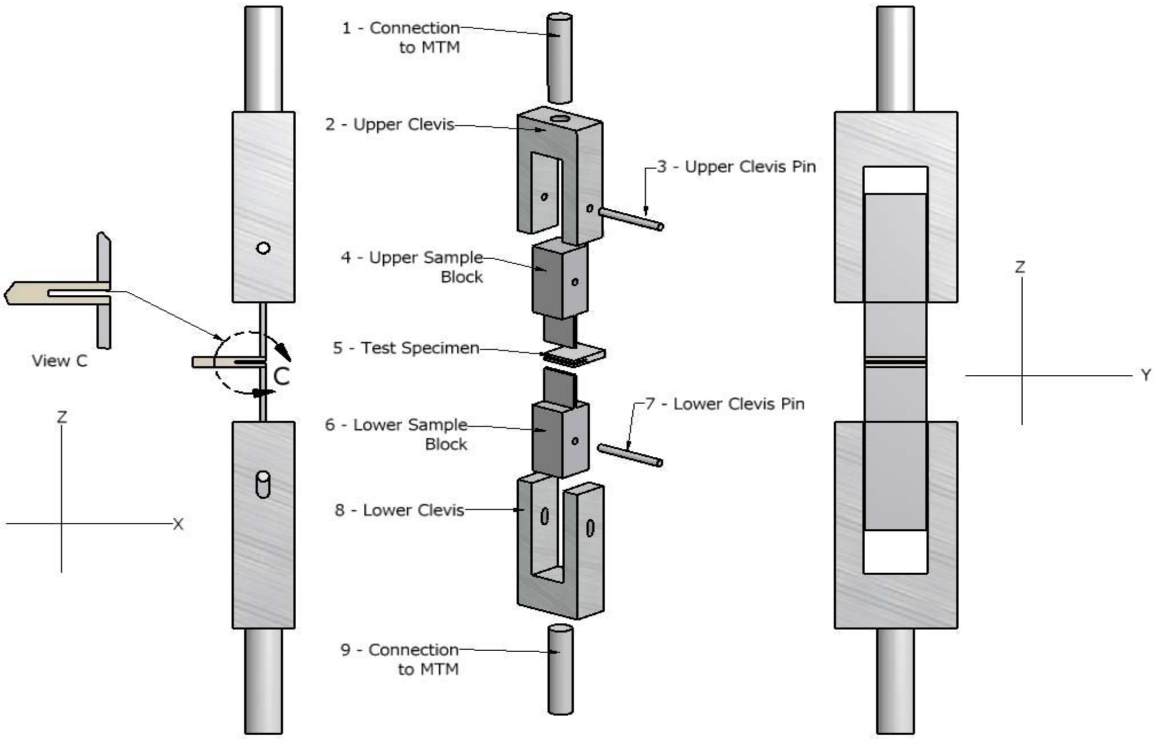
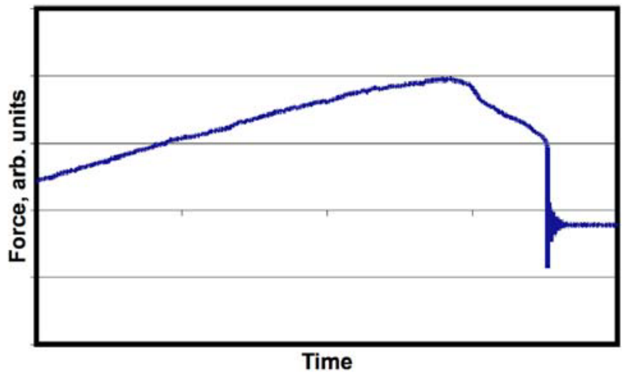


Figure 3. Suggested configuration for interfacing the micro-chevron to a materials testing machine.

