

RESIN-BOND WIRE SAW

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates to a resin-bond wire saw to be used for cutting of a silicon ingot and the like. In the resin-bond wire saw, abrasive grains are fixed to a wire with a resin bond (a resin adhesive). While a wire to be used for cutting is referred to as "a saw wire", the wire is herein referred to as "a wire saw."

BACKGROUND OF THE INVENTION

[0002] Conventionally, inner diameter blade dicers have been used for cutting silicon ingots. As a silicon ingot becomes larger, an inner diameter blade dicer has problems such as a decrease in productivity, generation of affected flow layers, a reduction in precision of cutting dimensions, and necessity of large equipment. Therefore, in recent years, cutting with a wire saw has become actively performed. Cutting with a wire saw is easy to deal with a silicon ingot having a large diameter. A plurality of wafers are obtainable in a single cutting work.

[0003] Wire saws include free abrasive grain wire saws and fixed abrasive grain wire saws. When a free abrasive grain wire saw is used, a wire such as a piano wire and an abrasive grain liquid, in which abrasive grains have been dispersed, are used. The abrasive grains include diamond particulates and silicon carbide particulates and the like.

The free abrasive grain wire saw causes the wire to travel while dropping the abrasive grain liquid in a cutting portion to perform cutting (JP 2008-103690 A). The free abrasive grain wire saw cuts an ingot by use of abrasive grains interposed between the wire and the ingot.

[0004] Since viscosity of the abrasive grain liquid fluctuates according to temperatures when using the free abrasive grain wire saw, there are irregular thicknesses of wafers or flatness of the wafers becomes deteriorated. The wire becomes worn by use of the abrasive grains when using the free abrasive grain wire saw, resulting in difficulty of using the thin wire. There are fears that an affected flow layer having a great thickness may be formed on a wafer surface when using the free abrasive grain wire saw.

[0005] To solve problems of the free abrasive grain wire saw, a fixed abrasive grain wire saw with abrasive grains fixed to a wire surface has been proposed. Methods for fixing abrasive grains to a wire surface include an electrodeposition method, a brazing method, and a resin-bonding method.

[0006] The electrodeposition method is performed by fixing abrasive grains to a wire surface by nickel plating and the like (For instance, JP 04-004105 B2, JP 2003-334763 A). The electrodeposition method is a method for embedding the abrasive grains in a nickel layer while precipitating nickel on a wire surface in a nickel plating liquid. In the electrodeposition method, the abrasive grains are

firmly fixed, resulting in excellent cutting performance of ingots.

[0007] In the electrodeposition method, the abrasive grains are deeply embedded in a plating layer. This method needs a plating film with a great thickness, resulting in low productivity and high cost. Since a wire has a great wire diameter due to a nickel plating layer, there is a possibility of the wire easily having a fatigue break.

[0008] In a brazing method, a brazing material layer is formed on a surface of a wire to embed the abrasive grains in the molten brazing material layer and the abrasive grains are fixed by the solidification of the brazing material layer (JP 2006-123024 A). When a brazing material has a high melting point, the wire is excessively heated at the time of melting the brazing material layer, resulting in lowered intensity of the wire. This makes it difficult to select a wire material in the brazing method. It is difficult to use a piano wire and a hard steel wire each having lower intensity at a low temperature and a stainless steel and a tungsten wire are used instead. Conversely, when the melting point of the brazing material is low, there are fears that heat of ablation at the time of cutting ingots may cause the brazing material to be melted and the abrasive grains to be lost.

[0009] In the resin bonding method, a mixture of a liquid resin bond (a resin adhesive) and abrasive grains is coated on a wire surface to be heated by a baking furnace (JP

2006-123024 A). The abrasive grains are fixed by the resin bond having cured by heating (JP 2000-263452 A, JP 2000-271872 A, and WO 98/35784). A hot-air drying system is known as a baking furnace (JP 09-035556 A, JP 2010-267533 A).

