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(54) **EARTHBORING TOOL AND METHOD OF CASEHARDENING**

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(57) **ABSTRACT**

A method of casehardening an earthboring tool component includes steps of providing an earthboring tool component and providing a semiconductor light emitting device carried by a mechanical arm. The mechanical arm is used to move the semiconductor light emitting device relative to the earthboring tool component. Light emitted by the semiconductor light emitting device is directed to a surface of the earthboring tool component so that it is casehardened.

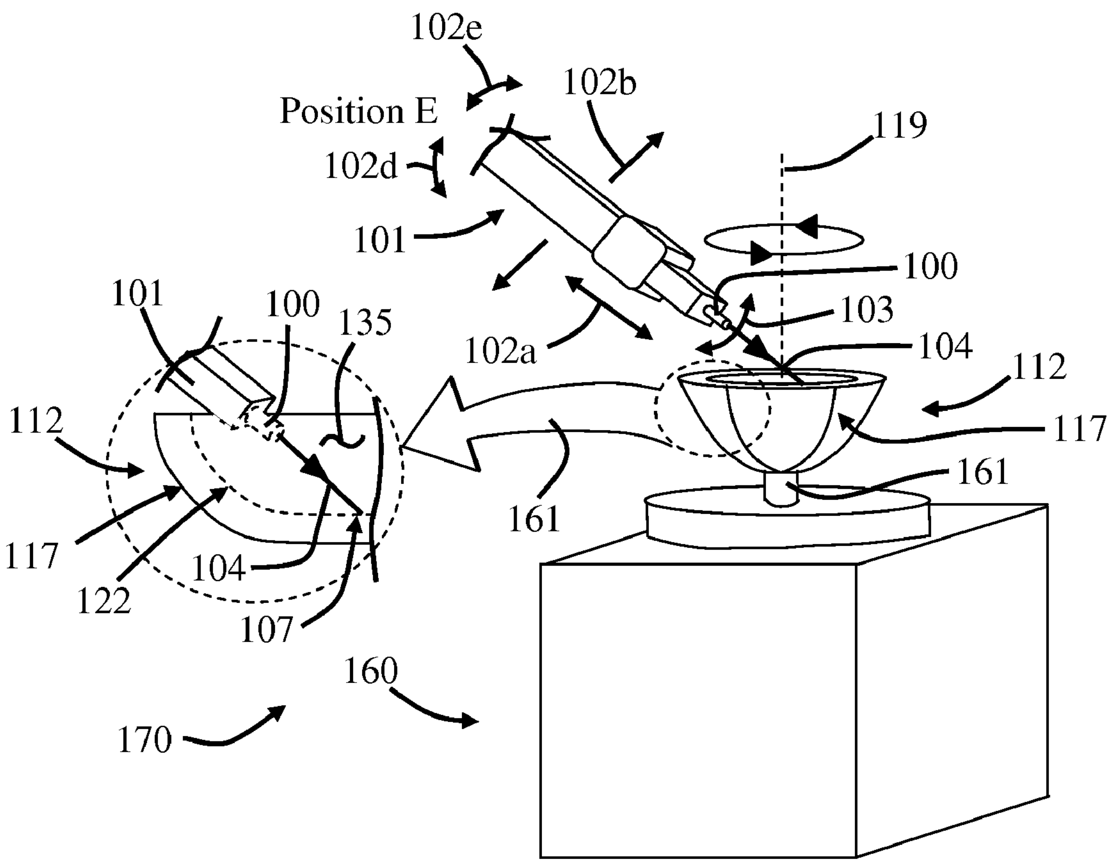


FIG. 1a

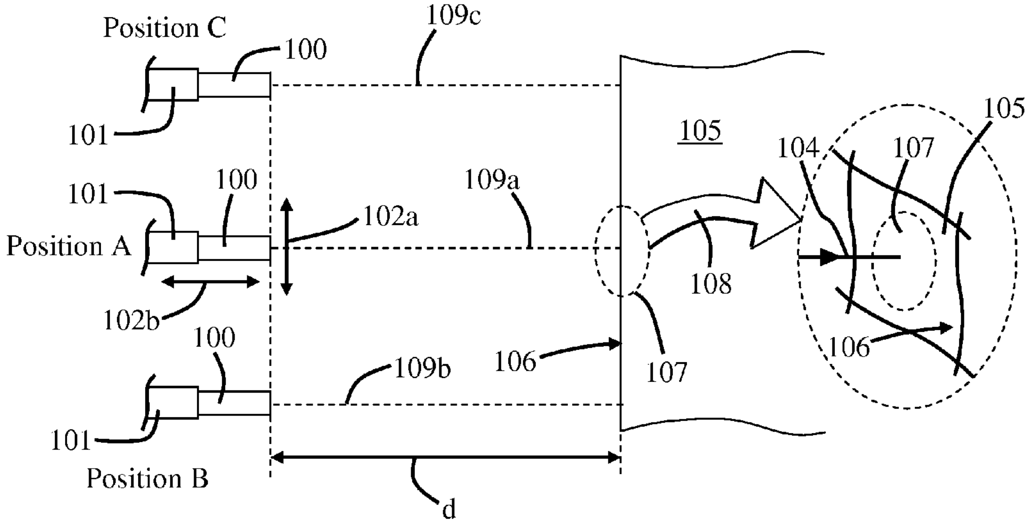

Position C
100
109c
101
105
105
104
107
101
100
109a
102a
Position A
108
102b
100
106
106
107
109b
100
101
Position B
d

