

LASER WELDING METHOD FOR DIAMOND WIRE AND SYSTEM

[0001] The present disclosure belongs to the technical field of diamond wire welding, and particularly relates to a laser welding method for a diamond wire and a system.

BACKGROUND

[0002] In the production process of single crystal silicon wafers, silicon rods are subjected to accelerating and decelerating forward and reverse cutting through multi-wire diamond wire gauze. In the cutting process, thanks to reasons such as machines, electric appliances, process parameters, and a matching degree of an electrically controlled software system, diamond wires often break. After the diamond wires break, workers need to weld or replace the diamond wires.

[0003] Current diamond wire welding methods include:

[0004] electric resistance welding, which is presently the common welding manner in the industry; this welding process has the defects of low welding success rate, long welding time, poor welding appearance, and low tensile strength, and these defects greatly affect the efficiency and yield of silicon wafer production; and

[0005] braze welding, which is a welding method of heating a brazing filler metal with a melting point lower than that of a weldment and a weldment to a melting temperature of the brazing filler metal and filling a gap of a solid workpiece with a liquid brazing filler metal to connect metals. Braze welding features small deformations and smooth and beautiful joints. After welding, the tensile strength of the weld seam is relatively low, and the weld seam is liable to breakage again, which affects subsequent use.

[0006] Regardless of the welding manners, a manual welding operation is needed in the whole course, so that the degree of automation is low. Moreover, the welding method is unreliable and low in efficiency. The welding position is low in tensile strength.

SUMMARY

[0007] To overcome defects in the prior art, an object of the present disclosure is to provide a laser welding method for a diamond wire and a system to overcome deficiencies in the prior art that a broken diamond wire cannot be welded with high quality and high efficiency.

[0008] In a first aspect, the present disclosure provides a laser welding method for a diamond wire, including:

[0009] positioning two ends of a broken wire to make the two ends opposite to each other;

[0010] cutting and cleaning sections of the two ends;

[0011] collecting pictures of the two ends, detecting and calculating concentricity of the two ends, and controlling the two ends to adjust positions automatically by a visual detection module to make the two ends concentric;

[0012] aligning a target heating light spot of a laser generation module to a molten pool part formed by the two ends and confined space around the two ends, and starting laser heating welding;

[0013] monitoring a real-time temperature and a real-time crystalline phase of the molten pool part, adjusting heating power of the laser generation module according to the real-time temperature, judging whether a matching degree between a real-time crystalline phase image and a target crystalline phase image is greater than a first threshold, and if the matching degree between the real-time crystalline phase image and the target crystalline phase image is greater than the first threshold, stopping welding; and

[0014] polishing a weld seam and performing annealing to complete welding.

[0015] In some embodiments, when laser heating welding is performed, the target heating light spot is aligned to the molten pool part to melt and gasify a metal to form a heated hole; whether a steam pressure in the heated hole and surface tension and gravity of a liquid metal achieve balance is judged by using the visual detection module; and if the steam pressure in the heated hole and the surface tension and gravity of the liquid metal achieve balance, the target heating light spot is controlled to move in welding directions of the two ends to form the weld seam.

[0016] In some embodiments, the molten pool part is monitored by using a near-infrared thermal imaging module to obtain a near-infrared image and a thermal imaging image, a parameter of a duty cycle of switching of the laser generation module is determined according to a gray level of the near-infrared image and a heat distribution coefficient of the thermal imaging image, and the heating power of the laser generation module is adjusted according to the parameter of a duty cycle of switching.

[0017] In some embodiments, a welding cycle is divided into a plurality of stages; based on diamond wires made from different materials, for each of the stages, a gray level constant of the corresponding near-infrared image and a heat distribution coefficient constant of the corresponding

thermal imaging image are determined; and the corresponding parameter of a duty cycle of switching is set to perform staged welding on the two ends of the broken wire.

[0018] In some embodiments, the laser generation module is a picosecond laser generator that performs the staged welding on the two ends of the broken wire by using a laser with a wavelength of 600-700 nm.

[0019] In some embodiments, target crystalline phase images are set respectively for the diamond wires made from different materials and with different specifications; and each of the target crystalline phase images is configured as a crystalline phase image obtained by selecting a diamond wire, aligning the target heating light spot of the laser generation module to a local part of the diamond wire, and collecting an image after the steam pressure and the surface tension and gravity of the liquid metal achieve balance at the local part and the diamond wire is heated in a radial direction.

[0020] In some embodiments, the two ends of the broken wire are placed on a magnetic platform provided with a V-shaped groove; the broken wire is pressed by a press block from top to bottom, and the ends of the broken wire stretch out of the magnetic platform at a set stretching distance; and a pressure F applied to the pressure block through an air cylinder is less than $[78500 \cdot N / (\cos a/2)] - (m_1 + m) \cdot g$, wherein the mass of the pressure block is m , the mass of the broken wire in contact with a unit area of the magnetic platform is m_1 , an included angle of the V-shaped groove in the magnetic platform is a , and the quantity of diamond particles on a contact surface between the broken wire and the magnetic platform is N .

