Title: METHOD OF LASER PROCESSING FOR SUBSTRATE CLEAVING OR DICING THROUGH FORMING “SPIKE-LIKE” SHAPED DAMAGE STRUCTURES

(57) Abstract: This invention provides an effective and a method of laser processing for separating semiconductor devices formed on a single substrate (6) or separating high thickness, hard and solid substrates (6), which is rapid. During preparation of the device or substrate (6) for the cleaving/breaking/dicing procedure an area of damage (8, 11) is achieved by obtaining deep and narrow damage area along the intended line of cleaving. The laser processing method comprises a step of modifying a pulsed laser beam (1) by a focusing unit (1), such as that an "spike"-shaped beam convergence zone, more particularly an above workpiece material optical damage threshold fluence (power distribution) in the bulk of the workpiece (6) is produced. During the aforementioned step a modified area (having a "spike"-type shape) is created. The laser processing method further comprises a step of creating a number of such damage structures (8, 11) in a predetermined breaking line by relative translation of the workpiece (6) relative the laser beam (1) condensation point.
FIELD OF INVENTION

The present method relates to laser material processing. More particularly it relates to methods for cleaving and/or dicing hard and brittle materials with a specially shaped laser beam. The invention is useful for separating semiconductor devices formed on a substrate.

BACKGROUND OF INVENTION

Wafer dicing plays a critical role in the fabrication of semiconductor devices, devices which are becoming ever smaller and more complex. The classical methods of dicing are based on the use of a diamond saw for silicon wafers thicker than 100 \( \mu \text{m} \) or by laser ablation if they are thinner.

Diamond disk saw technology is limited by its low processing speed (for hard materials). The diamond disk saw produces wide, chipped kerf and low quality edge in general, which in turn degrades device yield and lifetime. The technology is expensive, due to rapid diamond disk degradation, and unpractical owing to the need for water cooling and cleaning. Additionally, the performance is limited when the substrate that is being cut is thin.

Another classical laser processing technology, namely laser ablation, is also limited by its low processing speed and a kerf width which reaches 10-20 \( \mu \text{m} \) and is too wide for most applications. Furthermore, laser ablation induces cracks, leaves melted residuals and contaminates the cutting area with debris. A wide area heat affected zone can reduce the lifetime and effectiveness of a semiconductor device.

Together with ablation the diamond disk saw technique can not be used for speciality wafers where there may be other surface features, such as dye-attached films for adhesive stacking. Such additions make the traditional sawing or ablation processes more difficult and vulnerable to debris. In order to improve the quality of
separated devices other laser processing based methods and apparatus have been
developed.

One of which is a laser processing and laser processing apparatus described in a US patent No. US6992026, published on 31-01-2006. The said method and apparatus allows cutting a work-piece without producing traces of fusion and cracking perpendicularly extending out of a predetermined cutting line on the surface of the work-piece. The surface of the work-piece is irradiated with a pulsed laser beam according to the predetermined cutting line under conditions sufficient to cause multi-photon absorption, where the beam is aligned to produce a focal spot (or condensed point: a high energy/photon density zone) inside the bulk of the work-piece, consequently forming modified area along the predetermined cleaving line by moving the focal spot in the cleaving plain. After creating the modified area the work-piece can be mechanically separated with a relatively small amount of force.

The said processing method and its variations are currently known in the art as "stealth dicing". All its variations are based on production of internal perforations by a focused pulsed laser beam at a wavelength for which the wafer is transparent, but which is absorbed by nonlinear processes at the focus, e.g. as in the internally etched decorative blocks of glass. The internal perforation leaves the surface top and bottom pristine. The wafers are usually placed on a plastic adhesive tape that is mechanically stretched causing the perforations to crack. It is claimed that no debris, surface cracking or thermal damage, occurs unlike with prior processes. In addition to speciality and multi-layer wafers, microelectromechanical (MEM) system devices can also be separated this way.

