

LASER DRILLING AND CUTTING METHOD AND APPARATUS**TECHNICAL FIELD**

5 The present disclosure relates to a laser drilling and cutting method and apparatus. More particularly, the present disclosure relates to a method and apparatus for drilling and/or cutting a workpiece, such as a wafer, according to a cutting pattern. In particular, but not exclusively, the present disclosure relates to a method and apparatus for performing thermal cooling of a workpiece during laser cutting or drilling. The method and apparatus may be suitable for dicing a wafer into individual dies for fabrication of an integrated circuit.

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BACKGROUND

It is known to provide wafer processing methods, such as mechanical blade dicing and laser dicing, to produce cuts in wafers for the semiconductor industry. Mechanical processing may cause the wafer to chip, delaminate or crack. Laser processing causes the wafer to heat up which affects the integrity of the wafer.

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It is an aim of the present invention to address one or more of the disadvantages associated with the prior art. At least in certain embodiments, the present invention relates to a method and apparatus for cutting or drilling a wafer.

SUMMARY OF THE INVENTION

20 Aspects and embodiments of the invention provide a method of cutting a wafer to a cutting pattern, a cutting apparatus for cutting a wafer and a control unit for controlling a cutting apparatus as claimed in the appended claims.

25 According to an aspect of the present invention there is provided a method of cutting a wafer to a cutting pattern, the wafer having a first surface and a second surface, wherein the method comprises: using a laser source to emit a laser beam for cutting the wafer; using a laser scan head to direct the laser beam to perform at least one first cutting operation to cut at least a first segment of the cutting pattern in the first surface of the wafer, the laser scan head having a scanning area in which the laser beam can be directed.

30 The method may comprise dispersing droplets of a liquid onto the first surface of the wafer to provide cooling during the at least one first cutting operation. During the at least one first cutting operation, a first distribution of the liquid droplets over the first surface may be at least substantially uniform across at least substantially the whole of the scanning area of the laser scan head.

35 The laser scan head comprises one or more controllable optical element for controllably adjusting the trajectory of the laser beam. At least in certain embodiments, the laser scan head enables the trajectory of the laser beam to be controlled in two or more axis (i.e., two or more degrees of freedom). The scanning area corresponds to a region on the first surface of the wafer in which the laser beam can be controlled to perform the at least one first cutting operation. The scanning area is typically related to one or more constraint of the laser scan head, for example an angular range in which the laser beam can scan about the or each axis. The scanning area may be referred to as a field of view (FOV) of the laser scan head.

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The method according to the present embodiment comprises dispersing droplets of the liquid onto the first surface over the scanning area. Moreover, the liquid droplets have at least a substantially uniform distribution across the whole of the scanning area. At least in certain embodiments, this promotes cooling of the wafer during the at least one first cutting operation. The cooling may be performed irrespective of where the laser beam is incident on the first surface during the at least one first cutting operation. Cooling of the first surface may be performed across the scanning area where cutting may be performed during the at least one first cutting operation. The laser scan head may control the laser beam to perform first cutting operations in different locations to reduce localised thermal stresses. The distribution of the droplets across the first surface facilitates rapidly switching between the different locations. The droplets of liquid may be dispersed as a spray or a mist.

The liquid droplets may be dispersed onto the first surface throughout the at least one first cutting operation. The liquid droplets may be dispersed continuously or intermittently. The liquid droplets may be dispersed onto the first surface before initiating the at least one first cutting operation. The liquid droplets may be dispersed onto the first surface after the at least one first cutting operation is completed.

The droplets may be dispersed onto the first surface by a first liquid dispersal device. The first liquid dispersal device may disperse the droplets as a spray or a mist. The first liquid dispersal device may comprise a spray nozzle, a mist generator or an atomizer, for example.

The laser beam may have a beam width (diameter) in the range 15 μm to 40 μm . The laser beam may have a beam width of 15 μm , 25 μm , 35 μm or 40 μm , for example.

At least in certain embodiments, the droplets dispersed onto the first surface (or a majority thereof) have a maximum diameter which is smaller than or equal to a multiple of the beam width (diameter) and a predefined factor. The factor may be defined as one of the following numerical values: 4, 6, 8 or 10. In a first example, the laser beam may have a beam width of 25 μm and the droplets may have a diameter of less than 250 μm . In a second example, the laser beam may have a beam width of 15 μm and the droplets may have a diameter of less than 150 μm .

The method may comprise dispersing liquid droplets for cooling the second surface of the wafer during the at least one first cutting operation. The liquid droplets may be dispersed continuously or intermittently. During the at least one first cutting operation, a second distribution of the liquid droplets over the second surface may be at least substantially uniform across at least substantially the whole of the scanning area of the laser scan head. Cooling of the second surface may be performed across the scanning area where cutting may be performed during the at least one first cutting operation.

The droplets may be dispersed onto the second surface by the first liquid dispersal device. Alternatively, or in addition, droplets may be dispersed onto the second surface by a second liquid dispersal device. The

second liquid dispersal device may disperse the droplets as a spray or a mist. The second liquid dispersal device may comprise a spray nozzle, a mist generator or an atomizer, for example.

- At least in certain embodiments, the droplets dispersed onto the second surface (or a majority thereof)
- 5 have a maximum diameter which is smaller than or equal to a multiple of the beam width and a factor. The factor may have one of the following numerical values: 4, 6, 8 or 10. In a first example, the laser beam may have a diameter of 25 μm and the droplets may have a diameter of less than 250 μm . In a second example, the laser beam may have a diameter of 15 μm and the droplets may have a diameter of less than 150 μm .
- 10 The droplets may be composed of any suitable cooling liquid. At least in certain embodiments, the droplets may comprise or consist of water. In arrangements in which the first and second surfaces are cooled, the same liquid may be dispersed onto the first and second surfaces.

- The method may comprise cooling the liquid which is dispersed as droplets onto the first surface and/or
- 15 the second surface of the wafer. A liquid cooling device, such as a chiller, may be provided to cool the liquid prior to dispersal.

- Alternatively, or in addition, a second surface of the wafer may be at least partially submerged in a liquid to perform cooling during the at least one first cutting operation. A flow of a liquid may be established for
- 20 cooling the second surface of the wafer during the at least one first cutting operation. During the at least one first cutting operation, the flow of liquid may be directed onto the second surface of the wafer. The second surface may be submerged in a liquid provided in a cooling bath may be provided to cool of the second surface of the wafer during the at least one first cutting operation. The liquid may be water.

- 25 The method may comprise cooling the liquid in which the second surface of the wafer is submerged. A liquid cooling device, such as a chiller, may be provided to cool the liquid prior to dispersal.

- The at least one first cutting operation may form one or more aperture in the first surface. The one or more aperture formed by the at least one first cutting operation may comprise a groove or a channel in the first
- 30 surface of the wafer. At least in certain embodiments, the one or more aperture may extend only partway through the wafer. In other words, the one or more aperture may have a depth which is less than the thickness of the wafer. The method may comprise dispersing droplets of the liquid onto the first surface of the wafer to provide cooling during the at least one first cutting operation. The one or more aperture may have a depth in the range 100 μm to 350 μm ; 100 μm to 250 μm ; 150 μm to 250 μm ; or 150 μm to 200
- 35 μm . The one or more aperture may have a depth less than 100 μm , for example in the range 25 μm to 100 μm , or 50 μm to 100 μm .