[0010] The resin bonding method is suitable for producing long wire saws at low prices. Since vibrations of a wire saw generated during cutting of ingots are absorbed by a soft resin bond, it is possible to cause the wire saw to travel at high speed in a stable condition. It is possible to obtain a thin wafer. On the one hand, a resin-bond wire saw has a low holding strength of the abrasive grains, so that the abrasive grains are easily lost one after another during cutting. When a thermally cured resin bond is used, it takes a long period of time to cure the resin bond, resulting in long production time of the wire saw. When the resin bond is cured at a high temperature, air bubbles are generated by a volatile component.

PRIOR ART DOCUMENTS

PATENT DOCUMENTS

- [0011] Patent document 1: JP 2008-103690 A
Patent document 2: JP 04-004105 B2
Patent document 3: JP 2003-334763 A
Patent document 4: JP 2006-123024 A
Patent document 5: JP 2000-263452 A
Patent document 6: JP 2000-271872 A

Patent document 7: WO 98/35784

Patent document 8: JP 09-035556 A

Patent document 9: JP 2010-267533 A

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0012] It is an object of the present invention to provide a long-life resin-bond wire saw having superior cutting performance.

MEANS FOR SOLVING THE PROBLEMS

[0013] The inventors of the present invention have found out that the object of the present invention has been achieved by 1) using a resin including a novolak-type phenol resin, a resol-type phenol resin, and an amine-based silane coupling agent as a resin bond; and 2) curing the resin bond by infrared-ray irradiation. According to the present invention, it has become possible to effectively produce a long-life resin-bond wire saw having superior cutting performance with few lost of abrasive grains.

[0014] The summary of the present invention is described as below.

According to the present invention, there is provided a resin-bond wire saw in which abrasive grains are fixed to a surface of a metal core wire with a resin bond containing a phenol resin as an essential component. In a resin included in the resin bond to be used in the present invention, a plurality of peaks that

represent fragments at intervals of 208 (m/z) are detected in cations by a MALDI-TOF-MS method (mass spectrometry). Further, a peak that corresponds to a softening point between 175°C and 182°C is detected by a Thermogravimetry and Differential Thermal Analysis (TG-DTA) method (MALDI: Matrix-Assisted Laser Desorption Ionization method, TOF-MS: Time-Of-Flight Mass Spectrometry method).

[0015] The resin bond to be used in the present invention includes: 100 parts by weight of a novolak-type phenol resin; 10 parts by weight to 30 parts by weight of a resol-type phenol resin; and 0.1 part by weight to 5 parts by weight of an amine-based silane coupling agent.

ADVANTAGES OF THE INVENTION

[0016] According to the present invention, a long-life resin bond wire saw having superior cutting performance is materialized.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017]

FIG. 1 is an explanatory view illustrating a method for heating a paste coated on a wire with infrared rays;

FIG. 2 shows energy spectral distribution;

FIG. 3 is a cation measurement chart of mass spectrometry using a MALDI-TOF-MS method (Comparative Example);

FIG. 4 is a cation measurement chart of mass spectrometry using the MALDI-TOF-MS method (Example 1);

FIG. 5 is an anion measurement chart of mass spectrometry using the MALDI-TOF-MS method (Comparative Example);

FIG. 6 is an anion measurement chart of mass spectrometry using the MLADI-TOF-MS method (Example 1); and

FIG. 7 is a differential thermal analysis chart of Example 1 and Comparative Example.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] In a resin-bond wire saw of the present invention, abrasive grains are fixed to a surface of a wire with a resin bond containing a novolak-type phenol resin, a resol-type phenol resin, and an amine-based silane coupling agent.

[0019] A novolak-type phenol resin is obtained by condensation reaction of phenol compounds such as phenol, cresol, bisphenol A, and aldehyde such as formaldehyde in the presence of an acid catalyst. A resol-type phenol resin is obtained by condensation reaction of a phenol compound such as phenol, cresol and bisphenol A, and an aldehyde such as formaldehyde in the presence of a basic catalyst.

[0020] The resin bond may further contain a curing agent. The resin bond preferably contains 5 parts by weight to 20 parts by weight of a curing agent relative to 100 parts by weight of a novolak-type phenol resin.

