Teaching Lab Course on Electronic Packaging and Materials

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Abstract

With support from the National Science Foundation, we have developed a new lab course, *Electronic Packaging and Materials,* which is jointly offered by the Departments of Mechanical Engineering, Materials Science and Engineering, and Electrical Engineering. The lab project consists of three parts: Lab 1, *Dissection of Electronic Packaging*; Lab 2, *Processing of Electronic Packaging*; and Lab 3, *Reliability Testing of Electronic Packaging*. To complete the three labs, six weeks were required; one week for Lab 1, three weeks for Lab 2, and two weeks for Lab 3. Students were able to gain a good understanding on the electronic packaging. Future improvements planned for the course include expansion of the lab subjects, adding more experimental equipment, and establishing a closer correlation between the lectures and lab sessions.

Introduction

The lab course on Electronic Packaging and Materials (EPM) is the part of a program to establish a comprehensive electronic packaging program at the University of Washington sponsored by the National Science Foundation (NSF). A lecture course on EPM has been offered annually since Spring, 1995. However, it was realized that a single course without a lab section could not cover the entire area of EPM. As a first attempt, a new laboratory course was given in Winter, 1998 along with the lecture course.

The new laboratory course as well as the lecture course on EPM were jointly offered by the Departments of Mechanical Engineering (ME), Materials Science and Engineering (MSE) and Electrical Engineering (EE). The target students were undergraduate seniors and first-year graduate students. In total, 21 students took the lab section, 10 from ME and 11 from MSE, but none from EE. All the ME students were undergraduates and 7 out of the 11 from MSE were graduate students. This laboratory offered two sessions, a Tuesday session with 12 students and a Thursday session with 9 students.

The laboratory consisted of three main subjects: Lab 1, Dissection of Electronic Packaging; Lab 2, Processing of Electronic Packaging; and Lab 3, Reliability Testing of Electronic Packaging. The laboratory started in the fourth week of the quarter in order to allow students to obtain a basic understanding of EPM before they started the hands-on laboratory experience. To complete three laboratories, six weeks were required; one week for Lab 1, three weeks for Lab 2, and two weeks for Lab 3. A detailed time schedule and procedures are shown in Table 1. Basically, individual work and an individual lab report were required from each student, however, Lab 1 and Lab 3 were conducted as a group project, but still required an individual report.

Course Content

Lab 1: Dissection of Electronic Packaging

The objective of Lab 1 is to have students understand the common package features by examining the cross-section and components of electronic packaging (wire bonding, die, and lead frame). Three common plastic-based surface-mount packages, Plastic Quad Flat Package (PQFP), Plastic Leaded Chip Carrier (PLCC), and Small Outline Package (SOP), were prepared (Fig. 1). These packages were already molded and dissectioned by the Teaching Assistance (TA) ready for grinding and polishing in the lab. Students were divided into three groups with three or four students in each group and assigned each package. Photographs of specimens were taken with a low magnification (40x) stereoscope in one of the MSE laboratories followed by polishing. Students investigated four different package features: cross-section (A), wire bond (B), circuit pattern on the die (C), and lead fingers and die (D) (Fig 2). Students reported the 2-dimensional and 3-dimensional features of the assigned package, and the function of each component and its requirement. This was a group project, but an individual report was required.

Lab 2: Processing of Electronic Packaging

Based on the knowledge obtained from Lab 1, students experimented with Chip-On-Board (COB) processing (Fig. 3). This lab continued for three weeks, the first week for die attachment (Lab 2-1), second for wire bonding (Lab 2-2), and third for polymer encapsulation (Lab 2-3). Fig. 4 shows the entire processing steps in Lab 2. The die and the substrate were designed by the TA and fabricated by the Micro Fabrication Lab and the Physics Electronic Shop, respectively, at the University of Washington (Fig. 4 (a)). The die was a fully n-doped silicon 1 cm x 1 cm x 0.04 cm. The substrate was made of a polyimide-based PCB by etching with a centered Cu paddle and four Cu strips, which replaced a die paddle and lead fingers, respectively.

For Lab 2-1 (Fig. 4 (b)), firstly, students cleaned a given die and substrate with methanol to get rid of dust, finger prints, etc., and then measured the resistance (R_1 and R_2. Fig. 4 (a)) of a Si die between two corresponding Al bond pads. A die was placed on a specified area on a substrate after an epoxy-type adhesive was used. The assembly was then cured at room temperature for 6-8 hours. The assignment for that week was a summary of the lab and three wire bonding techniques – thermocompression, ultrasonic, and thermosonic – as the preparation for the next step.

