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APPARATUS FOR HOLDING ELECTRICALLY NON-CONDUCTIVE MATERIAL AND IMPROVING ELECTRON BEAM CUTTING THEREOF

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Fig.1.

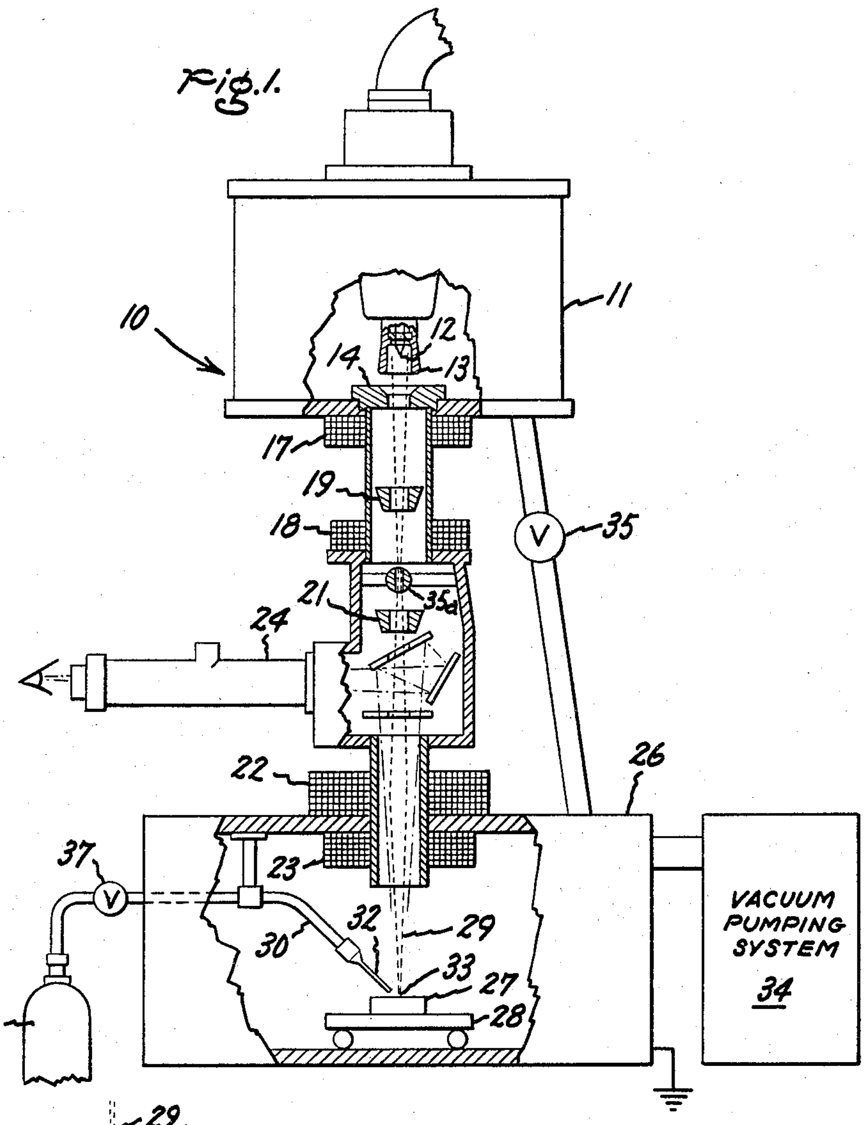
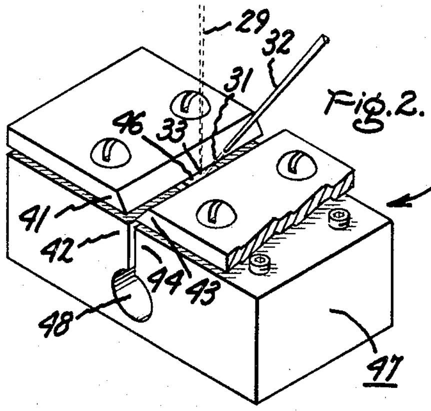


Fig.2.



Inventors:
Peter Cannon,
William R. Grams,
William L. Mowrey,
by Leo I. MaLossi
Their Attorney.

