Method for introducing at least one cutout or aperture into a sheetlike workpiece

The invention relates to a method for introducing at least one cutout or aperture into a sheetlike workpiece having a thickness of less than 3 millimeters. A microchip as a processor core typically has on its underside several hundred contact points closely spaced in relation to one another and distributed over a relatively small area. Because of this close spacing, these contact points cannot be applied directly to a circuit board, known as the motherboard. Therefore, a so-called interposer of insulating material is used as a connecting element, with which the contacting base can be enlarged. Such an insulation and redistribution layer consists for example of glass, glass-fiber-reinforced epoxy resin or silicon and must be provided with a multiplicity of apertures.

Glass is particularly advantageous as an interposer material because it is less costly than silicon and can be adapted with regard to its thermal expansion to that of the active components, for example microprocessors. The processing of the glass into usable interposers presents a challenge. In particular, cost-effective introduction of the multiplicity of apertures into the glass workpiece for the vertical interconnect access has not yet been achieved in a commercially viable way in the prior art.

For instance, DE 10 2010 025 966 B4 discloses a method in which, in a first step, focused laser pulses are directed onto the glass workpiece with a radiation intensity of such a strength as to cause local, athermal destruction along a channel in the glass. In a second method step, the channels are enlarged into holes, in that opposing electrodes are supplied with high-voltage energy, which leads to dielectric breakdowns through the glass workpiece along the channels. These breakdowns are enlarged by electrothermal heating and evaporation of hole material, until the process is stopped by switching off the energy supply when the desired hole diameter is achieved. As an alternative or in addition, the channels may also be enlarged by reactive gases, which are directed onto the locations for making the holes by means of nozzles. The breakdown locations may also be enlarged by supplied etching gas.

The comparatively complex process resulting from first having to break through the workpiece by the athermal destruction and in the next step having to enlarge the diameter of the channels to form holes is found to be disadvantageous.

A method for processing glass by producing filaments is known from US 2013/126573 A1. The term filament refers to a beam expansion without diffraction within a medium on the basis of self-focusing. Given a suitable choice of pulse energy and pulse duration, in particular in the case of the preferred use of pulse trains with a repetition rate in the megahertz range and pulse durations of less than 10 picoseconds, filaments are created as a result of contrary effects, to be specific the self-focusing on account of the Kerr effect and the defocusing due to diffraction on account of the small beam diameter. An equilibrium of the two effects allows the laser beam to propagate through the material, which is transparent to the wavelength, its diameter remaining at least substantially constant. In the case of the method described, the processing of the material is performed below the threshold for an optical breakthrough. Therefore, contrary to conventional material processing with picosecond and femtosecond pulses, a weak focusing of the laser beam is necessary.

The invention is based on the object that wet-chemical or dry etching can attack anisotropically at defects in the material. As a result, in a first step, defects created can be successively enlarged, and consequently a cutout or aperture can be created. This method allows the creation of a multiplicity of cutouts or apertures with significantly reduced expenditure of time. The object is achieved according to the invention by a method according to the features of claim 1. The further refinement of the invention can be taken from the subclaims.

The invention therefore provides a method in which for example a laser beam is directed onto the glass workpiece for such a short time that only a chain of modifications in the material of the workpiece takes place, preferably along a beam axis of the laser beam, without destruction of the workpiece occurring, and in which, in the next step, an anisotropic removal of material is carried

out only in those regions of the workpiece that previously experienced a defect by means of the laser beam, and thus a cutout or aperture is introduced into the glass workpiece. Typically, a linear chain of blisters is created in the workpiece by the laser radiation. The individual blisters are enlarged by the attack of the etching medium.

For the purposes of the present invention, the term aperture of a workpiece should be understand as meaning an opening passing through the entire thickness of the workpiece, such as for example a through-bore, while an opening that does not pass through the entire thickness of the workpiece, such as for example a blind hole, is referred to as a cutout.