[0021] In some embodiments, when the sections of the two ends are cut, a double-edged ring cutting tool is used, and a shear force is applied inward simultaneously in a radial direction of a certain section of the broken wire to form a welding section perpendicular to an axial center line of the broken wire at each of the ends.

[0022] In some embodiments, when the weld seam is polished, the weld seam formed on the molten pool part is wrapped by using a polishing mechanism, carborundum is embedded into a contact surface between the polishing mechanism and the weld seam, and the polishing mechanism is controlled to perform a high hertz micro-amplitude alternating frequency vibration to eliminate surface bubbles and impurities in the weld seam.

[0023] In a second aspect, the present disclosure provides a welding system applied to the above laser welding method for a diamond wire, including:

[0024] a positioning mechanism, configured to position two ends of a broken wire to make the two ends opposite to each other;

[0025] a cutting mechanism, configured to cut sections of the two ends;

[0026] a cleaning mechanism, configured to clean the two ends;

[0027] a visual detection module, configured to collect pictures of the two ends, detect and calculate concentricity of the two ends, and control the positioning mechanism to drive the two ends to adjust positions automatically to make the two ends concentric;

[0028] a laser generation module, configured to generate a target heating light spot aligning to a molten pool part formed by the two ends and confined space around the two ends, and start laser heating welding;

[0029] a detection module, configured to monitor a real-time temperature and a real-time crystalline phase of the molten pool part, adjust heating power of the laser generation module according to the real-time temperature, judge whether a matching degree between a real-time crystalline phase image and a target crystalline phase image is greater than a first threshold, and if the matching degree between the real-time crystalline phase image and the target crystalline phase image is greater than the first threshold, control the laser generation module to stop welding; and

[0030] a polishing mechanism, configured to polish the weld seam; and

[0031] an annealing mechanism, configured to anneal the welded and polished broken wire.

[0032] Compared with the prior art, the present disclosure at least has the following beneficial effects:

[0033] When the two ends of the broken wire are positioned, the pictures of the two ends are collected by using the visual detection module, and the two ends are controlled to adjust the positions automatically triaxially to ensure the concentricity; the target heating light spot is aligned to the molten pool part, so that the matching degree between the real-time crystalline phase image formed on the molten pool part and the target crystalline phase image is greater than the first threshold; by way of automatic control and detection, the welding process is completed; and finally, polishing and annealing are performed to complete welding; the welding method features a high degree of automation; moreover, the welding method, performing laser welding by using the laser generation module, is high in heating speed and efficiency; and the welding method realizes precise automatic welding by judging the crystalline phase image.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] The present invention is further described by utilizing drawings, and the embodiments in the drawings do not constitute a limitation to the present invention. Those of ordinary skill in the art further may obtain other drawings according to the drawings without making creative efforts.

[0035] FIG. 1 is a schematic diagram of a flow of a laser welding method for a diamond wire in an embodiment.

[0036] FIG. 2 is a schematic diagram of a flow of laser heating welding in an embodiment.

[0037] FIG. 3 is a schematic structural diagram of a positioning mechanism in an embodiment.

[0038] FIG. 4 is a schematic diagram where a press block presses a broken wire on a V-shaped groove of a magnetic platform in an embodiment.

[0039] FIG. 5 is a schematic structural diagram of an annealing mechanism in an embodiment.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0040] The technical solutions of the present disclosure will be described below clearly and completely in conjunction with the drawings. Apparently, the described embodiments are merely some of, rather than all of, the embodiments of the present disclosure. Based on the embodiments in the present disclosure, all other embodiments obtained by persons of ordinary skill in the art without making creative efforts fall within the protection scope of the present disclosure.

[0041] In the description of the present disclosure, it shall be noted that orientation or position relations indicated by the terms “central”, “upper”, “lower”, “left”, “right”, “vertical”, “horizontal”, “inner”, “outer”, etc. are based on orientation or position relations shown in the drawings, and are merely for facilitating the description of the present disclosure and simplifying the description, rather than indicating or implying the device or element referred to must have a specific orientation or be constructed and operated in a specific orientation, and therefore, they will not be interpreted as limiting the present disclosure. In addition, the terms “first”, “second” and “third” are for descriptive purposes only and shall not be construed as indicating or implying relative importance.

[0042] In the description of the present disclosure, in a case that a special device located between a first device and a second device is described, an intermediary device may or may not exist between the special device and the first device or the second device. In a case that the special device connected to other devices is described, the special device may be directly connected to the other devices without the intermediary device or may not be directly connected to the other devices with the intermediary device.