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APPARATUS FOR HOLDING ELECTRICALLY NON-CONDUCTIVE MATERIAL AND IMPROVING ELECTRON BEAM CUTTING THEREOF

Peter Cannon, Alplaus, William R. Grams, Ballston Spa, and William L. Mowrey, Scotia, N.Y., assignors to General Electric Company, a corporation of New York

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ABSTRACT OF THE DISCLOSURE

An apparatus is described for controlled cutting or drilling of a hard non-conducting material such as, for example, diamond by the use of a high energy beam of electrons focused in a vacuum work chamber. The workpiece is supported and enclosed by an adjustable vise member made of a metal having a high rate of thermal and electrical conductivity. The vise includes a cavity within a base portion thereof which serves as an effective electron-trapping cage. A very small expansion nozzle is mounted in the work chamber for accurately impinging flow of an appropriate gas upon the focal point of the electron beam upon the workpiece.

This invention relates to improvements in apparatus for and a method of cutting and drilling hard materials by electron beam techniques, and more specifically to the cutting of diamond crystals at greatly increased rates employing apparatus of simplified construction.

Various methods have been devised for machining diamonds, i.e. cleaving, bruting, sawing and scaife grinding as well as electron beam cutting. It is well known that much time and patience are required for diamond shaping by the earlier well-known processes and it is also known that the complicated and expensive apparatus proposed to date for the electron beam cutting of diamonds have prevented the latter method from acquiring commercial acceptance.

It is therefore a primary object of this invention to provide simplified apparatus for cutting a hard crystal under the combined effects of electron beam impact and gas impingement whereby wide variations in gas materials and concentration, beam current and potential are readily available for cutting various very hard materials with maximum effectiveness.

It is another object of this invention to provide an apparatus for and method of cutting a diamond crystal enabling the use of greatly simplified and less expensive equipment and yet at commercially attractive cutting rates.

It is another object of this invention to provide a novel vise for holding a nonconducting crystal for the cutting thereof by the use of an electron beam.

The aforementioned and other objects are provided in the practice of this invention by using an apparatus comprising in combination an electron emitter, electron optics and control means for focusing a stream of electrons from said emitter, a working chamber within which the stream of electrons from the electron emitter is focused on the workpiece, a single vacuum pumping system, a very small expansion nozzle having a large length/area ratio mounted in said chamber for accurately impinging a flow of an appropriate gas upon the point of focus on said workpiece and a vise construction having particular thermal and electrical properties for holding the workpiece during the cutting operation.

The practice of this invention is particularly well illustrated by the employment thereof to cut diamond material either as single crystal or as polycrystalline masses.

In the case of diamond-cutting the preferred gas for impingement is oxygen although carbon dioxide will also readily oxidize diamond at higher temperatures. In those instances in which it is proposed to cut other very hard materials by this method it may easily be determined whether some particular gas will be effective for accelerating the cutting action either as a decomposition catalyst or simply to accelerate gasification of the material in the cutting region. If no such advantageous action is afforded by any known gas such a jet of gas will at least serve to blow away the debris engendered by the electron beam during cutting.

The exact nature of this invention as well as other objects and advantages thereof will be readily apparent from consideration of the following specification relating to the annexed drawing in which:

FIG. 1 is a vertical cross section of one form of the electron beam generating device that may be used in the practice of this invention together with the gas lance and vise combined therewith in accordance with this invention; and

FIG. 2 is an isometric view of a preferred embodiment of a vise constructed in accordance with this invention showing in greater detail the simultaneous superimposition of the very fine stream of gas upon the impact area of the electron beam on the workpiece.

Electrons to effect the cutting action in the practice of this invention may be provided by an electron beam welder, such as a Hamilton-Zeiss electron beam welder No. ES-1002-A as manufactured by Hamilton-Electrona, Inc. Such an electron beam welding apparatus **10** is represented schematically in FIG. 1 and is ordinarily used commercially to join together materials such as refractory metals, ceramics, dissimilar metals, steels, aluminum, etc. utilizing a high energy density focused beam of electrons.

