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(54) **Splitting method for brittle materials**

(57) A method for the splitting of a wafer from a body (1) of material capable of undergoing thermally induced fracture, characterized in that a source of cooling (4,15) is used to extract heat from the body (1) of material along

a line or strip which progressively moves from one side of the body (1) to an opposite side thereof.

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Description

[0001] For the manufacture of solar cells and other semiconductor components, thin discs (wafers) of semiconductor materials are required. These wafers can either be grown with the correct thickness or they are manufactured from a compact block or crystal of a semiconductor material. The previously predominant manufacturing variant is sawing which preferably takes place with diamond saws or wire saws. Apart from the working complexity, sawing has the general disadvantage that a part of the material is converted to chips during sawing and that after the sawing saw damage remains at the surface of the wafer which has to be etched away again. In order to keep the material loss as small as possible, a splitting of the material would be more expedient than sawing. There is already the so-called "smart cut" process (see Q.-Y. Tong, U. Gösele "Semiconductor wafer bonding - Science and Technology", Wiley, 1999, p. 10 ff) in which hydrogen ions are implanted into a crystal up to a specific depth. During the subsequent heating up, the crystal splits at the depth of the highest implantation dose parallel to the surface. With this process, only very thin wafers can, however, be manufactured with a thickness of less than a micrometer. However, for solar cells, wafers of typically 10 to 50 micrometer thickness are required. These can no longer be economically manufactured using the smart cut process.

[0002] If one firmly attaches a thin layer of another material to a brittle material and this film is subjected to tensile stress, for example by temperature variation, then this leads to shear stresses in the underlying material which can lead to the tearing off of a thin layer of this material parallel to the surface (Zhiang Suo and J.E. Hutchinson, Int. J. Solid Structures 25 (1989) 1337-1353). This effect is normally undesired in the coating of materials. It was, however, proposed by von Dross et al to utilize this process for the splitting off of silicon wafers for solar cells ("Stress-induced large-area lift-off of crystalline Si films" in March 2007 sent to Applied Phys. A., manuscript No. 8819). As a strained layer a screen-printed metal layer was used here which was baked at 850°C. During cooling of the system to room temperature, the metal layer "rolls" up and away from the surface together with an approximately 40 µm thick silicon layer. By separating the metal layer one obtains a thin non-strained silicon wafer. The disadvantage of this process is the cost and complexity which is still relatively high as a result of the plurality of process steps that are necessary in order to apply the metal layer, to split off the thin wafer and to separate it again from the metal layer.

[0003] At the 17th workshop on crystalline silicon solar cells and modules held from Aug. 5-8, 2007 in Vail, CO, C. Baer presented a process for "laser induced splitting" of silicon, see the proceedings pages 20-25, patent application PCT/US2007/001911(2007). In this method a stationary or pulsed laser beam is focused with the aid of a cylindrical lens to a line at a specific depth beneath

a $\langle 111 \rangle$ orientated surface in a silicon single crystal, which represents a preferred splitting surface, and this line is moved over the surface. As a result of absorption, a material expansion is intended to arise at the focus of the laser which leads to a splitting off of the material at the depth of the laser focus. In order to initiate the splitting off, the margin of the crystal is scored at the intended depth. This process has not hitherto been verified. In particular it must be regarded as difficult in view of the high refractive capability of Si ($n = 3.5$) to focus the laser beam at a specific depth with an adequately high numerical aperture. Accordingly, it was also proposed to utilize non-linear optical effects for a more pronounced localization of the absorption which, however, makes the process even more complicated.

[0004] The object of the present invention is to present a method which enables the splitting off of thin wafers from a block of brittle material with high productivity and which operates without applied material and optical techniques.

[0005] In order to satisfy this object there is provided a method having the Features of claim 1 or claim 9, i.e. generally a method for the splitting of a wafer from a body of material capable of undergoing thermally induced fracture, characterized in that a source of cooling is used to extract heat from the body of material along a line or strip which progressively moves from one side of the body to an opposite side thereof.

[0006] Preferred embodiments of the invention are set forth in the dependent claims.