[0043] Techniques, methods, and devices known to persons of ordinary skill in the related art may not be discussed in detail. But in a proper circumstance, the techniques, methods, and devices shall be regarded as a part of the description.

[0044] It is found by the applicant(s) through research that when the diamond wire breaks, it is usually welded by way of electric resistance welding or braze welding in the prior art. The two manners have the problem of manual welding, and are low in welding efficiency, poor in consistency, and low in degree of automation. Affected by various welding factors, the quality of the welded diamond wire is poor, and the cutting performance is reduced remarkably. Particularly, with respect to high carbon steel with the carbon content between 0.92% and 0.98% or tungsten steel, thanks to poor plasticity, the above high carbon steel is easy to crack, so that the welding performance is poor. The melting point of the diamond wire made from the tungsten steel is above 2850°C, and a welding requirement cannot be met by a common welding machine.

[0045] In view of this, referring to FIG. 1, in a first aspect, an embodiment of the present disclosure provides a laser welding method for a diamond wire, including:

[0046] two ends of a broken wire are positioned to make the two ends opposite to each other, where the two ends are spaced apart at a certain distance;

[0047] sections of the two ends are cut, respectively, to make the two sections have the same sectional area, and the two ends are cleaned to remove oxidation films and oil stains on surfaces of the two ends;

[0048] pictures of the two ends are collected, the concentricity of the two ends is detected and calculated, and the two ends are controlled to adjust positions automatically by a visual detection module to make the two ends concentric; it shall be noted that the two ends of the broken wire are fixed by the positioning mechanism, respectively, and the positioning mechanism has a triaxial servo centering function and may align with the sections of the ends automatically according to a detection and calculation result of the concentricity;

[0049] the target heating light spot of the laser generation module is aligned to the molten pool part formed by the two ends and confined space around the two ends, and laser heating welding is started; it shall be noted that prior to the laser heating welding, as the two ends are spaced apart, when welding is started, the two ends are irradiated first by the target heating light spot, and besides the sections of the two ends, the target heating light spot further covers a section of line behind the

sections; and under laser heating of the target heating light spot, the molten pool part formed by the two ends and confined space around the two ends starts to be heated and melted;

[0050] a real-time temperature and a real-time crystalline phase of the molten pool part are monitored, heating power of the laser generation module is adjusted according to the real-time temperature, the temperature of the molten pool part is controlled to be higher than the melting point of a wire rod, whether a matching degree between a real-time crystalline phase image and a target crystalline phase image is greater than a first threshold is judged, and if the matching degree between the real-time crystalline phase image and the target crystalline phase image is greater than the first threshold, welding is stopped; specifically, the target crystalline phase image is tested in advance, broken wires made from different diamond wire materials and with different specifications are welded respectively by combining a plurality of groups of laser frequency parameters and power parameters to obtain a plurality of groups of diamond wire welding heads, each of groups of the diamond wire welding heads is subjected to a strength test, and the optimum target crystalline phase image and the corresponding welding control parameters are determined for each material and specification; in the welding process, the corresponding welding control parameters are set according to specific diamond wire materials and specifications, the matching degree between the real-time crystalline phase image and the target crystalline phase image is calculated, only when the matching degree is greater than the first threshold, can penetration of the molten pool part be judged, an ideal crystalline phase state is achieved, and welding is stopped; and

[0051] a weld seam at a welding point of the welded diamond wire is polished and annealing is performed to complete welding.

[0052] The laser welding method in the above embodiment changes the conventional manual welding manner by means of visual detection and automatic control, and realizes automatic welding, thereby improving the welding efficiency.

[0053] Referring to FIG. 2, as an implementation, when laser heating welding is performed, the target heating light spot is aligned to the molten pool part to melt and gasify a metal to form a heated hole; in the process, a liquid metal outside a wall of the heated hole flows, and surface tension of a wall layer and a steam pressure continuously produced in a cavity of the heated hole are definitely sustained and keep dynamic balance; as light beams enter the heated hole

continuously, the metal material outside the heated hole is kept flowing continuously; and in a balanced state, the heated hole is in a stable state of flowing all the time;

[0054] Therefore, whether the steam pressure in the heated hole and surface tension and gravity of the liquid metal achieve balance is judged by using the visual detection module. Whether the state of the heated hole is kept stable, whether the overall size is not expanded, and whether the metal material outside the heated hole is kept flowing continuously are judged. If so, it is judged that the current heated hole is balanced, and the target heating light spot is controlled to move in the welding directions of the two ends. With the movement of the light beam, the heated hole is in a stable state of flowing all the time, that is to say, the heated hole and the molten metal around the wall of the heated hole move with the moving direction of the target heating light spot. The molten metal fills the gap reserved after the heated hole moves to form the weld seam.