For effective time management, Lab 2-2 (Fig. 4 (c)) was conducted with an hour interval on one day. A group with three or four students learned and practiced the thermosonic wire bonding technique with 0.001” diameter Au wire within one hour and performed their own bonding on their own specimen successfully. For security, students made three or four Au wire bonding on each bonding pad to a Cu strip on the substrate. Each student took optical microscope photos of ball bonds and wedge bonds after the bonding (Fig. 5). At that time, a summary of the lab and a report on the properties and advantages and disadvantages of three common encapsulant materials were assigned.

The last step was the polymer encapsulation (Lab 2-3, Fig. 4 (d)). By use of dispensing systems, high viscosity (1,200,000 cps) encapsulant dam material was used to create a dam around the desired area and then cavity-fill encapsulant (20,000 cps) was applied to fill the cavity formed inside the dam. The curing step was followed at 150°C for one hour in a mechanical convection oven. Once all steps were done the final measurements of resistance across the ends of each Cu strip (R_{t1} and R_{t2}. Fig. 4 (e)) were performed again. Students were asked to write up a final report at the end of Lab 2 covering all the steps from the die attachment to encapsulation and analysis of the relationship between the measured resistance and the length of two bonding pads. The resistance of the longer distanced bond pads (R_2) was supposed to be two times that of the short one (R_1). This was individual work and an individual report.

Lab 3: Reliability Testing of Electronic Packaging

This was designed to help students enhance their knowledge on electronic packaging under severe environmental conditions. Students were required to understand the effect of various testing conditions. A high relative humidity (RH) and high temperature testing condition, for 1000 hours was selected due to the equipment capability. An TIL 117, optocoupler from Texas Instruments, Inc., was used for this purpose (Fig 6). This lab consists of two parts, the initial measurements (Lab 3-1) and the final measurements (Lab 3-2).

The Lab 3-1started in the week following Lab 1, since it needed a long period for completion. However, due to the time limitation, Lab 3 was conducted for 672 hours (4 weeks) rather than 1000 hours. The Lab 3-2 was done upon the completion of Lab 2. To study electrical performance, the test package in the circuit was tested with 10V and 1000Hz signals and the rise (t_r) and fall (t_f) times were measured (Fig. 6). By comparing the electrical performance and the microstructure of the package before and after the 85%RH/85°C testing, students were able to understand the effects of high temperature and high humidity on a plastic encapsulated package. The expected results were the increase in t_r and t_f (Fig. 7), and package fracture due to deformation of metallization, ball bond fracture, passivation layer cracks, package cracks, chip cracks, and voids in the encalpsulant (Fig. 8).

Successful Cases and Failure Cases / Future Improvement

Lab 1: Dissection of Electronic Packaging

The main work of Lab 1 was grinding and polishing. Students from MSE, who were already exposed to grinding and polishing procedures from other departmental lab courses, did quite well, while the ME students had a difficult time, which is evident from the fact that the ME students' specimens had many big and deep scratches. However, under low magnification stereoscope observation, the scratches were not obvious. Overall, this lab was successful.

Lab 2: Processing of Electronic Packaging

Problems surfaced during the Lab 2-2, wire bonding, due to the brittleness of the Au wire, the corrosiveness of the Cu strips on the PCB, and the thickness and thermal non-conductivity of the PCB. Because of the brittleness, we wasted time rethreading the wire to the capillary. Cu is a corrosive material even at room temperature. To remove the corrosion layer, students sanded the wire bonding area with abrasive paper before starting the bonding. Nevertheless, the Cu corroded again when it was heated up to 150°C for thermosonic wire bonding. It was concluded that a thin Au coating on PCB should have been done in advance to prevent the Cu strips from corroding. Also changing the substrate material from a polyimide (thermally non-conductive) to a ceramic (thermally conductive) would be recommended for easier bonding. In spite of these difficulties, each student could learn thermosonic wire bonding technique within 15 to 20 minutes and performed their own bonding successfully.

