

True 3D Through Hole Interconnections Formed by Femto-second Laser Irradiation / Wet Etching and Molten Metal Suction Method

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Abstract

We propose a new fabrication process, which can realize “true” 3D through-hole interconnections (THIs), using femto-second laser irradiation, wet etching and molten metal suction method (MMSM). “True” 3D through-hole interconnections defined here mean the through-holes having branches and/or cranked structures, which can NEVER be accomplished by the regular etching process such as deep reactive ion etching (DRIE). These structures would give us much more freedom to design THIs and expected to be applied to higher density and smaller packaging for micro electro mechanical systems (MEMS). We’ve successfully fabricated the “true” 3D THIs having the aspect ratio more than 9 in silica glass substrate.

Key words: through-hole interconnections, femto-second laser, wet etching, and MMSM

Introduction

Recently there are outstanding technological advances in the fabrication of through-hole interconnections (THIs) which can be applied to micro electro mechanical systems (MEMS) or high density packaging. In our laboratory, we have been developed the wafer level package (WLP) with THIs and the glass substrate with THIs which can be applied to image sensor and interposer [1] respectively. Fabricating these structures, dry etching technique, especially so called deep reactive ion etching (DRIE) is often used, because the technique makes it possible to form the vertical micro holes with high aspect ratio [2]. Due to the demand

of miniaturization of electron devices and packaging, THIs are believed to be one of the most promising candidates for these purposes.

When “true” 3D THIs such as branches or/and cranked structures become practical, there would be much more freedom to design THIs. These structures can never be made by DRIE due to the etching mechanism of it. Accordingly we propose a new fabrication process, which can realize the branches or cranked interconnections, using femto-second laser irradiation, wet etching and molten metal suction method (MMSM) [1]. The process is rather simple, and can fabricate higher aspect ratio THIs inside some transparent materials such as silica glass, borosilicate glass and sapphire crystal

for example. The technique will give us the great advantage to form more complex THIs which can be used in smaller packaging for MEMS.

Fabrication process

The fabrication process of 3D THIs consists of three main steps which are femto-second laser irradiation, wet etching and MMSM.

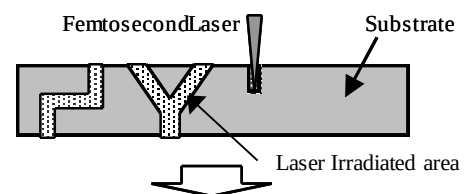
Femto-second laser emits $\sim 10^{13}$ s pulses. Irradiations of these extremely shorter pulses change the material structures drastically around the focused area. In the case of dielectrics, metallic plasma state can be created at the focal point. The light pulse ionizes the material almost instantaneously within one or few optical cycles by multi photon absorption, and submits a shock wave with subsequent fast (<100 ns) thermal quenching [3]. These phenomena have never been occurred by the light pulses of which width is wider than pico second, and only the light pulses shorter than pico second order including femto-second laser can make it happen. In the case of silica glass, laser irradiation is believed to cause the micro cracks around the focused area. In the case of single crystal sapphire, the single crystal becomes amorphous at the focal point [3][4][5].

Laser irradiated areas can be removed selectively by wet etching due to the higher etching rate of the area having partly broken or weaker covalent bond in comparison to laser non-irradiated area.

Fig.1 shows a schematic image of laser irradiation and wet etching process for making through holes. First, the focused laser pulses are irradiated inside a substrate. Moving focal point in X, Y, Z directions, micro patterns, such as branches and / or cranked shapes, can be drawn arbitrarily in a substrate. Then laser irradiated areas are removed from the

substrate to form through holes. Since the etchant such as hydrofluoric acid can etch the laser irradiated areas much faster than that of non-irradiated area, so 3D through holes according to irradiated X, Y, Z patterns are obtained. To make higher density through holes, high etching selectivity between the laser irradiated area and non-irradiated area is required. This selectivity is believed to depend on the laser irradiation conditions and the etching conditions, so first we have studied the conditions in detail.