Defects should be understood hereinafter as meaning locally limited blisters and/or chemical modification.

The cutout or aperture is in this case formed as a result of a successive etching open of a plurality of defects arranged in a row, in that the previously created defects, which are enlarged by the etching effect to form a cavity in the workpiece, are successively connected by the etching process. As a result, the etching fluid quickly passes from defect to defect. In this case, the influence of gravitational force is not decisive. Rather, the advancement of the etching is achieved in a comparable way from the top downward as in the opposite direction, so that in particular the etching process can begin at the same time on both outer sides.

The defects that are created as modifications within the workpiece have the effect that the etching process follows the line on which the defects are arranged. The line may be a straight line or follow virtually any desired contour, which is maintained precisely by the etching process. It is consequently also possible for the first time to create virtually any desired contour of cut.

Although a greater enlargement occurs as a result of the longer exposure time in the region of the defects toward the outer sides in comparison with defects lying further inward in the workpiece,

nevertheless an altogether small conical enlargement can be observed. After the completion of the etching process, the contour of the cutout or aperture thus created is characterized by a succession of cross-sectional enlargements and constrictions, the cross-sectional enlargements and constrictions not having to have a uniform cross-sectional area or a uniform distance from adjacent cross-sectional enlargements and constrictions. Since a structure thus described corresponds to the outer form of an earthworm (latin lumbricus terrestris), a person skilled in the art would describe this as an earthworm structure.

The term earthworm structure therefore covers regular and irregular cross-sectional enlargements and constrictions, the transition of which may be continuous or discontinuous. A cross-sectional enlargement or constriction may in this case extend in a cross-sectional plane in relation to the principal axis or be inclined thereto. Adjacent cross-sectional enlargements or constrictions may furthermore also have center points that do not lie on the same straight line, so that the cross-sectional enlargements or constrictions are arranged offset in relation to one another. The height of adjacent cross-sectional enlargements may also be uniform or deviate from one another. Furthermore, it goes without saying that the principal axis of the cutout or aperture may extend in an inclined manner, deviating from a normal to the surface of the workpiece, while the cross-sectional enlargements and constrictions are aligned in a plane parallel to the surface of the workpiece.

The earthworm structure is in this case comparable to another method known from the prior art, which is referred to as deep reactive ion etching (DRIE). This is an anisotropic dry etching process, which is likewise used for the production of microstructures in silicon, for example for the production of through silicon vias. When carrying out the method according to the invention, therefore, the following processes do not have to be adapted, or only slightly.

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the etching effect to form a cavity in the workpiece, are successively connected by the etching process. As a result, the etching fluid quickly passes from defect to defect. In this case, the influence of gravitational force is not decisive. Rather, the advancement of the etching is achieved in a comparable way from the top downward as in the opposite direction, so that in particular the etching process can begin at the same time on both outer sides.

The defects that are created as modifications within the workpiece have the effect that the etching process follows the line on which the defects are arranged. The line may be a straight line or follow virtually any desired contour, which is maintained precisely by the etching process. It is consequently also possible for the first time to create virtually any desired contour of cut.

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After the completion of the etching process, the contour of the cutout or aperture thus created is characterized by a succession of cross-sectional enlargements and constrictions, the cross-sectional enlargements and constrictions not having to have a uniform cross-sectional area or a uniform distance from adjacent cross-sectional enlargements and constrictions. Depending on the number and density of the defects to be etched open, the difference in the diameters of cross-sectional enlargements and constrictions may be less than 1 µm or less than 100 nm, so that the cutout or aperture may even appear as macroscopically smooth.

The modifications in the glass may be produced by a laser beam, which is shaped with the aid of a diffractive-optical element in such a way that a linear chain of modifications is created. The modifications may be created by a train of pulses or by a single pulse.

