

**Method for Simultaneously Cutting a Compound Rod of
Semiconductor Material into a Multiplicity of Wafers**

5 The invention relates to a method for simultaneously cutting a compound rod of semiconductor material into a multiplicity of wafers.

Workpieces of semiconductor material are conventionally
10 cut into wafers by means of a wire saw. Wire saws are used in the prior art to cut cylindrical mono- or polycrystalline workpieces of semiconductor material, for example silicon, simultaneously into a multiplicity of wafers in one working operation. The throughput of
15 the wire saw is in this case of great importance for the economic viability of the method.

Owing to the way in which they are produced, shorter and longer rod pieces are obtained in wafer production.
20 It is also often necessary to cut rod portions from a single crystal, for example in order to examine the crystal properties. In order then to increase the throughput when sawing these different rod lengths, a plurality of workpieces are to be clamped
25 simultaneously in the wire saw and cut in one working operation.

US 6119673 describes the simultaneous cutting of a plurality of cylindrical workpieces, which are arranged
30 coaxially behind one another. To this end a conventional wire saw is used, with a plurality of workpieces adhesively bonded respectively on a sawing strip being fixed with a certain spacing in a coaxial arrangement on a common mounting plate, by which they
35 are clamped in the wire saw and cut simultaneously.

This gives rise to a number of packets of wafers, corresponding to the number of workpieces, which are still fixed on the mounting plate. After the cutting, separating plates are placed loosely into the spacings
5 between the packets of wafers in order to avoid confusion of the wafers of the various packets.

US 6802928 B2 describes a method in which dummy pieces of the same cross section are adhesively bonded onto
10 the end surfaces of the workpiece to be cut, which are cut with the workpiece and are then discarded. This is intended to prevent the wafers obtained at the two ends of the workpiece from fanning out during the end phase of the cutting, and therefore to improve the wafer
15 geometry. This method has the crucial disadvantage that part of the gang length, which is limited by the dimensions of the wire saw, is used for cutting the "unused" dummy pieces. Furthermore the provision, handling and adhesive bonding of dummy pieces is very
20 elaborate and difficult to manage.

In the simultaneous cutting of a plurality of workpieces in a wire saw as described in US 6119673, the gang length of the wire saw also cannot be used
25 optimally since the workpieces to be cut have very different lengths owing to the way in which they are produced. This problem arises in particular whenever the workpieces consist of monocrystalline semiconductor material, since the known crystal pulling processes
30 only allow certain usable lengths of the crystals or, in order to monitor the crystal pulling processes - as already mentioned above - it is necessary to split the crystals and produce test samples at various positions of the crystal.

DE 102 006 050 330 discloses a method for simultaneously cutting at least two cylindrical workpieces into a multiplicity of wafers by means of a wire saw, in which 2 or more workpieces are selected
5 from a stock of workpieces, they are fastened behind one another on a mounting plate, a certain minimum distance being maintained respectively between the workpieces, clamped in the wire saw and cut perpendicularly to their longitudinal axis (geometrical
10 axis) by means of the wire saw. This method allows better use of the wire gang length. In order to avoid confusion, similarly as in the method described in US 6119673, separating pieces are inserted laterally between the wafer packets and then fixed on the wafer
15 carrier. The separating pieces also protect the wafer packets against tilting away laterally.

A feature common to all the known methods is that a distance between the rod pieces is to be maintained for
20 cutting the rod pieces.

It has been found that in the methods described above, geometrical variations of the wafers sawed from a rod of particular length assembled in this way occur
25 compared with the wafers cut from a single semiconductor rod of corresponding length. This is to be observed even when the composite rod and the single rod are equally long and the wire gang used is therefore the same.

