A Handling Solution for Easy Processing of Thin Glass with TGV

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Abstract— **Glass substrates with through-glass vias for electronic packaging and radio-frequency substrate applications have been demonstrated in a variety of formats from wafers to panels, yet adoption has been hindered by difficulty in handling thin glass in the fab. In this paper we describe successful processing of glass wafers on silicon handles, using our polymer-free temporary bonding process. One preferred handle is silicon, so that the glass-on-silicon unit is rigid, opaque, and compatible with existing silicon-processing equipment. With the Mosaic bond approach, no adhesive wicks into the glass vias, allowing good via fill. Furthermore, no solvent is required for post-debond cleaning. In this paper, we demonstrate fundamental process capability for implementation of this technology for volume manufacture of glass solutions.**

Keywords—glass, TGV, via, bonding, debond

I. Introduction

Today's high-performance circuits require that the package design and properties be included as part of the chip design. Glass substrates, and particularly low-alkali-containing glass, have emerged as advantaged for many packaging applications including integrated passive devices, such as 3D inductors, and for millimeter-wave substrates [1,2]. Thin substrates are generally desired, since starting with thin, smooth glass avoids the cost and yield reduction from back-grinding, but they do require support of a carrier or handle wafer through fabrication. Temporary polymeric adhesives using a variety of chemistries have been used successfully for thin Si substrates for some time [3-9], and continue to be of great value to the community. However, in the case of thin glass substrates with through-glass vias (TGV), a significant challenge of temporarily bonding with a polymeric adhesive is that in the liquid phase, adhesive can wick into the vias, and sometimes even out onto the top surface of the wafer. A further concern can be the temperature limitations of the adhesive.

In this paper we discuss the Mosaic temporary bond approach for supporting thin glass on a handle wafer for easy integration into existing processes. This approach allows processing to over 450°C, which distinguishes it from typical temporary bond solutions. However, the Mosaic bonding layer is sufficiently thin that requirements on device wafer smoothness are strict. For glass that has been formed in thin sheets, such as Corning Incorporated's Willow™ or Schott Glass AF32, the surfaces arrive smooth enough for this approach, while glass formed in boules and then sliced, such as fused silica, can be appropriately polished for bonding.

II. The Mosaic Temporary Bond

As in any bonding process, cleanliness is critical to Mosaic's bond. Prime Si wafers are usually pristine as received, but thin glass has to be shipped horizontally, with interleaf, as otherwise the jostling inevitable in shipping can cause breakage. Rigorous glass cleaning is necessary, and involves sonication in surfactant followed by standard semiconductor cleaning solutions such as "SC1", a dilute ammonium hydroxide/hydrogen peroxide mixture with megasonic agitation. In Fig. 1a, a bright light is used in transmission to high-light the significant number of particles left on glass when shipped on Tyvek™ interleaf. There are a sufficient number of particles that the glass has a non-uniform, almost hazy, appearance. A glass wafer after cleaning is shown in Fig. 1b, and in contrast, the only features that scatter the light are the edges of the wafer and parts of the support structure.

Mosaic's process for bonding glass to the handle wafer is outlined pictorially in Fig. 2. In this process, glass is first cleaned, and vias are created in the glass in the customer-specified design, and then the non-polymeric adhesive is applied to the handle wafer under vacuum. It is a thin, inorganic layer. The alignment and bonding processes take place at room temperature, with atmospheric pressure. The initial bond strength is adequate for simple handling, then a nitrogen furnace anneal to 250°C sets the bond strength to the desired value for processing. The initial bond will be weak or nonexistent if the roughness of the glass wafer is too large. Generally, we prefer rms roughness less than 0.6 nm. The stringent requirement for

