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Optical fiber packaging by lead (Pb)-free solder in V-grooves

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Abstract

Etched V-grooves along the [1 1 0] direction on (0 0 1) surface of Si wafers have been used to achieve high precision alignment between fibers in opto-electronic devices by epoxy-bonding. Nevertheless, the positioning of fibers using epoxy-bonding lacks long-term stability. We developed a novel technology of using metallic solder bonding instead of the organic epoxy-bonding.

The challenge is because of the fact that solder does not wet SiO_2 surface. To circumvent this problem, electron-beam evaporation was used to deposit a multi-layered metallic coating on the surfaces of fibers and V-grooved chips. Three types of coatings were investigated, and they are Ti/Au, Ti/Cu/Au, and Ti/Ni/Au. These metallic film coatings have good adhesion on the fiber and the V-groove. We utilized a low melting point Pb-free solder, eutectic 43Sn57Bi (in wt.%), with a melting point of 139 °C to bond an array of fibers to V-grooved chips. The mechanical and optical tests illustrated that we can achieve precision alignment of fibers by the soldering method and the bonded structure is stable at room temperature. The metallic solder bonding can be hermetic and it can isolate the optical device from ambient environment.

Keywords: Optical packaging; Optical fiber array; V-Grooved fiber array; Soldering packaging glass fiber array; Lead-free solder

1. Introduction

Etched V-grooves along the [1 1 0] direction on (0 0 1) surface of Si wafers have been used to achieve high precision alignment between fibers in opto-electronic devices such as laser diodes, active and passive multi-channel wave-guides, optical multi-channel switches, array wave-guides for high coupling efficiency and advanced optical packages. The fiber array is a key component for these multi-channel optical devices and elements [1,2]. Owing to the dependence of etching on crystal orientation on (0 0 1) Si wafer surfaces, the V-grooves can be made with uniformity and reproducibility. Optimized etching process gives a good control on the width and depth of V-grooves to hold the fibers. The bonded end-face of the chip together with the fibers can be polished to a high quality of optical finish. Hence, the V-grooves can be integrated with the passive or active wave-guide devices on a single Si chip, and the chip has been one of the advanced packaging technologies in optical devices.

The fiber array is produced by placing fibers in an array of V-grooves with another flat (un-etched) Si chip or glass plate on top of it or the fiber array can be sandwiched between two V-groove chips face-to-face [3]. Nevertheless, how to bond the fibers to the chips has been a challenging issue. Currently, the adhesive epoxy resin mixed with silica or other powder is used to bond the pigtailed fibers with the V-grooved silicon chips. The disadvantage of using epoxy is poor reliability in positioning the fibers for long-term stability.

To achieve a high precision alignment and long-term stability of optical fiber link package, we studied a novel technology of bonding fibers to V-grooved chips using metallic solder. We utilized a low melting point solder to bond the array of fibers to V-grooved chips. Because of its metallic strength, the solder will offer a much better thermal stability against creep than epoxy near room temperature. The solder also has a higher stability for thermal cycling, mechanical impacting, ambient aging, and moisture exposing. However, it is well-known that solder does not wet SiO_2 surfaces. Therefore, we deposit a coating of metal films on the V-groove surface and the surface of the optical fibers. The metallic films must adhere strongly to the SiO_2 surfaces and the molten solder should wet the thin films to achieve bonding. The metallic film coating on the fiber with good

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adhesion can also protect the fiber from infrared noise interference. In addition, the metallic solder bonding can be hermetic and it can isolate the optical device from ambient environment.

2. Experimental

A flow chart of packaging process is shown in Fig. 1. Standard 8-channel V-grooved chips were used in our experiment, and the width of the V-grooves is 125 μm. The fiber array was achieved by sandwiching it between two pieces of V-grooves, and the schematic structure is shown in Fig. 2(a).

Since solder does not wet SiO_2 glassy surfaces, the adhesion between glass and metallic coating has been one of the key points investigated in this research. First, we used a chemical method to treat the surface of silica fiber to improve the adhesion. A diluted HF solution was used to etch the surfaces of fibers and chips. We note that the chip surface has been oxidized. Then, we used electron-beam deposition method to deposit the layered thin films.