On account of the distinctive nature of the method, created cutouts or apertures have a characteristic form. Since the fundamentally isotropically acting etching process attacks particularly strongly at the modified regions in the workpiece and the modified region typically takes the form of a linear chain of modifications, a plurality of encircling, concentric structures is produced on the lateral surfaces of the cutout or aperture.

On account of the structure of the apertures, the method is particularly well suited for the production of interposers, since the concentrically encircling microstructures that are created as a result of the successive etching open of the defects provide a particularly good adhesive strength of the later metal layer in the hole.

The use of such workpieces as so-called interposers is particularly relevant in practice for the electrical connection of the terminals of a number of homogeneous or heterogeneous microchips. A microchip as a processor core typically has on its underside several hundred contact points closely spaced in relation to one another and distributed over a relatively small area. Because of this close spacing, these contact points cannot be applied directly to a circuit board, known as the motherboard. Therefore, an interposer is used as a connecting element, with which the contacting base can be enlarged.

Such an interposer preferably consists of glass or silicon and includes for example contact areas, redistributions, vertical interconnect accesses and also active and non-active components.

It has already been recognized according to the invention that the spacing of the cutouts to be introduced in such a way can be further reduced because the laser radiation does not cause the destruction of the workpiece but merely a modification or transformation, it also being possible at the same time for the laser power to be reduced. Particularly preferably, the laser is operated with a wavelength for which the glass workpiece is transparent, so that penetration of the glass workpiece is ensured. In particular, a substantially cylindrical modification zone

coaxially around the laser beam axis is ensured as a result, leading to a constant diameter of the aperture or the cutout.

A wavelength greater than 1.1 µm is particularly advantageous for silicon processing.

Particularly advantageous in the case of creating cutouts or apertures in the workpiece, in particular of silicon, is an alignment of the direction of propagation of the laser beam at an angle of the beam axis of approximately 0°, 45° or 90° in relation to the crystal symmetry.

The pulse duration can be significantly reduced in comparison with the method known from the prior art. In the case of a particularly advantageous refinement of the method according to the invention, the laser may be operated with a pulse duration of less than 100 nanoseconds to below 1 picosecond.

Given a suitable choice of pulse energy and pulse duration, in particular in the case of the preferred use of pulse trains with a repetition rate in the megahertz range and pulse durations of less than 10 picoseconds, filaments are created as a result of contrary effects, to be specific the self-focusing on account of the Kerr effect and the defocusing due to diffraction on account of the small beam diameter.

In principle, the method is not restricted to specific materials of the workpiece. Using a dielectric material such as glass appears to be promising. Using glass containing a significant proportion of aluminosilicate, in particular a boroaluminosilicate, appears to be particularly promising.

The workpiece is preferably subjected, at least in its modified regions, to an anisotropic removal of material, for example by an etching process, such as for example by liquid etching, dry etching or vapor phase etching, or by evaporation by means of high voltage or high frequency, in order in this way to introduce cutouts or apertures into the workpiece. The anisotropic removal of material means that, instead of a sequential removal process, a removal

process that acts over the surface area, which makes only low demands on the process, can be used for the actual removal of material. What is more, by using the exposure time, the removal of material can be carried out quantitatively and qualitatively equally for all of the regions that have been pre-treated in the way described, and accordingly modified, so that the total time expenditure for creating the multiplicity of cutouts or apertures is reduced significantly.

An equilibrium of the two effects allows the laser beam to propagate through the workpiece, which is transparent to the wavelength, its diameter remaining at least substantially constant.

At the same time, with high peak intensities in the laser beam, further effects, such as plasma formation, can also be used in an advantageous way for stronger defocusing.

In practice, the interaction between defocusing and self-focusing proceeds periodically, so that a chain of modified material regions is produced. Depending on how pronounced the effects are, a continuous channel, known as a plasma channel, may also be produced.