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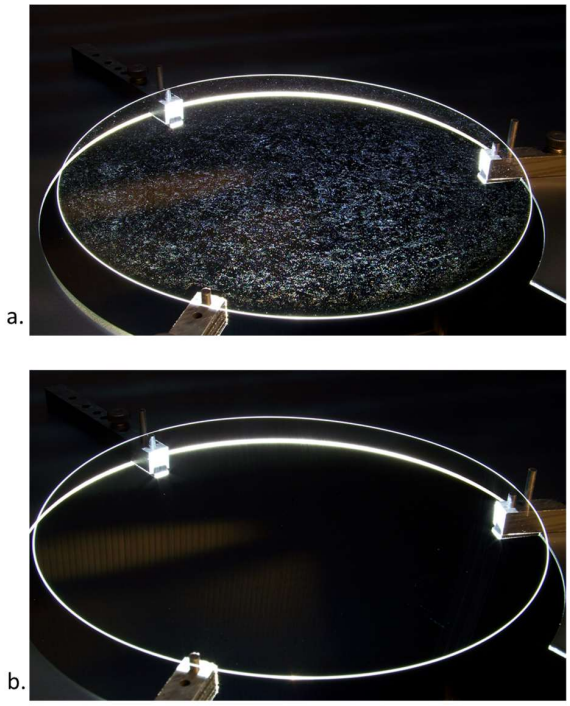

Figure 1. Images of 150mm glass wafer illuminated by bright light from below. a. A wafer as received in shipping interleaf. b. The same wafer after cleaning. No particles are left on the wafer to scatter the light, so the wafer appears uniformly dark except for the edge.

both handle wafer and the device wafer to have low roughness is similar to that required by a self-progressing Van der Waals bond. Unlike a Van der Waals bond, however, once set, the bond energy does not change significantly with subsequent anneals, even to over 400°C. The bonding layer does not decompose at this temperature, as evidenced by the fact that bubble defects do not grow between the glass and the handle wafer. At anneal temperature of 500°C, new bubble defects can form between the glass and the Si handle, and the bond energy changes slightly to a less strong bond. The anneal thus makes it, if anything, slightly easier to debond the glass from the handle wafer.

Typical roughness values for Corning Incorporated's Willow™ glass at 0.125 mm thick, on the order of 0.3 nm rms as measured by an optical profilometer, are well within the desirable range. Schott Glass AF32 is similarly smooth. Commercially available high purity fused silica wafers also bond readily. Etching glass can easily increase the roughness to more than 1 nm rms roughness, which is outside the ready bonding range, however, so cleaning and etching processes must be chosen carefully. Wafers with front-side patterning such as plated RDLs can also be too rough to bond this way, though standard commercially availably temporary bond materials can be used for the second side processing.

Cleanliness of wafers and fab space are both critical, as even small particles on either bond surface create tented regions on the bonded pairs. Not only does the cleanroom need to be Class 100 or better, but tools must also be will qualified. Because of the rigidity of the glass and the thinness of our adhesion layer, these bubble defects extend laterally much further than they do vertically, and are readily picked out by eye. For example, a 1.0 micron high particle will create a bubble with diameter of ~1 mm, for typical bond energy and thin glass. Despite the visual impact of the defects, for many applications, surface height variations of several microns over such a lateral distance will not adversely impact performance, while for others it can be important. In addition to environmental particles, unfinished edges of thin glass wafers can create significant and sizable particles during handling, and Mosaic has established processes to minimize that issue.

Mosaic has also identified the other principle contributors to particles in the bonding process, and designed processes leading to very low defects. Fig. 3a shows a wafer with 1.2% bubble area, and Fig. 3b shows one with nearly undetectable bubble