As the part of the final results, students were requested to measure the resistance from the one end of Cu strip to the another end (R_{t1} and R_{t2}. Fig. 4(e)). Students were expected to see some changes in resistance after completion of this procedure because the resistance of Au wires and Cu strips should be summed for the total resistance. However, because of the high resistance of the Si die and the low readability of the digital multimeter, the changes in the electrical resistance were not so noticeable. To improve Lab 2, a relatively low resistance Si die and highly readable multimeters should be used.

Lab 3: Reliability Testing of Electronic Packaging

Students were to have observed various failure modes in a given plastic package. However, 85%RH/85°C testing for approximately 672 weeks was found to cause only die cracks or wire bonding openings. This may be due to the fact that the packages were already exposed to reliability testing before being marketed. If the specimen made in Lab 2 were used, Lab 3 would be more interesting and more productive.

By electrical measurement, each group measured t_r and t_f of a given optocoupler. Each group was given only one optocoupler, which gave students non-reliance data. Use of more than five samples per group would be recommended.

Students Feedback

Almost all the students stated that they had fun and a great learning experience from this hands-on experiment. The laboratory had been most helpful in their understanding of important details of EPM. Some of their comments are as follows: (1) lack of correlation between classroom lectures and the lab contents. The lectures gave great weight to ME subjects such as analysis of stresses and strains, heat transfers, and so on. On the other hand, lab subjects were focused on MSE subjects, for instance, processing and macrostructure issues, (2) lack of equipment. We had only one microscope, one wire bonder, and one set of electrical characteristic measurement equipment in the EPM laboratory, and (3) lack of lecture time for reliability issues. Since reliability is a broad area in the area of electronic packaging and, more over, one of the laboratory topics was reliability issues, one week was not be enough for students to understand the subject completely.

Conclusion

In summary, the laboratory was most effective in enhancing the students' knowledge of EPM in general. A better correlation between lectures and laboratory sessions would be advantageous. Also having multiple sets of good quality equipment would be recommended for more effective teaching and learning. We are also developing a second EPM course with a strong emphasis on electrical properties of Integrated Circuit (IC) and packages. In addition, we plan to offer one or two graduate EPM courses next year.

References

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Biographical Information

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Youngmee Lee received BS in Metallurgy and Materials Science from the Hong-Ik University, Seoul, Korea in 1996. She is a currently a candidate for the Master's degree, conducting research on conductive adhesives and developing a laboratory course on Electronic Packaging and Materials, in the Department of Materials Science and Engineering at the University of Washington.

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Minoru Taya is Professor of Mechanical Engineering at the University of Washington. His research interests are in the areas of Electronic Packaging, Composites, Smart Materials, and Functional Gradient Materials. Dr. Taya is a Fellow of ASME, a Fellow of the American Academy of Mechanics, and was a past ASME Materials Division Chair. He currently serves as the chair of a joint committee of ASME EEP and Materials Divisions on Electronic Materials. He serves as Associate Editor for the *Journal of Applied Mechanics*.

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Yasuo Kuga is Professor of Electrical Engineering at the University of Washington. He has served as an Associate Editor of *Radio Science* (1993-1996) and *IEEE Trans. Geoscience and Remote Sensing* (1996-present). His research interests are in the areas of microwave and millimeter-wave remote sensing and high frequency devices.

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Mani Soma is Professor of Electrical Engineering and Associate Dean for Organizational Infrastructure, College of Engineering at the University of Washington. His research interests include the design, test, and reliability characterization of integrated circuits and systems. He is chairing a major industry-driven curriculum development effort, the IEEE Test Education Committee in the Computer Society. As Associate Dean, he works with the College faculty and ABET in curriculum and teaching improvements to meet the new ABET 2000 criteria.