- During the at least one first cutting operation, the wafer may be disposed in a first orientation in which the first surface of the wafer faces in a first direction. The method may comprise disposing the wafer in a second
- 40 orientation in which the second surface faces in the first direction and using the laser beam to perform at least one second cutting operation to cut at least a second segment of the cutting pattern in the second

surface. The at least one second cutting operation may form a cut (or aperture) in the second surface having a depth in the range 100 to 350 μm ; 100 to 250 μm ; 150 to 250 μm ; or 150 to 200 μm . The cut may comprise a groove or a channel in the first surface.

- 5 The cooling of the first and second surfaces may be reversed when the wafer is disposed in the second orientation. During the at least one second cutting operation, the first distribution of the liquid droplets over the second surface may be at least substantially uniform to provide cooling across the second surface. During the at least one second cutting operation, the second distribution of the liquid droplets over the first surface is at least substantially uniform to provide cooling across the first surface.

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The method may comprise performing a plurality of the first cutting operations and/or a plurality of the second cutting operations. The first and second cutting operations may be performed alternately. The wafer may be reconfigured in the first and second orientations for the respective first and second cutting operations.

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The successive first cutting operations on the first surface may be a continuation of each other to form a substantially continuous cut in the first surface. The successive second cutting operations on the second surface may be a continuation of each other to form a substantially continuous cut in the second surface.

- 20 The first and second cutting operations in the respective first and second surfaces may be at least substantially aligned with each other. A cut formed in the first surface during the first cutting operation and a cut formed in the second surface during the second cutting operation may be at least substantially aligned with (i.e. coincident with) each other.

- 25 The first cutting operation may comprise a first start point and a first end point on the first surface. The second cutting operation may comprise a second start point and a second end point on the second surface. The first and second start points may be at least substantially aligned with each other. Alternatively, or in addition, the first and second end points may be at least substantially aligned with each other.

- 30 The cutting pattern may be mirror-symmetrical about a plane of the wafer for the first and second cutting operations on the first and second surfaces.

- 35 The at least one first cutting operation may form at least one first aperture in the first surface, the at least one first aperture extending partway through the wafer. The at least one first aperture may comprise a groove or a channel in the first surface. The at least one second cutting operation may form at least one second aperture in the second surface, the at least one second aperture extending partway through the wafer. The at least one second aperture may comprise a groove or a channel in the second surface.

- 40 The at least one first cutting operation and/or the at least one second cutting operation may dice the wafer into one or more die or one or more individual component. The die may comprise an integrated circuit. The integrated circuit may be pre-formed on the wafer.

The cutting pattern may comprise or consist of a perimeter or a boundary of the one or more component or die. Alternatively, or in addition, the cutting pattern may comprise or consist of a perimeter or a boundary of an aperture to be cut in the wafer, for example in the form of a hole or a through-hole. Thus, the method
5 may be used in the laser drilling of a hole in the wafer.

The method may comprise dicing a plurality of the components or dies from the wafer. The method may comprise dicing one or more of the plurality of components or dies from a central region of the wafer; and then dicing one or more of the plurality of dies from an outer portion of the wafer.

10 The wafer may comprise or consist of a single-layer wafer. The first and second surfaces may correspond to the outer surfaces of the single-layer wafer. Alternatively, the wafer may comprise or consist of a multi-layer wafer. The wafer may consist of first and second layers bonded to each other. The first and second surfaces may correspond to the outer surfaces of the multi-layer wafer.

15 The wafer may be made of one or more of the following: silicon, lithium niobate (LiNbO_3), lithium tantalate (LiTaO_3), diamond, quartz, langasite and boules ($\text{La}_3\text{Ga}_5\text{SiO}_{14}$), gallium nitride (GaN), silicon carbide (SiC), silicon on sapphire(SOS), or any other suitable wafer material. The wafer may be formed of other materials, such as glass.

20 The wafer may have a thickness greater than or equal to 0.2mm, 0.3mm, 0.4mm or 0.5mm. The wafer may have a thickness less than or equal to 1mm, 1.5mm or 2mm. The wafer may have a thickness in one of the following ranges: 0.2mm to 1mm; 0.5mm to 1.5mm; 0.2mm to 0.5mm; 0.5mm to 1mm.

25 The laser beam may be a pulse laser beam. The pulse laser beam may have a pulse duration in the femtosecond, picosecond or nanosecond ranges.

The laser beam is emitted by a laser source. The laser source may be configured to emit radiation in the green or near infra-red wavelength.

30 The method may comprise trepanning the laser beam. The laser beam may be trepanned during the first cutting operation and/or the second cutting operation. A precession module may be provided to trepan the laser beam emitted by the laser source. At least in certain embodiments, trepanning the laser beam may reduce or remove tapering of the at least one cut made in the wafer; and/or increase a depth of the cut in
35 the wafer. Trepanning the laser beam may change the thermal gradient and/or thermal stress in the wafer. These changes may be derived from the resulting angle of the laser beam and/or a maximum speed of the laser beam when compared to a pulsed laser beam normal to the surface. The dispersal of the liquid droplets onto the first surface actively cools the first surface of the wafer. It has been determined that the cooling of the first surface enables trepanning of the laser beam when cutting the wafer. The wafer typically has a
40 brittle structure and may be prone to cracking or chipping during a cutting operation. The cooling of the first

surface of the wafer during the cutting operation helps to reduce or avoid cracking or chipping. This enables trepanning of the laser beam to cut the wafer.

The method may comprise adjusting a beam displacement and/or inclination.

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According to an aspect of the present invention there is provided a method of laser cutting or laser drilling a wafer, the wafer having a first surface and a second surface, wherein the method comprises: using a laser source to emit a laser beam for cutting or drilling the wafer; using a laser scan head to direct the laser beam to perform a cutting or drilling operation in the first surface of the wafer. The laser scan head has a scanning area. The method may comprise dispersing droplets of a liquid onto the first surface of the wafer to provide cooling during the cutting or drilling operation. During the cutting or drilling operation, a first distribution of the liquid droplets over the first surface may be at least substantially uniform across at least substantially the whole of the scanning area of the laser scan head.

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According to a further aspect of the present invention there is provided a control unit for controlling a cutting apparatus to cut a wafer according to a cutting pattern. The cutting apparatus may comprise a laser source and a laser scan head. The control unit may comprise one or more controller. At least in certain embodiments, the control unit is configured to control the cutting apparatus to perform the method(s) described herein.

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According to a further aspect of the present invention there is provided a cutting apparatus for cutting a cutting pattern in a wafer having first and second surfaces; wherein the apparatus comprises: a laser source for emitting a laser beam; a laser scan head for directing the laser beam to perform at least one first cutting operation to cut at least a first segment of the cutting pattern in the first surface of the wafer, the laser scan head having an scanning area in which the laser beam can be directed. The cutting apparatus may comprise a first liquid dispersal device for dispersing droplets of a liquid onto the first surface of the wafer to provide cooling during the at least one first cutting operation. The first liquid dispersal device may be configured such that, in use, the liquid droplets have a first distribution which is at least substantially uniform across at least substantially the whole of the scanning area of the laser scan head.

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The first liquid dispersal device may be configured to disperse the liquid droplets to form a spray or a mist. The first liquid dispersal device may comprise a spray nozzle for dispersing the droplets in a spray; and/or an atomizer for dispersing the droplets in a mist.