[0021] In the case where the curing agent is over 20 parts by weight relative to 100 parts by weight of the novolak-type phenol resin, a gas generated by the dissolution of the curing agent may cause bulges and cracks and the like. In the case where the curing agent is less than 5 parts by weight relative to 100 parts by weight of the novolak-type phenol resin and the compounding ratio of the resol-type phenol resin is small, there are fears that curing of novolak resins may be insufficient. In this case, although a resol-type phenol resin may be preferably added, it is further preferable to set the quantity of the curing agent to be compounded in the range of 5 parts by weight to 20 parts by weight. When the curing agent is added at the aforementioned ratio, the curing time for the paste described later is shorter.

[0022] Examples of the curing agent typically include hexamethylenetetramine, methylol melamine, methylol urea and the like. Among them, hexamethylenetetramine is preferable because the curing time thereof is short.

[0023] The resin bond may further contain 5 parts by weight to 15 parts by weight of a phenol compound such as phenol, cresol, and bisphenol A. The resin bond may further contain 1 part by weight or smaller of aldehyde such as formaldehyde. The resin bond may furthermore contain a small amount of a basic catalyst and water.

[0024] Since the resin bond contains 10 parts by weight to 30 parts by weight of a resol-type phenol resin relative to

100 parts by weight of a novolak-type phenol resin, it is possible to form a dense three-dimensional mesh structure by cross-linking. This makes it possible to realize firm joining between the resin bond and the abrasive grains. When the resol-type phenol resin is over 30 parts by weight relative to 100 parts by weight of the novolak-type phenol resin, viscosity of the paste becomes too low, resulting in difficulty in coating the paste on the wire. When the resol-type phenol resin is less than 10 parts by weight relative to 100 parts by weight of the novolak-type phenol resin, the curing speed of the resin bond becomes slower. This makes it difficult to cure the paste in a short period of time, resulting in slower production speed of the resin-bond wire saw.

[0025] When 0.1 part by weight to 5 parts by weight of an amine-based silane coupling agent is contained relative to 100 parts by weight of the novolak-type phenol resin, the adhesive strength between the resin bond and the wire increases. When the compounding ratio of the amine-based silane coupling agent is less than 0.1 part by weight relative to 100 parts by weight of the novolak-type phenol resin, it is not possible to expect an increase in adhesion. When over 5 parts by weight of the amine-based silane coupling agent is contained relative to 100 parts by weight of the novolak-type phenol resin, the curing of the novolak-type phenol resin is affected.

[0026] Examples of the amine-based silane coupling agent

include 3-aminopropyltrimethoxysilane, N-2-(aminoethyl)-3-aminopropyltrimethoxysilane, N-2-(aminoethyl)-3-aminopropylmethyldimethoxysilane, 3-aminopropyltriethoxysilane and the like.

[0027] The resin bond comprises: 100 parts by weight of the novolak-type phenol resin; 10 parts by weight to 30 parts by weight of the resol-type phenol resin; and 0.1 part by weight to 5 parts by weight of the amine-based silane coupling agent. The use of such a resin bond enables to obtain a long-life resin-bond wire saw with superior cutting performance.

[0028] A method for producing a resin-bond wire saw of the present invention includes the steps of: (a) preparing a paste (including a resin bond, a solvent, abrasive grains, and a filler); (b) preparing a wire; (c) coating the paste on a surface of the wire; and (d) heating the coated paste with infrared rays to be cured.

[0029] The resin bond is rapidly dehydrated and condensed by heating with infrared rays to form a dense three-dimensional cross-linking structure.

[0030] A traveling wire is coated with a paste by a dispenser method or a floating dice method and the like. The coating quantity of the paste is set so that the degree of concentration of the abrasive grains may be 50 to 120. The degree of concentration of the abrasive grains is a percentage of an area of the abrasive grains that occupies a projected area of a surface of the wire. In this

specification, when the projected area of the abrasive grains that accounts for the total projected area is 15%, the degree of concentration is set at 100. For instance, when the projected area of the abrasive grains that accounts for the total projected area is 30%, the degree of concentration is set at 200. And when the projected area of the abrasive grains that accounts for the total projected area is 7.5%, the degree of concentration is set at 50.