[0007] The process of the invention likewise relates to the fact that a thin layer of the material is split off by differential thermal expansion from a compact piece of the material from its planar base surface. In contrast to the above named process, the shear stress is however here not caused by the applied layer of foreign material or by heating at a specific depth, but rather it is produced in accordance with the invention in that a surface-near layer of the material is itself strongly cooled for a short time. When a heat source or a source of cooling only operates for a short time t on its surface, then the penetration of the change of temperature is of the order of

magnitude of $\sqrt{Dt}$ (D = thermal diffusivity). For silicon, D amounts to $0.9 \text{ cm}^2/\text{s}$ and thus for a period of action of $t = 28 \text{ } \mu\text{s}$ the depth of thermal penetration amounts to approximately $50 \text{ } \mu\text{m}$. Thus, in accordance with the invention, this short acting time of the refrigeration source is achieved in that the line of cooling is moved or guided with a specific speed over the surface, for example in that the surface rolls off on a cooled roll. The period of action of the cold roll on the surface of the material is then defined by the mechanical characteristics of the material and the roll, by the contact pressure and by the speed of rolling off. In accordance with the differential lattice constants of the material at the two temperatures T_1 (warm) and T_2 (cold) an internal stress arises

in the material which is so directed that a tendency exists to the splitting off of a wafer. This mechanical stress leads, in accordance with the invention, to the tearing of the material at a specific depth or to a further tearing of an already existing crack. In order to facilitate the splitting off process, the piece of material can here be orientated in just the same way as in laser induced splitting (for example Si $\langle 111 \rangle$), so that the surface parallel to the surface is a preferred splitting surface. In order to be able to increase the temperature gradients at the cold line, the material to be split can be brought to an adequately high external temperature t_i at which it still just undergoes brittle fracture. In order to facilitate the splitting off process, the material can be exposed to the action of ultrasound during the splitting off. In the same way, in order to facilitate the initiation of the splitting process, notches can be introduced at the side surface of the piece of material at the spacing of the wafer thicknesses that are aimed at, for example by diamond scoring or grinding as in the laser induced splitting, with the crack starting to propagate at the notches. For the further optimization of the process, these notches can be enlarged by short-term cooling down of the surface to short cracks prior to the actual splitting of the wafer. This short-term cooling down can likewise take place with the method of the invention of guiding a cold line over the scored surface. Thereafter, the actual splitting off of the wafer from the base surface of the material block takes place in that the base surface of the piece of material is guided, coming from the score marks, over the cold line at a specific speed. The splitting off of a plurality of wafers takes place directly after one another, with the piece of material being heated from the side opposite the splitting process for the compensation of the heat losses of the semiconductor material by the action of the cold and for the establishment and stabilization of an ideal material temperature T_1 . This opposed heating can, for example, take place by contact with a heater or also inductively.

[0008] The invention will now be described in more detail by way of example only and with reference to the accompanying drawings in which are shown:

Fig. 1 a basically cylindrical block of crystalline semiconductor material having a flat ground on one side thereof,

Fig. 2 the cylindrical block of material of Fig. 1 having notches ground into the side surface in the region of the flat with the notches extending from the flat into the block and with a cooled roll contacting the block at the flat in accordance with the invention,

Fig. 3 the same block as in Fig. 2 after having been moved over the cooled roll and now rotated through 90° with its planar end surface on the cooled roll, also in accordance with the invention

Fig. 4 a basically cylindrical block of crystalline semiconductor material similar to Fig. 1 but in this case without a flat ground on one side thereof and

Fig. 5 the cylindrical block of Fig. 4 seen end on and positioned over a bath of cryogenic fluid having a wave crest contacting the side surface of the block of material in accordance with the invention.

[0009] Turning first to Fig. 1 there can be seen a basically cylindrical block of crystalline semiconductor material 1, in this case silicon with a $\langle 111 \rangle$ orientation of its end face 2 which forms a planar base surface. A flat 3 is ground along one side of the cylindrical block.