SLOAN SL 1800 (E-beam evaporation) chamber was used to deposit the multi-layered metallic coatings on the surfaces of fibers and V-grooved chips. The deposition rate was 3 Å/s, and the vacuum was 10^{-7} Torr. Three types of multi-layered metallic film coatings were adopted in our design; they are Ti/Au, Ti/Cu/Au, and Ti/Ni/Au. The Ti (or Cr) thin film (∼0.05 μm) serves as an adhesive layer to the silica surface of the fiber, Ni (or Pt, or Cu) serves as the reaction layer (∼0.2 μm) for solder bonding, and Au (or Pd) serves as the surface passivation layer (∼0.2 μm) and to enhance solder wetting. Since Ni reacts rather slowly with molten solder, we will only need a thin layer of Ni [4]. The cross-sectional structure of the metallic coating is shown schematically in Fig. 2(b). The adhesion of the metallic coatings to fiber or chips was tested by "Scotch 600" tape to be excellent.

Considering the selection of the solder, it must satisfy the following requirements: (1) The solder should be lead-free to meet the environment concern of lead-poisoning. (2) It must

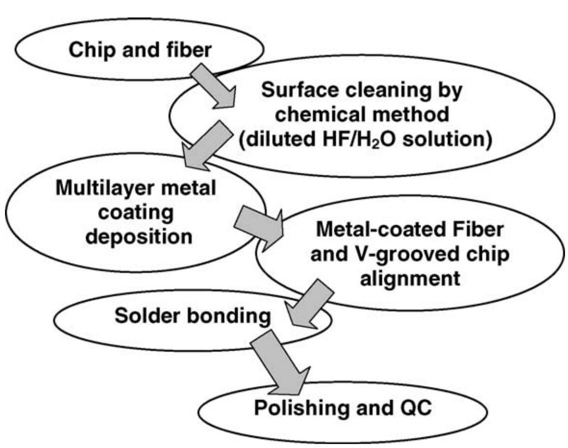
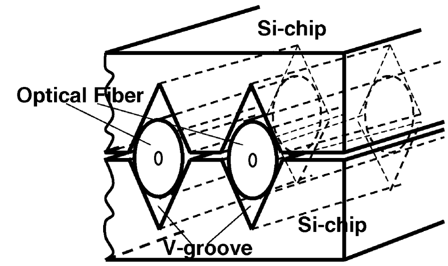


Fig. 1. Flow chart of the packaging process.

(a)



(b)

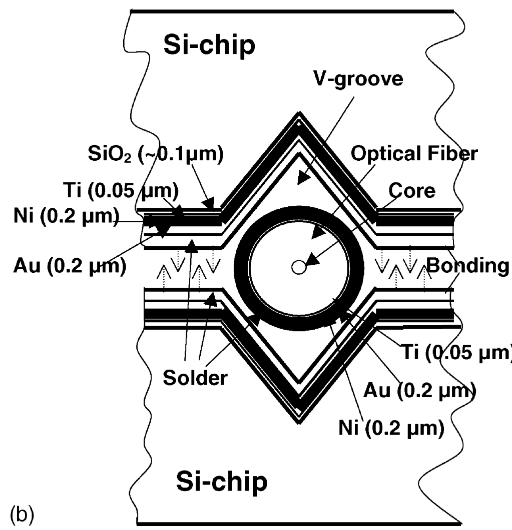


Fig. 2. (a) V-Grooved fiber array structure; (b) cross-section of the bonding structure.

have a low melting point because of the low glass transition temperature of the polymeric skin of the fiber/ribbon, so the melting point of the solder is limited to below 150 °C. For these reasons, the choice of the Pb-free solder is limited to SnBi and SnIn alloys. (3) Indium solder is not selected due to its high oxidation tendency. On the basis of all these consideration, we have chosen eutectic 43Sn57Bi (in wt.%) with a melting point of 139 °C to bond the fiber and the V-grooved chips. The soldering process was carried on a hot plate and the temperature of bonding was controlled in the range of 140–160 °C. The wetting proceeded at 140 °C for 30 s.

The strength of bonding was measured under tension (5 kg) by pulling the fibers out of the soldered V-grooves. By observation of the cross-sections and measurement of light passing through the fibers, we can decide the precision of alignment and the continuity of the fibers. Bellcore codes (GR-1221-core, 1999) [5] were used as reference for our reliability testing.