FIG. 1b

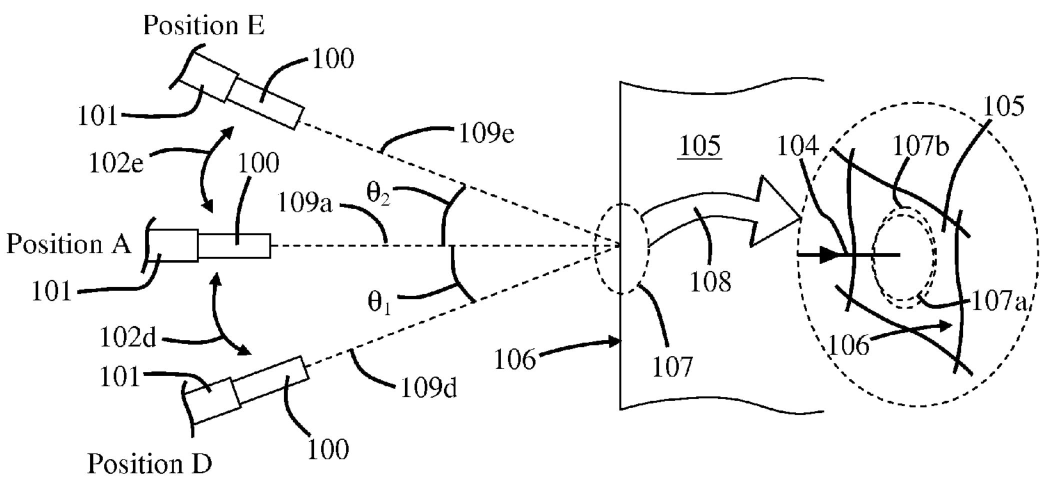

Position E
100
109e
101
105
105
104
107b
102e
100
109a
θ_2
Position A
108
101
θ_1
107a
102d
106
106
107
101
109d
Position D
100