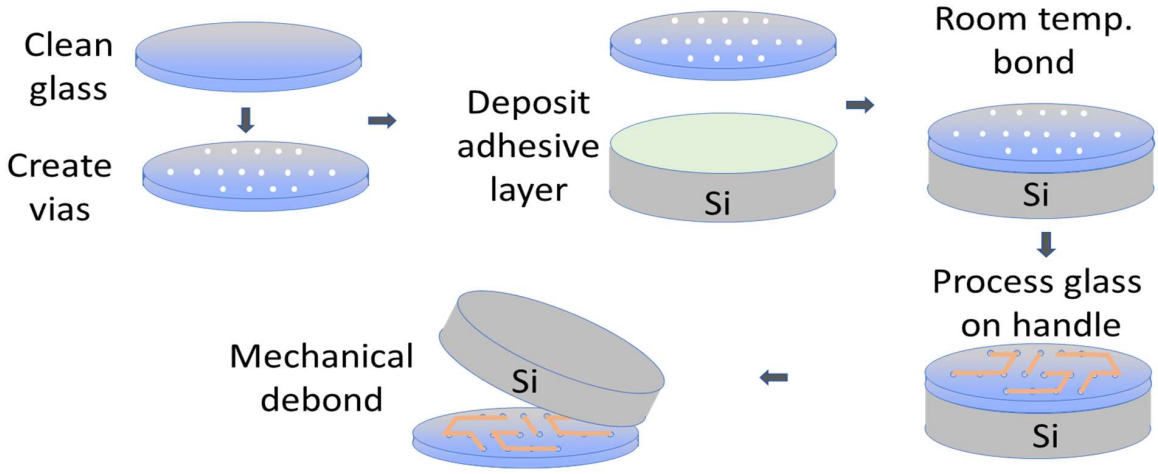

Figure 2. Schematic of bonding thin glass (blue discs) to a handle wafer (grey disks), and then processing and debonding the glass.

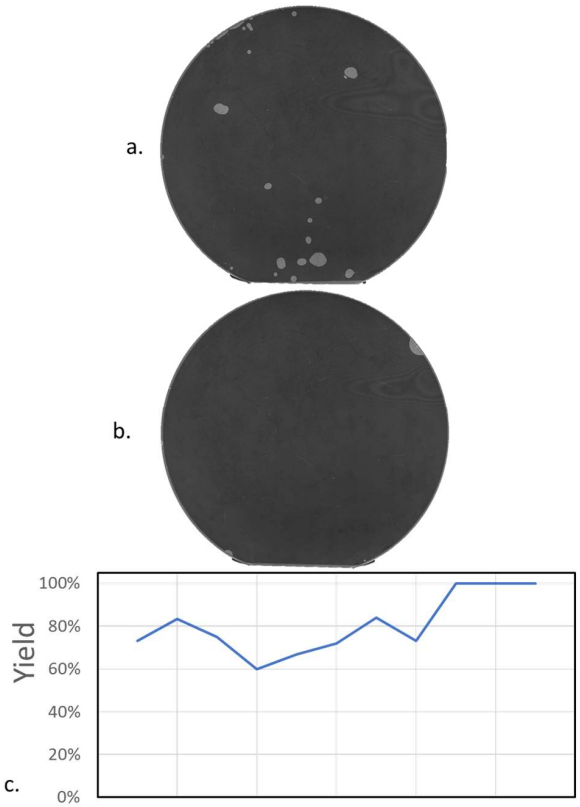

Figure 3 a. Optically scanned image of 150 mm diameter bonded pair (0.125mm thick glass on Si). Despite the number of defects visible, this has only 1.19% bubble-defect area. b. Optically scanned image of 150 mm diameter bonded pair after identification and elimination of the sources of particles, with 0.005% bubble-defect area c. Chart of run yield relative to a quality specification requiring less than 1.5% bubble defect areas, for recent Mosaic production runs of bonded pairs at 150 mm and 200 mm diameter.

area, bonded in Mosaic's facility after implementation of the improved particle-removing process. Using a defect area below 1.5% as a pass/fail criterion, yield statistics for recent runs of 6 wafers are shown in Fig. 3c, with the progression to essentially bubble-free samples. As wafer size increases, the cross-section for a particle fall-on increases, and it was notable that some of samples in the recent fully-yielding runs were 200mm diameter, and still with defect densities below 0.1%.

III. The Debonding Process

After processing the front side of the glass substrate, the wafer can be mechanically debonded to dicing tape for singulation. Mechanical debonders are commercially available from several companies, and we have successfully demonstrated debonding onto dicing tape using Cost Effective Equipment's Apogee™ Debonder, and the Süss MicroTec Wafer Debonder.

A schematic of debonding onto dicing tape is shown in Fig.4a. The thin glass is held flat by a vacuum chuck, while the handle wafer is removed. Very little stress is thus placed on the glass wafer. An image of a metallized 100mm wafer of 0.1 mm thick glass after debond is shown in Fig. 4b.