In principle, the formation of the filament may remain restricted to a subportion of the maximum material thickness of the material. The formation of the filament ends when the beam leaves the Kerr medium and diverges or when the intensity of the beam has subsided to such an extent that the defocusing diffraction outweighs the self-focusing.

Used in practice as the interposer is for example a glass-fiber-reinforced epoxy resin sheet that is provided with a number of holes. Running on the surface of the glass fiber mat are conductive tracks, which lead into the respective holes in order to fill them, and on the other side of the glass fiber mat lead to the terminal contacts of the processor core. If heating occurs, however, different expansions occur between the core processor and the glass

fiber mat, and there are consequently mechanical stresses between these two components.

The filaments could be introduced by laser processing, in which positioning of the processing head and the irradiation are carried out alternately. On the other hand, preferably a continuous relative movement is performed between the processing head and the workpiece while the radiation is being directed onto the workpiece, so that the laser beam is therefore passed over the workpiece continuously in a “flying” movement, so that therefore an uninterrupted changing of the relative position produces an extremely fast processing time.

In this case, the relative position of the material with respect to the processing head may be changed at a constant rate, so that in the case of a constant pulse frequency the spacing of the modifications to be created follows a predetermined modular dimension.

Particularly preferably, the radiation source is operated with a wavelength for which the workpiece is transparent, so that penetration of the workpiece is ensured. In particular, a substantially cylindrical modification zone coaxially around the beam axis is ensured as a result, leading to a constant diameter of the aperture or the cutout.

In addition, it may also be of advantage if a surface region is also additionally removed by the radiation source, in order to form the zone of action of the anisotropic removal in such a way that a conical inlet region of the filaments is produced. In this way, the later vertical interconnect access can be simplified. Moreover, the action of an etchant for example is concentrated in this region.

In the case of a refinement of the method according to the invention, the radiation source may be operated with a pulse duration of less than 50 ps, preferably less than 10 ps.

In the case of another refinement of the invention that likewise appears to be particularly promising, the workpiece is provided, in particular after the modification, with a surface-area metal layer, covering at least individual apertures, in particular a multiplicity of apertures, to be subsequently introduced. In a following step, the modified regions are removed in such a way that a cutout that is closed on one side by the metal layer is created. In this case, the metal layer is preferably applied after the modification, but before the removal of material, so that after the removal of material the metal layer, applied for example as a conductive track, closes the cutout and as a result forms at the same time an optimum base for a contact to be provided on it. The vertical interconnect access in this case takes place in the region of the cutout by processes known per se. Applying the metal layer as a conductive track also allows a desired circuitry to be created in an easy way.

In the case of another refinement of the method that likewise appears to be particularly promising, before a laser treatment the workpiece is coated over the surface area with an etching resist on at least one surface. By the laser beam acting as a preferred electromagnetic radiation source, the etching resist is removed on at least one surface and the modification in the workpiece is created at the same time in a punctiform zone of action. In this way, the non-modified regions are protected from undesired exposure in the subsequent etching process and the surface of the material is therefore not impaired. In this case, the etching resist does not hinder the modification of the material lying thereunder. Rather, the etching resist is either transmissive to the laser radiation or is removed in a virtually punctiform manner by the laser radiation, that is to say for example evaporated. Furthermore, it is not ruled out that the etching resist contains such substances that act in such a way as to assist the modification, that is to say for example to speed up the modification process.

It goes without saying that the metal layer described above may be applied to one of the outer surfaces of the material before the application of the etching resist, in order to use it as a basis

for the desired vertical interconnect access after the removal of the etching resist.

The etching resist could remain on the surface of the material after the completion of the treatment. Preferably, however, the etching resist is removed from the surface of the material in a way known per se after the anisotropic removal of material.

In principle, the method is not restricted to specific material compositions of the material. However, it appears to be particularly promising if the workpiece contains a significant proportion of an aluminosilicate, in particular a boroaluminosilicate.