FIG. 2a

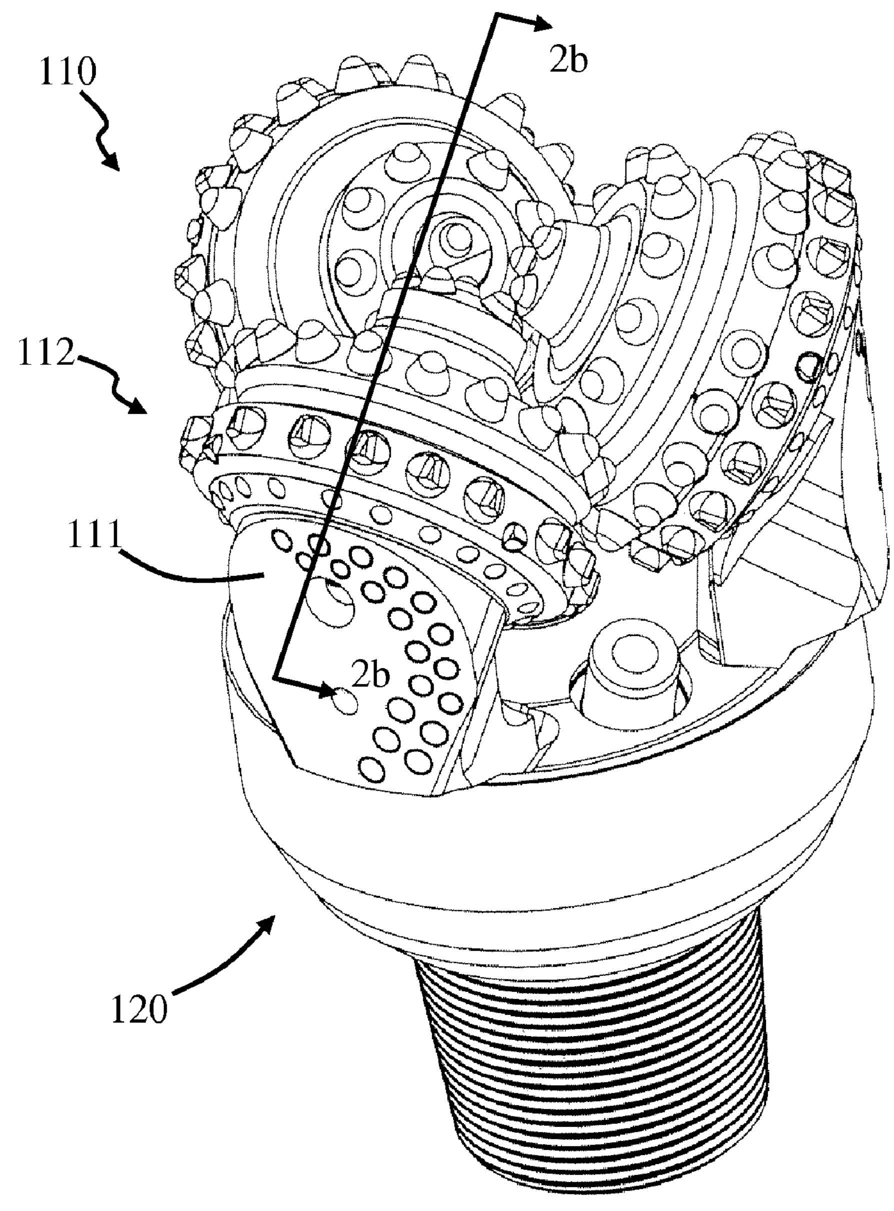


FIG. 2b

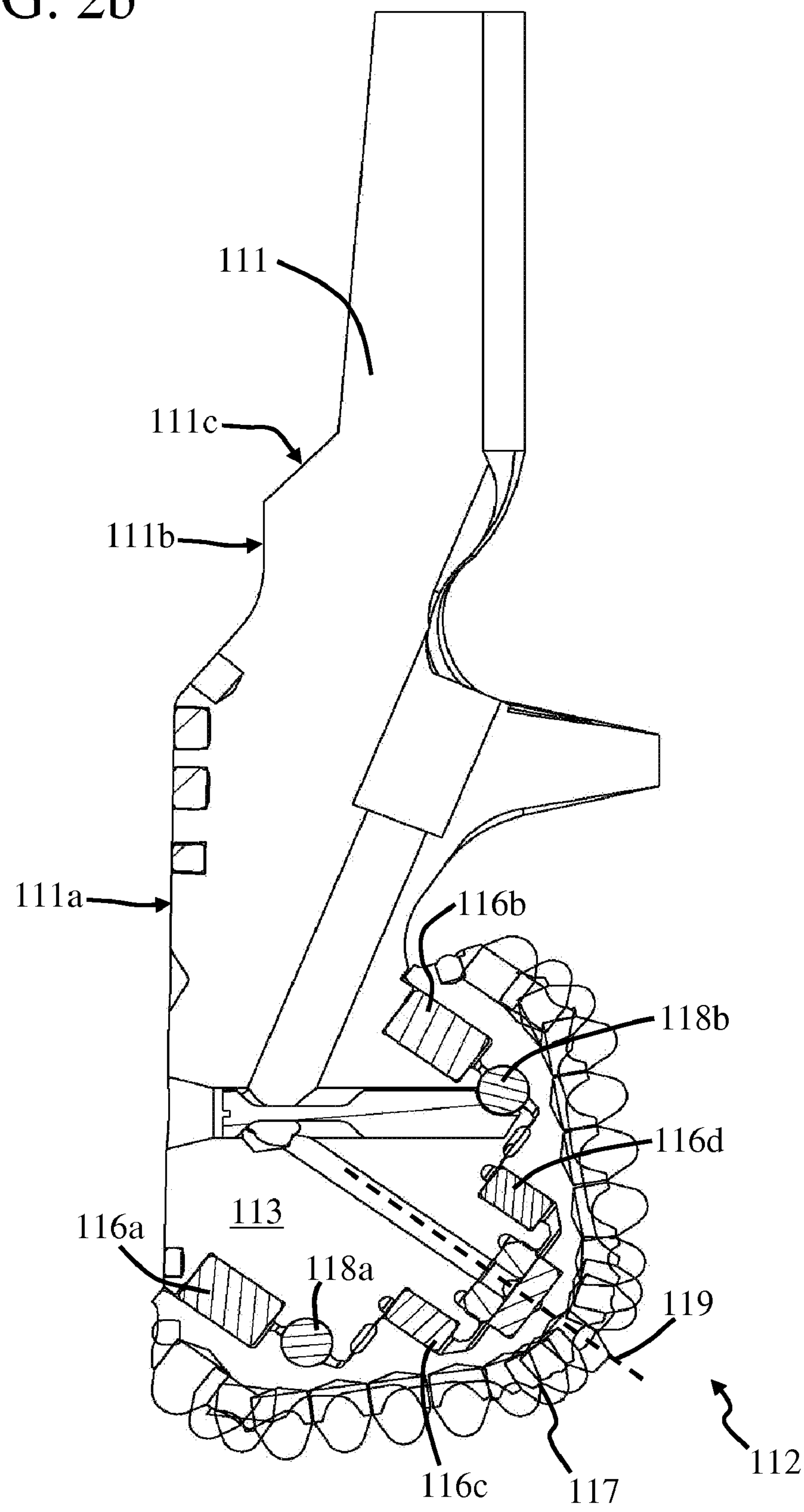

111
111c
111b
111a
116b
118b
116d
113
116a
118a
119
112
116c
117

FIG. 2c

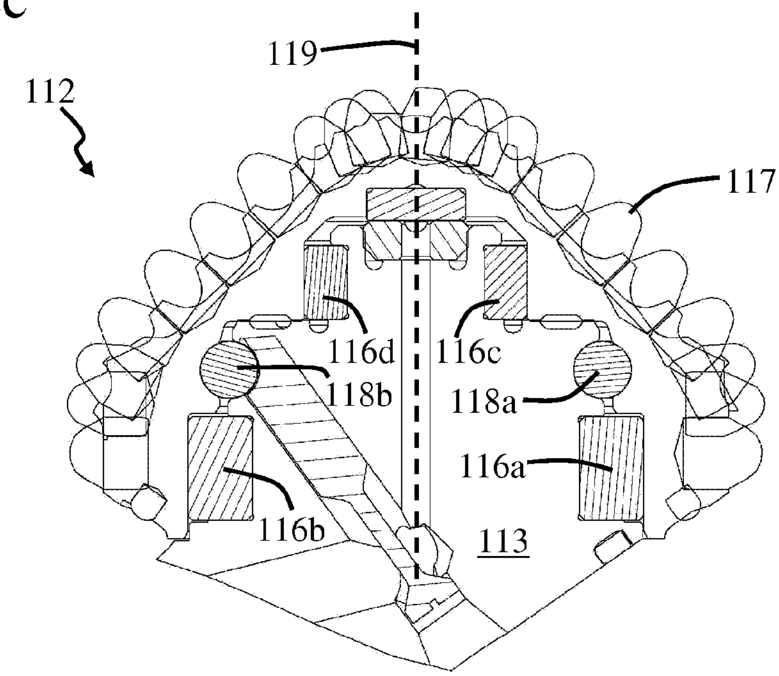

119
112
117
116d
116c
118b
118a
116a
116b
113

FIG. 2d

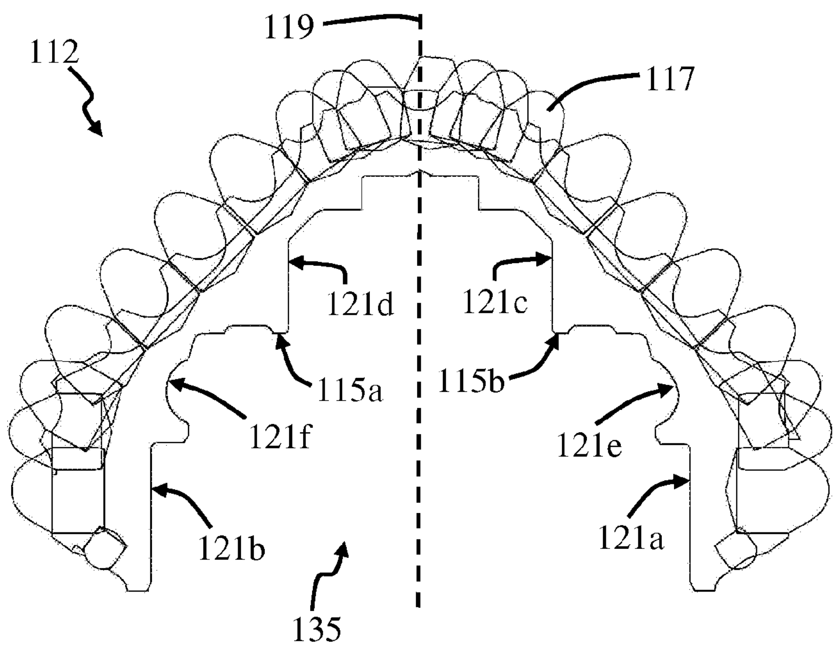