The disadvantages of stealth dicing become apparent as, typically, in order to perform Stealth Dicing a high numerical aperture (NA) lens must be applied, which results in a small depth of focus (DOF) and provides tight focusing conditions. This results in multiple cracks extending to random directions on the surface of cleaving and affects the lifetime of devices produced from of said cleaved wafers. Also, stealth dicing has it's draw backs when processing sapphire. These specific disadvantages are not apparent when wafers and substrates are of thicknesses of
up to ~ 120 - 140 \( \mu \text{m} \) and only require one pass per separation line to be diced. However, for thicker wafers (usually 4” or 6” sapphire wafers are >140 \( \mu \text{m} \) to 250 \( \mu \text{m} \) or more), a number of passes per separation line are required. As a consequence, the material is exposed to laser radiation for prolonged periods of time which has unfavorable influence to final device performance and yield. In addition, multi-pass processing slows down the total processing speed and throughput.

Another method for material processing is disclosed in a US patent application No. US2013126573, published on 23-05-2013. A method is provided for the internal processing of a transparent substrate in preparation for a cleaving step. The substrate is irradiated with a focused laser beam that is comprised of pulses having a pulse energy and pulse duration selected to produce a filament within the substrate. The substrate is translated relative to the laser beam to irradiate the substrate and produce an additional filament at one or more additional locations. The resulting filaments form an array defining an internally scribed path for cleaving the said substrate. Laser beam parameters may be varied to adjust the filament length and position, and to optionally introduce V-channels or grooves, rendering bevels to the laser-cleaved edges. Preferably, the laser pulses are delivered in a burst train for lowering the energy threshold for filament formation, increasing the filament length, thermally annealing of the filament modification zone to minimize collateral damage, improving process reproducibility, and increasing the processing speed compared with the use of low repetition rate lasers.

The application of this method results in rough processing applicable only to bare materials and is inconvenient for dicing owing to higher pulse energies required, which leads to unfavorable impact on final semiconductor device performance. In particular, if wafers are diced using this method, resulting light-emitting diodes (LED) are characterized by an increased leakage current, which is in case of high brightness (HB) and ultrahigh brightness (UHB) LEDs strongly reduces performance.

Another US patent application No. US2012234807, published on 20-09-2012, describes a laser scribing method with extended depth affectation into a work-piece. The method is based on focusing of a laser beam in such a way that
intentional aberrations are introduced. The longitudinal spherical aberration range is adjusted to be sufficient to extend depth of focus into a work-piece with a limited transverse spherical aberration range. The method also results in rough processing by high energy pulses to obtain vertical damage traces inside the work piece. High pulse energy is necessary due to the fact that a low numerical aperture lens (having a focal length of tens of millimeters) must be used, which results in loose focusing conditions - the focal spot has a very smooth spacial intensity profile, therefore resulting in operation conditions where above damage threshold energy density is achieved in a large area with a relatively small peak value. Due to the increased requirements for pulse intensity (needed for optical breakdown) an increase in pulse energy is required and makes the processing unattractive for HB and UHB LED where LED leakage current and chip wall rough cracking is critical as mentioned above.

Prior art methods impose limitations on substrate thickness, material type and processing quality used for wafer separation. In order to process thicker materials the above mentioned technologies require an increase in laser power or number of laser beam passes per separation line. As a consequence, this has advert effects both to the semiconductor device performance and the yield of production.

SUMMARY

In order to eliminate the drawbacks indicated above, this invention provides an effective and rapid laser processing method for separating semiconductor devices formed on a single substrate or separating high thickness, hard and solid substrates. During preparation of the device or substrate for the cleaving/breaking (dicing) procedure an area of damage is achieved that is characterized by the obtained deep and narrow damage area along the intended line of cleaving. The present method does not require multiple laser beam passes for per cutting line therefore increasing the yield of production. Henceforth the term "workpiece" will be defined to include the terms substrate, wafer, wafer sheet, device or similar item that
is prepared for processing and subsequent mechanical separation and will be used interchangeable.

The laser processing method comprises a step of modifying a pulsed laser beam by a focusing unit, in which the beam divergence and width are adjusted and focusing onto an workpiece is performed, such as that an "spike"-shaped beam convergence zone, more particularly an above workpiece material optical damage threshold fluence (power distribution) in the bulk of the workpiece is produced. The material is partially or completely transparent to the wavelength of said laser radiation and during the aforementioned step due to multiphoton absorption, preferably under sufficient conditions to produce localized melting or Coulomb explosions, a modified area (having a "spike"-type shape), also referred to as damage structure, in the bulk of the material is created.

The laser processing method further comprises a step of creating a number of such damage structures in a predetermined breaking line by relative translation of the object relative the laser beam condensation point. It should be apparent to a person skilled in the art that after forming such line the object can be separated or cut into two or more smaller pieces having a defined separation boundary, defined by the sequence of damage areas, by employing mechanical force.