[0055] The laser welding manner in the embodiment features a higher depth of fusion and a greater depth-to-width ratio, compensates the welding characteristic of the high carbon steel through heat stress generated by more concentration and less heat energy to improve the welding success rate of the high carbon steel diamond wire greatly, shorten the welding time of the high carbon steel diamond wire and reduce the dependence on the welding skill of personnel during high carbon steel diamond wire welding, and improves the degree of automation effectively. In addition, by means of this welding manner, the high energy density characteristic of laser may accord with welding of the tungsten steel diamond wire with a melting temperature above 2850°C.

[0056] As an implementation, when the real-time crystalline phase of the molten pool part is monitored, collecting the real-time crystalline phase image of the molten pool part and performing clustering analysis on the real-time crystalline phase image by using the scanning electron microscope confirms two results:

[0057] the first result is a result obtained based on solid-state crystalline phase clustering, where primary clustering is performed through distribution positions of solid-state crystalline phases and structural feature clustering is performed for the primary clustering result to obtain the first result;

[0058] the second result is a result obtained based on liquid-state crystalline phase clustering, where primary clustering is performed through distribution positions of liquid-state crystalline phases and structural feature clustering is performed for the primary clustering result to obtain the second result;

[0059] crystal distribution feature extraction is performed for the first result to obtain solid-state crystalline phase position feature information;

[0060] crystal distribution feature extraction is performed for the second result to obtain liquid state crystalline phase position feature information;

[0061] the solid state crystalline phase position feature and the liquid-state crystalline phase position feature represent position distribution information of the solid-state crystalline phases and the liquid-state crystalline phases in the real-time crystalline phase image, and a first proportion of the liquid-state crystalline phase distribution area in the real-time crystalline phase image is calculated;

[0062] in a similar way, with respect to the material and specification of the specific diamond wire, the target crystalline phase image is obtained according to the preset optimum welding control parameters, and the above clustering analysis is performed to obtain a second proportion of the liquid state crystalline phase distribution area in the target crystalline phase image is obtained as well;

[0063] By way of automatic detection and judgment, only when the ratio of the first proportion to the second proportion is greater than the first threshold, preferably, the first threshold is 98%, can a situation that the molten pool part of the diamond wire has been penetrated in the actual laser welding be verified, thus, welding can be stopped.

[0064] It shall be noted that as the major component in the diamond wire is silicon with partial carbon or tungsten, prior to laser heating, various components exist in the form of a solid state. After the diamond wire is subjected to laser heating to be melted, the components exist in the form of a liquid state. There is a difference of structural feature between solid-state and liquid-state crystalline phases, so that clustering analysis may be performed. Preferably, the above is clustering analysis on silicon element.

[0065] Therefore, in the embodiment, after the target heating light spot is aligned to the molten pool part, the image of the molten pool part is collected first by using the visual detection module, whether the steam pressure in the heated hole and the surface tension and gravity of the liquid metal achieve balance is judged, and if the steam pressure in the heated hole and the surface tension and gravity of the liquid metal achieve balance, the target heating light spot is then moved to form the weld seam; then, the real-time crystalline phase image of the molten pool part is collected by using the scanning electron microscope, clustering analysis on the real-time crystalline phase

image at least including a part of weld seam is performed, the first proportion of the liquid state crystalline phase distribution area in the real-time crystalline phase image is calculated and is compared with the second proportion of the liquid state crystalline phase distribution area in the target crystalline phase image, and when the ratio of the first proportion to the second proportion is greater than 98%, it is verified that the molten pool part of the diamond wire has been penetrated, the liquid state crystalline phase distribution is relatively ideal, and after welding is stopped and cooling is performed, a good weld seam quality can be achieved.

[0066] Preferably, target crystalline phase images are set respectively for the diamond wires made from different materials and with different specifications; and each of the target crystalline phase images is obtained by the following steps: a selected diamond wire made from a specific material and with a specific specification is selected; the target heating light spot of the laser generation module is aligned to a local part of the diamond wire; it shall be noted that the local part is an integral local part on the diamond wire; the metal is melted and gasified on the local part to form the heated hole; the heated hole is observed by using the visual detection module, the diamond wire is heated in the radial direction when the steam pressure and the surface tension and gravity of the liquid metal achieve balance to form a weld seam; and the crystalline phase image of the weld seam is collected by using the scanning electron microscope to obtain the target crystalline phase image.

[0067] The reason why an integral local part is selected on the diamond wire for welding is that the laser welding does not need to increase the welding material additionally but only needs to fuse two strands of raw materials after the raw materials at the two ends of the broken wire are melted. To improve the welding quality, it is compared with the weld seam formed on the integral diamond wire after laser heating. It may be guaranteed that after the broken wire is welded, the related physical parameters of the diamond wire are still kept meeting a single crystal silicon wafer cutting process, and the tensile strength of the welding position reaches the level of the original diamond wire basically.