119
112
117
121d
121c
115a
115b
121f
121e
121b
121a
135

FIG. 2e

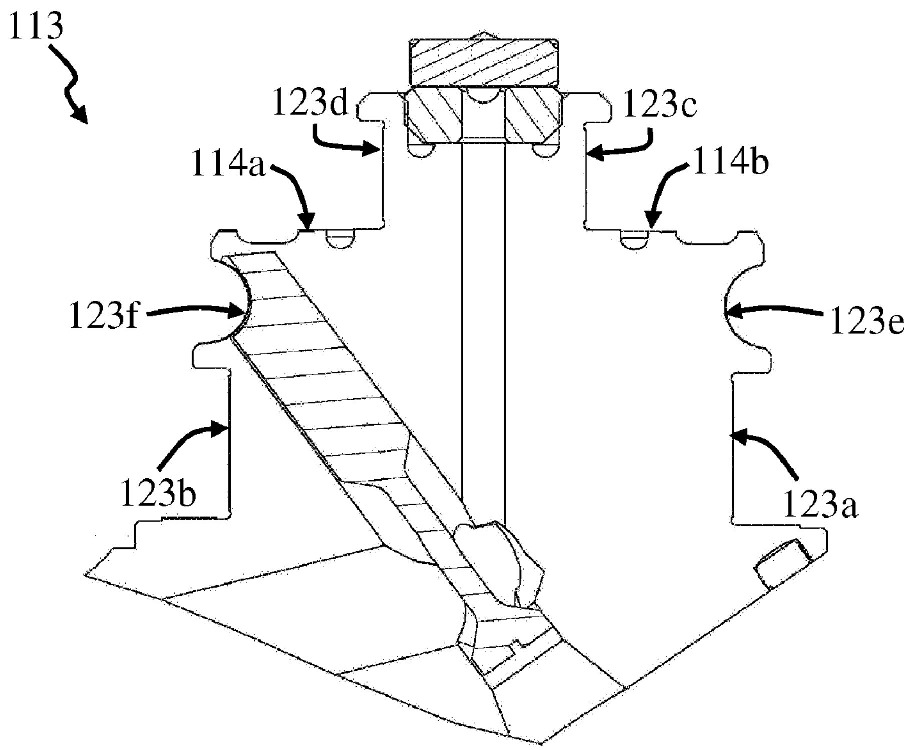


FIG. 3

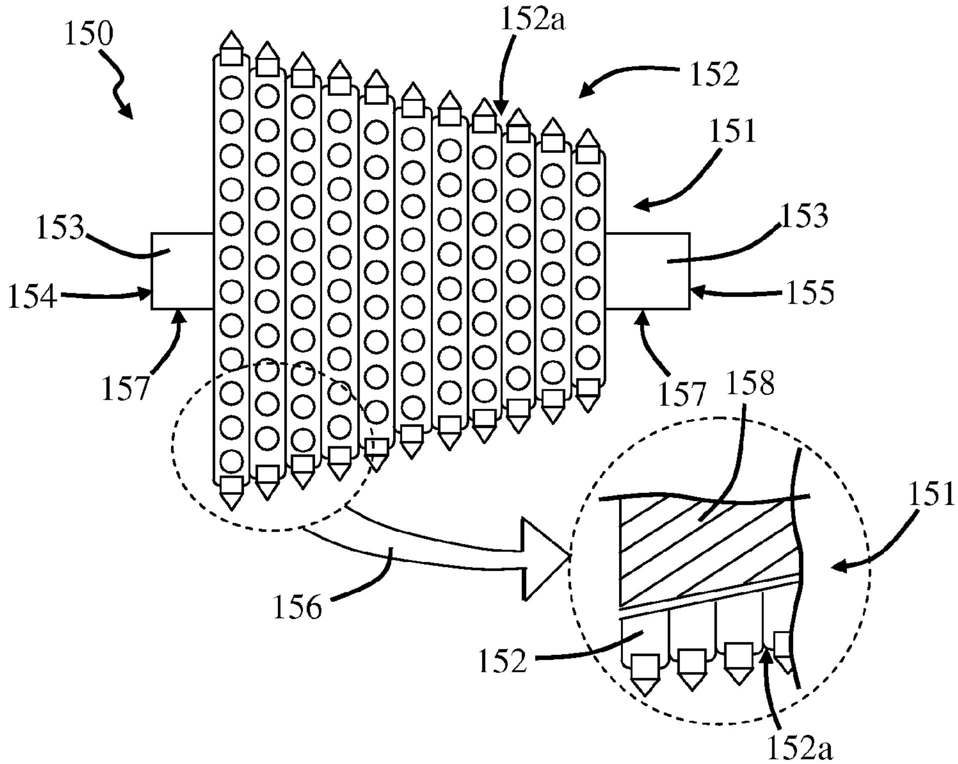

150
152a
152
151
153
153
154
155
157
157
158
151
156
152
152a

FIG. 4

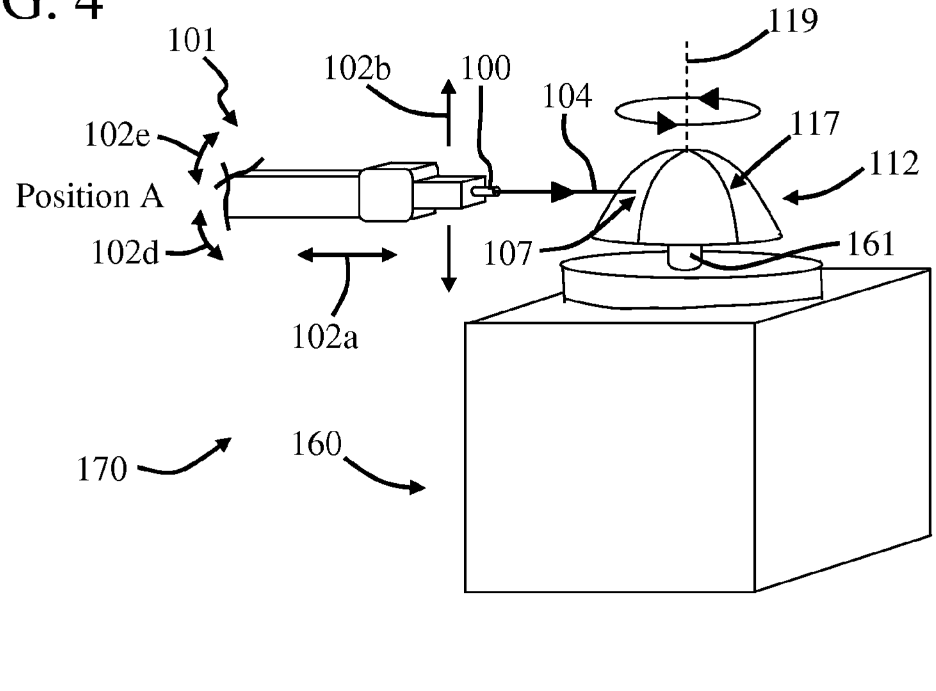

101
102b
100
119
104
117
102e
112
Position A
107