[0031] The viscosity of the paste is set at 3 Pa.s to 6 Pa.s by adding a solvent to the resin bond. The solvent volume is preferably set in the range of 100 parts by weight to 200 parts by weight relative to 100 parts by weight of the resin bond. While the solvent is not particularly limited, o-cresol having a low boiling point is preferable in view of reactivity.

[0032] Since the abrasive grains are not particularly limited, diamond abrasive grains, cubic boron nitride abrasive grains, alumina abrasive grains, and silicon carbide abrasive grains are used.

[0033] Among them, diamond abrasive grains have extremely high thermal conductivity, so that temperatures rapidly rise also in a shadow portion of irradiation to the abrasive grains when heating by infrared rays. This makes it possible to uniformly cure the resin bond, which is preferable to use the diamond abrasive grains. While the size of the abrasive grains is selected according to the

purpose or according to the diameter of the wire, the size of the abrasive grains is preferably some μm to 25 μm from a point of a cut of a silicone ingot having less cutting allowance. The diamond abrasive grains coated with a metal film such as nickel or titanium are also preferable as the abrasive grains. The diamond abrasive grains coated with a copper film are, however, not preferable because a copper atom reduces the efficiency of silicon solar cells. The resin-bond wire saw using diamond abrasive grains coated with a nickel film has fewer warps and saw marks of silicon wafers that have been cut than an electrodeposition wire saw.

[0034] It is preferable that the abrasive grains are appropriately dispersed on the surface of the wire to avoid clogging caused by silicon wastes created. It is preferable to contain 50 parts by weight to 120 parts by weight of the abrasive grains relative to 100 parts by weight of the resin bond.

[0035] A steel wire is preferably used as a wire. While the wire diameter of the steel wire is not particularly limited, the wire diameter is preferably 0.05 mm ϕ to 0.3 mm ϕ . Preferable examples of the steel wire include a wire rod obtained by thermally treated spring steel such as high-carbon steel and medium carbon low-alloy steel, a wire rod created by processed spring steel such as a hard steel wire, a piano wire, a stainless wire, a cold-rolled steel wire or an oil temper wire, a low alloy steel, a medium

alloy steel, high alloy steel, a steel wire rod with high-toughness and high fatigue strength such as maraging steel. [0036] A wire coated with a paste is heated by infrared rays while causing the coated wire to travel. This allows the paste to be cured. When the wire is heated by hot air with a conventional enamel furnace and the like, thermal curing occurs from a surface of the paste. As a result, water generated by reaction is trapped inside the paste, which may lead to generation of air bubbles. In contrast, when the paste is heated by infrared rays, near-infrared rays having a wavelength of about 1 μm are efficiently absorbed in water. This enables completion of cross-linking polymerization in a short period of time. When the paste is heated by infrared rays, water is evaporated in a short period of time. As a result, air bubbles are not easily generated in the paste. The infrared rays preferably have at least one spectrum peak in a band of the near-infrared rays each having a wavelength of 0.7 μm to 2.5 μm . The near-infrared rays each having a wavelength of about 1 μm (0.9 μm to 1.3 μm) are particularly preferable to inhibit air bubbles associated with evaporation of generated water.

[0037] According to infrared heating, curing reaction proceeds at higher speed than heating by hot air to obtain a uniform superstructure. As a result, a plurality of peaks that represent fragments at intervals of 208 (m/z) in cations are detected using the MALDI-TOF-MS method (mass

spectrometry). And a clear peak corresponding to a softening point is detected by the differential thermal analysis (DTA) method at 175°C to 182°C. The temperatures of the peak differ a little depending on the rate of temperature rise at the time of the differential thermal analysis. The peak in the differential thermal analysis reflects the uniform superstructure along with the peaks that represent the fragments at intervals of 208 (m/z). Such a uniform superstructure allows to increase hardness of the resin bond so that the abrasive grains may be firmly held. This makes it possible to obtain a resin-bond wire saw with superior cutting performance.