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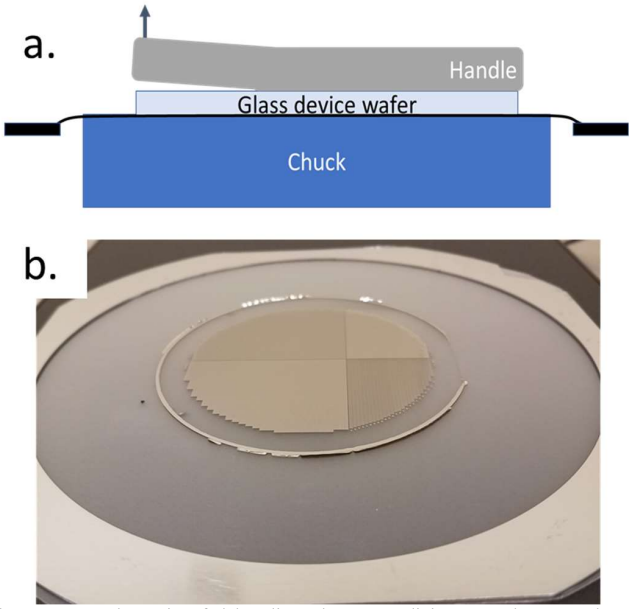

Figure 4. a. Schematic of debonding glass onto dicing tape. b. Example of metallized 0.1 mm-thick 100mm-diameter glass debonded, onto tape ring

Alternatively, after front-side processing, the glass wafer can be bonded to a secondary handle, and the Mosaic original handle can then selectively be debonded, thus leaving the thin glass substrate supported throughout. This situation is illustrated schematically in Fig. 5a. The result of such a transfer to a secondary handle, using commercially available 3M Wafer Support System polymeric temporary bonding material, is shown in Fig. 5b. A similar test, attaching a secondary handle

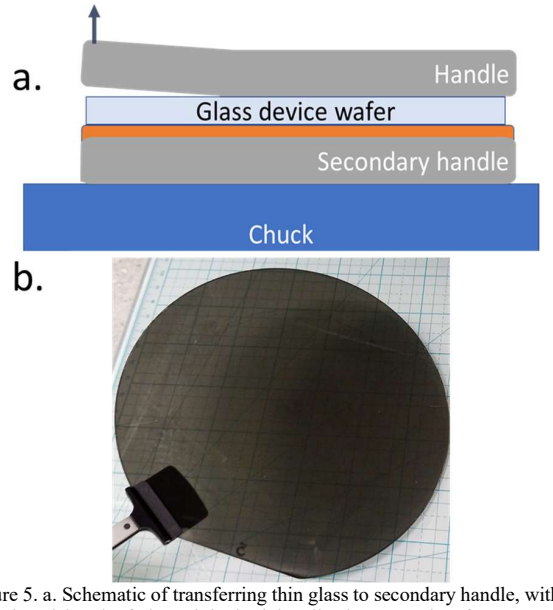

Figure 5. a. Schematic of transferring thin glass to secondary handle, with selective debond of the original Si handle. b. Example of a 150mm diameter thin glass wafer (0.125 micron) bonded to a secondary (glass) handle using the 3M Wafer Support System.

using Brewer Bond temporary adhesive, also allowed for selective debond of the original Mosaic handle.

`Mosaic can tune the strength of the temporary bond between glass wafer and Si handle to optimize for downstream processing needs, between very lightly bonded (~250 mJ/m^2) to very strongly bonded, but still temporary (~800 mJ/m^2). The standard bond energy, measured using a double cantilever (or "wedge") method [7], is approximately 400 mJ/m^2. This value is optimal for many applications, being strong enough to hold the bonded pair through grinding and polishing processes, yet relatively easy to initiate the mechanical debond afterwards. Bond energy values of over 800 mJ/m^2 have also been debonded with high yield. The translation from bond energy of the wafer pair to the tension required to mechanically debond is not straightforward given the changing characteristic lengths in a wafer geometry. However, experimentally, the tension values vary from about 25 N (at initiation of the debond) of a 150 mm wafer pair with bond energy of 400 mJ/m2, to 55 N (at initiation of the debond) of a 200 mm wafer with a bond energy of 800 mJ/m^2.