161
102d
102a
170
160

FIG. 5

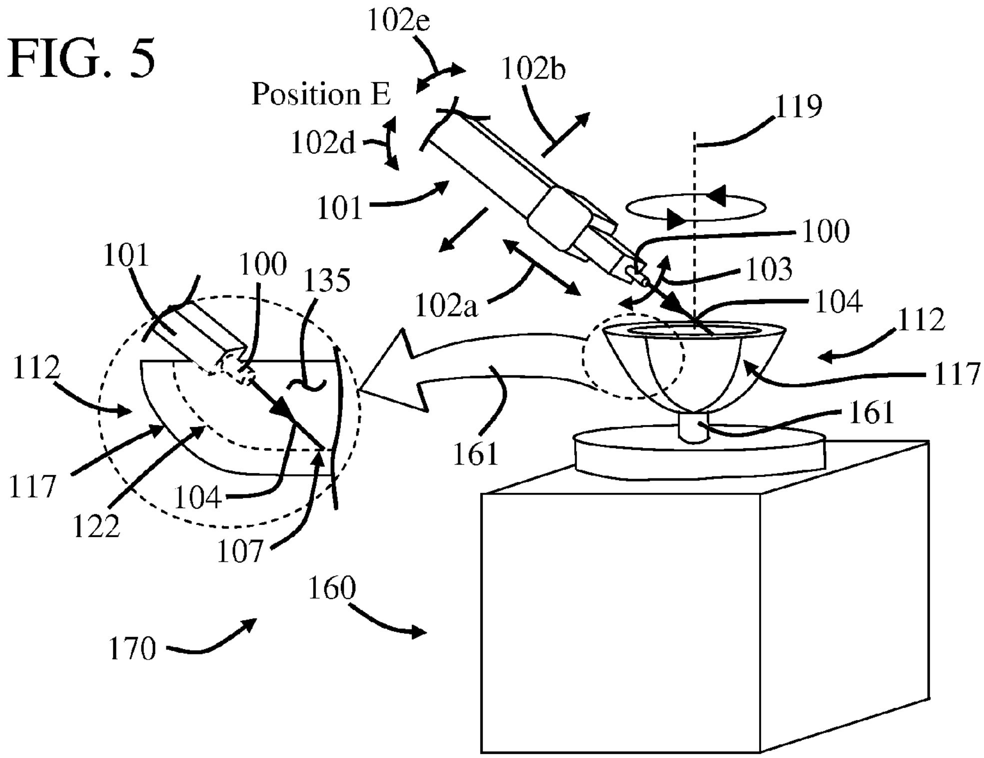

102e
Position E
102b
119
102d
101
100
101
100
135
103
102a
104
112
112
117
161
161
117
104
122
107
160
170

FIG. 6

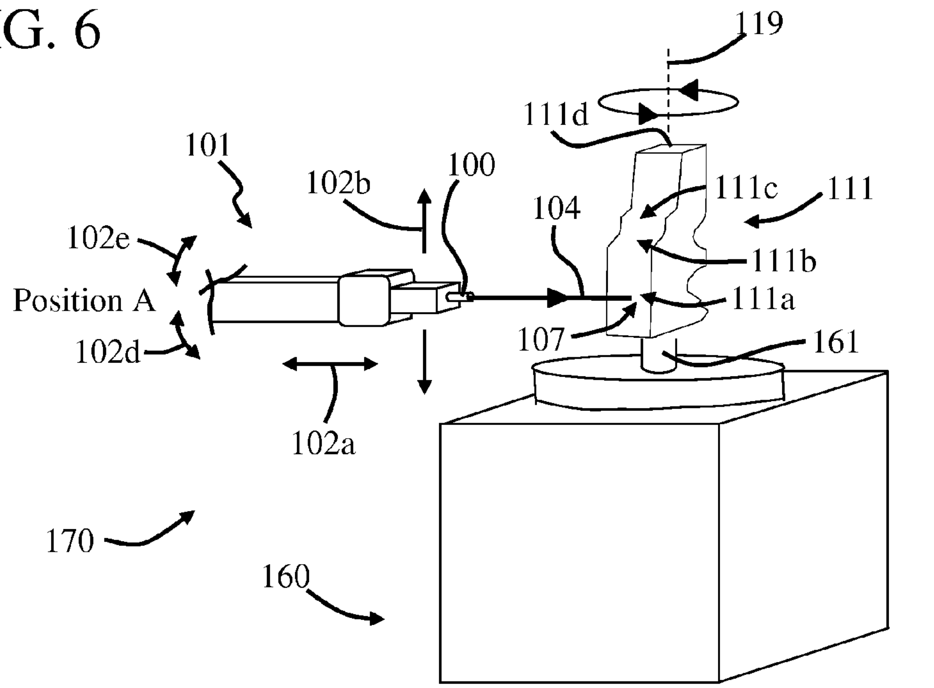

119
111d
101
102b
100
111c
111
104
102e
111b
Position A
111a
107
161
102d
102a
170
160