[0038] FIG. 1 is an explanatory view that illustrates heating a wire coated with a paste by infrared rays. In a method shown in FIG. 1, a half-cylindrical concave mirror 2 and a linear-shaped infrared ray heater 4 arranged in a longitudinal direction of the concave mirror 2 are used. The paste causes a wire 3 coated with the paste to travel in the longitudinal direction of the concave mirror 2 (an orthogonal direction to a paper surface). Infrared rays emitted from the infrared ray heater 4 are caused to reflect on a reflecting surface 8 to be focused in a collecting portion 6 (heating zone) in a size of about 10 mmφ. A plurality of concave mirrors 2 and a plurality of infrared ray heaters 4 may be arranged so as to surround a travel route of the wire 3.

[0039] The length of the collecting portion 6 is decided

according to the size and the number of the plurality of infrared ray heaters 4 and the plurality of concave mirrors 2. The wire 3 coated with the paste is caused to travel to heat the paste with infrared rays. The length of the collecting portion 6 may be typically 400 mm to 1,000 mm. To make the collecting portion 6 longer, the plurality of infrared ray heaters 4 may be arranged in series with a travelling direction (vertical direction to a paper surface) of the wire 3.

[0040] An infrared ray lamp having a peak in a near-infrared ray region is preferably used as an infrared ray heater 4. Examples of the infrared ray lamp to be used typically include a Short-arc Xenon Lamp and a lamp in which a tungsten filament is contained in a quartz glass tube.

[0041] It is difficult to measure the temperature of the wire 3 travelling the collecting portion 6. As a result of noting that breaking strength of the wire 3 decreases by heating, a heating temperature is set so as to secure 95% of the breaking strength before heating. Experimentally, when the temperature of the collecting portion 6 was measured by a sheath-type thermocouple having a diameter of 1 mm, the temperature was 500°C to 800°C. It is possible to cure the resin bond without foaming by causing the wire to travel at a rate of 1,000 mm/sec to 2,000 mm/sec using the infrared ray heater shown in FIG. 1.

[0042] As a method for infrared heating, a method for

irradiating infrared lasers may be used.

[0043] A filler made of inorganic particles is contained in the paste. The filler has effects to inhibit thermal expansion and heat shrinkage of the resin bond to decrease the loss of abrasive grains during cutting of ingots. 20 parts by weight to 100 parts by weight of the filler is preferably contained relative to 100 parts by weight of the resin bond. 30 parts by weight to 60 parts by weight of the filler is further preferably contained. While particulates of diamonds each having a size of about 2 μm to 3 μm may be suitable as filler, other inorganic materials (for example, silicon carbide particles) may also be used.

[0044] Stable performance is obtained when reheating the resin-bond wire saw treated with infrared heating. Reheating makes it possible to remove thermal strain that has occurred on the wire and the paste at the time of infrared heating. There is little change in breaking stress of the resin-bond wire saw and molecular structure of the resin bond by reheating.

[0045] Reheating is preferably performed at 100°C to 200°C for 1 hour to 5 hours. Even when it takes time to reheat, there is no possibility of productivity of the resin-bond wire saw being significantly lowered because it is possible to reheat a great number of bobbins with the resin-bond wire saw wound at one time. It is possible to obtain high productivity of the resin-bond wire saw by a combination of

infrared heating and reheating of the resin-bond wire saw.

[0046] The resin-bond wire saw of the present invention has a slit depth greater than the slit depth of a conventional resin-bond wire saw. This slit depth is a slit depth at the time when a test piece is cut and a wire saw is broken. The breaking of the wire saw is mainly evoked by the loss of abrasive grains. The resin-bond wire saw of the present invention has a higher fixing strength of the abrasive grains than the conventional resin-bond wire saw and thus has a slit depth greater than the slit depth of the conventional resin-bond wire saw.

[0047] The resin-bond wire saw of the present invention is at least 25% superior to the conventional resin-bond wire saw in warping, swell, and total thickness variation (TTV) of wafers. Compared with the conventional resin-bond wire saw, the resin-bond wire saw of the present invention makes it possible to obtain wafers having values of surface roughness (R_a , R_y) about 20% smaller. According to the resin-bond wire saw of the present invention, it is possible to obtain wafers having few affected flow layers on a surface of each of the wafers. The resin-bond wire saw of the present invention makes it possible to obtain wafers each having a high bending strength.