1. Femtosecondlaser irradiation



2. Wet chemical etching

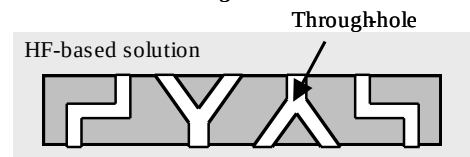


Fig.1: Process of forming 3D through holes using femto-second laser irradiation and wet etching

After the through holes formation, a conductive material is filled into the through holes by MMSM. Electro plating and CVD are often used to fill conductive material, however these process are difficult to fill them completely into arbitrarily-shaped holes such as cranked and branched holes. On the other hand, MMSM has been developed in our lab to fill molten metal into even the high aspect ratio holes with different dimensions at the same time and complicated holes using differential pressure.

Fig.2 shows schematic image of MMSM process.

First, a sample is set in a chamber. Then the chamber is evacuated until the pressure reaches few Pa, and the sample is dipped into the molten metal for a few minutes. Then, nitrogen gas is introduced until the chamber pressure becomes atmospheric. The molten metal is filled into the holes in this step. Lastly the sample is pulled up from the molten metal and cooled. In our study, Gold-Tin (Au:80wt%, Sn:20wt%) solder was filled into the holes. Gold-Tin has several advantages, such as lower melting point, high fluidity, smaller shrinkage on solidification, and low vapor pressure at the melting point. So Gold-Tin would be one of the most optimum materials for MMSM.

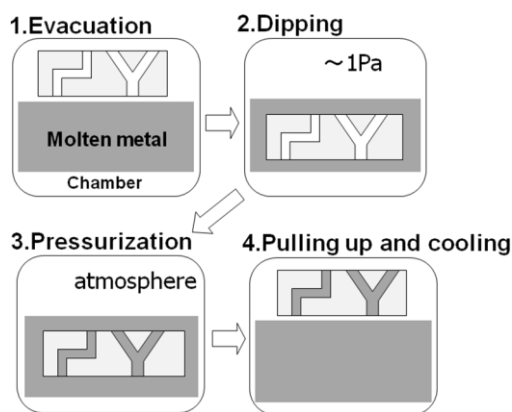


Fig.2: Process of molten metal suction method (MMSM)

Etching selectivity in silica glass

Fig.3 shows the dependence of etching selectivity on the scan velocity of focused laser beam in silica glass. Changing scan velocity of the laser beam, which means changing pulse overlaps at any points, etching selectivity between the laser irradiated area and non-irradiated area was examined. The parameters of laser irradiation are as follows, 800nm wavelength, 240fs pulse width, 3.5μJ/pulse

pulse energy, 200kHz repetition rate, and the etching is done by 10wt % hydrofluoric acid. The result shows the slower the scan velocity is, the higher the etching selectivity is. For example, the etching selectivity is around 70 at 1mm/s scan velocity, and around 40 at 5mm/s respectively. It would be the main reason that micro crack is increased gradually by multi pulse irradiations.