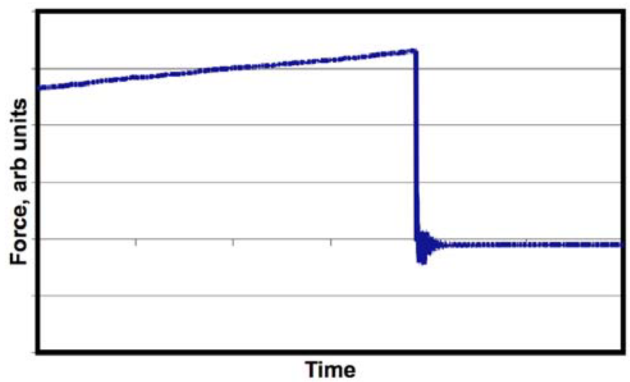
Another issue identified was providing an acceptable interface between the studs and the material testing machine. Since significant time was required to develop an acceptable interface, it was decided that the interface chosen would be described to the round robin participants and, as with the gluing process described above, added as an optional "additional information" section to MS5. A drawing showing this interface is shown as Figure 3.

It was also observed that the pull rate specified in MS5-1107 was too high to get optimal data. The new recommended pull rate is < 0.05 mm/s; this is being specified to the other participants in the round robin study.

An additional issue raised in the pilot study was the identification of the correct information that should be captured for analysis of the micro-chevron test structures. In consultation with the researcher at the pilot laboratory, a data sheet with spaces for collecting the required data was prepared. In addition to use in the pilot study, copies of the data sheet were included in the package sent to the remaining laboratories in the round robin.



(a)



(b)

Figure 4. Typical curves for a (a) successful measurement and (b) “failed” test. The curve for a failed test implies that the sample failure was due to some mechanism other than bond failure.

Alignment of Studs

MS5 specifies the recommended alignment. This is an area that may need further work to identify how much variation in the stud alignment can be accepted before the structure no longer works adequately.

Preliminary Results

Details of the pilot lab study will be published, along with the data from the remaining laboratories, upon completion of the round robin. The data from the pilot laboratory showed that the results were generally well behaved, with the data following one of the two characteristic curves for chevron-type structures. The two curves, shown as Figure 4(a) and Figure 4(b), are typical of a characteristic test and an anomalous test, respectively. While both tests show that the test structure has been measured to failure, the case represented in Figure 4(b) is typical of a failure other than bond rupture.

Round Robin/Future Work

The remaining laboratories participating in the round robin have, as of the date of this writing, received packages containing similar sets of twenty-five micro-chevron test structures. In addition to the samples and the copy of MS5-1107, the following additional information was sent to the labs:

1. Outline with schedule and contacts at the participating laboratories.
2. A test protocol, describing the expected steps and instructions for returning the data and fractured round robin samples to the experimental coordinator.
3. The modified test procedure, discussed above, to replace the steps specified in section 10 of MS5-1107.
4. Twenty-five copies of a data reporting sheet.
5. CD containing soft copies of this information.

Data taken by the participating laboratories are to be analyzed by the round robin organizing team, rather than the individual laboratories, using on-line tools provided by NIST (4).

The round robin is expected to conclude by the end of 2008, with an updated version of MS5 to be balloted and published soon after.

Modifications to MS5

The precision and bias information found through the round robin and any corrections and clarifications to the test procedure will be added to MS5, and the new version will replace the existing standard. This change will include replacing most of section 10, which is the detailed description of the test procedure, with a version based on the information sent in the package to the round robin participants. In addition, the information on the process for gluing the sample to the studs, as well as a description of one or more methods for connecting the studs to the materials testing machine, as mentioned above, will be added as appendices that are not formally part of the standard.

Future Activities

The micro-chevron has been identified as a possible candidate for development into a NIST Standard Reference Material® (SRM). SRMs (5) are certified reference materials issued by NIST that also meet additional NIST-specific certification criteria. They are, therefore, issued with a certificate or certificate of analysis that reports the results of its characterizations and provides information regarding the appropriate use(s) of the material. An SRM is prepared and used for three main purposes:

1. To help develop accurate methods of analysis.
2. To calibrate measurement systems used to facilitate exchange of goods, institute quality control, determine performance characteristics, or measure a property at the state-of-the-art limit.
3. To ensure the long-term adequacy and integrity of measurement quality assurance programs.

A micro-chevron SRM would allow for the verification of the test implementation and calibration of the test system for the user of the micro-chevron.

A future technical direction is the investigation of the effect of misalignment—both linear and rotational—on the outcome. This will require additional finite element modeling of non-ideal situations and determining how well the equations specified in MS5-1107 describe a micro-chevron test under non-ideal bonding conditions.

Acknowledgments

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