DESCRIPTION OF DRAWINGS

In order to understand the method better, and appreciate its practical applications, the following pictures are provided and referenced hereafter. Figures are given as examples only and in no way should limit the scope of the invention.

Figure 1. is an illustrative view of numerically simulated "spike" shape focused laser beam intensity distribution inside material at 17-30 μm depth obtained by focusing incoming Gaussian profile intensity distribution laser beam (incident from left);

Figure 2. is a view of numerically simulated "spike" shape focused laser beam intensity distribution inside material in the case of deeper focusing
conditions (at 140 - 230 \( \mu \)m depth) obtained by focusing incoming Gaussian profile intensity distribution laser beam;

Figure 3. is an schematic representation of preferred embodiment, wherein a single damage structure is produced by focusing laser radiation through the beam focusing unit;

Figure 4. is a view of numerically simulated paraxial and marginal laser ray focusing as achieved during focusing through the beam focusing unit inside material;

Figure 5. is an schematic representation of preferred embodiment, wherein a series of damage structures are produced to form a cleaving/breaking plane;

Figure 6. is a view of a photograph comparing "spike" shape focused laser beam intensity distribution and damage shape obtained inside material at 17-30 \( \mu \)m depth;

Figure 7. is a view of a photograph comparing "spike" shape focused laser beam intensity distribution and damage shape obtained inside material in the case of deeper focusing conditions (at 140-230 \( \mu \)m depth);

Figure 8. is a view of processing results for with accordance to implementation Example 1;

Figure 9. is a view of processing results for with accordance to implementation Example 2.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

This invention provides a laser processing method for separating semiconductor devices formed on a single substrate or separating hard and solid substrates. During preparation of a sample for the cleaving/breaking procedure an
area of damage is achieved that is characterized by the obtained deep and narrow damage area along the intended line of cleaving.

In the most preferred embodiment, the processing method comprises a step of irradiating a workpiece with a focused pulsed laser beam through a beam focusing unit in such a way that beam convergence zone (focal spot, focal point) is formed inside the bulk of the workpiece, creating damage structures matching or closely resembling the shape of the convergence zone. The convergence zone is formed in such a way that its spatial fluence distribution, where the fluence exceeds the damage threshold of the workpiece material, is the shape of a "spike"-like geometrical structure as exemplary shown in Fig. 1 or Fig. 2. The term "damage" is defined to refer to any kind of sufficient local modification of the material, by which the mechanical properties are altered enough to produce controlled crack (along the separation boundary) formation during later cleaving steps. The modifications, or damage structures (locally damaged zones, areas), are introduced by the mechanism of multiphoton absorption, which is possible if the workpiece material is partially or completely transparent to the central wavelength (material bandgap exceeds the energy of a single photon energy, preferably multiple times) of laser radiation used and sufficient photon densities achieved by using short and ultrashort pulses while employing beam focusing. It is preferred that the workpiece material features a band gap energy above 0.9 eV.

The processing method further comprises repeated irradiation of the sample at spaced positions where a number of damage structures form a breaking/separation line. This is preferably achieved by mounting the workpiece on a motorized assembly of linear translation stages and moving the workpiece in a desired direction along the intended cleaving line, thus forming the cleaving plane. It should be apparent to a person skilled in the art the different configurations of translation stages can be employed, including rotational stages including mobilizing the focusing unit, as long the relative movement of focusing unit and workpiece is ensured. Sapphire, silicon carbide wafers, diamond substrates or other high hardness devices that are difficult to process mechanically can be used as the
workpiece, especially when they feature high thickness (e.g. above 500 \( \mu \)m in thickness).