Table 1. Time schedule, used equipment, and procedures

Week	Laboratory Subject Procedures	Used Equipment
4th	**Lab 1 : Dissection of Electronic Packaging ***	
	1) Grinding and polishing assigned specimen 2) Taking low magnification photos.	QPFL, QLCC, SOP, abrasive papers, grinder and polisher, stereoscope.
5th	**Lab 3-1: Reliability Testing of Electronic Packaging -- Initial Measurement ***	
	1) Circuit construction for optocoupler 2) Measurement of rise time and fall time 3) Exposing to 85%RH/85°C for approximately for 4 weeks.	Optocoupler, circuit board, oscilloscope, function generator, multimeter,
6th	**Lab 2-1: Processing of Electronic Packaging -- Die Attachment ****	
	1) Cleaning a die and a substrate with methanol 2) Dispensing die attachment material 3) Die attachment 4) Curing at room temperature for 6~8hours.	Si die, substrate, epoxy-based adhesive, methanol, spatulas, wipers.
7th	**Lab 2-2: Processing of Electronic Packaging --Wire Bonding ****	
	1) Sanding wire bonding area on Cu and cleaning a die and substrate surface with methanol 2) Heating the die-substrate assembly up to 150 °C and thermosonic wire bonding 3) Measuring resistance between corresponding Cu strips 4) Taking pictures of ball and wedge bond with microscope.	Die-substrate assembly (from Lab2-1), Au wire (0.001" diameter), thermosonic wire bonder, abrasive papers, methanol, wipers, microscope.
8th	**Lab 2-3: Processing of Electronic Packaging –Encapsulation ****	
	1) Damming with the dam material and filling with the cavity-filling material 2) Curing at 150 °C for 1 hour 3) Measuring the final resistance between corresponding Cu strips.	Die-substrate assembly with wire bond (from Lab 2-2), epoxy-based encapsulant (dam material and cavity-filling material), dispenser, oven.
9th	**Lab 3-2: Reliability Testing of Electronic Packaging – Final Measurement ***	
	1) Same as initial measurement before environmental testing, 2) Comparing and analyzing results from Lab 3-1 and Lab 3-2.	Optocoupler, circuit board, oscilloscope, function generator, multimeter,

* Group project and individual report.
** Individual project and individual report

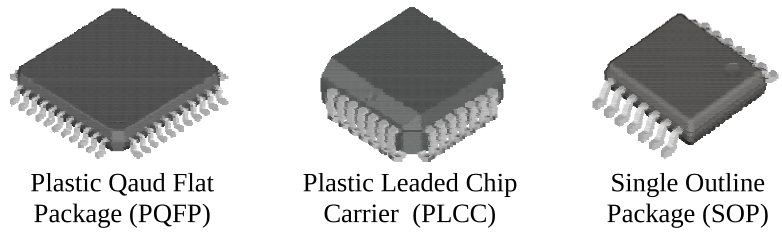


Fig. 1. Three common surface-mounting plastic packages [1]

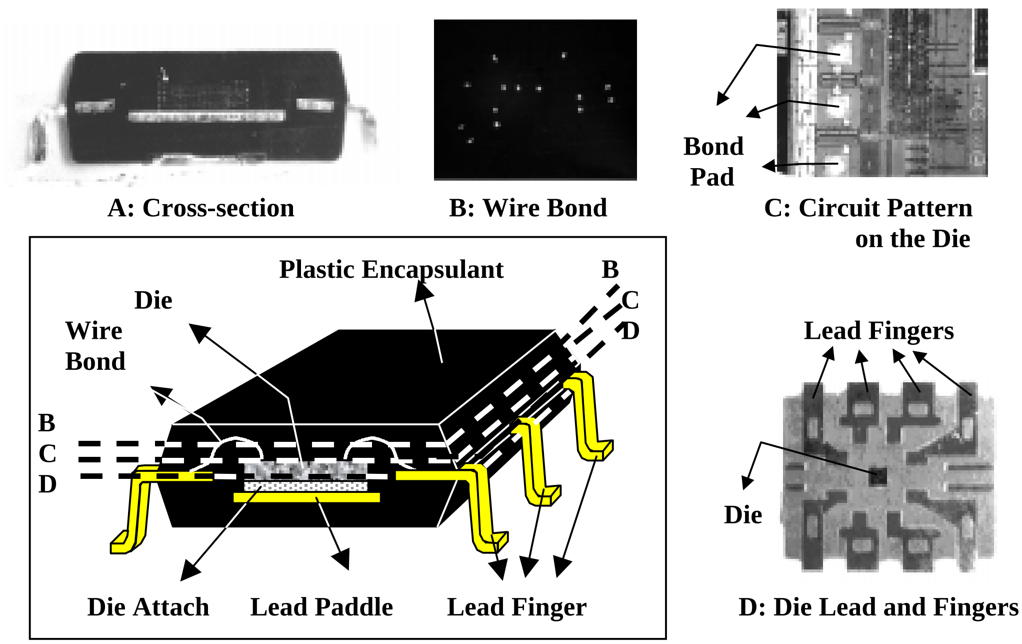


Fig. 2. Expected final results from Lab 1 (in the case of SOP)