3. Results and discussion

By optical microscopy at 30× magnification, we inspected the appearance of the fibers and the chips. They were bonded and then other tests such as adhesion and

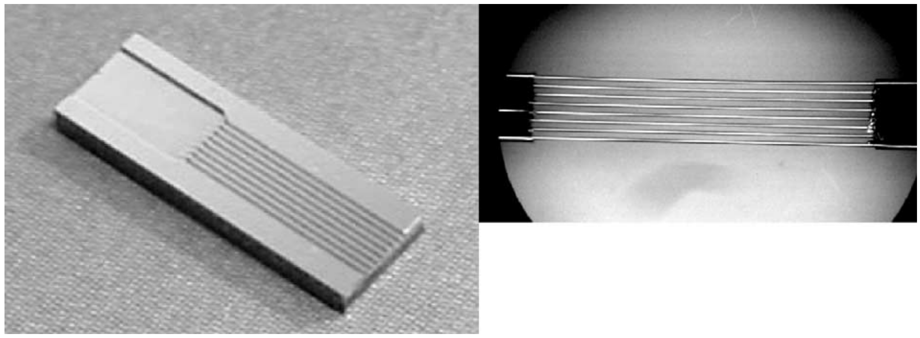


Fig. 3. Metal coated V-groove chip and 8-channel fibers.

optical transmission were carried out subsequently. Fig. 3 is the appearance of a good fiber and chip under optical microscope. All the measured properties of the three metallic coating structures are summarized. We use percentage to represent the distribution of the measured properties of our samples among perfect, good, and bad. All the data are plotted in Fig. 4.

By “Scotch 600” tape test, it means that if we cannot peel off the multi-layered metallic coating from the surface of fiber or chip by a Scotch tape, it implies the adhesion of our buffer layers is strong enough. From the data, we can see that for the adhesion, Ti/Cu/Au is better than Ti/Ni/Au. This is because the stress between the Ti and Ni is very large, and it affects the adhesion of the tri-layer structure. However, the wetting ability of the Ti/Ni/Au is found to be slightly better.

After solder bonding, we tested tensile strength of the bonded fibers by 5 kg weight at room temperature, and most of the failure fibers were due to broken fiber, rather than coating stripping from the chip. It shows that the adhesion of the bonding structure is very strong at room temperature. The cross-sectional observation showed that not every sample has had the solder filled the V-grooves completely around the fibers, as shown in Fig. 5. Some samples have voids without solder. During wetting, driven by the horizontal capillary force, the molten solder can run along the V-grooves to bond the fiber with the two V-grooved chips. The amount of solder running into the V-grooves should be of the right amount. If there is too much solder, the four-point contact between the fiber and the four walls of the V-grooves cannot be achieved. If there is less solder, there will be voids and the bonding strength is affected. By improving the packaging fixture in manufacturing, and by controlling the soldering condition better, like the temperature, time, and amount of solder, etc., it is possible to obtain good results. A sample having near perfect bonding is shown at the top in Fig. 5.

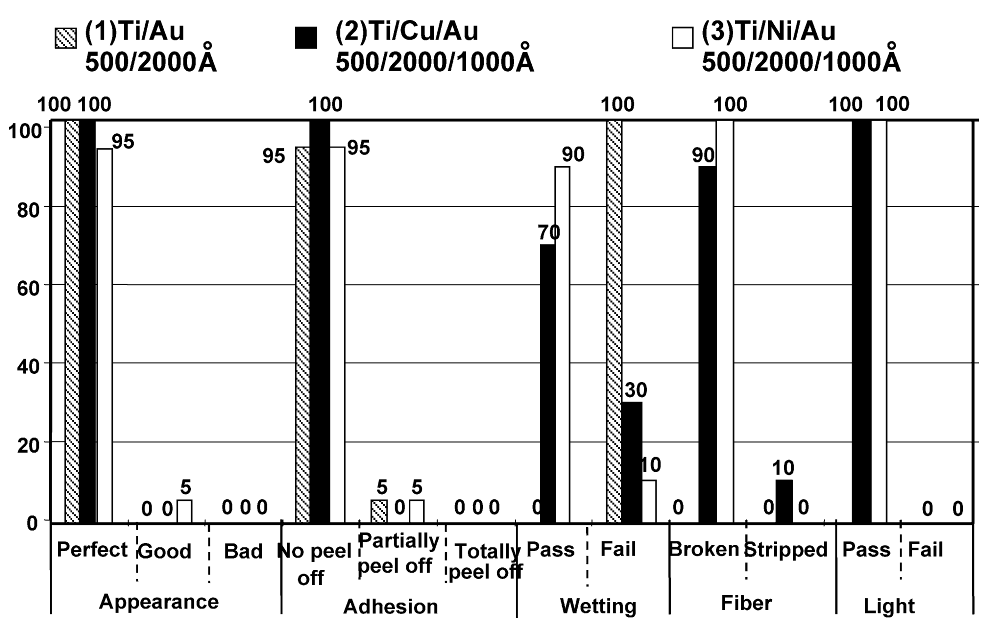


Fig. 4. Testing result of three different kind samples.