In the most preferred embodiment, the most appropriate way of realizing said steps is using a pulsed laser beam (1) source (2), preferably of a spherical-elliptical Gaussian intensity distribution, beam focusing unit (3,4,5), such as an arrangement of an beam shaping optics, e.g. beam expander (3), beam focusing element (4), means of stabilizing the distance between the beam focusing element (4) or unit (3, 4, 5) and the workpiece (6), as shown in Fig. 3, means for holding and translating (7) a workpiece (6), such a motorized translation stage assembly. Said pulsed laser beam source (2) is, preferably, a laser (2) capable of stably producing successive laser pulses of a constant polarization and having a well defined temporal envelope, preferably Gaussian, having a pulse duration set in the range of 100 to 15 000 fs, a central wavelength set in the range of 500 to 2000 nm, a frequency set in the range of 10 kHz to 2 MHz and a pulse energy sufficient to allow pulses behind the focusing unit (3,4,5) with a pulse energy in the range of 1 to 100 \( \mu \)J and fluence in the range of 0.1 to 100 J/cm\(^2\). Beam shaping optics (3), preferably comprise a beam expander (3), for example a Keplerian or Galilean type beam expander or any other configuration if necessary to achieve the proper beam width and divergence before the focusing element. The beam focusing element (4) preferably comprises an aspherical focusing (condensing) lens (4) or objective lens and preferably means of maintaining a preset distance between the lens and the sample, e.g. distance monitoring means with a piezoelectric nanopositioner or motorized linear translation stage (5), which maintains the distance between the beam focusing unit (3,4,5) and the workpiece (6) at the focusing element's (5) working distance, with a maximum amount of error up to approximately 2 \( \mu \)m for translation speed of 300 m/s. The beam focusing element (5) should be arranged in such a way that when the beam is focused into the bulk of the workpiece a "spike" shape focal spot (spatial distribution of the above damage threshold fluence) with a spacial high intensity distribution equivalent to and/or having the shape of a spike, and illustrated in Fig. 1 and also Fig 3. Produced damage structures (8) can also be made to extend from the first surface (9) of the workpiece into the bulk, when
necessary, e.g. by also inducing ablation (an ablation produced pit (10)) at the said surface (10). As the beam focusing element (4) an high numerical aperture is preferred (NA > 0.7), but in other embodiments can be selected in the range from 0.5 to 0.9, and the design which allows on optical laser beam components that are closer to the optical axis (center of beam focusing element) to be focused in such a way that a condensation zone closer to the workpiece first surface (9) is produced in contrast to beam components propagating at a greater transverse distance to the optical axis, which are focused at a greater depth (distance form the first workpiece (6) surface (9)). An exemplary ray tracing image of said "spike" shaped convergence zone is shown in Fig. 4.

The distance between each laser pulse delivered on the surface be in the range from 1 µm to 10 µm and can be adjusted by changing the motorized translation stage assembly (7) movement velocity. The cleaving/breaking (11) plane is formed by linear movement of motorized translation stage assembly (7). The number of passes (repeated translations) for a single cleaving line should be up to 2, nonetheless it is not limited, the process of creating the cleaving/breaking plane is shown if Fig. 5. In this case tight focusing and sharp "spike" shape focused intensity distribution are combined and can be controlled by manipulating aspherical lens parameters, material optical properties or incoming beam properties.

The resulting topography of the cleaving/breaking surface is shown in Fig. 6 and 7. It should be apparent to a person skilled in the art that different lengths of damage structures can be achieved to produce effective breaking of complex workpieces.

In another preferred embodiment, the same beam focusing unit (3,4,5) is employed to simultaneously focus up to 4 laser beams in order to produce multiple condensation points thus increasing processing speed.

In another embodiment, during the step of irradiating a workpiece with a focused pulsed laser beam through a beam focusing unit, the beam focusing unit is arranged to include at least one diffraction element, augmenting or replacing the beam shaping optics, that shapes the incoming beam in such a way that after the
beam passes through the beam focusing element the "spike"-shaped intensity distribution is achieved.

Yet in another embodiment, during the step of irradiating a workpiece with a focused pulsed laser beam through a beam focusing unit, the beam shaping element is arranged to include at least one adaptive optics member that shapes the incoming beam in such a way that after the beam passes through the beam focusing element the "spike"-shaped intensity distribution is achieved. This allows using a larger variety of incoming beams (or more particularly differently modulated beams) or allow compensation for fluctuating processing parameters. The beam shaping member can be based on Deformable Mirrors, Piezoelectric Deformable Mirrors or similar.

Yet in another embodiment, during the step of irradiating a workpiece with a focused pulsed laser beam through a beam focusing unit, with accordance with the previous embodiment the adaptive optics member can be substituted with at least one phase and/or amplitude modulator member such as Liquid Crystal Light Modulator or micro-mirror matrix.