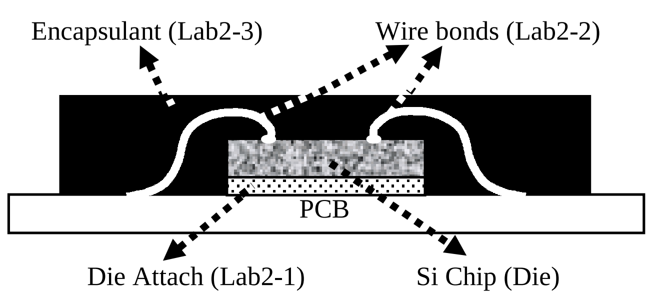
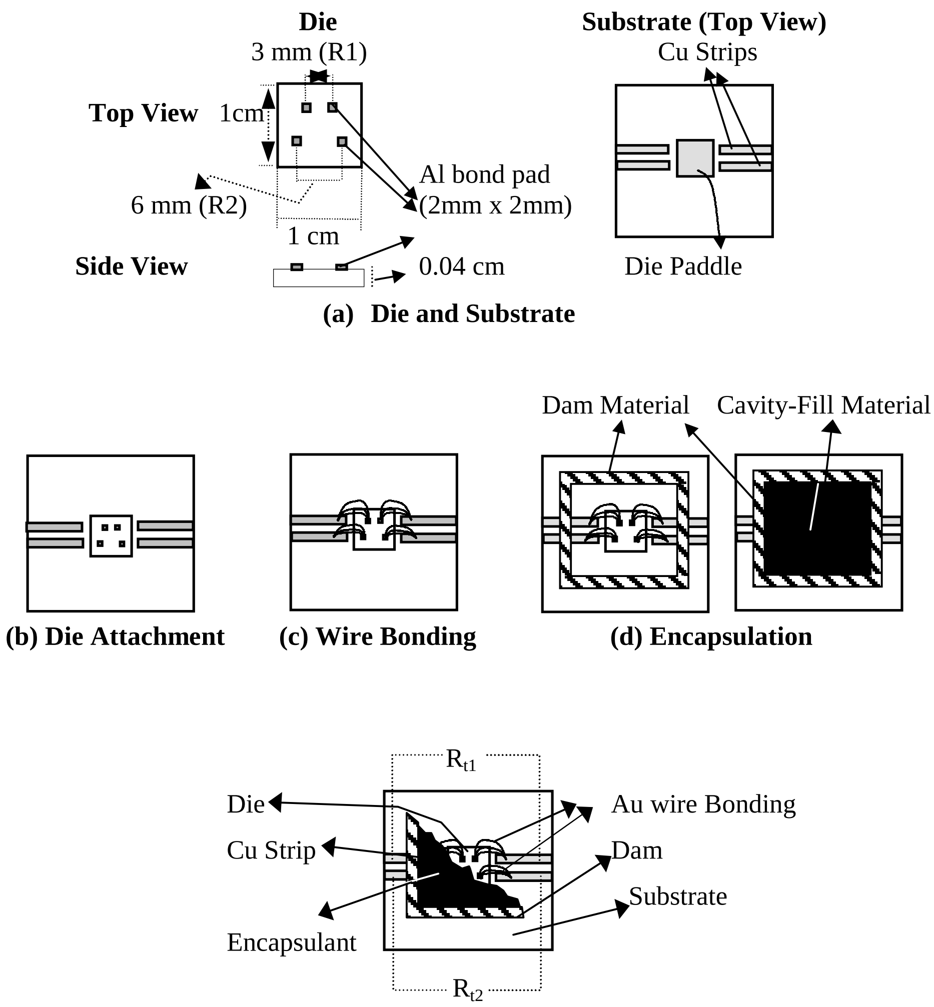


Fig. 3. Cross-section of typical Chip on Board (COB)[4]

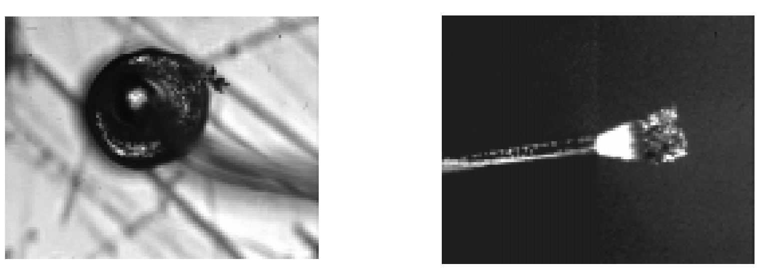


(a) Die and Substrate

(b) Die Attachment **(c) Wire Bonding** **(d) Encapsulation**

(e) Final Measurement

Fig. 4. Processing steps of Lab2[4]



