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Face-Down Bonding with Sealed Cavity for Micromechanical Device Packaging

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Face-down bonding of a chip which has a sealed cavity for micromechanical devices was developed. The sealed cavity was realized by adhesion of a frame formed around a working space of a micromechanical device to a substrate. Planarization of the frame surface, chip separation and face-down bonding are essential in this process. As a demonstration, we have successfully bonded a SAW device.

1. Introduction

Recently, multichip-module (MCM) technology has been the focus of extensive development. MCM is a packaging scheme which mounts several chips onto a single module. The following three steps are involved in MCM packaging. (1) Bare chips are directly mounted on a substrate. (2) Electrical connections are made by various techniques including wire bonding, tape automated bonding and flip-chip bonding. (3) The module is then covered with resin.

Micromechanical devices such as surface acoustic wave (SAW) devices require some space for their motion. MCM packaging techniques cannot be directly applied to micromechanical devices because the resin may hinder mechanical motion of these devices. Thus, a packaging method for micromechanical devices that operate in a sealed cavity is in high demand in order to preserve compatibility with the MCM packaging scheme.

In this study, we have successfully realized the sealing of a cavity of a micromechanical device and its direct bonding onto a substrate. Figure 1 shows the principle behind the packaging scheme. A SAW device was used as the micromechanical device to be encapsulated.

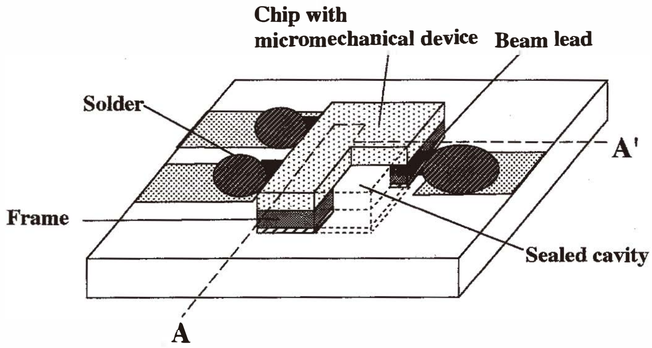

Fig. 1. Principle of face-down bonding with a sealed cavity.

2. Materials and Methods

Figure 2 shows the fabrication process for the face-down bonding with a sealed cavity. (1) A groove was made in a $LiNbO_3$ wafer and filled with resin which was then cured. (2) To fabricate the beam lead, an electroplating base was deposited on the wafer. A photoresist was patterned and copper was electroplated using the photoresist as a mold. The resist and the electroplating base were then removed. The copper beam lead was about 15 μm thick. (3) The surface was planarized in order to achieve face-down bonding. (4) An adhesion layer for bonding was formed using photosensitive polyimide. (5) A frame was patterned with O_2 RIE using aluminum mask. (6) Chips were separated. (7) Chips were bonded face-down. (8) The connection between the beam lead and metal wires on the substrate was achieved by soldering. Another bonding method as thermal or ultrasonic bonding can also be applied.

In order to realize this process, three technical problems: planarization of the frame surface (Fig. 2 step 3), chip separation (Fig. 2 step 6) and face-down bonding (Fig. 2 step 7) were solved as follows.

2.1 *Planarization*

In order to effectively seal the cavity by the face-down bonding, the frame surfaces must be flat. The adhesion layer was formed on the frame that surrounds the working space of the micromechanical device. Because beam leads for electrical feedthrough have to be formed through the frame, the frame surface is susceptible to having steps around the beam leads. Therefore it is necessary to planarize these steps prior to the face-down chip bonding.

In general, planarization processes involve polishing or spin-on methods. In this study, resin was chosen as a planarizing material. It is, however, difficult to polish cured resin and to planarize by spinning-on resin.

Dill of IBM has reported the following method which he referred to as the "top cap"