The cutting apparatus may comprise a second liquid dispersal device for dispersing droplets of a liquid onto the second surface of the wafer to provide cooling during the at least one first cutting operation. The second liquid dispersal device may be configured such that, in use, the liquid droplets have a second distribution which is at least substantially uniform across at least substantially the whole of the scanning area of the laser scan head. The second liquid dispersal device may be configured to disperse the liquid droplets to form a spray or a mist. The second liquid dispersal device may comprise a spray nozzle for dispersing the droplets in a spray; and/or an atomizer for dispersing the droplets in a mist.

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The cutting apparatus may comprise a carrier for supporting the wafer. The wafer may be fixedly held in the carrier. The carrier may be rotatable about a first axis to dispose the wafer in a first orientation in which the first surface faces in a first direction and a second orientation in which the second surface faces in the first direction.

At least in certain embodiments the carrier is rotatable to reverse the orientation of the wafer. The wafer may be disposed in the first orientation to perform the at least one first cutting operation; and in the second orientation to perform the at least one second cutting operation. The first axis may be disposed in a plane of the wafer. The first axis may correspond to a longitudinal axis or a transverse axis of the wafer. A drive mechanism may be provided to rotate the carrier about the first axis. The drive mechanism may comprise an electric motor. The control unit may be configured to control the drive mechanism selectively to dispose the wafer in the first and second orientations for performing the first and second cutting operations.

The laser source may be a pulse laser source configured to emit a pulse laser beam. In use, the pulse laser source may emit a pulse laser beam. The pulse laser beam may have pulse durations in the femtosecond, picosecond or nanosecond ranges.

The laser source may be configured to emit radiation in the green or near infra-red wavelength.

The cutting apparatus may comprise a cooling device, such as a chiller, for cooling the liquid to be dispersed onto the first surface and/or the second surface of the wafer.

The cutting apparatus may comprise a vision system for aligning the wafer. The vision system may comprise one or imaging sensor for determining a position of the wafer. The carrier may be configured to make adjust the position of the wafer in dependence on a signal received from the imaging sensor. The carrier may be configured to automatically adjust the position of the wafer, for example to translate the wafer.

The cutting apparatus may comprise a system for trepanning the laser beam. The cutting apparatus may comprise a precession module for trepanning the laser beam. Trepanning of the laser beam may be performed during the first cutting operation and/or the second cutting operation. The precession module may be disposed between the laser source and the laser scan head. At least in certain embodiments, trepanning the laser beam may reduce or remove tapering of a cut made in the wafer; and/or enable a deeper cut into the wafer. Trepanning the laser beam may change the thermal gradient and/or thermal stress in the wafer. These changes may be derived from the resulting angle of the laser beam and the maximum speed of the laser beam when compared to a pulsed laser beam normal to the surface. In use, the dispersal of the liquid droplets onto the first surface provides active cooling of the first surface of the wafer. It has been determined that the cooling of the first surface enables trepanning of the laser beam when cutting a wafer. The wafer typically has a brittle structure and may be prone to cracking or chipping

during a cutting operation. The cooling of the first surface of the wafer during the cutting operation helps to reduce or avoid cracking or chipping while trepanning the laser beam.

The cutting apparatus may comprise means for adjusting the displacement and/or inclination of the beam.

- 5 The beam adjustment means may comprise one or more controllable optic element.

According to a further aspect of the present invention there is provided a method of cutting a wafer to a cutting pattern, the wafer having a first surface and a second surface, wherein the method comprises:

- using a laser source to emit a laser beam for cutting the wafer;
10 controlling the laser beam to perform at least one first cutting operation to cut at least a portion of the cutting pattern in the first surface of the wafer; and
controlling the laser beam to perform at least one second cutting operation to cut at least a portion of the cutting pattern in the second surface of the wafer;
wherein, during the at least one first cutting operation, the wafer is disposed in a first
15 orientation in which the first surface of the wafer faces in a first direction; and
during the at least one second cutting operation, the wafer is disposed in a second orientation in which the second surface faces in the first direction.

- The method may comprise performing a plurality of the first cutting operations and a plurality of the second
20 cutting operations. The first and second cutting operations may be performed alternately. The wafer may be reconfigured in the first and second orientations for the respective first and second cutting operations.

- At least in certain embodiments successive first cutting operations on the first surface may be a continuation of each other to form a substantially continuous cut in the first surface. Alternatively, or in addition,
25 successive second cutting operations on the second surface may be a continuation of each other to form a substantially continuous cut in the second surface.

- The at least one first cutting operation may form at least one first aperture in the first surface, the at least one first aperture extending partway through the wafer. The at least one first aperture may comprise a
30 groove or a channel in the first surface. The at least one second cutting operation may form at least one second aperture in the second surface, the at least one second aperture extending partway through the wafer. The at least one second aperture may comprise a groove or a channel in the second surface.

- According to a further aspect of the present invention there is provided a control unit for controlling a cutting
35 apparatus to cut a wafer according to a cutting pattern. The cutting apparatus may comprise a laser source, a laser scan head and a carrier for supporting the wafer. The control unit may comprise one or more controller. The control unit may be configured to control the cutting apparatus to perform the method described herein.

- 40 According to a further aspect of the present invention there is provided a cutting apparatus for cutting a cutting pattern in a wafer having first and second surfaces; wherein the apparatus comprises: a laser source

for emitting a laser beam; a laser scan head for directing the laser beam to perform at least one first cutting operation; and a carrier for supporting the wafer. The carrier may be rotatable about a first axis controllably to dispose the wafer in a first orientation in which the first surface faces in a first direction, and a second orientation in which the second surface faces in the first direction.

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The carrier may be rotatable to reverse the orientation of the wafer. The wafer may be disposed in the first orientation to perform the at least one first cutting operation; and in the second orientation to perform the at least one second cutting operation. The first axis may be disposed in a plane of the wafer. The first axis may correspond to a longitudinal axis or a transverse axis of the wafer. The carrier may comprise a drive mechanism operable to rotate the carrier about the first axis. The drive mechanism may comprise an electric motor.

The cutting apparatus may comprise a precession module for trepanning the laser beam. Trepanning of the laser beam may be performed during the first cutting operation and/or the second cutting operation.

15 The beam displacement and/or inclination may optionally be adjusted. The precession module may be disposed between the laser source and the laser scan head.

The cutting apparatus may comprise a control unit. The control unit may be configured to control the carrier selectively to dispose the wafer in a first orientation in which the first surface faces in a first direction and a second orientation in which the second surface faces in the first direction.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

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BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

35 Figure 1 shows a plan view of a workpiece to be diced in accordance with an embodiment of the present invention;

Figure 2A shows a side elevation of a one of a plurality of components formed integrally with the workpiece shown in Figure 1;

Figure 2B shows a plan view of the component shown in Figure 2A;

40 Figure 3A shows an exploded view of a workpiece in the form of a multilayer wafer;

Figure 3B shows a perspective view of the assembled multilayer wafer shown in Figure 3A;

Figure 4 shows a schematic representation of a laser cutting apparatus for cutting a workpiece in accordance with an embodiment of the present invention;

Figure 5 shows a scanning area of the laser scan head corresponding to a portion of the wafer;

Figure 6 shows a schematic representation of a control unit for controlling operation of the laser cutting apparatus shown in Figure 3;

Figure 7 shows a schematic representation of a cooling system for the laser cutting apparatus shown in Figure 6;

Figure 8 shows a schematic representation of a method of laser cutting a workpiece in accordance with an embodiment of the present invention;

Figure 9 shows a schematic representation of components in a wafer to illustrate a method of sequentially dicing components in accordance with an embodiment of present invention.

DETAILED DESCRIPTION

A method and apparatus for laser cutting a workpiece 5 in accordance with an embodiment of the present invention is described herein with reference to the accompanying Figures.