FIG. 7

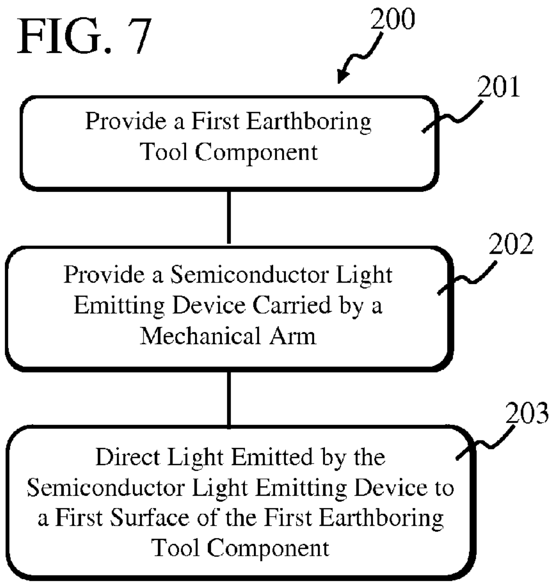


FIG. 8

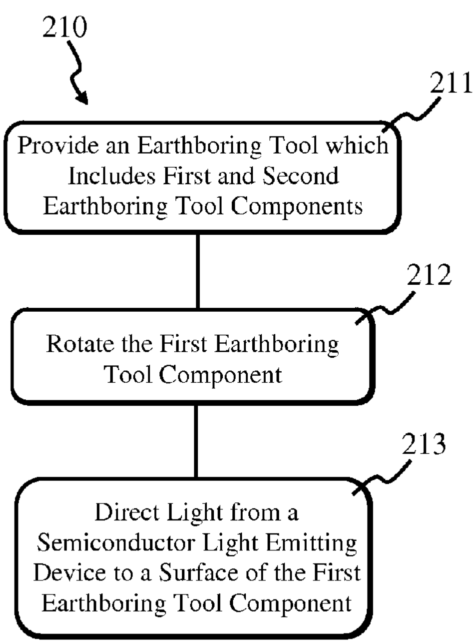
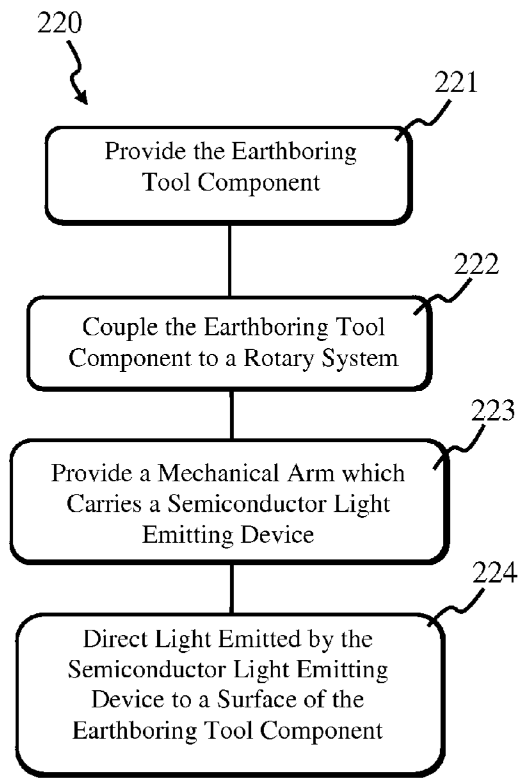


FIG. 9



EARTHBORING TOOL AND METHOD OF CASEHARDENING

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] This invention relates generally to earthboring tools for cutting earthen annulus.

[0003] 2. Description of the Related Art

[0004] Earthboring tools are commonly used to bore holes by cutting through earthen annulus. Such holes may be bored for many different reasons, such as drilling for oil, minerals and water. One type of earthboring tool used for boring is a rotary earth bit. Several examples of rotary earth bits are disclosed in U.S. Pat. Nos. 3,550,972, 3,847,235, 4,136,748, 4,427,307, 4,688,651 and 4,741,471. A rotary earth bit generally includes one or more earth bit cutting cones rotatably mounted to corresponding lugs with a hub unit, as well as ball and roller bearings. The lugs generally form a portion of an earth bit body and, as the earth bit body rotates, the cutting cone rotates in response to contacting earthen annulus.

[0005] Another type of earthboring tool is a mechanized boring cutter, with an example being disclosed in U.S. Pat. No. 4,040,493. A mechanized boring cutter generally includes a hub unit rotatably mounted to a shaft and a cutting cone frictionally engaged with the hub unit. The hub unit is often rotatably mounted to the shaft using ball bearings.

[0006] It is known that earthboring tools wear out with use. As a result, they are often casehardened to reduce the amount of wear they experience. Examples of casehardened earthboring tools are disclosed in U.S. Pat. Nos. 4,303,137, 4,627,882, 4,643,051, 4,660,444 and 4,781,770. Casehardening sometimes involves subjecting the earthboring tool to a carburization process. However, there are several problems with using a carburization process.

[0007] A carburization process is typically a "batch process", wherein a number of earthboring tool components are heated by a large and expensive furnace at the same time. The components are heated at the same time because it is not economical, or otherwise beneficial, to heat fewer components using a carburization process. Since the components are heated at the same time, they are casehardened in the same way without providing an option for selective casehardening. Further, the region of the earthboring tool component that is casehardened is often casehardened non-uniformly so its hardness undesirably varies from one location to another.

[0008] The carburization process also requires a long period of time. The furnace can provide temperatures in excess of 1700° F., resulting in a carburization process that can take ten or more hours. After the earthboring tool component is heated by the furnace, it is generally slow cooled, quenched and machine finished, which requires additional time.

[0009] Another problem is that the earthboring tool components typically include low alloy carbon steel, wherein the amount of carbon is generally less than one-quarter of one percent. Low alloy carbon steel often wears down faster than higher alloy carbon steel, so low alloy carbon steels are often case carburized to allow them to function with acceptable wear in earthboring tools. During the case carburizing process, the amount of carbon in the surface of the steel is increased by introducing an expensive carbon rich gas into the atmosphere in the furnace when the batch of earthboring tool components is being heated.