30

Besides the thickness variation (TTV, GBIR), the planarity of the two surfaces of the semiconductor wafer is of great importance. After cutting a semiconductor single crystal by means of a wire saw,

for example a silicon single crystal, the wafers thereby produced have an undulating surface. In the subsequent steps, for example grinding or lapping, this waviness can be removed partially or fully depending on
5 the wavelength and amplitude of the waviness and the depth of the material removal. In the worst case, such surface irregularities ("undulations", "waviness"), which may have periodicities of from a few mm up to for example 50 mm, are still detected even after polishing
10 on the finished semiconductor wafer where they have a negative effect on the local geometry.

The disadvantages of the methods known from the prior art are found to be particularly significant for the
15 bow and warp parameters as a measure of the deviation of the actual wafer shape from the desired ideal wafer shape (or "sori"). This pertains in particular to the warp of the wafers. The warp is defined in SEMI Standard M1-1105, and indicates the difference of the
20 minimum and maximum deviations of the mid-plane of a wafer relative to a reference plane on the backside of the wafer. Expressed simply, the warp represents a measure of the deformation of the wafer.

25 It was therefore an object of the invention to avoid such geometrical variations and, in particular, to improve the warp of the wafers fabricated from the compound rod.

30 The Inventors have discovered that these geometrical variations in the prior art are attributable to technical process changes which are due to the spacing of the rod pieces.

The object is achieved by a method for simultaneously cutting a compound rod of semiconductor material into a multiplicity of wafers by means of a wire saw, comprising the following steps:

- 5 a) selecting at least two workpieces from a stock of workpieces, which have been cut from one or more semiconductor rods;
- 10 b) grinding at least one of the two end surfaces of each rod;
- c) cementing the at least two workpieces together on their ground end surfaces by using a fastening means,
15 to produce a compound rod piece and fixing the compound rod piece in the longitudinal direction on a mounting plate, there respectively being only a distance between the workpieces due to the fastening means located between them;
- 20 d) clamping the mounting plate with the compound rod piece fixed thereon in the wire saw; and
- e) cutting the compound rod perpendicularly to its
25 longitudinal axis by means of the wire saw.

The cutting of a workpiece in step a) is preferably carried out with a wire saw. The use of an internal hole saw is likewise suitable.

- 30 The fastening means used in step c) may preferably be an adhesive.

Grinding the end surfaces so that the two end surfaces of the at least two workpieces, which adhesively bond

together, are plane-parallel, allows the adhesive joint between the two rod pieces to be made as small as possible.

5 Preferably, only rod pieces from neighboring rod positions of the same semiconductor rod are cemented together. The two rod pieces therefore preferably have the same crystal specification (for example defect properties, doping, etc.).

10

Preferably, exactly two rod pieces are cemented together.

Furthermore, the rod pieces are preferably cemented
15 together while aligning the pulling edges (making them flush).

The rod cemented together preferably has a total length of less than or equal to 380 mm.

20

A two-component adhesive is preferably used as the adhesive. For example, high-performance two-component adhesives of the Araldite brand from Huntsman Advanced Materials are suitable for this.

25

Lastly, the compound rod is cut up into wafers by means of a wire saw. The wire sawing step itself is carried out according to the prior art.

30 The compound rod is preferably ground round before the wire sawing step. It is, however, likewise preferable to grind the workpieces round before they are assembled to form the compound rod.

When sawing a single crystal into individual rod pieces, it is conventionally cut to the geometrical axis. Subsequently, however, the individual rod pieces (after orientation) are conventionally ground round
5 parallel to the crystal axis. The difference between the geometrical axis and the crystal axis results in a corresponding tilt of the end surfaces, which is corrected by corresponding right-angled grinding of the end surfaces.

10

The situation is different for workpieces which previously occupied neighboring positions in the single crystal. Here, it is also conceivable and preferable to obviate grinding the end surfaces and for the
15 workpieces to be assembled into a compound rod before grinding them round, i.e. to grind the workpieces round in the composite.

Assembling rod pieces to form a compound rod without
20 using separating pieces, and subsequent sawing, results in an even higher economic viability compared with the prior art since the use of the wire saw is further improved.

