Avoiding silicon/glass bonding damage with fusion bonding method

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Received March 15, 2004

A novel fusion bonding method between silicon and glass with Nd:YAG laser is described. This method overcomes the movable mechanical parts damage caused by the electrostatics force in micro-electronic machine-system (MEMS) device during the anodic bonding. The diameter of laser spot is 300 μm, the power of laser is 100 W, the laser velocity for bonding is 0.05 m/s, the average bonding tension is 6.3 MPa. It could distinctly reduce and eliminate the defects and damage, especially in movable sensitive mechanical parts of MEMS device.

OCIS codes: 220.4000, 140.3390, 160.2750, 160.6000.

The technique of anodic bonding enables glass to combine with metal, alloy with semiconductor, and glass with semiconductor bonding in lower temperature without any glue[1]. The bonding interface is of great airproof and permanent stability. Anodic bonding is simple in requirement of equipment and convenient in operation, so it is one of the most frequently used methods to make micro-electronic machine-system (MEMS) apparatus and seal or package them[2].

The process of anodic bonding requires to put the 800-1200 V voltage on the sealed and packaged apparatus. Thus the packaged parts cling and bond together under the function of chemical change caused by the static power[3]. However, this electric current is put on the rest of the moveable sensitive parts, which are not necessary to be sealed and packaged, and therefore the property of the sealed and packaged parts maybe deteriorate, lose effect, and even damage[4]. Although many improvements have been made on anodic bonding[5], none of them is fairly ideal. So it greatly limits the use of the anodic bonding method in the field of MEMS.

This letter describes a novel fusion bonding method between the silicon and glass, which is successfully fulfilled with Nd:YAG laser. It effectively avoids the effects on the moveable parts in the bonding between the silicon and glass caused by the electric field. The conditions, such as the power of Nd:YAG laser, which affect the quality of bonding are also analyzed. This method has been successfully applied in the bonding seal and package between the silicon and glass with ultrathin sensitive film, and an ideal result has been obtained.

The fusion bonding with laser (FBL) takes advantage of the special property of the laser beam[6], to pierce through glass but not silicon, and the energy of the laser beam is absorbed at the interface between the glass and silicon, and therefore the purpose of the fusion bonding is achieved. The principle of the fusion bonding of the silicon/glass with Nd:YAG laser is shown in Fig. 1.

When Nd:YAG laser irradiates the silicon wafer, the Pyrex7740 glass is of high transmission. However, the crystalline silicon wafer is of a high absorptivity on the infrared of 1.06-μm wavelength. Therefore, the photon energy of the Nd:YAG laser is greatly absorbed by the glass at the interface between the silicon and glass, and then through interactive collision the energy is transmitted to the atoms around. The average time for collision is at the amount of 10^{-12} which is far less than the maintaining time of laser irradiating. Within the laser irradiating time, the atoms at the interface can be excited, the energy will be transmitted form one to another, and eventually the energy transmitted to the atoms at the interface will change into heat, which can increase the crystal temperature, then the fusing together bonding is achieved.

Based on the former bonding setting of the silicon/glass, a Nd:YAG laser light source and its relevant light path controller are added and adjusted to the experimental devices. The polished and general RCA-rinsed silicon wafers are spattered. The Pyrex7740 glass wafers are experienced as the following processes: the rinsing by ultrasonic, acetone, ethanol, and repeated rinsing by deionized water, and then baking under a infrared lamp in the surrounds of nitrogen. After that the wafers are aligned as shown in Fig.1, and a pressure of 10 – 30 MPa at both sides of the silicon/glass to make them have a close physical contact is added. When the laser beam pierce the glass cover board and the would-be bonding glass, a considerable part of energy is absorbed by the silicon wafer at the interface of the silicon and glass wafers. In the experiment, the would-be bonding sample should be inclined 15 degree in case the reflected light returns along the original path and causes damage to the light source together with its fiber. Therefore, by using the laser

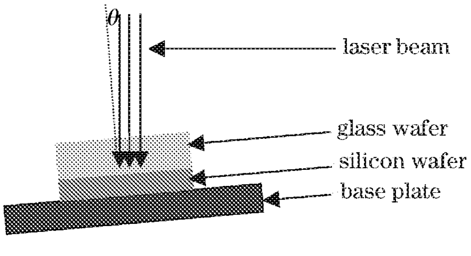

Fig. 1. Schematic drawing of transmission-welding principle applied to silicon-glass FBL.

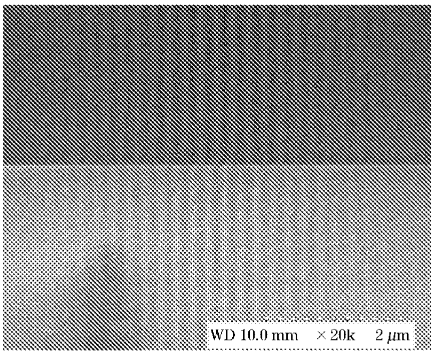

Fig. 2. SEM photograph in a cross-sectional view of interface in the glass after FBL (100 W).