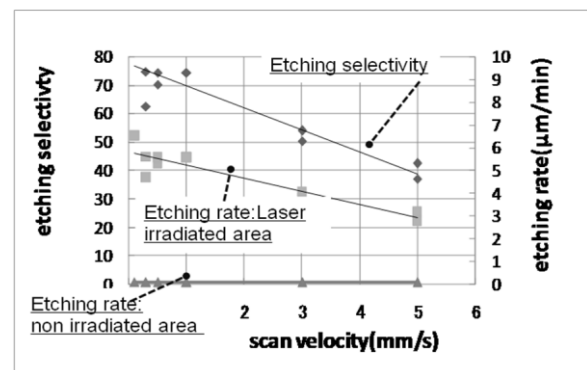


Fig.3: Dependence of etching selectivity on the laser scan velocity

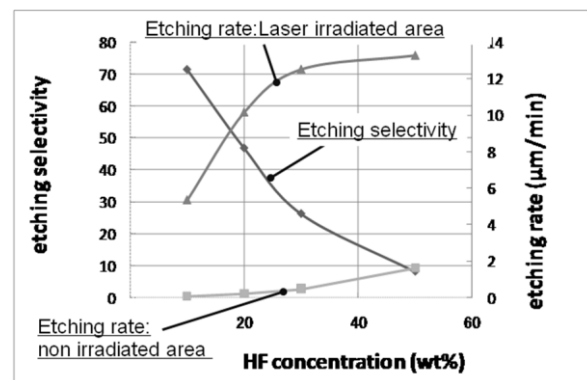


Fig.4: Dependence of etching selectivity on the HF concentration

Fig.4 shows the dependence of etching selectivity on the concentration of hydrofluoric acid for silica glass. The laser scan velocity is set 1mm/s and other conditions are the same as listed above. The result shows the lower the concentration of the etchant is, the larger the etching selectivity. For exam-

ple, the etching selectivity is 10 at 50 wt% concentration of hydrofluoric acid, and 70 at 10wt% concentration respectively. This behavior is understood that when lowering the concentration the etching rate of non-irradiated area is decreasing much faster than that of irradiated area.

Therefore lower scan velocity and lower concentration can fabricate the optimum through holes with high etching selectivity. However the lower scan velocity will decrease the throughput, so we've set the scan velocity around 1.0 mm/s and 10wt% hydrofluoric acid as the fabrication conditions.

Fabrication of the 3D micro-holes in silica glass

Fig.5 shows cross sectional images of the holes fabricated in this study. Fig. 5(a) gives a branched hole and fig. 5(b) gives cranked hole respectively. Two different holes are crossed each other with a little spacing. The diameters of the holes on the substrate are 75 μm and the depth is 430 μm . The pitch of the cranked hole, branched hole is 600 μm and aspect ratio of the micro holes are more than 13 for cranked hole, and more than 9 for branched hole respectively.

Through-hole interconnections in silica glass

Fig.6 shows cross-sectional images of the holes after metal filling. Since Au-Sn is not wet to the silica glass essentially, Au-lands, which have good wettability to the Au-Sn, were patterned at the opening of the holes so that the filled Au-Sn adheres to the Au-lands.

In order to make THIs, we grind the bottom side of the substrate until the Au-Sn solder is exposed after the MMSM. Fig.7 shows a cross-sectional

image of interposer with 3D THIs demonstrated in this study. Electrical connection of the interposer was investigated using a pressure sensor mounted on the interposer. After mounting the unit onto a PCB, the pressure sensor was operated normally. From this, the 3D THIs would have enough potential for interposer application.

Air tightness of the THIs was also investigated by Helium leakage test. A glass substrate including THIs was bounded to another substrate using Au(10wt%)-Sn(90wt%) to form a sealed cavity for the leakage test (fig. 8). The leakage rate of the THIs was estimated below 2×10^{-8} atm cc/sec which is applicable to electronics packaging application.