[0068] Because the target crystalline phase image has been determined in advance according to the specific specification of the diamond wire, the target crystalline phase image includes the liquid state silicon crystalline distribution area and the ideal structural feature. By way of image comparison, the ratio of the liquid state crystalline phase distribution area therein is judged. In addition to manual reexamination with naked eyes, after confirmation, welding is stopped.

[0069] As an implementation, in the welding process, the molten pool part is monitored by using a near-infrared imaging module to obtain a near-infrared image and a thermal imaging image; the near-infrared image and the thermal imaging image are transmitted to an imaging processing module for processing to obtain a grey level of the near-infrared image and a heat distribution coefficient of the thermal imaging image; the grey level and the heat distribution coefficient are analyzed and processed to judge that where the heat distribution in the molten pool part is uneven; for the area where the heat is centralized, heating power of the laser generation module is reduced by adjusting a parameter of a duty cycle of switching of the laser generation module; for the area insufficient in heat, heating power of the laser generation module is increased by adjusting the parameter of a duty cycle of switching of the laser generation module, so that the total power of the diamond wire in the welding process is kept at a relatively stable level, which guarantees the quality consistency of the weld seam.

[0070] As an implementation, a welding cycle is divided into a plurality of stages; based on diamond wires made from different materials, for each of the stages, a gray level constant of the corresponding near-infrared image and a heat distribution coefficient constant of the corresponding thermal imaging image are determined; and the corresponding parameter of a duty cycle of switching is set to perform staged welding on the two ends of the broken wire.

[0071] The welding cycle may include five welding stages: pre-heating, cleaning, welding, tempering, and thermal refining. Based on the diamond wire made from a specific material and with a specific specification, for each of the welding stages, the group of parameters with the best welding quality is obtained as the optimum welding control parameters through multi-group tests by setting the preset welding control parameters in advance, and the optimum laser welding power is determined for each of the stages to obtain the corresponding parameter of a duty cycle of switching; additionally, the ideal grey level constant of the near-infrared image and the ideal heat distribution coefficient constant of the thermal imaging image in each of the stages may be determined by testing the five welding stages in advance, and the grey level constant and the heat distribution coefficient constant are compared with those of the near-infrared image and the thermal imaging image obtained by using the near-infrared thermal imaging module in the welding process to achieve precise heating control in the plurality of welding stages.

[0072] Optionally, the laser generation module is a picosecond laser generator that performs the staged welding on the two ends of the broken wire by using a laser with a wavelength of 600-700 nm.

[0073] With respect to the five welding stages: pre-heating, cleaning, welding, tempering, and thermal refining, welding with adaptive laser is performed according to demands on heat and temperature rise. For example, in the pre-heating stage where the demand on heat is not high, laser with a lower efficiency and a lower energy density may be emitted; in the welding stage where the demand on heat is high and rapid temperature rise is required, a laser with a higher frequency and a higher energy density may be emitted; and in the tempering and thermal refining stages where relatively stable heat needs to be kept, the welding quality is finely adjusted, and laser with a higher frequency and a moderate energy density may be emitted.

[0074] Through the above laser adjusting function, different laser frequencies and energy densities may be switched automatically according to the welding stages in a programmed preset manner, so that the refined control of welding is improved. Moreover, through the staged laser welding control, the appearance and diameter consistency of the welded diamond wire may be improved. Without the addition of extra welding materials, to achieve immediate use after welding, it is particularly important to control the welding process. In the tempering stage, the diameter of the weld seam may be adjusted with the laser with a higher frequency and a moderate energy density, so that the outer diameter is kept consistent basically.

[0075] In the welding process, the requirement for fixing stability at the two ends of the broken wire is very high. If the two ends are loose in position in the welding process, the welding quality will be affected, which directly results in the inconsistency of appearance and diameter of the diamond wire. Therefore, to solve the problem, in the embodiment, the two ends of the broken wire are placed on the magnetic platform provided with the V-shaped groove. It shall be noted that the topmost end of the broken wire still exceeds the top of the V-shaped groove. Then the broken wire is pressed from top to bottom by using the press block. The press block is made from polyurethane and presses toward the broken wire perpendicularly to guarantee that the pressed diamond wire is evenly stressed as much as possible to prevent the diamond wire subjected to oblique stress from performing a circular motion around the center, so as to reduce the tensile strength of the diamond wire. Moreover, the polyurethane press block applies a reasonable pressure value to the diamond wire and has a reasonable hardness value to guarantee that diamond

particles on the diamond wire will not pierce into the polyurethane body and the press block will not crush the diamond particles when the press block positions the diamond wire.

[0076] The ends of the broken wire stretch out of the magnetic platform at a set stretching distance. Preferably, the stretching distance of the diamond wire is a set value, which is 1.5-2 times the diameter thereof. Moreover, in the welding process, thanks to a high carbon content and impurities of the diamond wire, a phenomenon of volatilization will occur and the diamond wire is needed to feed and fill. Therefore, the magnetic platform may move horizontally under the action of the triaxial servo centering mechanism. When laser welding is performed, the target heating light spot is aligned to the molten pool part formed by the two ends and confined space around the molten pool part, and after the molten pool part starts to melt, the two ends of the broken wire move oppositely and contact each other to achieve better fusion. A servo motor in the triaxial servo centering mechanism is in a quantitative feed manner, so that the diamond wire stretches forward.