[0010] Other methods of casehardening involve using gas lasers that emit light or electron emitters that emit electrons. However, gas lasers and electron beam emitters are expensive and difficult to accurately align with the earthboring tool. They are difficult to align because they are unwieldy and the alignment often requires mirrors. Hence, it is desirable to provide other casehardening methods that are simpler, more time efficient and less costly.

BRIEF SUMMARY OF THE INVENTION

[0011] The present invention provides a method of casehardening an earthboring tool component. The method includes steps of providing a first earthboring tool component and a semiconductor light emitting device carried by a mechanical arm. The method also includes a step of directing light emitted by the light emitting device to a first surface of the first earthboring tool component, wherein the first surface is casehardened in response to being heated by the light. The properties of the light are chosen so that the amount of time needed to caseharden the first earthboring tool component is significantly reduced.

[0012] In some situations, the light emitting device is moved, using the mechanical arm, so that a second surface of the first earthboring tool component is exposed to the light and casehardened in response. In some situations, the first earthboring tool component is moved so the light is provided to the second surface. In this way, selected surfaces of the first earthboring tool component are casehardened.

[0013] In some embodiments, the first earthboring tool component is replaced with a second earthboring tool component. In this way, the first and second earthboring tool components can be casehardened separately and provided with different amounts of casehardening. The second earthboring tool component is exposed to light emitted by the light emitting device so that a surface of it is casehardened. The first and second earthboring tool components can be coupled together to form an earthboring tool. The first and second earthboring tool components are often coupled together so that their casehardened surfaces face each other. In this way, these surfaces experience less wear when they engage each other.

[0014] These and other features, aspects, and advantages of the present invention will become better understood with reference to the following drawings and description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIGS. **1***a* and **1***b* are side views of a semiconductor light emitting device carried by a mechanical arm and directed at an earthboring tool component, in accordance with the invention.

[0016] FIG. **2***a* is a perspective view of a rotary earth bit which can be casehardened, in accordance with the invention.

[0017] FIG. **2***b* is a cross-sectional view taken along a cut-line **2***b*-**2***b* of the earth bit of FIG. **2***a*.

[0018] FIG. **2***c* is a more detailed view of a cutting cone and hub unit included with the rotary earth bit of FIG. **2***a*.

[0019] FIG. **2***d* is a more detailed view of the cutting cone of FIG. **2***c* with the hub unit removed from it.

[0020] FIG. **2***e* is a more detailed view of the hub unit of FIG. **2***c* removed from the cutting cone.

[0021] FIG. **3** is a side view of an earthboring tool embodied as a mechanized boring cutter.

[0022] FIGS. **4**, **5** and **6** are perspective views of an earthboring tool casehardening system, in accordance with the invention.

[0023] FIG. **7** is a flow diagram of a method of casehardening an earthboring tool component, in accordance with the invention.

[0024] FIGS. **8** and **9** are flow diagrams of methods of assembling an earthboring tool, in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0025] FIGS. **1***a* and **1***b* are side views of a semiconductor light emitting device **100** carried by a mechanical arm **101**. In accordance with the invention, light emitting device **100** is carried by mechanical arm **101** so it is directed at an earthboring tool component **105**. Semiconductor light emitting device **100** can be of many different types, but, in this embodiment, it is a laser diode. A laser diode is much smaller than a gas laser and an electron beam emitter, so it can be easily moved from one position to another. Further, a laser diode generally uses less power and requires less cooling than a gas laser and electron beam emitter. Mechanical arm **101** can be of many different types, such as those found in U.S. Pat. Nos. 4,545,713, 4,626,999, 4,892,992 and 6,920,375. Earthboring tool component **105** can be a component of many different types of earthboring tools, a few of which will be discussed in more detail below with FIGS. **2***a* and **3**.

[0026] In accordance with the invention, mechanical arm **101** moves light emitting device **100** in a controlled manner relative to earthboring tool component **105**. The manner in which mechanical arm **101** moves device **100** can be controlled in many different ways, such as with a computer system (not shown). For example, mechanical arm **101** can be used to move the position of light emitting device **100** along a predetermined path relative to earthboring tool component **105** in response to one or more control signals from the computer system.

[0027] In accordance with the invention, light emitting device **100** is repeatably moveable, by using mechanical arm **101**, between many different positions relative to earthboring tool component **105**. A few of these positions are denoted as Positions A, B, C, D and E in FIGS. **1***a* and **1***b*. In Position A, light emitting device **100** is directed at earthboring tool component **105** so its optical path extends along a reference line **109***a*. Light emitting device **100** emits light **104**, as indicated by an indication arrow **108**, so that light **104** is directed along its optical path. In this embodiment, reference line **109***a* intersects a surface **106** of earthboring tool component **105**, wherein surface **106** is flat so that reference line **109***a* is oriented perpendicular to it. However, it should be noted that surface **106** can have many other shapes, such as curved, but it is shown here as being flat for simplicity.

[0028] In this embodiment, Positions B and C correspond to light emitting device **100** being positioned so that its optical path is directed along reference lines **109***b* and **109***c*, respectively. Reference lines **109***b* and **109***c* are parallel to reference line **109***a*, so that they are also perpendicular to surface **106**. Light emitting device **100** is moveable between Positions A, B and C by moving it, using mechanical arm **101**, in opposed directions indicated by a direction arrow **102***a*.

[0029] Light emitting device **100** is positioned by mechanical arm **101** so that reference lines **109***a*, **109***b* and **109***c* extend a distance d between light emitting device **100** and surface **106**. However, in accordance with the invention, light emitting device **100** is repeatably moveable, in response to moving mechanical arm **101**, in opposed directions towards and away from surface **106**, as indicated by a direction arrow **102***b*. In this way, distance d is adjustable in response to adjusting the position of light emitting device **100** with mechanical arm **101**.