EXAMPLES

[0048] Cutting performance of a resin-bond wire saw of the present invention is verified by the experiments below.

[0049] A paste having following components was adjusted using a resin bond having the following components to produce a resin-bond wire saw employing the following production lines:

[0050] [Example 1]

(1) Compounding ratio of a resin bond

A novolak-type phenol resin (Product name: Shonol BRP-5417; produced by Showa Denko K.K.): 80 parts by weight	(Composition) 86 weight % of novolak-type phenol resin; 5 weight % of phenol; 9 weight % of hexamethylenetetramine
A resol-type phenol resin (Product name: Shonol BRL-131; produced by Showa Denko K.K.): 20 parts by weight	(Composition) 80 weight % of resol-type phenol resin; 5.9 weight % of phenol; 0.6 weight % of formaldehyde; 1.2 weight % of NaOH; 12.2 weight % of moisture; 0.1 weight % of other auxiliary agent
An amine-based silane coupling agent (Product name: Sila-Ace S330; produced by JNC Corporation): 1 part by weight	

(2) Compounding ratio of a paste

A resin bond: 100 parts by weight
Diamond abrasive grains coated with nickel (average particle diameter: 10 μm to 20 μm): 80 parts by weight
A filler (silicon carbide powder; #8000): 50 parts by weight
A solvent (o-cresol): 150 parts by weight

(3) Production lines of resin-bond wire saws

(a) Outline of the lines

Wire feeder→ coating equipment→ heating apparatus→
winder→ reheating furnace

(b) Wire feeder: Equipment configured to feed a wire wound to bobbins

(c) Coating equipment: a paste was homogeneously applied to a surface of the wire by a dice in the shape of a water jet.

(d) Heating apparatus: an apparatus configured to heat the wire coated with a paste. Three infrared gold image furnaces, model No. RHL-E410-N (heating length: 265 mm, maximum output: 4kw) produced by Ulvac-Riko, Inc. were used in series. FIG. 2 shows energy spectral distribution of a lamp.

(e) Winder: a winder configured to wind up the resin-bond wire saw to the bobbins.

(f) Reheating furnace: a convection-type heating furnace configured to heat the resin-bond wire saw wound up to the bobbins with a winder.

(4) Materials and production conditions

(a) Wire: a piano wire (wire diameter: 120 μm , breaking strength: about 42N)

(b) Travelling rate of wire: 1,200 mm/sec.

(c) Amount of coating of paste: 0.01 g/m

(d) Temperatures of the infrared gold image furnaces: 720°C to 750°C (thermocouple measurement)

(The temperatures where the resin-bond wire saw has a breaking strength of not less than 40N.)

(e) Temperature and time in a reheating furnace: 180°C, 2 hours

[0051][Example 2]

(1) Compounding ratio of the resin bond

A novolak-type phenol resin (Product name: Shonol BRP-5417; produced by Showa Denko K.K.): 85 parts by weight	(Composition) 86 weight % of novolak-type phenol resin; 5 weight % of phenol; 9 weight % of hexamethylenetetramine
A resol-type phenol resin (Product name: Shonol BRL-131; produced by Showa Denko K.K.): 15 parts by weight	(Composition) 80 weight % of resol-type phenol resin; 5.9 weight % of phenol; 0.6 weight % of formaldehyde; 1.2 weight % of NaOH; 12.2 weight % of moisture; 0.1 weight % of other auxiliary agent
An amine-based silane coupling agent (Product name: Sila-Ace S330; produced by JNC Corporation): 1 part by weight	

(2) Compounding ratio of the paste

A resin bond: 100 parts by weight
Diamond abrasive grains coated with nickel (average particle diameter: 10 μm to 20 μm): 80 parts by weight
A filler (silicon carbide powder; #8000): 50 parts by weight
A solvent (o-cresol): 170 parts by weight

A resin-bond wire saw was produced in the same manner as in Example 1 except for the above.