[0010] Fig. 2 shows a first step I of a first embodiment of the use of the method of the invention including the initiation of the splitting process at the generally cylindrical single crystal silicon body 1 having the planar base surface 2 using a cooled roll 4 which initially contacts the flat 3. The roll 4 can either sit in a bath of cryogenic fluid for example a liquefied gas such as nitrogen or can be internally cooled by such a cryogenic fluid. As mentioned the base surface 2 of the crystal preferably has a $\langle 111 \rangle$ orientation in accordance with the invention so that preferred splitting planes extend parallel to the base surface. At the start, i.e. preferably before the step shown in Fig. 2, notches 5 are scored or ground into the ground side surface of the crystal 1, i.e. at the flat 3, at spacings corresponding to the intended wafer thickness. In a first method step I the side surface of the crystal, which has been brought to an ideal temperature, typically but not necessarily a temperature above ambient, e.g. 300°C , is guided in the direction of the arrow 6 once over the cooled roll 2, whereby a splitting process is initiated at all notches 5 resulting in fine cracks 7 at the position of the bottoms of the notches, with the fine cracks lying in $\langle 111 \rangle$ planes in this example which extend perpendicular to the central longitudinal axis 8 of the cylindrical body 1.

[0011] In the second method step II of the invention, as illustrated in Fig. 3, the silicon crystal 1 is rotated through 90° , is subjected to opposing heating at the end opposite to the planar base surface or rear side 2 with a heating device 9 and the base surface 2 is guided or moved over the cooled roll 4 in the direction of the arrow 10 starting from the side (flat 3) at which the already initiated cracks 7 are located, whereby the wafer 11 progressively splits off from the body 1 and is finally completely separated from it (not shown) in which it assumes a generally flat shape as soon as it is at thermal equilibrium because it is no longer subjected to internal stresses. Such a wafer can then be further processed. The split off wafer is captured by suitable measures, whereupon the method step II is repeated until the material has been split into further wafers and used up.

[0012] It should be noted that the use of a flat 3 is not essential simply expedient because it improves the contact area and thus the heat transfer to the cooled roll 4. That is to say the semiconductor body could be cylindrical

as shown in Fig. 4 but with the notches only extending over a strip along one side of the cylindrical body 1 as shown or at least suggested in Fig. 2.

[0013] In Fig. 4 the notches 5 have been ground so that they extend all around the cylindrical body. This could actually also be the case for the first embodiment shown in Figs. 2 and 3. In the embodiment of the method shown in Fig. 5 the cylindrical body 1 is mounted so that it can rotate on an axle 12 concentric to the central longitudinal axis 8 in the direction of the arrow 13 above a wave 14 of a cryogenic fluid contained in a bath 16. The cryogenic fluid 15 can, for example, be a liquefied gas such as liquid nitrogen, with a strip 17 of the cylindrical side surface of the body 1 contacting the wave of cryogenic fluid, i.e. dipping into the crest of the wave. The wave can be a travelling wave, for example travelling from the left to the right in Fig. 5 or from the right to the left, or indeed alternately in both directions, or it can be standing wave. It could also be a fountain of cryogenic fluid, possibly with a shape similar to that shown as the wave in Fig. 5 and obtained by pumping the fluid through a plate having an orifice corresponding to the wave shape that is desired, for example a rectangular orifice to generate a flow of cryogenic fluid contacting the body 1 along the desired rectangular strip.

[0014] A heater, for example a radiant heater 9 can be provided in this embodiment to compensate for heat loss from the body 1 and to enhance the thermal shock to which it is subjected and enhance the splitting process.

[0015] In this embodiment the body can be continually rotated while progressively increasing the depth of immersion in the cryogenic fluid in order to ultimately split the block of material 1 into the individual wafers. Alternatively once the block 1 has been split all around its periphery, or around part of its periphery, it can be treated further in accordance with the method step II of Fig. 3.

[0016] It should also be noted that the wave 14 of cryogenic fluid of Fig. 5 could also be substituted for the cooled roll 4 of Figs. 2 and 3. In this case the body 1 of material could be moved over a stationary wave crest in the same way as the corresponding body 1 is moved over the roll 4 of generally fixed position in Figs. 2 and 3. Alternatively, the wave 14 could be a travelling wave moving, for example from the right to the left in Figs 2 and 3, with the position of the body of material being held substantially constant for the or each pass of the wave 14.

[0017] This possibility of holding the body of material in a substantially fixed position and moving the source of cooling relative to the body of material can naturally apply not only to the wave of cryogenic fluid as the source of cooling but also to the use of a cooled roll, i.e. the cooled roll 4 could also be moved relative to the body of material 1.