25 On the other hand, the compound rod according to the invention behaves similarly as a single rod in the sawing process. The geometrical variations observed in the prior art can be avoided.

30 Preferably, the following procedure is adopted in detail:

a) First the workpieces, possibly of different lengths, cut from a crystal by means of a bandsaw are ground

round.

After grinding round, the rod piece end surfaces are ground at a defined angle setting with respect to the crystal axis and orientation setting. The two end sides
5 of the rod piece are then exactly parallel to one another;

b) The rod pieces prepared in this way are stored and made available to a planning system for assembly. The
10 planning system determines the optimal configuration for maximal use of the gang length and suggests this for the preparation of a compound rod;

c) The selected rod pieces are prepared for the
15 cementing: i.e. cleaning the positions to be cemented, applying the cement in a defined layer thickness (for example by means of a serrated spatula), alignment by means of a cementing device, assembly and fixing the packet flush,
20 cementing and fixing the sawing strip and finally curing the adhesive;

d) Sawing the compound rod by means of the wire saw;

25 e) Detecting the cementing position, removing cement and separating the rods. The rod pieces are preferably provided beforehand with a corresponding marking on the lateral surface for the purpose of material identification.

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Example

In order to use the wire gang length in wire saws as efficiently as possible, two rod pieces (from the same

original semiconductor rod) were cemented together and "wafered", i.e. cut into wafers, by wire sawing.

5 To this end a rod piece of silicon, in the state not ground round, was sawed into 2 rod pieces with lengths of 97 mm and 91 mm respectively. The two rod pieces were cemented together with a two-component adhesive of the Araldite brand on the end faces and in alignment with the correct pulling edges.

10

This "compound rod" was subsequently ground round and sawed by means of a wire saw using zinc wire into wafers, and fully analyzed.

15 An advantage in this case is that the Araldite brand two-component adhesive used can be sawn through. In the example, the rod orientations for the two rod pieces were the same.

20 Essentially the workpieces are selected from a stock of workpieces, possibly of different lengths, so that the gang length of the wire saw is used optimally. Since no separating pieces are used, the adhesive joint between the assembled workpieces is minimal and the capacity of
25 the wire saw is therefore utilized better, which further increases the productivity of the process compared with the prior art.

30 A conventional wire saw may be used in the method according to the invention. The essential components of these wire saws include a machine frame, a forward feed device and a sawing tool, which consists of a gang of parallel wire sections. The workpiece is generally fixed on a mounting plate and clamped with it in the

wire saw.

In general, the wire gang of the wire saw is formed by a multiplicity of parallel wire sections, which are
5 tensioned between at least two (optionally even 3, 4 or more) wire guide rolls, the wire guide rolls being rotatably mounted and at least one of the wire guide rolls being driven. The wire sections generally belong to a single finite wire, which is guided spirally
10 around the roll system and is unwound from a stock roll onto a receiver roll. The gang length refers to the length of the wire gang, measured in the direction parallel to the axes of the wire guide rolls and perpendicularly to the wire sections, from the first to
15 last wire section.

During the sawing process, the forward feed device induces a mutually opposite relative movement of the wire sections and the workpiece. As a consequence of
20 this forward feed movement, the wire, on which a sawing suspension is applied, works through the workpiece to form parallel sawing kerfs. The sawing suspension, which is also referred to as slurry, contains hard material particles for example of silicon carbide,
25 which are suspended in a liquid. A sawing wire with firmly bound hard material particles may also be used. In this case, it is not necessary to apply a sawing suspension. It is merely necessary to supply a liquid cooling lubricant, which protects the wire and the
30 workpiece against overheating and at the same time transports workpiece swarf away from the cutting grooves.