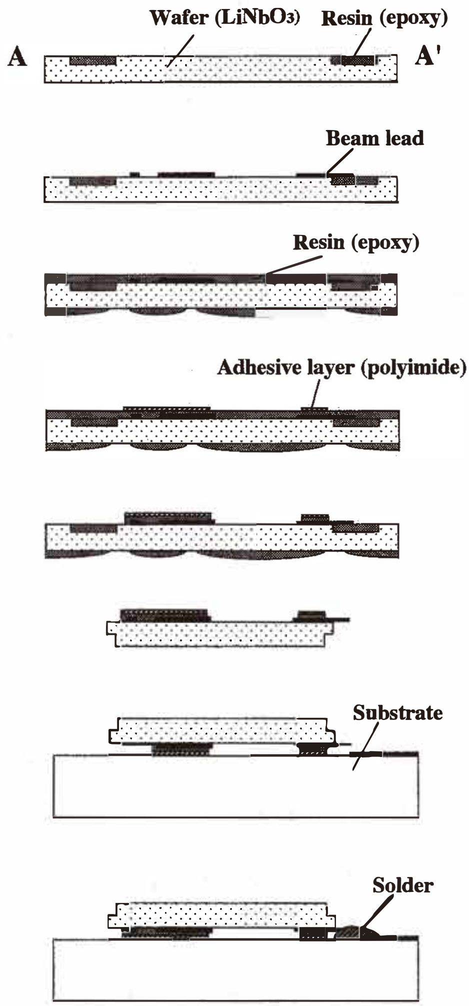

Fig. 2. Fabrication process for face-down bonding with a sealed cavity. (Cross section A-A' in Fig. 1.)

method.[1] Resin was applied on an uneven wafer and a flat plate was pushed on the wafer in order to planarize the resin surface. The flat plate was removed from the wafer after curing. In this process selection of materials for the planarization plate and the resin is essential. Teflon and deliquescent substrates such as NaCl and KBr[2,3] were tested as materials for the planarization plate. The former can be removed after curing because of its nonadhesive property, but its surface is not flat. On the other hand, the latter can be removed by dissolving in water and they have flat surfaces. However they are expensive.

For these reasons gold-deposited silicon plate which has a SiO_2 layer between the gold and Si layers was used. Figure 3 shows the planarization process. The nonadhesive property between SiO_2 and gold was utilized. After baking, the resin adheres to the gold, but the Au/SiO_2 interface can be separated. Finally gold on the resin was etched off. Details of the process are as follows. (1) Resin was applied on the wafer and degassing was carried out in a vacuum. (2) A flat silicon plate with gold on its oxidized surface was pushed on the resin-coated wafer, which caused the resin to overflow around to the back of the wafer. The resin was cured. (3) The flat plate was removed from the wafer. (4) Gold which was left on the resin was etched off using aqua regia. The excess overflow resin was removed using a dicing saw. Figure 4 shows a SEM micrograph of the resin surface after planarization. This picture was taken after forming the frame, that is after step 6 in Fig. 2. An almost flat surface can be seen at the place where beam leads are embedded in the epoxy. Figure 5 shows the surface profile of the resin on the beam lead measured with a surface profilometer. It indicates a step height of 0.5 μm. Wafer surfaces were almost planar and were thus applicable for the face-down bonding.

Resin materials must meet the following requirements: (1) heat resistance; (2) inertness to chemicals; (3) good adhesion to SiO_2 and gold; (4) ease of delineation; (5) low curing temperature; (6) no outgas and (7) low degree of shrinkage. To minimize the shrinkage, a chemical-reaction-type resin such as epoxy is suitable. Epoxy consists of an amine or an acid anhydride as hardener. The epoxy which uses the amine hardener cannot be applied to this process because it cannot withstand the chip face-down bonding temperature of 300°C. On the other hand, the epoxy using acid anhydride withstands this temperature, and hence we chose this type of epoxy (Epotek 377, Epoxy Technology Inc.).

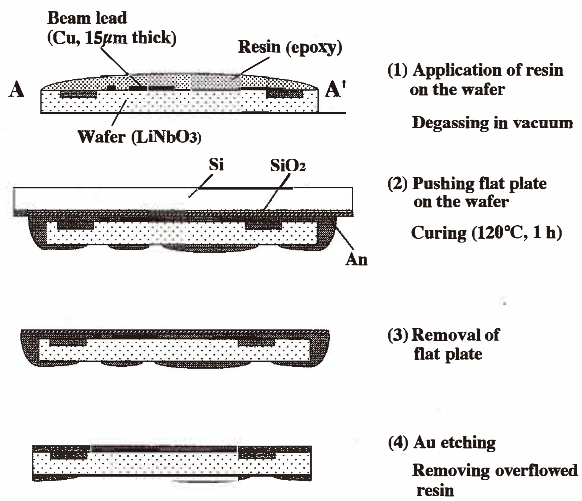

Fig. 3. Planarization process. (Cross section A-A' in Fig. 1.)

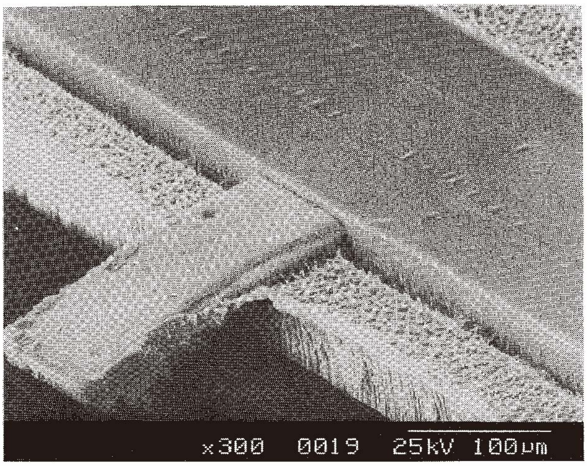

Fig. 4. SEM micrograph of epoxy surface after planarization process.