[0018] It should also be noted that the cooled roll could have a surface profile matched to that of the side surface of the body of material, whereby to improve the heat transfer from the body of material to the cooled roll. E.g. the body of material could be ground to provide a gen-

erally cylindrical outer surface, for example as shown in Fig. 4 and the roll could have a complementary concave surface having a radius of the concave surface equal to that of the cylindrical surface of the body of material, so that the concave surface contacts the body of material along a strip of the side surface. If this is done then a second cooled roll with a flat surface would be used for the method step of Fig. 3, so that the desired line of contact with the planar base surface 2 results. If a body of material with a flat is used, as shown in Fig. 1 then the cooled roll 4 would have a flat surface and the same cooled roll could be used for the method steps of Figs. 2 and 3, although this is not essential.

[0019] Finally Fig. 5 shows an ultrasonic transducer 20 which, in this embodiment, is mounted on the axle 12 and used to couple sonic energy into the body 1 to enhance the splitting process. An ultrasonic transducer can also be used in the embodiment of Figs 2 and 3 for the same purpose.

Claims

1. A method for the splitting off of a wafer from a body or compact piece (1) of a brittle material, i.e. a material capable of undergoing brittle fracture, having a planar base surface (2), **characterized in that** the material is cooled at its base surface (2) along a line which, starting from one side of the base surface, is guided with a specific speed (in the direction of the arrow 10) over the base surface (2).
2. A method in accordance with claim 1, **characterized in that** the piece of material is oppositely heated at the side opposite to the base surface.
3. A method in accordance with claim 1 or claim 2, **characterized in that** the piece of material includes notches at the margin.
4. A method in accordance with claim 3, **characterized in that** the surface with the notches is exposed in a first working step to the action of cooling.
5. A method in accordance with any one of the preceding claims, **characterized in that** the material is additionally exposed to the action of ultrasound.
6. A method in accordance with any one of the preceding claims, **characterized in that** the material is a single crystal with a preferred splitting direction parallel to the base surface.
7. A method in accordance with any one of the preceding claims, **characterized in that** the cooled line is realized by a cooled metal roll over which base surface of the material rolls.

8. A method in accordance with any one of the preceding claims 1 to 7, **characterized in that** the cooled line is realized by a bath of coolant which has the form of a wave-soldering bath over which the material is guided. 5
9. A method for the splitting of a wafer (6) from a body of material capable of undergoing thermally induced fracture, **characterized in that** a source of cooling (4; 14) is used to extract heat from the body of material (1) along a line or strip which progressively moves from one side of the body to an opposite side thereof. 10
10. A method in accordance with claim 9 wherein said body of material (1) has a side surface extending around an axis of said body and a planar base surface (2) and said line or strip progressively moves over said planar base surface from said one side of said body to said opposite side thereof. 15 20
11. A method in accordance with claim 9 or claim 10 and comprising the further step of forming at least one notch (5) in said body at least at said one side to facilitate crack initiation at a desired position. 25
12. A method in accordance with claim 11 wherein at least one said notch is formed all around said body of material. 30
13. A method in accordance with claim 9 wherein said strip or line extends along said side surface of said body of material and is moved from said first side around said side surface to said opposite side and then further back to said first side., e.g. by continued rotation of said body of material (1) about its axis. 35
14. A method in accordance with claim 13 used for crack initiation at the base of notches formed in said side surface and followed by the repeated use of the method of claim 10 for the subdivision of the body of material into individual wafers. 40
15. A method in accordance with claim 11 wherein said crack initiation is also thermally induced using a source of cooling to produce differential thermal expansion at a base of the or each said notch. 45

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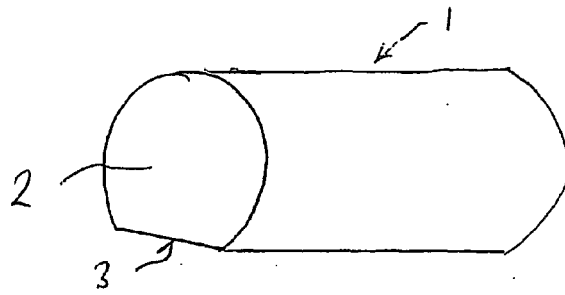