The method and apparatus are described herein with respect to a reference frame comprising a longitudinal axis X, a transverse axis Y and a vertical axis Z. The workpiece 5 is described herein as being supported in a horizontal (XY) plane coincident with the longitudinal axis X and the transverse axis Y. It will be understood that the present invention is not limited to this particular arrangement. Other mounting arrangements for the workpiece 5 are contemplated.

The method and apparatus according to the present embodiment use a laser beam 11 to cut the workpiece 5 according to a cutting pattern PT1. The laser beam 11 in the present embodiment is used to dice one or more component 13 from the workpiece 5. The cutting pattern PT1 defines a profile or geometry of a cut to be performed by the laser beam 11. As described herein, the laser beam 11 is controlled to perform one or more cutting operation. The or each cutting operation comprises controlling the laser beam 11 to scan the cutting pattern PT1 on a surface of the workpiece 5. The laser beam 11 cuts at least partway through the workpiece 5 in the or each cutting operation. The one or more cutting operation is performed to dice the workpiece 5, thereby separating the individual component(s) 13 from the workpiece 5. The cutting pattern PT1 in the present embodiment defines a perimeter or boundary of the or each component 13 to be diced from the workpiece 5. Alternatively, or in addition, the cutting pattern PT1 may comprise or consist of a perimeter or a boundary of an aperture to be cut in the workpiece 5. For example, the cutting pattern PT1 may define a circumference of a through-hole or a bore hole to be formed in the workpiece 5.

As shown in Figure 1, the workpiece 5 in the present embodiment comprises a wafer 5 of semiconductor. The method and apparatus described herein may be used to cut other types of workpiece 5. The or each component 13 may comprise a semiconductor device or a semiconductor circuit (also known as a die). A side elevation and a plan view of an individual component 13 are shown in Figures 2A and 2B respectively. The cutting of the wafer 5 may be referred to as die singulation or wafer dicing. The die singulation is performed after forming a circuit pattern (not shown) on the wafer 5. The circuit pattern may be formed

using photolithography (also known as optical lithography). Other techniques may be used to form the circuit pattern.

5 The wafer 10 has a uniform thickness and forms a substrate which supports an electrical circuit. As shown in Figure 1, the wafer 5 may, for example, comprise or consist of a disc. The wafer 5 has a first surface 5A and a second surface 5B. Each of the first and second surfaces 5A, 5B is substantially planar. In the arrangement illustrated in Figure 3, the first and second surfaces 5A, 5B are disposed in the horizontal (XY) plane. The wafer 5 has a monocrystalline structure. The wafer 5 is composed of a semiconductor. The wafer 5 may, for example, be made of one or more of the following: silicon, lithium niobate (LiNbO₃),
10 lithium tantalate (LiTaO₃), diamond, quartz, langasite and boules (La₃Ga₅SiO₁₄), gallium nitride (GaN), silicon carbide (SiC), silicon on sapphire(SOS), or any other suitable wafer material. The wafer 5 may be formed of other materials. For example, the wafer 5 may be composed of glass.

The wafer 5 may have a single layer composition, i.e. the wafer 5 may consist of one layer of wafer. A
15 circuit pattern may be formed on an outer surface of the wafer 5. In the present embodiment, the wafer 5 comprises a plurality of layers. An exploded view of the wafer 5 is shown in Figure 3A. The wafer 5 is referred to herein as having a multilayer composition. The layers of the multilayer composition may be bonded to each other in a face-to-face arrangement. A circuit pattern may be formed on an outer surface of the multilayer wafer. Alternatively, as shown in Figure 3A, a circuit pattern may be formed at an interface
20 between two adjacent layers of the multilayer wafer. The circuit pattern may be formed on a surface of one of the layers prior to bonding the layers together. A perspective view of the wafer 5 is shown in Figure 3B.

An apparatus 100 in accordance with an embodiment of the present invention is shown in Figure 4. The apparatus 100 comprises a laser source 101 for emitting the laser beam 11. The laser beam 11 has a
25 beam width (diameter) in the range 15 μ m to 40 μ m. The laser beam 11 may have a beam width of less than or equal to 25 μ m. The laser source 101 may, for example, emit radiation in the green or near infra-red wavelength. The laser source 101 may, for example, comprise a diode-pumped ultrafast laser. The laser source 101 in the present embodiment is a 5-W Yb-doped sub-pico laser source having a wavelength of 515 nm. The laser source 101 emits a pulse laser beam 11 having pulse durations in the femtosecond,
30 picosecond or nanosecond ranges. The wavelength may be less than or greater than 515 nm. The laser source 101 is a pulse laser having a pulse duration of 10 fs and a frequency up to 200 kHz. The pulse duration may be less than or greater than 10 fs. The laser source 101 in the present embodiment has a beam quality factor M2 which is better than 1.3. Other types of laser source 101 may be used, for example having a different wavelength and/or pulse duration and/or output energy and/or beam quality. The wafer
35 5 is fixedly held in a workpiece carrier 103.

The laser beam 11 emitted from the laser source 101 is passed through a Quarter Wave Plate ($\lambda/4$ Plate) 105 to a beam conditioning unit 107. The laser beam 11 is conditioned by the beam conditioning unit 107 and output to a laser precession module 109. The precession module 109 is configured to trepan the laser
40 beam 11. The laser beam 10 is introduced into a scan head 111. In the present embodiment, a mirror 113 is provided to reflect the laser beam 11 into the scan head 111. As shown in Figure 3, the mirror 113 in the

present embodiment reflects the laser beam 11 along the vertical axis Z. The mirror 113 may be omitted, for example by changing the orientation of the laser source 101 or the scan head 111. A lens 115 is provided to focus the laser beam 11 output from the scan head 111. The lens 115 in the present embodiment is in the form of a telecentric lens 115. The telecentric lens 115 in the present embodiment is a 100mm telecentric lens. Other types of lens may be used.

The scan head 111 is configured to control the trajectory of the laser beam 11 to follow the cutting pattern PT1. The scan head 111 in the present embodiment comprises a galvanometer scanner. The scan head 111 comprises one or more optical element, such as a mirror (not shown). The orientation of the one or more optical element is controllable to adjust the trajectory of the laser beam 11. The scan head 111 has a scanning area ASC (also known as a field of view FOV) within which the trajectory of the laser beam 11 is controllable. The laser beam 11 is controllable within the scanning area ASC. The scanning area ASC is shown in Figures 4 and 5. In the illustrated example, the scanning area ASC is smaller than the surface area of the wafer 5. The wafer 5 may be moved relative to the scan head 111 to enable cutting of the whole of the cutting pattern PT1. In-plane translation of the wafer 5 (within the XY plane in the present embodiment) enables scanning of the cutting pattern PT1 by the laser beam 11. The workpiece carrier 103 may be mounted on a moving bed (not shown) to enable translation of the wafer 5 along the longitudinal axis X and/or the transverse axis Y.