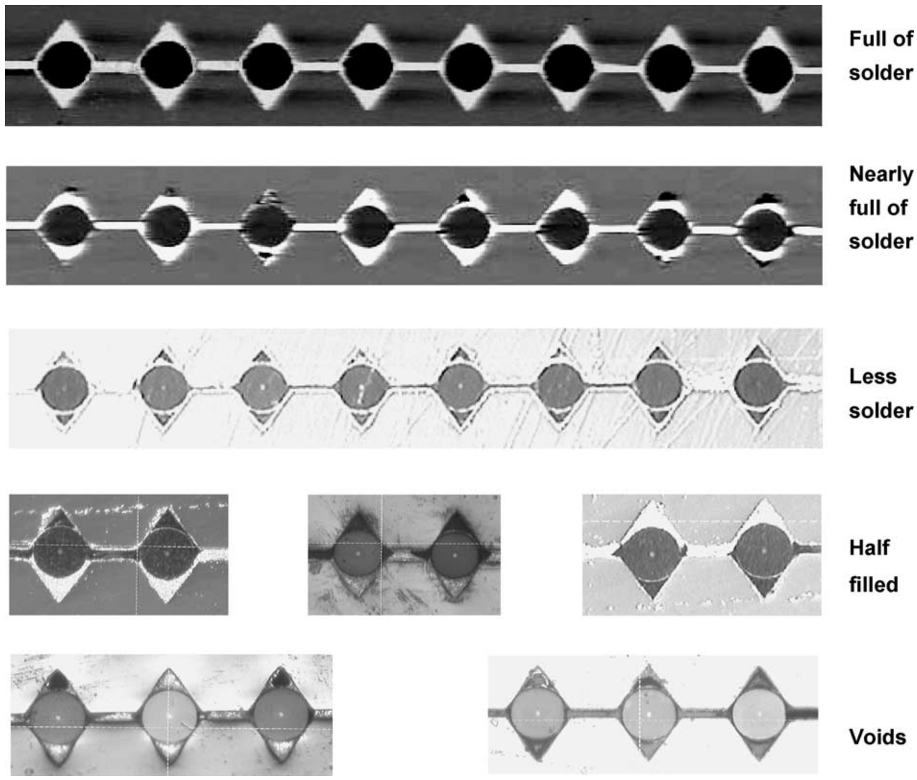


Fig. 5. Cross-section images of soldering bonded samples.

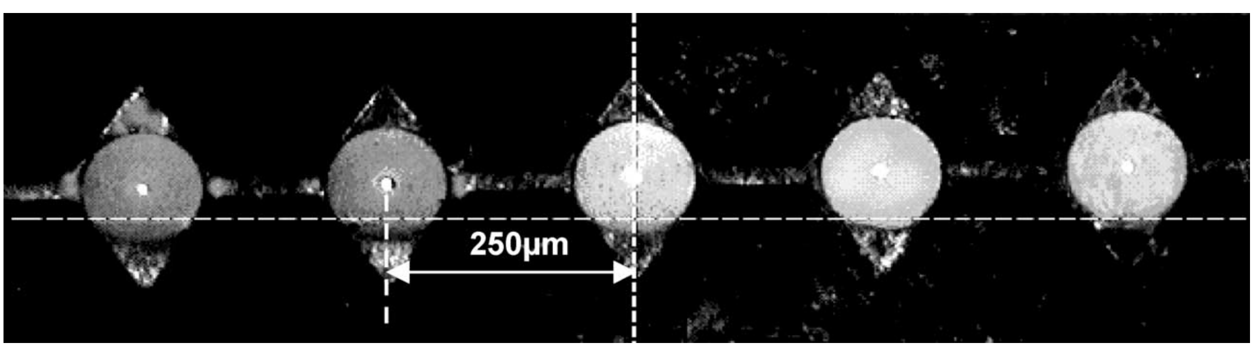


Fig. 6. Light through testing.

Fig. 6 is the results of the light test. We can see the point of light passing through the center of each fiber. These fiber arrays can be sent for the measure of the optical insertion loss.

4. Conclusion

In this study, we developed a novel technology of bonding optical fibers to V-grooved chips using solder. With metallic thin film coatings and low melting lead-free solder, we have bonded arrays of fibers into V-grooved chips. The mechanical and optical tests illustrated that we can realize the precise alignment of fibers by the soldering method and the bonding structure is strong at room temperature. Further improvement can be expected by improving the manufacturing facility and the conditions of thin film coating and solder wetting. Thus, the use of solder to bond fibers to V-grooved chips has a very promising future in optical packaging technology.

Acknowledgements

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