In essence, the electron gun **11** consists of a cathode, heated tungsten filament **12**, an electrostatic beam collimating electrode or grid **13** and apertured anode **14**. Cathode **12** is the source of electrons and is supplied with heating current from a filament voltage supply, not shown. An accelerating voltage is supplied to cathode **12** from a source, not shown of adjustable high negative direct current voltage. The anode **14** is connected to the casing of electron beam welder **10**, which is grounded. The difference in potential between cathode **12** and anode **14** causes electrons emitted from the cathode to be accelerated through anode **14** as shown by the dotted lines. Control electrode **13** is normally maintained at a voltage, which is more negative than the voltage applied to cathode **12**. The magnitude of this bias, or voltage difference, controls the beam current in the same manner as the grid in an ordinary vacuum tube controls triode plate current.

The electron optics of the embodiment shown herein consist of adjustment coils **17** and **18**, tungsten diaphragms **19** and **21**, the main electromagnetic focusing lens **22** and coil **23** for electron beam deflection.

Preferably, focusing of the electron beam by means of the electron optics system enables concentration of the electron beam at its focal point in a very small spot having a diameter of approximately 0.010 inch at maximum power and less than 0.005 inch at lower powers. An optical viewing system **24** is provided for convenience of the operator.

The focal point of the high energy density electron beam is produced in work chamber **26** at some point at which the workpiece being cut is located for the cutting action. For purposes of this invention the workpiece is held in the vise **27** resting upon table **28**. Table **28** preferably is movable both in the longitudinal and transverse directions and may also be provided with a tilting, rotary motion. The mechanisms required for moving table **28** from outside the work chamber **26** are not shown, because such means are conventional.

In accordance with this invention vise **27** is of special construction as shown in FIG. 2. To enable coaction with the electron beam **29** the micro-stream gas lance **30** is mounted within chamber **26** so that a very fine gas stream **31** emitted from needle-like point **32** impinges exactly upon the focal point **33** of electron beam **29**.

The entire internal volume of electron beam welder **10** is kept under vacuum by means of the vacuum pumping system **34**, generally comprising a mechanical pump (not shown) connected in series with a high-speed oil diffusion pump (not shown). Preferably a vacuum shut-off valve **35** is provided in a conduit interconnecting work chamber **26** and electron gun **11** in addition to ball valve **35*a*** in the column of welder **10** whereby electron gun **11** can be isolated while the work chamber is open to the atmosphere. The high voltage power supply, the auxiliary power supply and the control apparatus for both the vacuum exhaust system and the electrical system are conventional and are not shown in the interest of simplicity.

The gas to be impinged upon the impact area of the electron beam will be of particular value, if it actually chemically or catalytically promotes the cutting action. In the case of the cutting of diamonds, oxygen is preferred because it is effective at about 300° C., while carbon dioxide oxidizes diamond at about 1200° C. The gas under pressure is admitted to the system from tank **36** with the admitting pressure being controlled by metering valve **37**. Although it is not shown in the drawing, work chamber **26** will ordinarily have a viewing window to enable the operator to observe the process being conducted within work chamber **26**.

Steigerwald U.S. 2,793,281 (FIG. 9) discloses apparatus for the drilling of holes in diamond crystals by the use of a high energy density focused beam of electrons in an oxygen atmosphere with the oxygen being admitted to occupy the entire chamber wherein the electron stream impinges upon the diamond crystal workpiece. Unfortunately, however, the apparatus disclosed requires the use of a multi-chambered vacuum vessel with the entire vacuum vessel requiring a series of at least three exhaust (vacuum pumping) systems in order to differentially pump the several chambers thereof. Such construction involves considerable initial cost and its successful operation demands sufficient of the operator's attention to control the vacuum pumps that little time is available to the operator for observing the cutting or drilling operation. As an illustration, without the benefit of the invention disclosed herein, the technician wishing to cut or drill diamonds with an apparatus such as is disclosed in FIG. 1 would have to modify this apparatus by adding at least two extra vacuum pumping systems including the requisite exhaust ducts, seals, valves and vacuum instrumentation for these additional vacuum systems in order to cut diamonds by known teachings. Further, the extreme criticality of the placement of the diamond crystal in the prior art apparatus relative to the opening through which the electron beam enters the working chamber is obviated by the practice of this invention.

Thus, by the use of the process and apparatus disclosed herein the investment in equipment and operating expense is considerably reduced and wide variations in oxygen concentration, beam current and potential may readily be employed in order to best accommodate the cutting of various substances. As described herein above, a simple single chamber vacuum system serviced by a single vacuum pumping system may successfully be employed, because of the use therewith of multiple function vise **27** and the highly localized gas flow **31** provided by gas lance **32**.