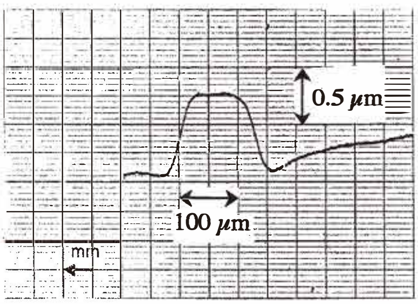

Fig. 5. Surface profile of epoxy on beam lead.

2.2 *Chip separation*

Dicing is the most common method used to separate a wafer into chips. In order to avoid cutting the beam lead on the wafer, a half-cut dicing process which involves a combination of dicing and dry etching of the epoxy in the groove was used. Figure 6 shows the chip separation process. (1) The wafer was fixed to a plate with wax during dicing and dry etching, because the back side of the wafer does not stick to adhesive tape due to some remaining epoxy. (2) The back side of the wafer was scribed (half-cut) by a dicing saw until the epoxy became exposed. (3) The epoxy was etched out using O_2 RIE. (4) The back side of the wafer was stuck to adhesive tape to avoid scattering of chips during dissolution of the wax. (5) The wax was dissolved in water. (6) The chips were removed from the tape.

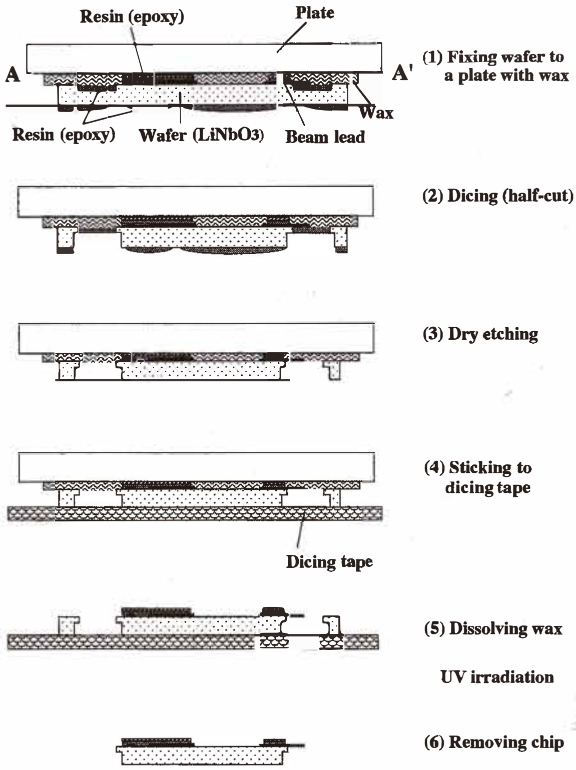

Fig. 6. Chip separation process. (Cross section A-A' in Fig. 1.)

Selection of the materials for the tape and the wax in this process is important. The adhesive strength of the tape must be sufficient to hold the chips during the wax dissolution, yet allowing the easy removal of chips. A UV curable dicing tape (Adwill D-615, Lintec Corp.) is satisfactory for this purpose. UV light irradiation weakens the adhesive strength of this tape and chips can be easily removed from the tape after this irradiation.

The adhesive agent of the tape must be resistant to the solvent which is used to remove the wax. Since it is affected by organic solvents, a water-soluble wax which can be removed by hot water must be used. In the hot water, wax melts easily and chips can be removed from the plate. The remaining wax on the chips is melted in the hot water. If the melting viscosity of the wax is high, chips cannot be easily separated from the plate. Since wax must withstand O_2 RIE, the RF power used in the RIE process is limited. We experimentally choose a wax (Aqua wax 531, Nikka Seiko Co., Ltd.) which satisfies these requirements. Melting viscosity of this wax is 120 cp and it withstands O_2 RIE at RF power less than 80 W.

2.3 *Face-down chip bonding*

In this process, adhesion is realized by thermal bonding using an adhesive layer on the frame. Figure 7 shows the setup for thermal bonding. Adhesion between the chip and the substrate is realized using polyimide at the interface. We choose a photosensitive polyimide (Photoneece UR-3140, Toray Industries, Inc.) as the adhesive layer. This polyimide is normally baked at 350°C after the developing process. However, its adhesive property is lost when it is baked at this temperature. The adhesion to the underlying epoxy is poor at baking temperatures lower than 100°C. Therefore, the suitable baking temperature is around 150°C.