In use, the scan head 111 controls the trajectory of the laser beam 11 to control a point location where the laser beam 11 impinges on one of the first and second surfaces 5A, 5B of the wafer 5. The scan head 111 thereby controls the laser beam 11 to perform cutting of the wafer 5. The scan head 111 is configured to control the speed at which the laser beam 11 follows the cutting pattern PT1. The scan head 111 may be configured to manipulate the laser beam 11 in two or more axes (i.e., two or more degrees of freedom). Two axis manipulation (i.e., two degrees of freedom) may controllably place the laser beam 11 within a plane. Three axes manipulation (i.e., three degrees of freedom) may controllably place the laser beam 11 within a plane and a focus depth. Five axis manipulation (i.e., five degrees of freedom) may controllably place the laser beam 11 within a plane, a focus depth and a beam angle. The scan head 111 in the present embodiment is a two-axis scan head 111 for placement of the laser beam 11 in a plane. In the illustrated arrangement, the scan head 111 is configured to place the laser beam 11 in the horizontal XY plane coincident with one of the first and second surfaces 5A, 5B of the wafer 5. The scan head 111 in this arrangement may be referred to as an XY scan head 111. The scan head 111 in the present embodiment comprises a galvanometer scanner.

The laser beam 11 is controlled to cut the workpiece 5 according to a cutting pattern PT1. The cutting pattern PT1 is preferably defined within the scanning area ASC of the scan head 111. The scan head 111 can control the trajectory of the laser beam 11 to follow the whole of the cutting pattern PT1 without requiring a change in the horizontal position of the wafer 5 relative to the scan head 111. The scan head 111 may thereby control the trajectory of the laser beam 11 to follow the cutting pattern PT1 within the scanning area. In a variant, the wafer 5 may be movable relative to the scan head 111 to increase the effective

scanning area ASC. For example, the wafer 5 may translate in the XY plane relative to the scan head 111 to increase the effective scanning area. The size of the cutting pattern PT1 may thereby be increased.

As illustrated in Figure 6, a control unit 121 is provided to control the operation of the scan head 111. As described herein, the control unit 121 is configured to control the scan head 111 to cause the laser beam 11 to scan the cutting pattern PT1 on an incident surface of wafer 5. The control unit 121 controls operation of the scan head 111 to cause the laser beam 11 to scan the cutting pattern PT1. The control unit 121 comprises a controller 123 and a memory means 125. The controller 123 comprises one or more electronic processor 127. The one or more electronic processor 127 comprises at least one electrical input 129 for receiving an input signal; and at least one electrical output 131 for outputting an output signal. The memory means 125 comprises one or more memory device 125. The controller 123 is configured to execute a set of computational instructions stored on the memory device 125 to perform the method(s) described herein. A set of pattern data PD1 defining the cutting pattern PT1 is stored on the memory device 125. The pattern data PD1 defines the geometry of the cutting pattern PT1. The pattern data PD1 in the present embodiment also comprises a set of cutting instructions which define a sequence for cutting the cutting pattern PT1. The control unit 121 is configured to output a first control signal CS1 to control operation of the scan head 111 to cause the laser beam 11 to scan the cutting pattern PT1. The first control signal CS1 is an electrical signal which is generated in dependence on the cutting pattern PT1. The set of cutting instructions may be predefined and stored on the memory device 125. In a variant, the cutting instructions may be generated dynamically in dependence on the geometry of the cutting pattern PT1. The control unit 121 may be configured to process the cutting pattern PT1 and automatically generate a set of cutting instructions for controlling the scan head 111.

The control unit 121 in the present embodiment is configured to receive feedback from the imaging system 133. The imaging system 133 may, for example, comprise one or more photoelectric sensor. The imaging system 133 outputs an imaging signal SIMG to the control unit 121. The imaging signal provides an indication of the position of the wafer 5 and/or the laser beam 11. The imaging signal is an electrical signal which is input to the at least one electrical input 129 of the one or more electronic processor 127. The control unit 121 is configured to control the scan head 111 in dependence on the imaging signal, for example to adjust the trajectory of the laser beam 11 to provide increased accuracy during the or each cutting operation. Alternatively, or in addition, the workpiece carrier 103 may enable in-plane adjustment of the position of the wafer 5. The workpiece carrier 103 may be controlled in dependence on the imaging signal to locate the wafer 5 in a reference position. The control unit 121 may output a second control signal CS2 to control operation of the workpiece carrier 103.

The apparatus 100 in accordance with the present embodiment is configured to dice the wafer 5 to separate the or each individual component 13. The process of controlling the laser beam 11 to dice the wafer 5 may be referred to as laser dicing. The apparatus 100 performs one or more cutting operation to cut completely through the wafer 5, thereby enabling the or each component 13 to be separated. The or each cutting operation comprises or consists of cutting at least a portion of the cutting pattern PT1. The cutting pattern PT1 may be sub-divided into a plurality of segments. Each cutting operation may consist of cutting one of

the plurality of segments of the cutting pattern PT1. The cutting operation for each of the plurality of segments may be performed in respect of one more of the first and second surfaces 5A, 5B of the wafer 5. For example, a first cutting operation may be performed in respect of the first surface 5A; and a second cutting operation may be performed in respect of the second surface 5B. The first and second cutting operations may be performed in respect of the same segment of the cutting pattern PT1. As described in more detail herein, the orientation of the wafer 5 relative to the scan head 111 may be reversed (for example by rotation about the transverse axis X or the longitudinal axis Y) to perform the first and second cutting operations on the first and second surfaces 5A, 5B respectively of the wafer 5. It will be understood that the cutting pattern PT1 is mirror symmetrical about the XY plane in the first and second cutting operations.

Die singulation comprising one or more cutting operations in respect of each side of the wafer 5 is believed to be patentable independently.

As shown in Figure 7, the apparatus 100 comprises cooling means 141 for cooling the wafer 5 during the or each cutting operation. The cooling means 141 is configured to supply a cooling liquid to the wafer 5 to perform cooling of at least one of the first and second surfaces 5A, 5B. The cooling means 141 may comprise a chiller for cooling the cooling liquid prior to cooling the wafer 5.

The cooling means 141 comprises a first liquid dispersal device 143A for dispersing droplets of a cooling liquid. The cooling liquid may, for example, comprise or consist of water. The first liquid dispersal device 143A is configured to disperse liquid droplets onto one or more of the first and second surfaces 5A, 5B. In particular, the first liquid dispersal device 143A is configured to disperse liquid droplets onto the first surface 5A or the second surface 5B which is being cut by the laser beam 11. The surface being cut by the laser beam 11 may be referred as a cutting surface or a front surface of the wafer 5. The first liquid dispersal device 143A may be configured to disperse the liquid droplets as a mist or a spray. The first liquid dispersal device 143A may comprise a spray nozzle, a mist generator or an atomizer, for example. A spray nozzle 144 is shown in Figure 7 by way of example. The liquid droplets typically have a diameter which is less than or equal to 25 μm , 15 μm or 10 μm . When incident on the first surface 5A of the wafer 5, the liquid droplets preferably have a diameter which is less than or equal to ten times (x10) the beam width. A pump 145 supplies the liquid to the first liquid dispersal device 143A. A chiller (not shown) may be provided for chilling the cooling liquid supplied to the first liquid dispersal device 143A.

The first liquid dispersal device 143A is configured to disperse liquid droplets onto the surface which is oriented towards (i.e. facing) the scan head 111. The first liquid dispersal device 143A is configured to direct the liquid droplets downwardly onto the first surface 5A or the second 5B oriented towards the scan head 111. In the arrangement illustrated in Figure 1, the first liquid dispersal device 143A is configured to disperse the liquid droplets onto the first surface 5A. For the sake of brevity, the first liquid dispersal device 143A is described herein as distributing the liquid droplets onto the first surface 5A. In use, the liquid droplets are distributed over the first surface 5A of the wafer 5. The first liquid dispersal device 143A is configured to provide an at least substantially uniform distribution of the liquid droplets across at least substantially the whole of the scanning area. In use, the liquid droplets are dispersed across the first surface 5A corresponding to the scanning area of the scan head 111. Thus, the liquid droplets are distributed evenly

over the wafer 5 to perform cooling over at least substantially the whole of the working region where cutting may be performed. It will be understood that the first liquid dispersal device 143A would distribute liquid droplets onto the second surface 5B when the orientation of the wafer 5 is reversed.