The cylindrical workpieces, which are assembled to form

a compound rod, may consist of a material that can be processed by means of a wire saw, for example poly- or monocrystalline semiconductor material such as silicon. In the case of monocrystalline silicon, the workpieces
5 are generally produced by sawing an essentially cylindrical silicon single crystal into crystal pieces with a length of from several centimeters to several tens of centimeters. The minimum length of a crystal piece is generally 5 cm. The workpieces, for example
10 the crystal pieces consisting of silicon, generally have very different lengths but always the same cross section. The term "cylindrical" is not to be interpreted as meaning that the workpieces must have a circular cross section. Rather the workpieces may have
15 the shape of any generalized cylinder, although the application of the invention to workpieces with a cylindrical cross section is preferred. A generalized cylinder is a body which is bounded by a cylinder surface with a closed directrix curve and two parallel
20 planes, i.e. the base surfaces of the cylinder.

The compound rod is preferably fastened not directly on the mounting plate, but first on a so-called sawing strip or sawing support. The workpiece is generally
25 fastened on the sawing strip by adhesive bonding.

The mounting plate is clamped with the compound rod fixed thereon in a wire saw, and cut into wafers simultaneously and essentially perpendicularly to its
30 longitudinal axis.

The invention will be explained below with the aid of figures.

Fig. 1 schematically shows two workpieces **11** and **12** assembled to form a compound rod **1**, an adhesive joint **2**, a sawing strip **3** and a mounting plate **4**.

5 The workpieces **11** and **12** are assembled with a two-component adhesive to form a compound rod **1**. The fabrication accuracy of the end surfaces, on which the two workpieces are adhesively bonded together, allows the adhesive joint **2** to be selected as small as
10 possible.

The workpieces **11** and **12** assembled to form a compound rod **1** are cemented onto a sawing strip **3**.

The compound rod **1** comprising the two workpieces **11** and **12** and with the sawing strip **3** is fixed on a mounting
15 plate **4** and clamped in a wire saw.

Table 1 shows various comparative values of geometrical parameters for assembled rod pieces according to the prior art (column 2) and for compound rods according to
20 the invention (column 3).

Three values of three different quantile values are given for each parameter: thus, Wav_max 97.7% = 6.29 $\mu\text{m}/\text{mm}$ means that 97.7% of the wafers have a Wav_max of
25 56.29 $\mu\text{m}/\text{mm}$ or less, etc.

A significant improvement over the prior art is found for virtually all studied parameters and quantile values.

30

The geometry of the wafer in the saw's forward feed direction is determined, for example, by a scanning capacitive sensor pair. First, the difference of the front- and backside signals is taken. In order to

determine the waviness, a window with a length of 10 mm is passed over the evaluation curve thus obtained. The maximum deviation within the window generates a new value for the window center (rolling boxcar filtering).

- 5 The greatest deviation (peak-to-valley (PV)) within the entire scan over the wafer is the Waviness_max (Wav_max). The Waviness_in is determined in the same fashion, but only the first 50 mm of the scan (wire saw incision region) are considered (similarly to this:
10 Wav_out).

Bow and warp represent a measure of the deformation of the wafer. Warp is the sum of the maximum deviation (upward and downward) of the neutral fiber of the
15 entire wafer from a reference plane (three-dimensional).