The thermal bonding process is as follows: (1) The chip is mounted face-down on the substrate; (2) the substrate is heated up to 300°C and (3) polyimide is adhered to the substrate by pressing.

3. Results and Discussions

Figures 8 and 9 show SEM micrographs of the chip after the chip separation process and after face-down bonding, respectively. Figure 10 is a photograph of the chip after beam lead bonding. The device was successfully bonded on the substrate and the working space was sealed. Bonding integrity at the interface between the frame and the substrate could be observed from the back by using glass as the substrate. The step height at the frame surface of the beam lead shown in Fig. 5 did not influence the bonding. A contaminated frame surface cannot be bonded; hence the adhesive surface must be kept clean.

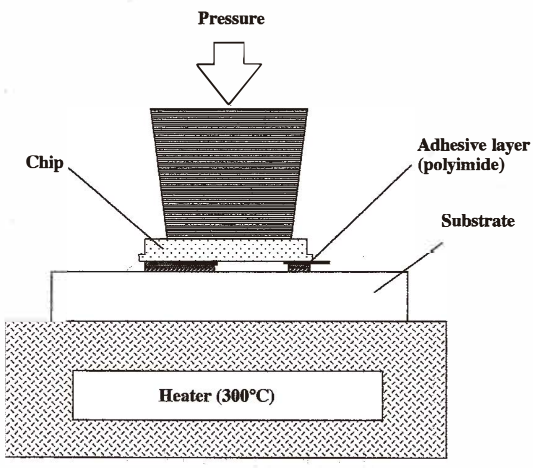

Fig. 7. Setup for thermal bonding.

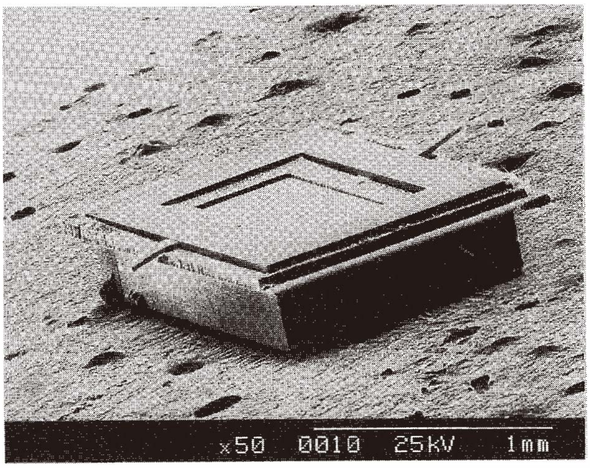

Fig. 8. SEM micrograph of the chip after chip separation.

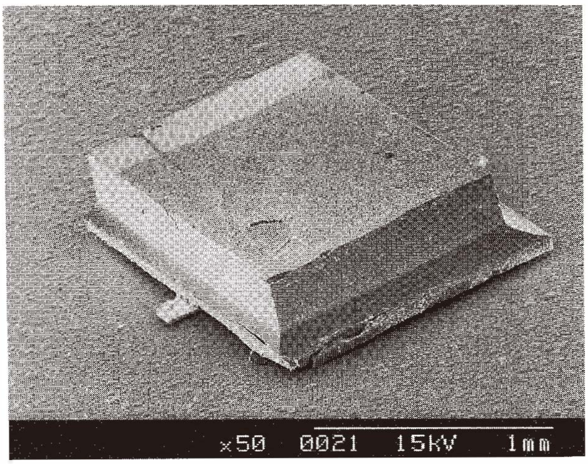

Fig. 9. SEM micrograph of the chip after face-down bonding.

4. Conclusion

In this study, we have developed a process for face-down bonding of a chip with a sealed cavity for micromechanical devices. The device characteristics are not affected by the resin coating, because the package has a sealed cavity. A SAW device was successfully bonded using this method.

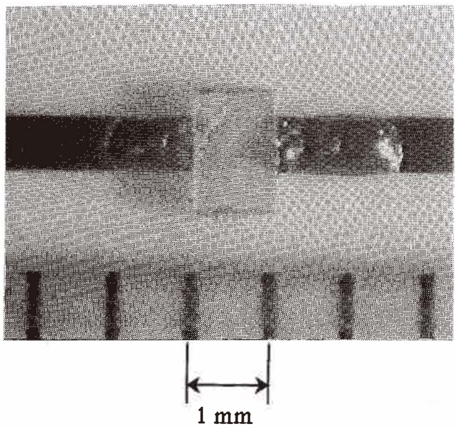

Fig. 10. Photograph of the chip after beam lead bonding.

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