In order to better disclose the present invention the following examples are provided. Nonetheless, the disclosed examples and the mentioned parameters are provided to help understand the invention better and in no way limit its extent. These parameters can be changed in a wide interval, reproducing similar or different results, yet the main concept of the dicing process remains the same.

Yet in another embodiment, during the step of irradiating a workpiece with a focused pulsed laser beam through a beam focusing unit, with accordance with a previous embodiment the adaptive optics member can be substituted with at least one passive diffractive element beam modulating element, such as a flat-top beam shaping diffractive optical element, diffractive optical elements for aberration correction or another element, an all cases of appropriate parameters. The passive diffractive element is selected by a person skilled in the art in such a way that a beam, modulated with such an element, can be focused with the beam focusing element achieving a "spike"-shaped intensity distribution. It should be noted that the
said element can also be arranged in the optical path after the beam focusing element during irradiation.

In order to better disclose the present invention the following examples are provided. Nonetheless, the disclosed examples and the mentioned parameters are provided to help understand the invention better and in no way limit its extent. These parameters can be changed in a wide interval, reproducing similar or different results, yet the main concept of the dicing process remains the same.

Example 1

Workpiece material is Al2O3. The workpiece is in the form of a substrate (slab) with a thickness of approximately 140 µm. The laser source is a femtosecond laser having an output radiation wavelength 1030 nm, pulse width below 300 fs (full width at half maximum/1.41), set at an output frequency of 100 kHz. The focusing unit is arranged with a 0.8 NA focusing objective lens, as the beam focusing element. Pulse energy after the beam focusing unit is selected to be 5 µJ and fluence approximately 0.7 kJ/cm², condensation zone is formed 10 µm below the first surface of the wafer. Distance between damage structures is 3 µm. Processing speed, more particularly the translation speed of the linear translation stage, 300 mm/s. Results after processing (left) and after breaking/dicing (right) are shown in Fig. 8.

Example 2

Workpiece material is Silicon carbide, 4H polytype (4H-SiC). The workpiece is in the form of a substrate (slab) with a thickness of approximately 100 µm. The laser source is a femtosecond laser having an output radiation wavelength 1030 nm, pulse width below 300 fs (full width at half maximum/1.41), set at an output frequency of 100 kHz. The focusing unit is arranged with a 0.5 NA focusing objective lens, as the beam focusing element. Pulse energy after the beam focusing unit is selected to be 30 µJ and fluence approximately 1 kJ/cm², condensation zone is formed 30 µm below the first surface of the wafer. Distance between damage structures is 3 µm. Processing speed, more particularly the translation speed of the linear translation stage, 300 mm/s. Results after processing (left) and after breaking/dicing (right) are shown in Fig. 9.
Example 3

Lens aspherical coefficients have some freedom to choose, depends on incident beam divergence and targeting focusing depth interval. In the case of incident beam divergence - 1mRad (as measured behind the beam divergence control unit), targeting focusing depth inside sapphire interval from 17 µm to 140 µm, aspheric lens coefficients are for first lens surface: $R = 2.75$ (radius of curvature); $k = -0.5426984$ (conic constant, as measured at the vertex); nonzero coefficients $A_4 = -9.0053074 \times 10^{-3}$; $A_6 = 9.0053074 \times 10^{-3}$; $A_8 = 1.136379 \times 10^{-4}$; $A_{10} = -4.2789249 \times 10^{-6}$ and for second surface: $R = -3.21$; $k = -1.241801$; $A_4 = 9.0053074 \times 10^{-3}$; $A_6 = -1.359751 \times 10^{-3}$; $A_8 = 1.136379 \times 10^{-4}$; $A_{10} = -4.2789249 \times 10^{-6}$; refractive index $n = 1.597$, design wavelength 830 nm.
CLAIMS

1. A laser processing method for substrate cleaving or dicing comprising a step of irradiating a workpiece with a pulsed laser beam; wherein laser pulses are delivered on to the surface of the workpiece for cleaving; wherein workpiece means an object to be cleaved or dice with at least one flat surface; wherein workpiece is transparent for the laser radiation; wherein sequence of damaged zones produce a cleaving plane; wherein produced cleaving plane enables easy breaking along desired line of substrate separation, characterized in that said processing method comprises steps of: modifying said laser beam with a beam focusing unit arranged to focus the laser beam into the bulk or first workpiece surface facing the beam focusing unit and also the bulk of the workpiece in such a way that the above workpiece bulk material optical damage threshold fluence distribution follows a "spike"-like shape, wherein the length of the "spike"-like shape fluence distribution is greater than its transverse dimension; producing a series of damage structures the shape of said "spike"-like shape fluence distribution, along the intended cleaving plane.