[0077] In the process, to control the broken wire effectively to prevent the broken line from shifting or rotating, it is set that

[0078] the mass of the press block is m ;

[0079] the included angle of the V-shaped groove in the magnetic platform is a ;

[0080] two bevels of the V-shaped groove are subjected to vertical pressures F_1 and F_2 , respectively;

[0081] it is assumed that the diamond particles are cylinders with a diameter of 0.005 mm;

[0082] the mass of the broken wire in contact with the unit area of the magnetic platform is m_1 ;

[0083] the pressure applied by the air cylinder to the press block is F ;

[0084] it is set that the compressive strength of the diamond is 2000 Mpa;

[0085] it is set that there are N diamond particles on the contact surface;

[0086] formulae are as follows:

[0087] $[(m_1+m)*g+F]*1/2*\cos a/2=F_1=F_2$

[0088] $[(m_1+m)*g+F]*1/2*\cos a/(N*\pi*0.00000625)<2000\text{Mpa}$

[0089] Finally, the pressure F applied by the air cylinder to the press block is less than $[78500*N/(\cos a/2)]-(m_1+m)*g$.

[0090] Only when the pressure F applied by the air cylinder to the press block satisfies the above formulae, can the diamond particles not be crushed, and an effective pressing force is kept to prevent the diamond wire from twisting and shifting.

[0091] Additionally, the welding strength of the diamond wire is in direct proportion to the welding area and the welding quality of the molten pool. Therefore, in the welding process, it is extremely important to guarantee the concentricity of the two end surfaces of the diamond wire. The relative depth of parallelism of the sections of the two ends, the sections, and the flatness of the edges of the sections decide the welding quality of the weld seam. A conventional manner is to cut by using a straight edge. Thus, the obtained diamond wire is easily subjected to deformations, including easy crimping of the edges of the sections, bevels of the sections, straight lines of the sections, and the like. The welding quality of the diamond wire cut under such a condition cannot be guaranteed.

[0092] Therefore, in the embodiment, when the sections of the two ends are cut, the double-edged ring cutting tool is used to apply a shear force inward in the radial direction of a certain section of the broken wire simultaneously, which guarantees that the outer diameter at the cut of the diamond wire is evenly and simultaneously stressed in the cutting process. Under the action of the even radial force, a stress crack is generated along the section, and finally, the diamond wire is cut off at the ends of the diamond wires along the perpendicular section to form the welding section perpendicular to the axial center line of the broken wire, which guarantees the degree of parallelism of the welding sections of the two ends and the flatness of the edges of the sections, thereby further guaranteeing that the sections are better fused during welding and improving the welding quality.

[0093] As an implementation, when the weld seam is polished, the weld seam formed on the molten pool part is wrapped by using a polishing mechanism, carborundum is embedded into a contact surface between the polishing mechanism and the weld seam, and the polishing mechanism is controlled to perform a high hertz micro-amplitude alternating frequency vibration to eliminate surface bubbles and impurities in the weld seam.

[0094] Because the diameter consistency of the broken wire has been high after laser welding, the outer diameter of the weld seam is slightly greater than that of the diamond wire, and in this case, an accurate grinding manner may be directly used. The grinding mechanism is controlled to perform a micro-amplitude alternating frequency vibration at a high frequency of 30-50 khz/s for accurate grinding directly with the embedded carborundum. Moreover, at the high frequency, it may be guaranteed that the appearance quality of the diamond wire is in a better state, thereby achieving a low defective occurrence rate in a silicon wafer cutting process in the later stage.

[0095] Referring to FIGs. 3-5, in a second aspect, an embodiment of the present disclosure provides a welding system applied to the above laser welding method for a diamond wire, including:

[0096] positioning mechanisms 11, configured to position ends 10 of a broken wire to make the two ends opposite to each other, each of the positioning mechanisms 11 including a magnetic platform 20 provided with a V-shaped groove 21, a press block 22, and a triaxial servo centering mechanism, where the press block 22 presses the broken wire on the V-shaped groove 21 of the magnetic platform 20, the triaxial servo centering mechanism controls the magnetic platform 20 and the press block 22 to move synchronously to achieve centering and diamond wire feeding; as shown in FIG. 3, the single positioning mechanism 11 fixes one of the ends 10 of the broken wire, and to complete laser welding of the diamond wire, two positioning mechanisms 11 are needed to position the two ends, respectively, to make the two ends opposite to each other;