The vise **27** is particularly adapted to holding a nonconducting workpiece, such as an ordinary diamond crystal, in the position shown whereby the electron beam **29** and the highly concentrated gas flow **31** may be accurately superimposed. Massive copper jaws **41, 42** and **43, 44** are shown holding a diamond crystal **46** with these jaws serving simultaneously as a heat sink to quickly conduct away any heating effect contributed to diamond **46** by the electron beam and also as a Faraday cage around the diamond. Copper clamping plates **41** and **43** are adjustable relative to the copper block base **47**, which provides shoulders **42, 44** to coact with plates **41, 43.** Preferably, the jaws have only a narrow gap between them but extend up fom about ¼ inch to about ½ inch above diamond crystal **46.** Cavity **48** extending through base **47** serves as an effective electron-trapping cage.

During the cutting of nonconductive material, it is important that the material be firmly held by the coacting jaws of vise **28** to prevent any movement of the crystal as the result of an electrical charge accumulated thereon during the bombardment. The Faraday cage effect, of course, minimizes the "charging up" of crystal **46** thereby rendering more effective the cutting action of the electron beam. Single crystal, near-gem quality stones and industrial carbonados as well as sintered diamond compacts have been successfully and quickly cut employing the process and apparatus of this invention.

In the cutting operation the nonconductive diamond crystal **46** is fixed in vise **27**, which in turn is placed upon table **28** in the proper position for focusing the electron beam **29** between the jaws of vise **27**. The work chamber pressure should be kept low enough to prevent arcing around the electron gun structure caused by continued cutting. After the vacuum has been drawn in the working chamber **26,** electron beam **29** is initiated and focused. If it is desired to drill a hole through crystal **46,** table **28** is not moved; if it be desired to make a cut through crystal **46,** the cutting action is obtained simply by moving table **28** (and thereby diamond **46**) relative to beam **29.**

If the cutting of the diamond **46** is conducted in the absence of the microjet **31** of oxygen, the cut face of the diamond, which resembles the appearance of flame-cut steel, indicates the formation of graphite thereon. However, graphite does not form at any other place on diamond crystal **46.**

When the stream **31** of oxygen is employed the debris generated during electron bombardment is quickly removed from the cut surface of the stone leaving a smoother surface than is the case with cuts produced in the absence of oxygen. Also, the cutting rate is increased by a factor of about 5. As an example, a 1-carat gem can be cut by the use of this invention in about 10 minutes. To compare this last mentioned cutting action with the conventional sawing of a diamond crystal, a gem of this size may take as long as eight hours to saw. Further, when the gas lance is employed, the beam current and potential may be reduced to some degree thereby reducing the amount of crystal lost during the cutting action. As an example, in the cutting of diamonds with electron beam cutting at 130 k.v. supplemented with the oxygen lance having a flow rate for oxygen of as little as 0.03 cubic feet per hour, it was found that the beam current could be reduced from 10 milliamperes to less than 1 milliampere. Also, in the cutting of diamonds, in the absence of flow from the gas lance the electron beam must be employed at a slow pulse rate in order to minimize crystal breakage, while the addition of the gas output from the lance enables substantially continuous smooth cutting by pulsing the electron beam at a very rapid rate i.e. about 35 c.p.s. This last factor, of course, is particularly important with respect to increasing the rate of cutting.

The manner in which the impinging gas stream is supplied to focal point **33** is important and it is preferable to use a cylindrical expansion nozzle (such as a hypodermic needle) having a large length/radius ratio greater than about 10:1 and located at a distance from the point of electron beam impingement such that the radial spreading of the gas stream does not exceed about twice the nozzle outlet diameter.