- 5 In the present embodiment, the cooling means 141 also comprises a second liquid dispersal device 143B for dispersing droplets of a cooling liquid. The cooling liquid may, for example, comprise or consist of water. The second liquid dispersal device 143B is configured to disperse liquid droplets onto the other one of the first and second surfaces 5A, 5B. The second liquid dispersal device 143B is configured to disperse liquid droplets onto the first surface 5A or the second surface 5B which is not being cut by the laser beam 11.
- 10 The surface which is not being cut by the laser beam 11 may be referred to as a non-cutting surface or a back surface of the wafer 5. The second liquid dispersal device 143B may be configured to disperse the liquid droplets as a mist or a spray. The second liquid dispersal device 143B may comprise a spray nozzle, a mist generator or an atomizer, for example. The liquid droplets typically have a diameter which is less than or equal to $25\mu\text{m}$, $15\mu\text{m}$ or $10\mu\text{m}$. When incident on second first surface 5A of the wafer 5, the liquid
- 15 droplets preferably have a diameter which is less than or equal to ten times (x10) the beam width. The pump 145 supplies the liquid to the second liquid dispersal device 143B. A chiller (not shown) may be provided for chilling the cooling liquid supplied to the second liquid dispersal device 143B.

- The second liquid dispersal device 143B is configured to disperse liquid droplets onto the surface which is
- 20 oriented away from the scan head 111. The second liquid dispersal device 143B is configured to direct the liquid droplets onto the first surface 5A or the second 5B oriented away the scan head 111. In the arrangement illustrated in Figure 3, the second liquid dispersal device 143B is configured to disperse the liquid droplets onto the second surface 5B. For the sake of brevity, the second liquid dispersal device 143B is described herein as distributing the liquid droplets onto the second surface 5B. In use, the liquid droplets
- 25 are distributed over the second surface 5B of the wafer 5. The second liquid dispersal device 143B is configured to provide an at least substantially uniform distribution of the liquid droplets across at least substantially the whole of the scanning area. In use, the liquid droplets are dispersed across the second surface 5B corresponding to the scanning area of the scan head 111. Thus, the liquid droplets are distributed evenly over the wafer 5 to perform cooling over at least substantially the whole of the working
- 30 region where cutting may be performed. It will be understood that the second liquid dispersal device 143B would distribute liquid droplets onto the first surface 5A when the orientation of the wafer 5 is reversed.

- As shown in Figure 7, a cooling chamber 147 is provided behind the workpiece 5. The cooling chamber 147 is formed in the workpiece carrier 103 in the present embodiment. The second liquid dispersal device
- 35 143B is configured to establish a flow of the droplets of the cooling liquid through the cooling chamber 147. The cooling chamber 147 comprises an inlet 149 and an outlet 151. The second liquid dispersal device 143B is configured to introduce the liquid droplets through the inlet 149. The liquid droplets are exhausted from the cooling chamber 147 through the outlet 151. A drain (not shown) may optionally be provided for draining accumulated liquid from the cooling chamber 147. The liquid droplets are incident on the non-
- 40 cutting surface or the back surface of the wafer 5. The liquid droplets may enter apertures formed in the second surface 5B of the wafer 5, for example by an earlier cutting operation. Advantageously, this may

promote cooling of the wafer 5, for example to promote rejection of thermal energy caused by a cutting operation on the other side of the wafer 5. In a variant, a cooling liquid may be introduced into the cooling chamber 147. The wafer 5 may be in contact with the cooling liquid in the cooling chamber. The second surface 5B may be immersed in the cooling liquid. The cooling liquid may form a cooling bath. A flow of the cooling liquid may be established through the cooling chamber 147. The cooling liquid may be circulated through the cooling chamber 147.

The wafer 5 is mounted in the workpiece carrier 103. The workpiece carrier 103 in the present embodiment is configured to rotate the wafer 5 to reverse the orientation of the wafer 5 relative to the scan head 111. Thus, the workpiece carrier 103 is operable selectively to orient one of the first and second surfaces 5A, 5B towards the scan head 111. In the present embodiment, the workpiece carrier 103 comprises a drive mechanism 153 for rotating the wafer 5 about the longitudinal axis Y. The drive mechanism 153 is controlled by the control unit 121. The control unit 121 is configured to control the drive mechanism 153 to orient the first surface 5A of the wafer WF1 towards the scan head 111 to perform the first cutting operation; and to orient the second surface 5B of the wafer WF1 towards the scan head 111 to perform the second cutting operation.

The laser beam 11 is operative to cut at least partway through the wafer 5 in the or each cutting operation. For example, the laser beam 11 may make a cut having a depth in the range $50\mu\text{m}$ to $150\mu\text{m}$. A single cutting operation may be sufficient to cut through the wafer 5. For example, if the wafer 5 has a thickness less than $150\mu\text{m}$ or $200\mu\text{m}$, a single cutting operation may be sufficient to cut through the wafer 5. At least in certain embodiments, the precession module 109 is configured to trepan the laser beam 11. The trepanning of the laser beam 11 may enable the depth of the or each cut in the wafer 5 to be increased. A single cutting operation may not be sufficient to cut through the wafer 5, for example if the wafer 5 has a greater thickness. The wafer 5 in the present embodiment has a thickness greater than $200\mu\text{m}$, for example $250\mu\text{m}$ or $300\mu\text{m}$. The laser source 101 in the present embodiment may cut only partway through the wafer 5 in the or each cutting operation.

The apparatus 100 is configured to perform a plurality of the cutting operations to cut through the wafer 5, i.e. to dice the wafer 5. Each of the cutting operations is effective to cut partway through the wafer 5. The cutting operations could be performed from the same side of the wafer 5, for example to trace the cutting pattern PT1 two or more times. However, the apparatus 100 in the present embodiment is configured to perform the cutting operations on opposite sides of the wafer 5. A first cutting operation is performed in respect of the first surface 5A; and a second cutting operation is performed in respect of the second surface 5B. Each of first and second cutting operations may comprise cutting at least a portion of the cutting pattern PT1 on each of the first and second surfaces 5A, 5B. At least in certain embodiments, each of the first and second cutting operations comprises a segment of the cutting pattern PT1. The same segment of the cutting pattern PT1 may be cut on each of the first and second surfaces 5A, 5B. For example, the segment may define the perimeter of one or more of the components 13. Each of the first and second cutting operations may be performed one or more times to dice the wafer 5 and enable the individual component(s) 13 to be separated from the wafer 5. Alternatively, each of the first and second cutting operations may

comprise cutting the entire cutting pattern PT1 on each of the first and second surfaces 5A, 5B. The cutting pattern PT1 may be cut on each of the first and second surfaces 5A, 5B in the respective first and second cutting operations. Each of the first and second cutting operations may be performed one or more times to dice the wafer 5 and enable the individual component(s) 13 to be separated from the wafer 5.

5

Optionally, the apparatus 100 comprises an integrated focus variation probe. The focus variation probe may have a 10x objective lens that has a field of view of 2x2 mm, a working distance of 15.5 mm, a vertical resolution of 100 nm, and a sampling distance of 1 μm .