[0097] a cutting mechanism, configured to cut sections of the two ends, respectively, where the cutting mechanism is a double-edged ring cutting tool, and each of the ends of the diamond wire is cut off along a perpendicular section to form a welding section perpendicular to an axial center line of the broken wire at each of the ends;

[0098] a cleaning mechanism, configured to clean the two ends, respectively, where oil grease on the surface of the broken wire is dissolved by way of spraying alcohol to remove oxidization films and oil stains on the ends of the broken wire, so as to prevent air holes and slag inclusions in the welding process;

[0099] a visual detection module, configured to collect pictures of the two ends, detect and calculate concentricity of the two ends, and control the positioning mechanism to drive the two ends to adjust positions automatically to make the two ends concentric;

[00100] a laser generation module, configured to generate a target heating light spot aligning to a molten pool part formed by the two ends and confined space around the two ends, and start laser heating welding, where, preferably, the laser generation module is a picosecond laser generator that performs the staged welding on the two ends of the broken wire by using a laser with a wavelength of 600-700 nm;

[00101] a detection module, configured to monitor a real-time temperature and a real-time crystalline phase of the molten pool part, adjust heating power of the laser generation module according to the real-time temperature, judge whether a matching degree between a real-time

crystalline phase image and a target crystalline phase image is greater than a first threshold, and if the matching degree between the real-time crystalline phase image and the target crystalline phase image is greater than the first threshold, control the laser generation module to stop welding, where the detection module includes a scanning electron microscope, a near-infrared thermal imaging module, and a processing module, the scanning electron microscope collecting the real-time crystalline phase image of the molten pool part, the processing module performing clustering analysis on the real-time crystalline phase image to judge whether the matching degree between the real-time crystalline phase image and the target crystalline phase image is greater than the first threshold, and the near-infrared thermal imaging module monitoring the molten pool part to obtain a near-infrared image and a thermal imaging image, transmitting the near-infrared image and the thermal imaging image to the processing module to process, processing the near-infrared image and the thermal imaging image to obtain a grey level of the near-infrared image and a heat distribution coefficient of the thermal imaging image, determining a parameter of a duty cycle of switching of the laser generation module, and adjusting heating power of the laser generation module according to the parameter of a duty cycle of switching;

[00102] a polishing mechanism, configured to polish a weld seam, where the polishing mechanism wraps the weld seam formed on the molten pool part, carborundum is embedded into a contact surface between the polishing mechanism and the weld seam, and the polishing mechanism is controlled to perform a high hertz micro-amplitude alternating frequency vibration to eliminate surface bubbles and impurities in the weld seam; and

[00103] an annealing mechanism, configured to anneal the welded and polished broken line, where a lot of heat will be generated in the welding process of the diamond broken wire; after welding, in the room temperature cooling process, some heat energy cannot be released, resulting in that the molten pool part and a heat effect area of the molten pool part generate heat stress, so that the tensile strength of materials in the molten pool part and the heat effect area of the molten pool part is reduced; as shown in FIG. 5, in the annealing mechanism, the diamond wire is clamped and suspended by using a clamping apparatus 31, a heating electrode 32 of the annealing mechanism is in contact with both ends of the molten pool part, the heating electrode 32 is a low resistance alloy conductor that heats and anneals the molten pool part and the heat effect area of the molten pool part, and an insulating material 33 is outside the heating electrode 32 to prevent electric shock.

[00104] Compared with the prior art, the present disclosure provides a laser welding method for a diamond wire and a system. When the two ends of the broken wire are positioned, the pictures of the two ends are collected by using the visual detection module, and the two ends are controlled to adjust the positions automatically triaxially to ensure the concentricity; the target heating light spot is aligned to the molten pool part, so that the matching degree between the real-time crystalline phase image formed on the molten pool part and the target crystalline phase image is greater than the first threshold; by way of automatic control and detection, the welding process is completed; and finally, polishing and annealing are performed to complete welding; the welding method features a high degree of automation; moreover, the welding method, performing laser welding by using the laser generation module, is high in heating speed and efficiency; and the welding method realizes precise automatic welding by judging the crystalline phase image.

[00105] It shall be finally noted that the present disclosure is not limited to the above implementations. The above is merely the preferred embodiments of the present disclosure and is not used to limit the present disclosure. Any modification, equivalent replacement, improvement, etc. made within the spirit and principle of the present disclosure shall be regarded as within the protection scope of the present disclosure.