Table 1

Tested Parameter (Minimum avg., Sigma)	Comparative examples (Prior art)	Results Compound Rod (Invention)
Wav_max 2.3%	5.13 $\mu\text{m}/\text{mm}$	2.80 $\mu\text{m}/\text{mm}$
Wav_max 50.0%	12.94 $\mu\text{m}/\text{mm}$	7.96 $\mu\text{m}/\text{mm}$
Wav_max 97.7%	56.29 $\mu\text{m}/\text{mm}$	22.73 $\mu\text{m}/\text{mm}$
Wav_in 2.3%	3.30 $\mu\text{m}/\text{mm}$	2.52 $\mu\text{m}/\text{mm}$
Wav_in 50.0%	11.72 $\mu\text{m}/\text{mm}$	4.44 $\mu\text{m}/\text{mm}$
Wav_in 97.7%	56.29 $\mu\text{m}/\text{mm}$	11.89 $\mu\text{m}/\text{mm}$
Wav_out 2.3%	2.87 $\mu\text{m}/\text{mm}$	1.52 $\mu\text{m}/\text{mm}$
Wav_out 50.0%	6.41 $\mu\text{m}/\text{mm}$	5.37 $\mu\text{m}/\text{mm}$
Wav_out 97.7%	17.23 $\mu\text{m}/\text{mm}$	22.66 $\mu\text{m}/\text{mm}$
GBIR 2.3%	13.19 μm	11.75 μm
GBIR 50.0%	16.10 μm	15.84 μm
GBIR 97.7%	45.28 μm	25.14 μm
LSR 2.3%	4.83 $\mu\text{m}/\text{mm}$	4.78 $\mu\text{m}/\text{mm}$
LSR 50.0%	13.09 $\mu\text{m}/\text{mm}$	7.81 $\mu\text{m}/\text{mm}$
LSR 97.7%	34.75 $\mu\text{m}/\text{mm}$	18.95 $\mu\text{m}/\text{mm}$
Bow/Warp 2.3%	-5.59 μm	-3.80 μm
Bow/Warp 50.0%	-1.65 μm	-1.64 μm
Bow/Warp 97.7%	1.96 μm	0.40 μm

Linear Shape Range (LSR) corresponds to the sum of the
5 maximum deviations of the neutral fiber of a scan in
the saw's forward feed direction from a straight
reference line (two-dimensional).

GBIR, formerly also referred to as TTV, corresponds to
10 the total thickness variance (difference between
thickness maximum and minimum).

For example, the measuring instrument MX 7012 (High
Resolution Thickness and Surface Profiler for as-sawn
15 Wafer) from E+H Eichhorn+Hausmann is suitable for
determining said geometrical parameters.

Also, the warp distribution (quantile values in %
against warp number in μm) of the cut wafers was

determined once for a single rod (not assembled from individual workpieces), a compound rod according to the invention and a rod assembled from workpieces according to the prior art (separated from one another, with
5 separating pieces). All the rods had the same length of 380 mm, the same crystal specification and the same orientation.

A significant improvement in the warp distribution is
10 found compared with the assembled workpieces in the prior art. This confirms that, during wire sawing, compound rods according to the invention do not behave like single rods assembled from workpieces.

15 For orders with a demanding warp specification, the invention therefore makes it possible to produce a multiplicity of wafers from compound rods, which have a relatively narrow distribution of the "warp" geometrical parameter at a comparatively low level.
20

Fig. 2 shows the distribution of the Wav_max parameter likewise for a rod assembled from two workpieces according to the prior art and a compound rod according to the invention, which is also assembled from two
25 workpieces but according to the invention these are separated from one another only by a fastening means (two-component adhesive). The Wav_max values are respectively represented for seven lots of workpiece A and workpiece B in the vicinity of the cementing
30 position of workpieces A and B. After the cutting, a lot comprises a plurality of wafers which are subsequently received in cassettes (wafer boxes) ("split lots"). The Wav_max value per wafer was determined for each lot. **5** shows the bonding position
35 or cementing position between the workpieces A and B

for the compound rod.

In the double rod according to the prior art, there is a distance between the lots A1 and B1. The workpieces
5 are not cemented together, rather they are cemented at a certain distance from one another on a sawing strip.

A significant jump in the Wav_max value is found between lots A1 and B1 for the double rod according to the prior art. Such a jump in the waviness does not
10 occur in the compound rod according to the invention after the sawing: the waviness values of lots A1 and B1 are virtually identical, which illustrates the advantage of the method according to the invention.