(a) Ball Bond on the Die **(b) Wedge Bond on the Substrate**

Fig. 5. Ball-wedge bond made by a student in the lab

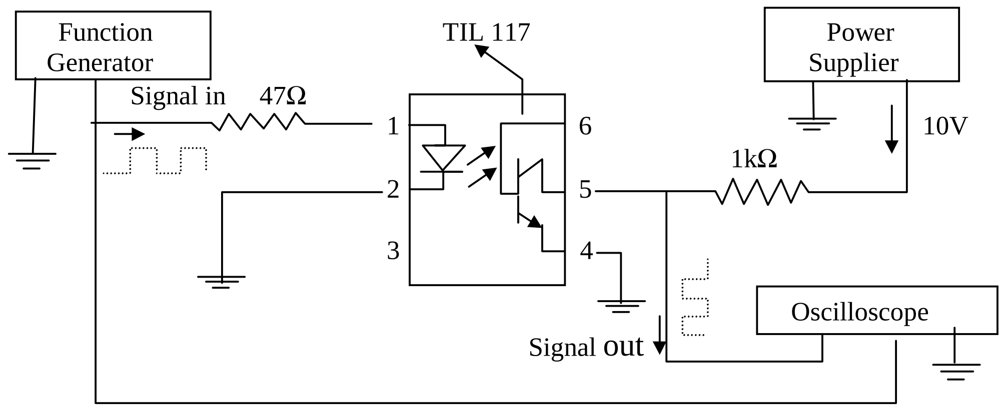


Fig. 6. Test Circuit[3]

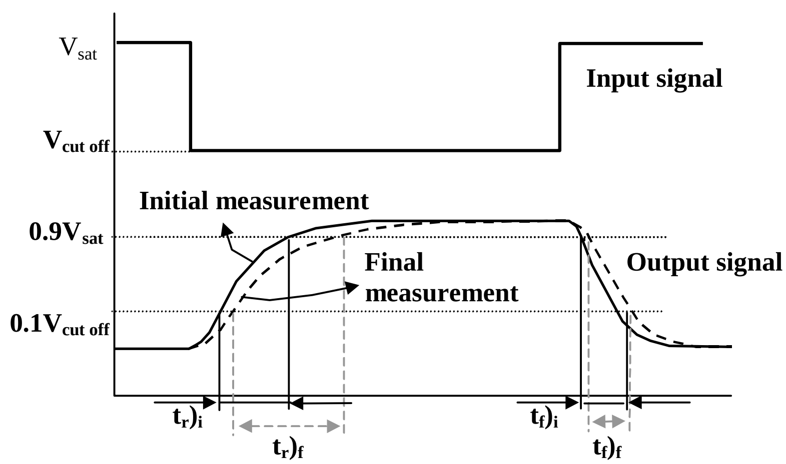


Fig. 7. Testing results from Lab 3

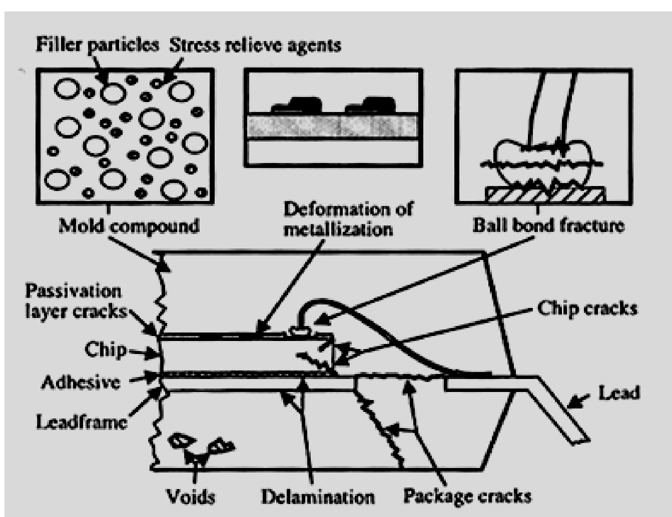


Fig. 8. Expected results from Lab 3[2]