[0052] [Comparative Example]

A novolak-type phenol resin (produced by SUMITOMO BAKELITE CO., LTD.) available in the market was used as a resin bond and a vertical-type enamel baking furnace was used as a heating apparatus. The vertical-type enamel baking furnace heated a wire using heated air circulating within a furnace core tube. A heating element of the furnace was a nichrome wire. Heating was performed by the vertical-type enamel baking furnace at the temperature of 300°C for 20 minutes of heating time. A resin-bond wire saw was obtained in the same manner as in Example 1 except for the above.

[0053] Slit depths of resin-bond wire saws obtained in Examples 1 and 2 were compared with a slit depth of a resin-bond wire saw obtained in Comparative Example.

(1) Test method for slit depths

A multi-crystal silicon piece having a size of 1 cm × 1 cm × 2 mm was set upward a resin-bond wire saw that was horizontally pulled to move downward to measure slit depths. Downward speed of the piece: 0.9 mm/min.

(2) Cutting conditions

Resin-bond wire movement: amplitude 80 mm, speed: reciprocating motion of 400 mm/min.

(3) Cutting time: until breaking

[0054] Table 1 shows results of a slit depth test. Table 2 shows abrasive grain residual ratios of wires after the test.

[0055] [Table 1]

Samples	Example 1	Example 2	Comparative Example
Slit depths (mm)	11.0	11.0	6.5

[Table 2]

Samples	Example 1	Comparative Example
Abrasive grain residual ratios (%)	92	50

As shown in Table 1, slit depths of the resin-bond wire saws obtained in Examples 1 and 2 are about 1.7 times as great as a slit depth of the resin-bond wire saw obtained in Comparative Example. As shown in Table 2, the abrasive grain residual ratio of the resin-bond wire saw in Example 1 is about 1.8 times as great as the abrasive grain residual ratio of the resin-bond wire saw in Comparative Example.

[0056] The hardness of the resin bond was investigated to investigate a reason for such a difference. Case 1: The resin bond used in Example 1 was cured by heating. Heating conditions: The heating temperature of the resin bond increased from the room temperature to 180°C at 15°C/hour and the temperature was kept at 180°C for 2 hours.

Case 2: The novolak-type phenol resin used in Comparative

Example was cured by heating under the same heating conditions as in case 1.

[0057] The Rockwell hardness of a cured product obtained was measured using a hardness tester (ATK-F3000; 1/4" use of a steel ball, Load: 100 kgf) produced by Akashi Seisakusho. Table 3 shows results of Rockwell hardness.

[0058] [Table 3]

Samples	Case 1	Case 2
Rockwell hardness (HRM)	111.6	109.7

As shown in Table 3, the resin bond in Example 1 has a higher hardness than the resin bond in Comparative Example. This is one of reasons why the slit depth of the resin-bond wire saw of the present invention is great.

[0059] [Analysis]

The network molecular structures and physical properties of the resin bond in Example 1 and the resin bond in Comparative Example were investigated.

[0060] Mass spectrometry was performed by the MALDI-TOF-MS method (MALDI: Matrix-Assisted Laser Desorption Ionization method, TOF-MS: Time-Of-Flight Mass Spectrometry method).

Used equipment: AXIMA-CFR⁺ (Produced by Shimadzu Corporation)

Analysis mode: Linear mode (cations, anions detected)

Degree of vacuum: 10⁻⁵ Pa or smaller

Matrix: 2,5-dihydroxybenzoic acid

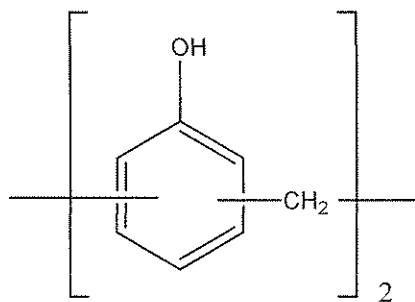
Laser wavelength: 337 nm (nitrogen laser)

[0061] FIGS. 3 to 6 show measurement charts of mass

spectrometry by the MALDI-TOF-MS method. FIG. 3 is a cation detection chart of the resin bond in Comparative Example. FIG. 4 is a cation detection chart of the resin bond in Example 1. FIG. 5 is an anion detection chart of the resin bond in Comparative Example. FIG. 6 is an anion detection chart of the resin bond in Example 1.