15 Lots (not represented in the figure) following lot B7 show higher Wav_max values. The higher quantile values indicated in **Table 1** are thereby also explained. Such a rise in the waviness, however, also occurs in single rods and is not a focus of attention in the scope of
20 this invention. **Fig. 2** relates only to the profile of the waviness in the region of the transition of workpiece A and workpiece B.

For orders with a demanding waviness specification, the
25 invention therefore makes it possible to produce a multiplicity of wafers from compound rods, which have a relatively narrow distribution of the "waviness" parameter (cf. **Table 1**), in particular while avoiding the jump observed in the prior art in the region of the
30 bonding position of the assembled workpieces, as shown in **Fig. 2**.

Patent Claims

1. Method for simultaneously cutting a compound rod of
5 semiconductor material into a multiplicity of wafers
by means of a wire saw, comprising the following
steps:
 - a) selecting at least two workpieces from a stock of
workpieces, which have been cut from one or more
10 semiconductor rods;
 - b) grinding at least one of the two end surfaces of
each rod;
 - c) cementing the at least two workpieces together on
their ground end surfaces by using a fastening means,
15 to produce a compound rod piece and fixing the
compound rod piece in the longitudinal direction on a
mounting plate, there respectively being only a
distance between the workpieces due to the fastening
means located between them;
 - 20 d) clamping the mounting plate with the compound rod
piece fixed thereon in the wire saw; and
 - e) cutting the compound rod perpendicularly to its
longitudinal axis by means of the wire saw.
- 25 2. Method according to Claim 1, wherein a workpiece is
cut in step a) with a wire saw or an internal hole
saw.
3. Method according to Claim 1 or 2, wherein workpieces
30 from neighboring rod positions of the same
semiconductor rod are cemented together.
4. Method according to one of Claims 1 to 3, wherein
exactly two workpieces are cemented together.

5. Method according to one of Claims 1 to 4, wherein the workpieces are cemented together while aligning the pulling edges (making them flush).
5
6. Method according to one of Claims 1 to 5, wherein the rod cemented together has a total length of less than or equal to 380 mm.
- 10 7. Method according to one of Claims 1 to 6, wherein the fastening means is an adhesive for cementing the at least two workpieces together.
- 15 8. Method according to Claim 7, wherein the fastening means is a two-component adhesive for cementing the at least two workpieces together.
- 20 9. Method according to one of Claims 1 to 8, wherein the compound rod is ground round before the wire sawing step according to e).
- 25 10. Method according to one of Claims 1 to 8, wherein the workpieces are already ground round before they are assembled to form the compound rod.
- 30 11. Method according to Claim 10, wherein the grinding of the end surfaces according to b) is not carried out, and the workpieces are assembled to form a compound rod before grinding them round, if the workpieces occupied neighboring rod positions in the original semiconductor rod.
12. Method according to one of Claims 1 to 11, wherein the two end surfaces of the workpieces are ground at

a defined angle setting with respect to the crystal lattice and orientation setting, so that the end surfaces of the workpieces are exactly parallel to one another.

5

13. Method according to one of Claims 1 to 12, wherein the workpieces are provided with a corresponding marking on the lateral surface for the purpose of material identification.

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14. Compound rod, containing at least two workpieces of semiconductor material bonded together on the parallel end surfaces, which behaves substantially as a single rod of semiconductor material, not assembled from workpieces, when being cut into a multiplicity of wafers by means of a wire saw, in particular with the distribution of the warp values of the wafers made from the compound rod differing only insubstantially from the warp values of the wafers obtained from a single rod.

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15. Compound rod according to Claim 14, wherein the Waviness_max parameter of the wafers cut from a first workpiece, in the region of the end surface cemented together with an end surface of a second workpiece, differs only insubstantially from the Waviness_max of the wafers cut from a second workpiece, likewise in the region of the end surface cemented together with the end surface of the first workpiece.

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16. Semiconductor wafer, cut from a compound rod according to Claim 14 or Claim 15 by means of a wire saw.