CLAIMS

What is claimed is:

1. A laser welding method for a diamond wire, comprising:
positioning two ends of a broken wire to make the two ends opposite to each other;
cutting and cleaning sections of the two ends;
collecting pictures of the two ends, detecting and calculating concentricity of the two ends,
and controlling the two ends to adjust positions automatically by a visual detection module to make the two ends concentric;
aligning a target heating light spot of a laser generation module to a molten pool part formed by the two ends and confined space around the two ends, and starting laser heating welding;
monitoring a real-time temperature and a real-time crystalline phase of the molten pool part, adjusting heating power of the laser generation module according to the real-time temperature, judging whether a matching degree between a real-time crystalline phase image and a target crystalline phase image is greater than a first threshold, and if the matching degree between the real-time crystalline phase image and the target crystalline phase image is greater than the first threshold, stopping welding; and
polishing a weld seam and performing annealing to complete welding.
2. The laser welding method for a diamond wire according to claim 1, wherein when laser heating welding is performed, the target heating light spot is aligned to the molten pool part to melt and gasify a metal to form a heated hole; whether a steam pressure in the heated hole and surface tension and gravity of a liquid metal achieve balance is judged by using the visual detection module; and if the steam pressure in the heated hole and the surface tension and gravity of the liquid metal achieve balance, the target heating light spot is controlled to move in welding directions of the two ends to form the weld seam.
3. The laser welding method for a diamond wire according to claim 2, wherein the molten pool part is monitored by using a near-infrared thermal imaging module to obtain a near-infrared image and a thermal imaging image, a parameter of a duty cycle of switching of the laser generation module is determined according to a gray level of the near-infrared image and a heat distribution coefficient of the thermal imaging image, and the heating power of the laser generation module is adjusted according to the parameter of a duty cycle of switching.

4. The laser welding method for a diamond wire according to claim 3, wherein a welding cycle is divided into a plurality of stages; based on diamond wires made from different materials, for each of the stages, a gray level constant of the corresponding near-infrared image and a heat distribution coefficient constant of the corresponding thermal imaging image are determined; and the corresponding parameter of a duty cycle of switching is set to perform staged welding on the two ends of the broken wire.

5. The laser welding method for a diamond wire according to claim 4, wherein the laser generation module is a picosecond laser generator that performs the staged welding on the two ends of the broken wire by using a laser with a wavelength of 600-700 nm.

6. The laser welding method for a diamond wire according to claim 5, wherein target crystalline phase images are set respectively for the diamond wires made from different materials and with different specifications; and each of the target crystalline phase images is configured as a crystalline phase image obtained by selecting a diamond wire, aligning the target heating light spot of the laser generation module to a local part of the diamond wire, and collecting an image after the local part achieves balance between the steam pressure and the surface tension and gravity of the liquid metal and is heated in a radial direction.

7. The laser welding method for a diamond wire according to any one of claims 1-6, wherein the two ends of the broken wire are placed on a magnetic platform provided with a V-shaped groove; the broken wire is pressed by a press block from top to bottom, and the ends of the broken wire stretch out of the magnetic platform at a set stretching distance; and a pressure F applied to the pressure block through an air cylinder is less than $[78500 \cdot N / (\cos a/2)] - (m_1 + m) \cdot g$, wherein the mass of the pressure block is m , the mass of the broken wire in contact with a unit area of the magnetic platform is m_1 , an included angle of the V-shaped groove in the magnetic platform is a , and the quantity of diamond particles on a contact surface between the broken wire and the magnetic platform is N .

8. The laser welding method for a diamond wire according to claim 7, wherein when the sections of the two ends are cut, a double-edged ring cutting tool is used, and a shear force is applied inward simultaneously in a radial direction of a certain section of the broken wire to form a welding section perpendicular to an axial center line of the broken wire at each of the ends.

9. The laser welding method for a diamond wire according to claim 8, wherein when the weld seam is polished, the weld seam formed on the molten pool part is wrapped by using a polishing

mechanism, carborundum is embedded into a contact surface between the polishing mechanism and the weld seam, and the polishing mechanism is controlled to perform a high hertz micro-amplitude alternating frequency vibration to eliminate surface bubbles and impurities in the weld seam.

10. A welding system applied to the laser welding method for a diamond wire according to any one of claims 1-9, comprising:

- a positioning mechanism, configured to position two ends of a broken wire to make the two ends opposite to each other;

- a cutting mechanism, configured to cut sections of the two ends;

- a cleaning mechanism, configured to clean the two ends;

- a visual detection module, configured to collect pictures of the two ends, detect and calculate concentricity of the two ends, and control the positioning mechanism to drive the two ends to adjust positions automatically to make the two ends concentric;

- a laser generation module, configured to generate a target heating light spot aligning to a molten pool part formed by the two ends and confined space around the two ends, and start laser heating welding;

- a detection module, configured to monitor a real-time temperature and a real-time crystalline phase of the molten pool part, adjust heating power of the laser generation module according to the real-time temperature, judge whether a matching degree between a real-time crystalline phase image and a target crystalline phase image is greater than a first threshold, and if the matching degree between the real-time crystalline phase image and the target crystalline phase image is greater than the first threshold, control the laser generation module to stop welding; and

- a polishing mechanism, configured to polish the weld seam; and

- an annealing mechanism, configured to anneal the welded and polished broken wire.