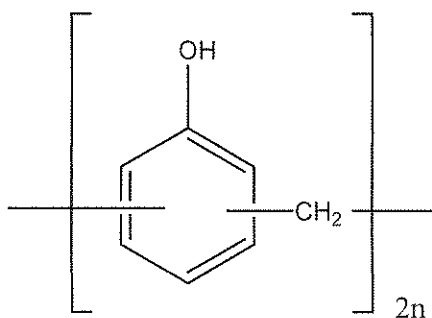
[0062] Peaks (arrows) that represent fragments at intervals of 208 (m/z) are seen in FIG. 4 (Example 1). It is presumed that the fragments at intervals of 208 (m/z) were generated as a result of cleavage (fragmentation) of cross-linking in four portions including aromatic rings in the following structural formula (structural unit; C₁₄H₁₂O₂: molecular weight: 212).

[0063][Chemical formula 1]



This indicates that the following structure is regularly aligned in a network molecular structure as repetitive fragments in the resin bond in Example 1.

[0064] [Chemical formula 2]



(n is a natural number)

In FIG. 3, FIG. 5, and FIG. 6, no peaks (arrows) that represent fragments at regular intervals were detected. Accordingly, it is assumed that there is no structure indicating Chemical formula 1 in the resin bond in Comparative Example.

[0065] From the aforementioned results regarding FIGS. 3 to 6, it is assumed that the molecular structure representing fragments at intervals of 208 (m/z) was generated by heating the resin bond with infrared rays.

[0066] FIG. 7 is a differential thermal analysis chart of the resin bond in Example 1 and the resin bond in Comparative Example.

Used apparatus: TG8120 (Rigaku)

Rate of temperature rise: 10°C/min.

Atmosphere: N₂ gas flow

Certified reference material: Alumina (Al₂O₃)

Sample weight: about 10 mg

[0067] In the chart of the resin bond in Example 1 shown in FIG. 7, a clear peak of a softening point can be seen at 175°C to 182°C. In contrast, in the resin bond in

Comparative Example, only a peak of an unclear softening point can be seen at about 190°C. Since the superstructure in the resin bond in Comparative Example is not uniform, no transition with a structural change occurs. Accordingly, it is assumed that no peak of a clear softening point can be seen. The resin bond in Example 1 has a superstructure composed of fragments at intervals of 208 (m/z), so that the hardness is considered to be high. The reason why the hardness of the resin bond in Comparative Example is low is assumed that the superstructure is not uniform.

INDUSTRIAL APPLICABILITY

[0068] The use of the resin-bond wire saw of the present invention makes it possible to effectively cut wafers of high quality from silicon ingots.

CLAIMS

1. A resin-bond wire saw in which abrasive grains are fixed to a surface of a metal core wire with a resin bond including a phenol resin as an essential component,

the resin-bond wire saw being characterized in that a resin included in the resin bond shows a plurality of peaks that represent fragments at intervals of 208 (m/z) in cations by mass spectrometry using a Matrix-Assisted Laser Desorption Ionization-Time Of Flight Mass Spectrometry method, and

the resin bond shows a peak that corresponds to a softening point around 180°C by differential thermal analysis using a Thermogravimetry and Differential Thermal Analysis method.

2. The resin-bond wire saw according to claim 1, wherein a resin included in the resin bond is a composition essentially consisting of: 100 parts by weight of a novolak-type phenol resin; 10 parts by weight to 30 parts by weight of a resol-type phenol resin; and 0.1 part by weight to 5 parts by weight of an amine-based silane coupling agent.

ABSTRACT OF THE DISCLOSURE

A resin-bond wire saw in which abrasive grains are fixed to a surface of a wire with a resin bond containing a novolak-type phenol resin, a resol-type phenol resin, and an amine-based silane coupling agent. The resin bond shows a plurality of peaks at intervals of 208 (m/z) that represent fragments in cations in Matrix-Assisted Laser Desorption Ionization-Time Of Flight-Mass Spectrometry (mass spectrometry) and a peak that corresponds to a softening point at 175°C to 182°C in Thermogravimetry and Differential Thermal Analysis (differential thermal analysis).

[Selected drawing] FIG. 4