The glass wafer after debond has no visible residue. We are using XPS to explore exactly what is different between the glass prior to debonding and after, and thus far have not identified any difference. The handle wafer can be cleaned of the applied adhesion layer with a short oxygen plasma.

IV. TGV AND ASSOCIATED PROCESSES

When TGV glass is temporarily bonded to a handle wafer, the vias, penetrating through the glass, terminate at the surface of the handle wafer. Thus, the via-fill process is more similar to a Si blind-via-fill, than to a printed circuit board via-fill for through vias. Because the bond does not go through a liquid stage in the course of bonding, there is nothing to wick into the vias to contaminate the subsequent metallization process, unlike what can happen with a polymer above its melt temperature.

A requirement for achieving high quality, void-free filling of blind vias is that the profile be straight-sided or tapered, but not re-entrant. This allows a sputtered adhesion layer to reach through-out, and allows good conformally- and fully-filled vias. After the electroplating, bonded wafers can continue through front-side processing. At the end, a mechanical debond is all that is required to reveal the bottom of the vias, as opposed to a back-grinding reveal process.

An example of a bonded pair with fully-filled vias is shown in Fig. 6. As can be seen in Fig. 6a, the vias are void-free. The top via diameters are approximately 30 μm, the wafer thickness is 100 μm, and the overburden is 4 μm thick. Fig. 6b shows a 150 mm bonded pair after plating. The plated bonded pairs were sent for CMP to remove the overburden. The bond strength was sufficient to withstand all shear stresses, and planarization was readily accomplished, as shown in Fig. 6c, without modifications to the standard CMP approach for glass. The wafers were subsequent annealed to 400° C, and no evidence of cracking of the substrate or of microcracks in the near via areas,

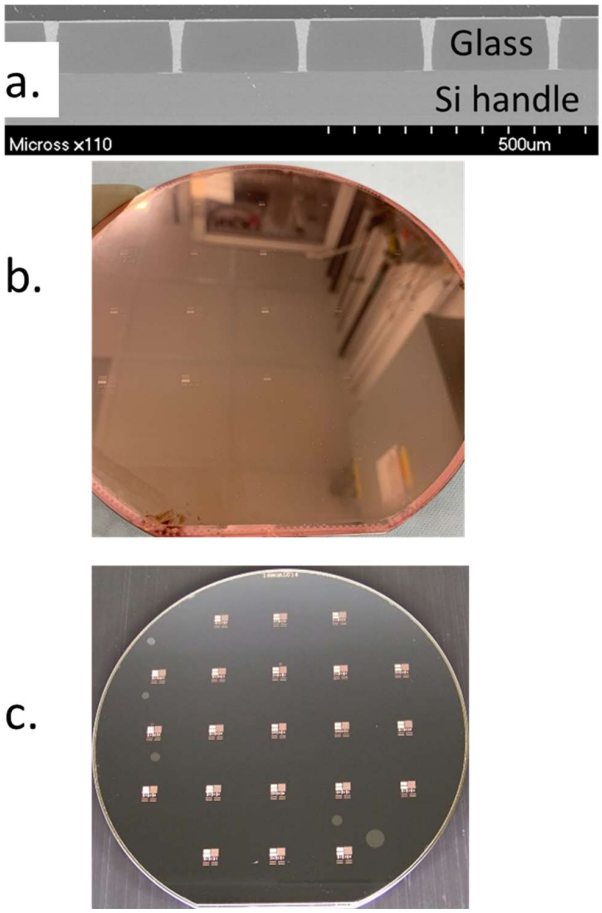

Figure 6. a. Tapered, fully-filled vias filled with a sputtered adhesion layer, an MOCVD Cu seed layer, and Cu electroplating. The fill is void-free. b. Wafer as Cu-plated. c. After CMP to remove overburden, still on the Si handle. (Cross-section micrograph courtesy of Micross.)

or of any other issues, were detected with careful microscopy of all the vias over several wafers.