In the case of another refinement of the invention that is likewise particularly appropriate for practical implementation, the spacing of filaments created adjacently in the workpiece along a separating line is realized in such a way that the modified regions are directly alongside one another or have a very small spacing from one another, in order in this way to delineate defined material regions.

The separation takes place after the introduction of the filaments along the separating line as a result of internal stresses of the material or on account of the effect of an external force. Alternatively or additionally, the internal stresses may also be caused by thermal stresses, in particular by a strong difference in temperature.

The invention allows various embodiments. For further clarification of its basic principle, one of these is described below and represented in the drawing, in which

Figure 1 shows a method sequence for introducing cutouts into a workpiece;

Figure 2 shows possible distinctive forms of various cutouts;

Figure 3 shows further possible distinctive forms of various cutouts,

in each case in a basic representation.

Figure 1 shows a flow diagram with a number of method steps for introducing an aperture into a sheetlike workpiece by irradiating with laser radiation and subsequent etching, with individual method steps for introducing an aperture into a sheetlike workpiece 1. For this purpose, in Figure 1a laser radiation 2 is directed onto the surface of the workpiece 1. The thickness d of the workpiece 1 is in this case up to 3 mm. The time of exposure to the laser radiation 2 is chosen to be extremely short, so that only a modification of the workpiece 1 concentrically around a beam axis of the laser beam occurs. For this purpose, the laser is operated with a wavelength to which the workpiece 1 is transparent. Such a modified region with defects 3 is represented in Figure 1b in the form of a linear chain of blisters. In a subsequent method step, represented in Figure 1c, the action of an etching medium that is not represented causes an anisotropic removal of material to occur in those regions of the workpiece 1, formed by the defects 3, that previously experienced a modification by the laser radiation 2. As a result, a cutout 4 is produced as an aperture in the workpiece 1 along the cylindrical zone of action.

The aperture has a plurality of encircling, concentric structures on the lateral surface, as can be seen in the representations of Figures 2a and 2b and also Figure 3a to 3c.

The cutout 4 is in this case formed as a result of a successive etching open of a plurality of defects 3 arranged in a row, in that the previously created defects 3, which are enlarged by the etching effect to form a cavity in the workpiece 1, are successively connected by the etching process. As a result, the etching fluid quickly passes from defect 3 to defect 3. Because in this case the influence of gravitational force is not decisive, the advancement of the etching takes place from above and below and begins at the same time on both outer sides. As a result of the relatively long time of exposure to the etching medium in the

region of the outer sides, there is a conical enlargement of the defects 3 in the region of the outer surfaces, as can be seen in Figure 2b.

The defects 3 that are created as modifications within the workpiece 1 have the effect that the etching process follows a line 5, on which the defects 3 are arranged. The line 5 may be a straight line or follow virtually any desired contour, which is maintained precisely by the etching process. It is consequently also possible for the first time to create virtually any desired contour of cut.

Although a greater enlargement occurs as a result of the longer exposure time in the region of the defects 3 toward the outer sides in comparison with defects 3 lying further inward in the workpiece, nevertheless an altogether small conical enlargement can be observed.

After the completion of the etching process, the contour of the cutout 4 or aperture thus created is characterized by a succession of cross-sectional enlargements and constrictions, the form of which resembles an earthworm, the cross-sectional enlargements and constrictions not having to have a uniform cross-sectional area, as can be seen for example in Figures 2b and 3c, or a uniform distance a1, a2 from adjacent cross-sectional enlargements and constrictions, such as that shown in Figure 3c. A cross-sectional enlargement or constriction may in this case be arranged in a cross-sectional plane in relation to the principal axis or, as shown in Figure 3a, be inclined thereto.

Adjacent cross-sectional enlargements or constrictions may furthermore also have center points that lie on a common line 5 inclined with respect to the surface of the workpiece 1, so that the cross-sectional enlargements or constrictions are arranged offset in relation to one another, it being possible for the cross-sectional enlargements or constrictions to be inclined in relation to the outer surface, as shown in Figure 3a, or aligned parallel to the outer surface, as shown in Figure 3b.