2. The method according to claim 1, characterized in that the workpiece is wafer shaped substrate, wherein the substrate material is an hard and brittle material such as sapphire, silicon, silicon carbide, diamond or similar.

3. The method according to claim 1 and 2, characterized in that said laser beam focusing by said beam focusing unit is achieved by guiding the beam through at least one beam divergence control unit arranged in the beam focusing unit, such as an adjustable beam expander, and in succession guiding said beam through at least one beam focusing element having high numerical aperture in the range of 0.5-0.9 NA, such as a aspherical beam focusing lens or an at least one objective lens.
4. The method according to one of claims 1 to 3, characterized in that said beam focusing element focuses said beam in such a way that transverse beam components that strike the focusing element closer to the optical axis are focused closer to the first surface of the workpiece, where as the transverse components which strike the focusing element further from the optical axis are focused further in the bulk of the workpiece material relative to the first workpiece surface.

5. The method according to one of claims 1 to 4, characterized in that said focusing unit comprises means of maintaining the distance between said beam focusing unit and first workpiece surface, such as an piezoelectric nanopositioner, motorized linear translation stage or similar.

6. The method according to claim 1 to 5, characterized in that said "spike"-like shaped focused laser beam intensity distribution inside material is adapted for effective processing with regard to the properties of the material and said workpiece dimensions by either or/and: changing laser beam divergence before said focusing element, focusing element surface design, focusing depth, by means of an actuator unit or other processing parameters.

7. The method according to one of claims 1 to 2 and 4 to 6, characterized in that said laser beam focusing by said beam focusing unit is achieved by guiding the beam through at least one adaptive optics member in the beam focusing unit and in succession guiding said beam through at least one beam focusing element, such as a spherical, aspherical beam focusing lens or an at least one objective lens.

8. The method according to one of claims 1 to 2 and 4 to 6, characterized in that said laser beam focusing by said beam focusing unit is achieved by guiding the beam through at least one phase and/or amplitude modulator member in the beam focusing unit and in succession
guiding said beam through at least one beam focusing element, such as a spherical, aspherical beam focusing lens or an at least one objective lens.

9. The method according to one of claims 1 to 2 and 4 to 6, characterized in that said laser beam focusing by said beam focusing unit is achieved by guiding the beam through at least one passive diffractive element beam modulating element in the beam focusing unit and at least one beam focusing element, such as a spherical, aspherical beam focusing lens or an at least one objective lens.

10. The method according to claims 1 to 9, characterized in that said laser beam wavelength is in the range of 500 to 2000 nm.

11. The method according to claims 1 to 10, characterized in that said laser pulse duration is in the range of 100 fs to 15000 fs.

12. The method according to claims 1 to 11, characterized in that said laser pulse repetition rate is in the range of 10 kHz to 2 MHz.

13. The method according to claims 1 to 12, characterized in that said laser pulse energy is in the range of 1 to 100 mikrojoule.

14. The method according to claims 1 to 13, characterized in that said pulsed laser beam fluence is in the range from of 0.1 to 100 J/cm².

15. The method according to claims 1 to 14, characterized in that said series of damage structures features a distance between the damage structures in the range from of 1 to 10 mikrometers.
AMENDED CLAIMS
received by the International Bureau on 04 September 2015 (04.09.2015)

1. A laser processing method for substrate cleaving or dicing comprising a step of irradiating a workpiece with a pulsed laser beam, through; wherein laser pulses are delivered on to the surface of the workpiece for cleaving; wherein workpiece means an object to be cleaved or diced with at least one flat surface; wherein workpiece is transparent for the laser radiation; wherein workpiece material is sapphire or diamond; wherein sequence of damaged zones produce a cleaving plane; wherein produced cleaving plane enables easy breaking along desired line of substrate separation, characterized in that said processing method comprises steps of: modifying said laser beam with a beam focusing unit arranged to focus the laser beam into the bulk of the workpiece material, in such a way that the above workpiece bulk material optical damage threshold fluence distribution follows a "spike"-like shape, wherein beam focusing unit comprises at least one beam focusing element having high numerical aperture in the range of 0.5-0.9 NA, wherein the length of the "spike"-like shape fluence distribution is greater than its transverse dimension; producing a series of damage structures the shape of said "spike"-like shape fluence distribution, along the intended cleaving plane, while maintaining the distance between said beam focusing unit and first workpiece surface with means of maintaining distance.