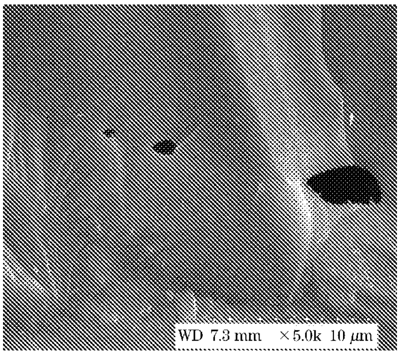

Fig. 3. SEM photograph in a cross-sectional view of interface in the glass after FBL (300 W).

energy of the high power density, the bonding of the silicon and glass is achieved.

Figure 2 shows the scanning electron microscopy (SEM) picture of the bonding interface of the silicon and glass wafers with the different laser powers (100 W). Above the bonding interface is Pyrex7740 glass, the thickness of the bonding interface is about 70 nm shown by SEM. From the cutting interface of the laser bonding, we find that the silicon and glass wafers have already fused. The average tension of 12 bonded samples with this laser power is 6.3 MPa.

Figure 3 shows the crack on the silicon wafer caused by the different over-large laser powers (300 W) and uneven heat distribution. There are some micro-holes with different diameters in the interface, which are made by the plasmas gas bombardment with over-large laser power in the interface. When the laser penetrates the glass and reaches the silicon surface, most of laser energies is absorbed. The temperature in the silicon surface increases rapidly to a ultra-high degree in a small area in very short time. Some glass in the interface is changed into gas of plasmas and extravagates. Some micro-holes happen when the areas are cold. The laser power is too large to make the silicon and glass bond successfully.

Figure 4 shows the SEM picture of the silicon wafer torn from the incomplete bonding interface caused by a over-small laser power (50 W). From the picture, we can see some branches made up of glass on the surface of the silicon wafer. It shows that the silicon wafer is partly bonded with the glass. The laser power is too small to make the silicon and glass bond completely.

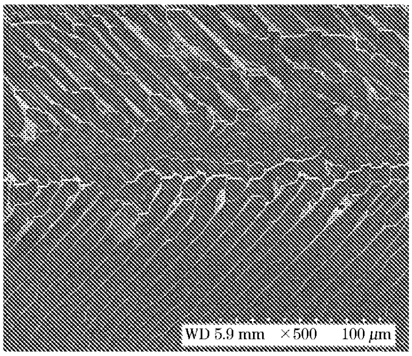

Fig. 4. SEM photograph in a cross-sectional view of fracture on silicon after FBL (50 W).

From the above, we can see that the defects of the former silicon/glass method can be effectively overcome by the fusion bonding with Nd:YAG laser. The features of the technique is as following. (1) This bonding method does not need electrical fields, which successfully avoids the usual damage and even deformity to the moveable parts of the apparatus caused by the electrical field power in the bonding. That is the most advantage of FBL. (2) As the laser beam is reduced to 300 μm in diameter, the bonding in a small area can be realized, which is different from the traditional anodic bonding in which the whole apparatus is involved. (3) Without a redistribution of Na^+, the compositions of the glass in bonding area are not changed, therefore there is no changes in the physical property of the glass and thus there is no property changes of the whole apparatus caused by the redistribution of Na^+ as there is in the traditional anodic bonding.

Meanwhile, the final bonding quality is affected by the laser power density whether it is large or small, the action time whether long or short, the poor situation of the interface of the silicon, and glass wafers before bonding. The popularization of this method is greatly limited due to the inherent defects, such as uneven distribution of the laser power density and the limitation of beam spots. We can get the ideal bonding results with the laser with 300-μm diameter of the laser spot, 100-W laser power, and 0.05-m/s laser velocity for bonding.

This work was supported by Beijing Committee of Education Foundation (No. KM200310005009). D. Yang's e-mail address is daohongyang@emails.bjpu.edu.cn.

References

1. T. Rogers and J. Kowal, Sensors and Actuators A **46,** 113 (1995).
2. E. T. Enikov and J. G. Boyd, International J. Engineering Science **38,** 135 (2000).
3. X. Chauffleur, G. Blasquez, and P. Pons, Sensors and Actuators A **46,** 121 (1995).
4. G. Blasquez and P. Favaro, Sensors and Actuators A **101,** 156 (2002).
5. J.-T. Huang and H.-A. Yang, Sensors and Actuators A **102,** 1 (2002).
6. U. M. Mescheder, M. Alavi, and K. Hiltmann, Sensors and Actuators A **97,** 422 (2002).