Bonded glass with TGV can also be metallized with a conformal via fill. An example of a wafer with conformally gold-plated via-fill and RDL wafer after debond is shown in Figure 7. The Si wafer is removed, leaving the thin glass fully supported on the dicing tape in its frame. Except occasionally) around the perimeter of the glass wafer (and not in this image), there is no evidence of the metal layer sticking to the silicon carrier so the debonding process is very clean.

The shear stresses involved in CMP can be considerable, as can those for a grinding process. While the glass discussed in much of this paper is formed thin (e.g. Corning Willow™ glass), the Mosaic bond is also useful for holding smooth wafers to a handle for subsequent thinning.

Figure 7. 100mm TGV glass wafer with conformal gold fill and front-side RDL, after debonding onto dicing tape. The clean silicon handle wafer is also shown.

As an example, thinning and polishing of high purity fused silica from 0.35 mm to 0.18 mm, supported on a handle wafer, was successfully demonstrated both for 100 mm wafers and for 200 mm wafers (in collaboration with Disco Corporation.) The handles were chosen to be fused silica, because of the difference in thermal expansion between fused silica and Si. The thickness of the handles was 0.5 mm. Because the bond material is very thin (<1 micron) the starting total thickness variation in the stack is essentially that of each starting wafer in the stack, and we have found the tolerances to be very tight for commercially available fused silica wafers.

The stacks were back-ground with a wheel grinder, then polished with CMP. There were vias in the fused silica prior to being bonded to the handle, and the vias showed no chipping after the either the grind or the polishing step. Not only were the samples successfully thinned and polished, but the polish was good enough that the thinned fused silica could be flipped to bond the grind/polish side to a secondary handle. In order to best observe the quality of the bond, Si was used for the re-bonded handle. An image of the thinned 100 mm fused silica wafer bonded to Si is shown in Fig. 8.

V. Conclusions

The material properties of glass make it an attractive material for next generation applications, particularly in RF and packaging applications. For this reason, there has been a great deal of interest over the past decade to leverage glass solutions,

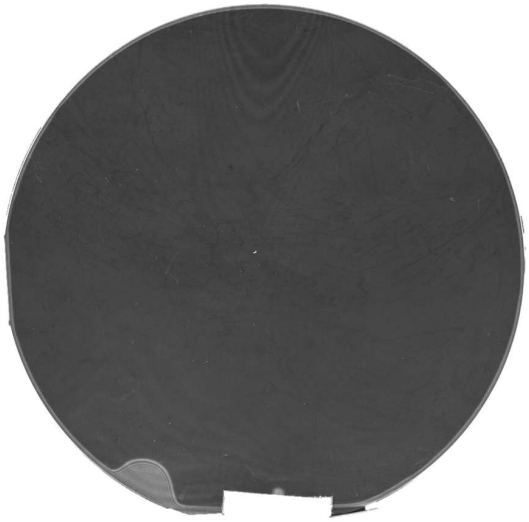

Figure 8. Fused silica after grind and polish, with the newly polished side bonded to a Si handle to visualize quality of the bond. (Collaboration with Disco Corporation.)

but challenges to implement these solutions in a high-volume environment has been a challenge. A new temporary bonding technology provides an excellent solution for high volume implementation of thin glass solution. Utilizing a temporary bond layer for thin (~100 μm) glass on a silicon handle wafer, the glass with and without TGV can be processed using the same processes matured for silicon wafers. This solution is viable at elevated temperatures (up to 400 C and above) without outgassing, and uses a straightforward mechanical debond approach. Not only does this avoid costly back-grinding operations, it is well-suited for bonding multiple layers of thin substrates for 2.5D and 3D integration. As described here, important demonstrations have been completed showing the viability of utilizing mature manufacturing processes for thin glass using this approach. These include electroplating for vial-fill, CMP, lithography, etch and other finishing processes. These developments provide viable paths to establish thin glass solutions for next generation RF and packaging challenges.

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