2. The method according to claim 1, characterized in that said laser beam focusing by said beam focusing unit is achieved by guiding the beam through at least one beam divergence control unit arranged in the beam focusing unit, such as an adjustable beam expander, and in succession guiding said beam through at least one beam focusing element, whereby the beam focusing element is an aspherical beam focusing lens or an at least one objective lens.

3. The method according to one of claims 1 to 2, characterized in that said beam focusing element focuses said beam in such a way that transverse beam
components that are incident on a surface of the focusing element closer to the optical axis are focused closer to the first surface of the workpiece, whereas the transverse components that are incident on the surface of the focusing element further from the optical axis are focused further in the bulk of the workpiece material relative to the first workpiece surface.

4. The method according to one of claims 1 to 3, characterized in that said means of maintaining the distance is arranged to contain distance monitoring means an piezoelectric nanopositioner or motorized linear translation stage or similar.

5. The method according to claim 1 to 4, characterized in that "spike"-like shaped focused laser beam intensity distribution inside material is adapted for effective processing with regard to the properties of the material and said workpiece dimensions by either or/and: changing laser beam divergence before said focusing element, focusing element surface design, focusing depth, by means of an actuator unit or other processing parameters.

6. The method according to one of claims 1 to 5, characterized in that said laser beam focusing by said beam focusing unit is achieved by guiding the beam through at least one adaptive optics member in the beam focusing unit and in succession guiding said beam through at least one beam focusing element, such as a spherical, aspherical beam focusing lens or an at least one objective lens.

7. The method according to one of claims 1 to 6, characterized in that said laser beam focusing by said beam focusing unit is achieved by guiding the beam through at least one phase and/or amplitude modulator member in the beam focusing unit and in succession guiding said beam through at least one beam focusing element, such as a spherical, aspherical beam focusing lens or an at least one objective lens.
8. The method according to one of claims 1 to 7, characterized in that said laser beam focusing by said beam focusing unit is achieved by guiding the beam through at least one passive diffractive element beam modulating element in the beam focusing unit and at least one beam focusing element, such as a spherical, aspherical beam focusing lens or an at least one objective lens.

9. The method according to claim 1 to 8, characterized in that said laser beam focusing unit is employed to simultaneously focus up to 4 laser beams.

10. The method according to claims 1 to 9, characterized in that said laser beam wavelength is in the range of 500 to 2000 nm.

11. The method according to claims 1 to 10, characterized in that said laser pulse duration is in the range of 100 fs to 15000 fs.

12. The method according to claims 1 to 11, characterized in that said laser pulse repetition rate is in the range of 10 kHz to 2 MHz.

13. The method according to claims 1 to 12, characterized in that said laser pulse energy is in the range of 1 to 100 microjoule.

14. The method according to claims 1 to 13, characterized in that said pulsed laser beam fluence is in the range from of 0.1 to 100 J/cm².

15. The method according to claims 1 to 14, characterized in that said series of damage structures features a distance between the damage structures in the range from of 1 to 10 micrometers.
In view of the Search Report, the following amendments to the Claims are being proposed:

Claim 1 amended;
Claim 2 as filed cancelled;
Claims 3, 4, 5 as filed amended to get new claims 2, 3, 4;
Claims 6, 7, 8, 9 as filed renumbered to 5, 6, 7, 8;
New claim 9 added;
Claims 10 to 15 remain unchanged.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. B23K26/00 B23K26/06 C03B33/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
B23K C03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>X</td>
<td>WO 2014/079570 AI (LIGHT IN LIGHT SRL ET AL) 30 May 2014 (2014-05-30) paragraphs [0031] - [0033], [0046], [0170]; claim 26; figure 12</td>
<td>1-15</td>
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Further documents are listed in the continuation of Box C.

See patent family annex.

* * Special categories of cited documents:

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Date of the actual completion of the international search

30 June 2015

Date of mailing of the international search report

10/07/2015

Name and mailing address of the ISA

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<thead>
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