10 Optionally, the apparatus 100 comprises a beam conditioning unit 107, for example a chromatic confocal probe.

Optionally, the apparatus 100 comprises a wafer holding system with a modular design to adapt to wafers with different sizes and shapes.

15

Optionally the apparatus 100 according to the invention comprises a high-precision X and Y mechanical stages with linear motors for positioning the workpiece 5. At least in certain embodiments the linear motors have a resolution of 250 nm. The repeatability may be $\pm 0.75\mu\text{m}$.

20 A method 200 of dicing a wafer 5 in accordance with an embodiment of the present invention will now be described with reference to Figure 8. The method 200 provides double-sided machining or drilling of the wafer 5. The method 200 may be performed using the apparatus 100 described herein. The wafer 5 in the present embodiment is a multilayer wafer but the method may be performed in respect of a wafer composed of a single layer. The method 200 optionally comprises annealing the wafer 5 (BLOCK 220). The annealing of the wafer may help to reduce inherent material stress. One or more groove may optionally be formed on an internal surface of the wafer (BLOCK 230). The annealing of the wafer 5 and/or the formation of the one or more groove may optionally be omitted. A first cutting operation is performed to make a first cut in a first surface 5A of the wafer 5 (BLOCK 240). The first cut may, for example, have a depth of approximately 150 μm . The wafer 5 is then flipped by rotating about the transverse axis X or the longitudinal axis Y (BLOCK 250). The orientation of the wafer 5 is thereby reversed such that the second surface 5B is oriented towards the scan head 111. The wafer 5 may optionally then be aligned with the scan head 111 (BLOCK 260). For example, the wafer 5 may be re-positioned in a predetermined or reference location. A second cutting operation is performed to make a second cut in a second surface 5B of the wafer 5 (BLOCK 270). If necessary, additional cutting operations may be performed to dice the wafer 5. For example, the wafer 5 may be flipped again to return to the original position in which the first surface 5A is oriented towards the scan head 111 (BLOCK 280). The wafer 5 may optionally be aligned with the scan head 111. The process is repeated to dice the or each component 13 from the wafer WF1. During the first cutting operation and/or the second cutting operation, the collimated laser beam 11 may be rotated about its central axis (i.e. precession). The method 200 is completed when the wafer 5 has been cut to the cutting pattern PT1 is complete (BLOCK 290).

As described herein, the method may optionally comprise aligning the wafer 5 prior to performing the first cutting operation and/or the second cutting operation. The workpiece carrier 103 may be configured to adjust the position of the wafer 5, for example to adjust the location of the wafer along the longitudinal axis X and/or the transverse axis Y. The alignment of the wafer 5 may be performed using the imaging system 133 and/or mechanical alignment devices. The method may comprise positioning the wafer 5 in the XY plane such that one or more target (such as a marking or an aperture provided on the wafer 5) is disposed in a predetermined position.

During the first cutting operation and/or the second cutting operation, one or more of the first and second liquid dispersal devices 143A, 143B may operate to promote cooling of the wafer 5. The application of a cooling liquid to the first surface 5A and/or the second surface 5B may reduce thermal stress in the wafer 5.

The apparatus 100 and the method 200 dice the wafer 5 into individual components 13. Each of the component 13 may, for example, comprise one or more electrical circuit. The one or more electrical circuit may be formed on the wafer 5 using known techniques, such as photolithograph. As shown in Figure 9, the components 13 are distributed across a surface of the wafer 5. The wafer 5 is illustrated as having an inner first region R1 (unshaded in Figure 9); and an outer second region R2 (shaded in Figure 9). The first region R1 is disposed in a central region of the wafer 5. The second region R2 extends at least partway around the first region R1. In the illustrated arrangement, the first region R1 comprises a circular area in the centre of the wafer 5; and the second region R2 comprises an annular region. Other profiles are contemplated. For example, the first region R1 may comprise a rectangular area; and the second region R2 may comprise a rectangular frame. One or more component 13 is disposed within the first region R1 and the second region of the wafer 5. The method 200 described herein may optionally comprise dicing the or each component 13 disposed in the first region R1 before dicing the one or more component 13 disposed in the second region R2. Thus, the or each component 13 disposed in the first region R1 may be diced before the or each component 13 in the second region R2. The control unit may control the apparatus 100 to perform the method(s) described herein. This approach may help to maintain the structural integrity of the wafer 5 during dicing. The wafer 5 is illustrated as being circular, but this process is not limited in this respect.

The apparatus 100 and the method 200 according to an embodiment of the present invention have been described with particular reference to dicing the wafer 5 to separate the or each individual component 13. Alternatively, or in addition, the apparatus 100 may be configured to cut one or more aperture in the first surface 5A and/or the second surface 5B, the one or more aperture extending only partway through the wafer 5. The aperture may, for example, comprise or consist of a groove or a channel in the wafer 5. The one or more cutting aperture may be performed to cut the one or more aperture in the first surface 5A and/or the second surface 5B without dicing the wafer 5. The control unit 121 controls the laser scan head 111 such that the laser beam 11 trace or scans the cutting pattern PT1 to cut the one or more aperture in the first surface 5A and/or the second surface 5B. The aperture may be formed while the wafer 5 is held in a fixed orientation while the one or more aperture is cut in the first surface 5A or the second surface 5B.

Alternatively, the orientation of the wafer 5 may be reversed to cut one or more aperture in the first and second surfaces 5A, 5B. The cooling means 141 may be used to cool the wafer 5 during the or each cutting operation. The cooling means 141 is configured to supply a cooling liquid to the wafer 5 to perform cooling of at least one of the first and second surfaces 5A, 5B. In particular, the liquid droplets WD may be dispersed
5 onto the first surface 5A and/or the second surface 5B in the form of a spray or a mist.

The wafer 5 is disposed in a first orientation for performing at least one first cutting operation on the first surface 5A. A mist or a spray of liquid droplets, for example in the form of micro water droplets, is applied onto the first surface 5A (and optionally also the second surface 5B) of the wafer 5. The laser beam 11
10 performs at least one first cutting operation on the first surface 5A of the wafer 5 while the mist or the fine spray of liquid droplets WD is applied onto the first surface 5A. The laser beam 11 is controlled to follow at least a portion of the cutting pattern PT1 to form one or more cut in the first surface 5A. The liquid droplets WD may be micro droplets WD, for example having a diameter less than or equal to 25 μm , 15 μm or 10 μm . The liquid droplets WD may have a maximum diameter which is smaller than or equal to a width of the
15 laser beam 11 multiplied by a factor of ten (10). The beam width is normally between 15 μm to 40 μm . By way of example, the laser beam 11 may have a beam width (diameter) of 25 μm and the liquid droplets WD may have a diameter which is less than 250 μm . The liquid used for cooling the wafer 5 may be water. Other liquids may be used to form the liquid droplets WD.

The first cutting operation may end when a saturation point is reached on a first surface of a wafer 5. The wafer 5 is then disposed in a second orientation for performing at least one second cutting operation on the second surface 5B. The wafer 51 is rotated through 180 degrees about an in-plane axis (such as the longitudinal axis X or the transverse axis Y) and disposed in the second orientation for cutting the second surface 5B with the laser beam 11. A mist or a spray of liquid droplets, for example in the form of micro
25 water droplets, is applied onto the second surface 5B (and optionally also the first surface 5A) of the wafer 5. The laser beam 11 performs at least one second cutting operation on the second surface 5B of the wafer 5 while the mist or the fine spray of liquid droplets WD is applied onto the second surface 5B. The laser beam 11 is controlled to follow at least a portion of the cutting pattern PT1 to form one or more cut in the first surface 5A. Optionally, a flow of a cooling liquid may be applied onto the first surface 5A of the wafer
30 5 while the second surface 5B of the wafer 5A is undergoing a cutting operation.