As can be seen in Figure 3c, the respective centroids of the areas of adjacent cross-sectional enlargements have an offset, so that they are in particular not arranged on a common straight line.

PATENT CLAIMS

1. A method for making a recess or an opening in a planar workpiece having a thickness of less than 3 mm, the method comprising: irradiating the planar workpiece with laser radiation comprising a single pulse of laser radiation having a spatial beam that reacts with the planar workpiece over an entire thickness of the planar workpiece along a beam axis of the laser radiation, the spatial beam of the laser radiation propagating through the planar workpiece to modify the planar workpiece by forming a plurality of flaws, whereby no recess or opening into the planar workpiece is yet produced; and etching the plurality of flaws to create the recess or the opening in the planar workpiece.

2. The method of claim 1, wherein the flaws comprise a linear chain of blisters which are separated from each other along the chain.

3. The method of claim 2, wherein the linear chain of blisters extends across the thickness of the planar workpiece.

4. The method of claim 1, wherein the flaws along the beam axis do not touch one another.

5. The method of claim 1, wherein the flaws extend along the beam axis from one surface of the planar workpiece as far as to a second surface of the planar workpiece.

6. The method of claim 1, wherein the etching reduces an average thickness of the planar workpiece.

7. The method of claim 1, wherein the laser radiation has a wavelength to which the material of the planar workpiece is transparent.

8. The method of claim 1, wherein the laser radiation has a pulse length of less than 100 picoseconds.

9. The method of claim 8, wherein the laser radiation has a pulse length of less than 12 picoseconds.

10. The method of claim 1, further comprising: creating the spatial beam with an optical system having spherical aberration or with a diffractive optical element.

11. The method of claim 1, wherein the laser radiation includes paraxial beams and edge beams,each with a respective focal point layer, and wherein a difference between the focal point layers of the paraxial beams and the edge beams along the beam axis is >100 µm.

12. The method of claim 11, wherein the difference is >250 µm.

13. The method of claim 1, wherein a lateral surface of the recess or the opening forms an earthworm structure.

14. The method of claim 1, wherein a material of the planar workpiece includes a glass, silicon,and/or sapphire.

15. The method of claim 1, wherein the laser radiation comprises a sequence of pulses, wherein the single pulse is part of the sequence of laser pulses, and wherein each of the pulses of the sequence of pulses comprises a spatial beam that reacts with the planar workpiece over the entire thickness of the planar workpiece along the beam axis of the laser radiation.

16. The method of claim 1, wherein the etching is performed successively with etching fluid traveling from flaw to flaw and thereby joining the flaws to one another to form the recess or the opening.

17. The method of claim 1, further comprising, prior to the etching, applying a planar layer.

18. The method of claim 17, wherein the planar layer is a metal layer which covers the recess or the opening to be formed by the etching.

19. A method for making a recess or an opening in a planar workpiece having a thickness of less than 3 mm, the method comprising: irradiating the planar workpiece with laser radiation comprising a single pulse of laser radiation having a spatial beam that reacts with the planar workpiece over an entire thickness of the planar workpiece along a beam axis of the laser radiation, the spatial beam of the laser radiation propagating through the planar workpiece to modify the planar workpiece by forming a plurality of flaws, the plurality of flaws comprising a linear chain of blisters within the planar workpiece that are separated from each other along the chain; and etching the plurality of flaws to create the recess or the opening in the planar workpiece.

20. The method of claim 19, wherein the etching is performed successively with etching fluid successively traveling from blister to blister along the linear chain of blisters to join the blisters together and thereby create the recess or the opening in the planar workpiece such that a lateral surface of the recess or the opening has an earthworm structure.

21. The method of claim 19, wherein the linear chain of blisters extends across the thickness of the planar workpiece.