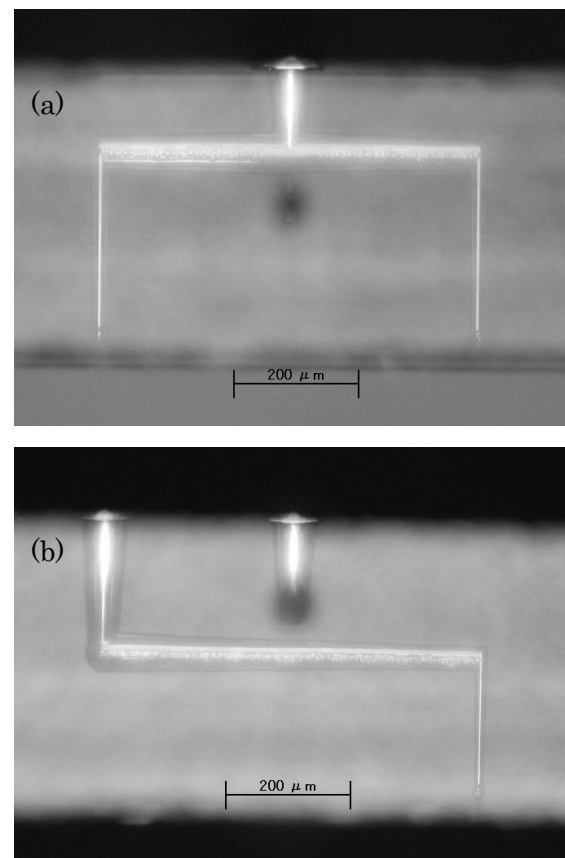


Fig.5 Cross-sectional image of micro holes in silica glass. (a) branched hole, (b) cranked hole

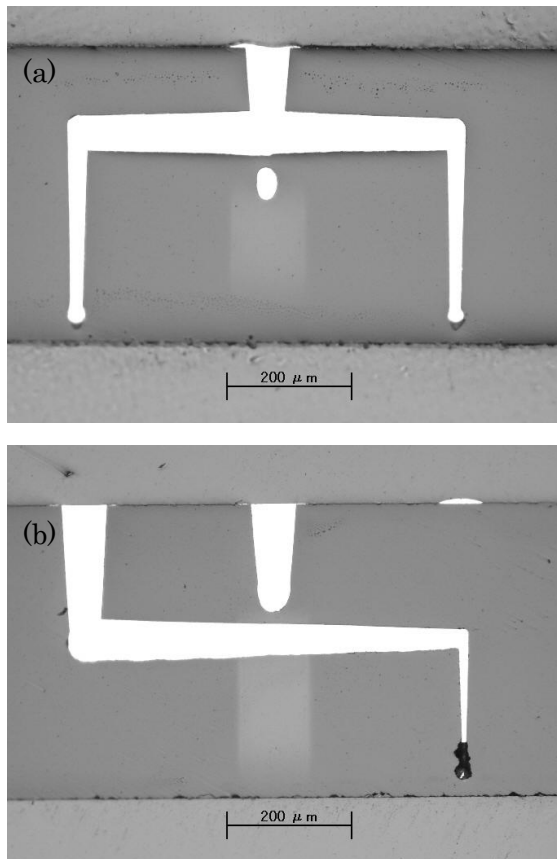


Fig.6: Cross-sectional image of THIs in silica glass.

(a) branched hole, (b) cranked hole

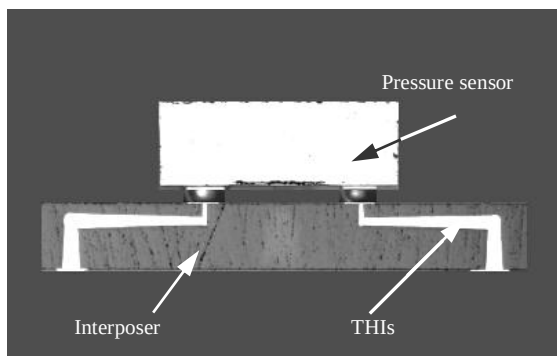


Fig.7: Pressure sensor mounted on the interposer

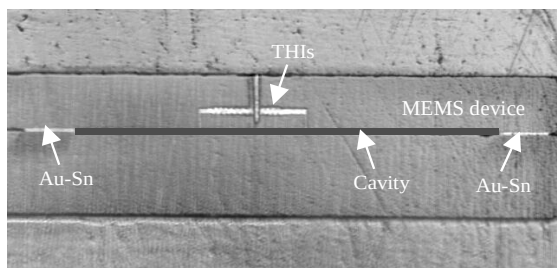


Fig.8: Test sample for He leakage test

Summary

Using femto-second laser irradiation, wet etching and MMSM, we've demonstrated that "true" 3D through hole interconnections (THIs) can be fabricated in silica glass substrate, which can never be accomplished by regular etching process. 3D THIs such as branches or cranked structures were obtained successfully. The initial evaluation results seem to be promising for not only interposer applications, but also package applications.

Acknowledgements

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