FIG. 1

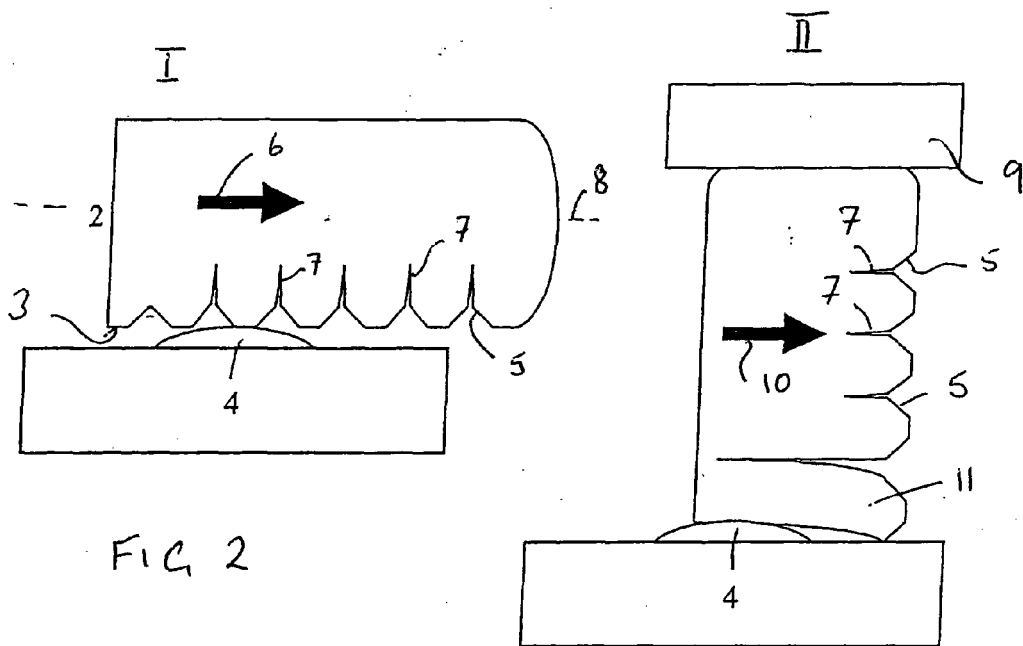


FIG. 2

FIG. 3

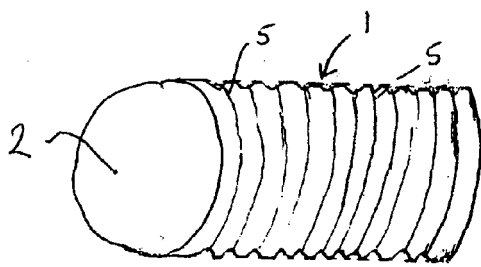


FIG. 4

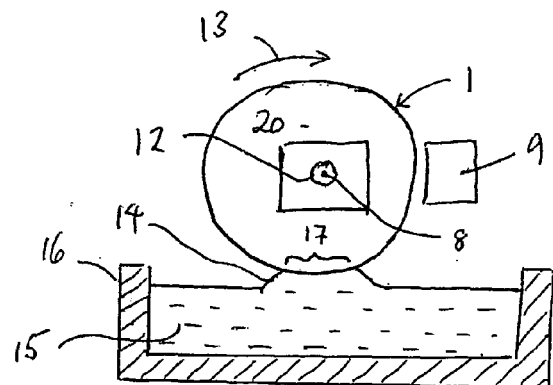


FIG. 5



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 07 02 1572

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	DE 34 03 826 A1 (SIEMENS AG [DE]) 8 August 1985 (1985-08-08) * the whole document *	1-15	INV. B28D1/22 B28D5/00
A	EP 0 729 815 A (SHINETSU HANDOTAI KK [JP]) 4 September 1996 (1996-09-04) * the whole document *	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			B28D C03B
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 31 March 2008	Examiner Rijks, Mark
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 07 02 1572

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31-03-2008

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REFERENCES CITED IN THE DESCRIPTION

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- **ZHIANG SUO ; J.E. HUTCHINSON.** *Int. J. Solid Structures*, 1989, vol. 25, 1337-1353 [0002]