A cutting operation on the first surface 5A or on the second surface 5B comprises making one or more cuts by the laser beam 11 emitted by the laser source 101. The or each cutting operation may be performed until a saturation point is reached on that surface 5A, 5B of the wafer 5. Once the saturation point is reached
35 on a surface 5A, 5B of the wafer 5, the wafer is flipped (i.e. rotated). At least one cutting operation may then be performed on the opposite one of the first and second surfaces 5A, 5B. A saturation point is the limit at which the penetration rate of the laser beam decreases.

Optionally, for a wafer 5 have a multi-layered composition, annealing of one or more of the layers is
40 performed before starting the or each cutting operation. One or more grooves may be formed on an internal surface of one or more of the layers.

It will be appreciated that various changes and modifications can be made to the present invention without departing from the scope of the present application.

CLAIMS

1. A method of cutting a wafer to a cutting pattern, the wafer having a first surface and a second surface, wherein the method comprises:
 - 5 using a laser source to emit a laser beam for cutting the wafer;
 - using a laser scan head to direct the laser beam to perform at least one first cutting operation to cut at least a first segment of the cutting pattern in the first surface of the wafer, the laser scan head having a scanning area in which the laser beam can be directed; and
 - 10 dispersing droplets of a liquid onto the first surface of the wafer to provide cooling during the at least one first cutting operation;
 - wherein, during the at least one first cutting operation, a first distribution of the liquid droplets over the first surface is at least substantially uniform across at least substantially the whole of the scanning area of the laser scan head.
- 15 2. A method as claimed in claim 1 comprising dispersing liquid droplets for cooling the second surface of the wafer during the at least one first cutting operation;
 - wherein, during the at least one first cutting operation, a second distribution of the liquid droplets over the second surface is at least substantially uniform across at least substantially the whole of the scanning area of the laser scan head.
- 20 3. A method as claimed in claim 1 or claim 2, wherein the droplets of liquid are dispersed onto the first surface and/or the second surface as a spray or a mist.
4. A method as claimed in any one of claims 1, 2 or 3 comprising establishing a flow of a
 - 25 liquid for cooling the second surface of the wafer during the at least one first cutting operation;
 - wherein, during the at least one first cutting operation, the flow of liquid is incident on the second surface of the wafer.
5. A method as claimed in any one of the preceding claims, wherein, during the at least one
 - 30 first cutting operation, the wafer is disposed in a first orientation in which the first surface of the wafer faces in a first direction; the method comprising:
 - disposing the wafer in a second orientation in which the second surface faces in the first direction and using the laser beam to perform at least one second cutting operation to cut at least a second segment of the cutting pattern in the second surface.
- 35 6. A method as claimed in claim 5 comprising performing a plurality of the first cutting operations and a plurality of the second cutting operations, wherein the first and second cutting operations are performed alternately, the wafer being reconfigured in the first and second orientations for the respective first and second cutting operations.

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7. A method as claimed in claim 6, wherein successive first cutting operations on the first surface are a continuation of each other to form a substantially continuous cut in the first surface; and/or successive second cutting operations on the second surface are a continuation of each other to form a substantially continuous cut in the second surface.
- 5
8. A method as claimed in any one of claims 5, 6 or 7, wherein the cut formed in the first surface during the first cutting operation is at least substantially aligned with the cut formed in the second surface during the second cutting operation.
- 10
9. A method as claimed in any one of claims 5 to 8, wherein the first cutting operation comprises a first start point and a first end point on the first surface; and the second cutting operation comprises a second start point and a second end point on the second surface; wherein the first and second start points are at least substantially aligned with each other, and the first and second end points are at least substantially aligned with each other.
- 15
10. A method as claimed in any one of claims 5 to 9, wherein the cutting pattern is mirror-symmetrical about a plane of the wafer for the first and second cutting operations on the first and second surfaces.
- 20
11. A method as claimed in any one of the preceding claims, wherein the at least one first cutting operation and/or the at least one second cutting operation dice the wafer into one or more die or one or more individual component
- 25
12. A method as claimed in claim 11 comprising dicing a plurality of the dies or components from the wafer, wherein the method comprises dicing one or more of the plurality of dies or components from a central region of the wafer; and then dicing one or more of the plurality of dies from an outer portion of the wafer.
- 30
13. A method as claimed in any one of the preceding claims, wherein the at least one first cutting operation forms at least one first aperture in the first surface, the at least one first aperture extending partway through the wafer; and/or the at least one second cutting operation forms at least one second aperture in the second surface, the at least one second aperture extending partway through the wafer.
- 35
14. A method as claimed in any one of the preceding claims, wherein the wafer is a single-layer wafer, the first and second surfaces are the outer surfaces of the single-layer wafer; or the wafer is a multi-layer wafer, the first and second surfaces are the outer surfaces of the multi-layer wafer.
15. A method as claimed in any one of the preceding claims comprising trepanning the laser beam.

16. A control unit for controlling a cutting apparatus to cut a wafer according to a cutting pattern, wherein the cutting apparatus comprises a laser source and a laser scan head; the control unit comprising one or more controller, wherein the control unit is configured to control the cutting apparatus to perform the method claimed in any one of the preceding claims.

5

17. A cutting apparatus for cutting a cutting pattern in a wafer having first and second surfaces; wherein the apparatus comprises:

a laser source for emitting a laser beam;

10 a laser scan head for directing the laser beam to perform at least one first cutting operation to cut at least a first segment of the cutting pattern in the first surface of the wafer, the laser scan head having a scanning area in which the laser beam can be directed; and

a first liquid dispersal device for dispersing droplets of a liquid onto the first surface of the wafer to provide cooling during the at least one first cutting operation;

15 wherein the first liquid dispersal device is configured such that, in use, the liquid droplets have a first distribution which is at least substantially uniform across at least substantially the whole of the scanning area of the laser scan head.

18. A cutting apparatus as claimed in claim 17, wherein the first liquid dispersal device comprises:

20 a spray nozzle for dispersing the droplets in a spray; or
an atomizer for dispersing the droplets in a mist.

19. A cutting apparatus as claimed in claim 17 or claim 18 comprising a second liquid dispersal device for dispersing droplets of a liquid onto the second surface of the wafer to provide cooling during the at least one first cutting operation;

25 wherein the second liquid dispersal device is configured such that, in use, the liquid droplets have a second distribution which is at least substantially uniform across at least substantially the whole of the scanning area of the laser scan head.

30 20. A cutting apparatus as claimed in any one of claims 17, 18 or 19 comprising a carrier for supporting the wafer, the carrier being rotatable about a first axis to dispose the wafer in a first orientation in which the first surface faces in a first direction and a second orientation in which the second surface faces in the first direction.

35 21. A cutting apparatus as claimed in any one of claims 17 to 20, wherein the laser source is configured to emit beam is a pulse laser beam having pulse durations in the femtosecond, picosecond or nanosecond ranges.

40 22. A cutting apparatus as claimed in any one of claims 17 to 21, wherein the laser source is configured to emit radiation in the green or near infra-red wavelength.

23. A cutting apparatus as claimed in any one of claims 17 to 22 comprising a precession module for trepanning the laser beam.