The construction of the gas lance or gas jet device in the form of a simple, narrow expansion nozzle makes the operation of the apparatus easy to achieve over a wide pressure range in the working chamber. In particular, it makes for flexibility in setting process conditions, especially in the rate of oxygen, or other gas delivery, without interfering with the passage of electrons to the point of electron beam impingement and without the necessity of adhering to very specific and rigid spacing requirements. All that is necessary in the practice of this invention is that the expansion nozzle be so dimensioned that the gas leaving the nozzle is able to make the transition from viscous to molecular flow, thereby giving appreciable direction and form thereto and permitting predictability of the extent of spread of the flow to an accuracy of at least about 50 percent. In the case of a cylindrical nozzle, as noted above, the length/radius should be about 10:1 or greater. Because of this design criterion the criticality of the placement of the end of the nozzle relative to the work point is considerably diminished. The data for the selection of particular length/radius ratios or equivalent parameters in the case of non-cylindrical nozzles may be found by referring to the textbook, "Scientific Foundations of Vacuum Technique" by S. Dushman (2nd edition, 1962, John Wiley and Sons Inc.) in chapter 2, Flow of Gases Through Tubes and Orifices.

The only restriction on the quantity of gas flow through the nozzle is that it be proportioned to the overall capacity of the pump system. The device disclosed herein has been successfully operated when the pressure in the manifold of the vacuum pumping system a short distance from the working chamber is of the order of 10 microns of mercury. The capacity to operate at such low pressures (pressures even lower than the aforementioned may be used) is due to the particular mode of gas delivery and is particularly advantageous in promoting longer filament life for the electron source.

This new and relatively inexpensive apparatus and technique, with its faster, smoother cutting action and lowering of thermal stresses will render the shaping of diamonds already set in tool shanks economically attractive by enabling the ready readaption of such a diamond tool to any desired use. Further, using this invention, small slices may be quickly removed from natural diamonds to ascertain whether there may be higher quality diamond material within the stone than appears from a view of the outer surface.

Various modifications are contemplated and may obviously be resorted to by those skilled in the art without departing from the spirit and scope of the invention, as hereinafter defined by the appended claims, as only a preferred embodiment thereof has been disclosed.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. In an apparatus for electron beam cutting comprising an electron emitter, means for focusing at a location removed from said emitter a beam of electrons emitted from said electron emitter, said focusing means being constructed to recollect said focused electrons into a cylindrical region of increased current density, a working chamber within which said cylindrical region is focused, means for evacuating said working chamber and said electron emitter and means in said working chamber for positioning a material to be cut at said cylindrical region, the improvement in said positioning means comprising a vise having a base portion and adjustable clamping means supported thereon for coaction therewith located in said

working chamber for holding and substantially enclosing an electrically nonconducting material to be cut between said base portion and said clamping means, said base portion and clamping means being made of a metal having a high rate of thermal and electrical conductivity, and said base portion having formed therein an electron-trapping cavity and a slot placing said electron-trapping cavity in communication with the region of coaction between said base portion and said clamping means.

2. The improvement substantially as recited in claim **1** wherein the vise is made of copper.

3. In an apparatus for electron beam cutting comprising an electron emitter, means for focusing at a location removed from said emitter a beam of electrons emitted from said emitter, said focusing means being constructed to recollect said focused electrons into a cylindrical region of increased current density, a working chamber within which said cylindrical region is focused, means for evacuating said working chamber and said emitter and means in said working chamber for positioning a material to be cut at said cylindrical region, the improvement comprising in combination:

(a) a vise having a base portion and clamping means supported thereon for coaction therewith located in said working chamber for holding and substantially enclosing an electrically non-conducting material to be cut between said base portion and said clamping means, said base portion and clamping means being made of a metal having a high rate of thermal and electrical conductivity, and said base portion having formed therein an electron-trapping cavity and a slot placing said electron-trapping cavity in communication with the region of coaction between said base portion and clamping means, and

(b) a gas lance supported within said working chamber and directed toward the focal point of said cylindrical region for impinging a concentrated stream of gas upon the cylindrical region of increased current density.

4. The improvement substantially as recited in claim **3** wherein the gas lance is a cylindrical expansion nozzle having a length/radius ratio greater than about 10.

5. The improvement substantially as recited in claim **4** with the nozzle outlet of the gas lance located at a distance from the focal point of said cylindrical region such that the radial spread of a gas stream emitted therefrom does not exceed about two times the diameter of the nozzle at the outlet thereof.

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RICHARD M. WOOD, *Primary Examiner.*

W. D. BROOKS, *Assistant Examiner.*

U.S. Cl. X.R.

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