[0030] It should be noted that, in this example, the movement of light emitting device **100** in directions **102***a* and **102***b* corresponds to linear movement because the angles between reference lines **109***a*, **109***b* and **109***c* do not change relative to each other. Further, in this embodiment, the angles between reference lines **109***a*, **109***b* and **109***c* do not change relative to surface **106** because it is flat, as mentioned above.

[0031] As indicated by indication arrow **108**, light emitting device **100** emits light **104** so it flows along reference line **109***a* and is incident to surface **106** and forms a light receiving region **107**. A light receiving region can also be formed where reference lines **109***b* and **109***c* intersect surface **106**, such as when light emitting device **100** is in Positions B and C, respectively. However, light receiving regions from device **100** being in Positions B and C are not shown here for simplicity. The area of light receiving region **107** generally depends on many different factors, such as the shape of the beam of light emitted by light emitting device **100**. The area of light receiving region **107** also depends on the angle of the optical path of device **100** relative to surface **106**, as will be discussed in more detail presently.

[0032] As shown in FIG. **1***b*, mechanical arm **101** can move light emitting device **100** to many other positions, a few of which are denoted as Positions D and E. In Positions D and E, the optical path of light emitting device **100** extends along reference lines **109***d* and **109***e*, respectively. Reference lines **109***d* and **109***e* are at angles θ_1 and θ_2, respectively, relative to reference line **109***a*, and intersect surface **106** proximate to the same location as reference line **109***a*. In this example, a light receiving region **107***a* corresponds to light **104** incident to surface **106** from reference line **109***a* and a light receiving region **107***b* corresponds to light **104** incident to surface **106** from reference lines **109***d* and **109***e*.

[0033] It should be noted that angles θ_1 and θ_2 correspond to the angle of incidence of the optical path of light emitting device **100**. The angle of incidence increases as angles θ_1 and θ_2 increase and the angle of incidence decreases as angles θ_1 and θ_2 decrease. As the angle of incidence increases the area of the light receiving region increases. Further, as the angle of incidence decreases the area of the light receiving region decreases. In this way, light receiving region **107***b* has a greater area than light receiving region **107***a* and light receiving region **107***a* has a smaller area than light receiving region **107***b*.

[0034] Mechanical arm **101** moves light emitting device **100** in opposed directions indicated by a direction arrow **102***d* when moving light emitting device **100** between Positions A and D. Further, mechanical arm **101** moves light emitting device **100** in opposed directions indicated by a direction arrow **102***e* when moving light emitting device **100** between Positions A and E. It should be noted that, in this example, the movement of light emitting device **100** in directions **102***d* and **102***e* corresponds to angular movement because the angles between reference lines **109***a*, **109***d* and **109***e* change relative to each other. Hence, as shown in FIGS. **1***a* and **1***b*, light emitting device **100** can be linearly and angularly moved, using mechanical arm **101**, between different positions relative to earthboring tool component **105**. It should be noted that earthboring tool component **105** can also be moved relative to light emitting device **100** and mechanical arm **101**, as will be discussed in more detail with FIGS. **4**, **5** and **6**.

[0035] Earthboring tool component **105** generally includes steel, which can have many different grades. In accordance with the invention, the grade of steel included with component **105** is chosen to include approximately 0.40% carbon, although more carbon can be included in other embodiments. This amount of carbon is generally larger than that used in earthboring tool components subjected to the carburization process. The amount of carbon included in the steel is chosen to obtain a desired amount of case hardening in response to being exposed to light **104**. To provide the desired amount of casehardening, the amount of carbon included in the steel can be less if the time the steel is exposed to light **104** is increased. Further, to provide the desired amount of casehardening, the amount of carbon included in the steel can be more if the time the steel is exposed to light **104** is decreased.

[0036] The portions of earthboring tool component **105** below light receiving regions **107**, **107***a* and **107***b* are heated and casehardened in response to receiving light **104**. For example, portions of earthboring tool component **105** at a depth below surface **106** and within or proximate to light receiving regions **107**, **107***a* and **107***b*, are heated and casehardened. The depth below surface **106** that is casehardened is often referred to as the case depth. More information regarding casehardening can be found in U.S. Pat. Nos. 4,643,051 and 4,660,444.

[0037] Using light emitting device **104** to caseharden earthboring tool component **105** is useful because component **105** can be casehardened in a less amount of time. For example, the carburization process can take ten or more hours to caseharden component **105**. However, component **105**, or portions thereof, can be casehardened sufficiently enough within tens of seconds to one or more minutes.

[0038] The amount of casehardening provided to earthboring tool component **105**, as well as the case depth, can be controlled in many different ways. For example, light **104** emitted by semiconductor light emitting device **100** can have many different amounts of power. However, an amount of power in a power range between about two kilowatts and six kilowatts was found to be useful in casehardening surface **106** sufficiently. As the amount of power in light **104** increases, more casehardening is provided because the temperature of surface **106** increases more. If the amount of power in light **104** increases less, then less casehardening is provided because the temperature of surface **106** increases less. In this way, the amount of casehardening provided to earthboring tool component **105** can be controlled by controlling the amount of power of light **104**.

[0039] The amount of optical power of light **104** provided to surface **106** can be adjusted in response to adjusting the position of light emitting device **100** relative to the earthboring component with mechanical arm **101**. The amount of power of light **104** can be adjusted because it depends on the position and orientation of light emitting device **100** relative to earthboring tool component **105**. For example, the power can be adjusted by adjusting distance d. As distance d decreases, the power provided to surface **106** increases because there are fewer optical losses experienced by light **104**. As distance d increases, the power provided to surface **106** decreases because there are more losses experienced by light **104**. In this way, the distance between laser **100** and surface **106** can be adjusted, with mechanical arm **101**, to adjust the amount of casehardening provided to earthboring tool component **105**.

[0040] The amount of optical power, and hence the amount of casehardening provided to earthboring tool component **105** can also be controlled by controlling the intensity of light **104**. The intensity of light **104** within the light receiving region can be controlled in many different ways, such as by controlling angles θ_1 and θ_2. As angles θ_1 and θ_2 increase, the intensity of light **104** decreases because the angle of incidence is larger and the light receiving region is larger. Further, as angles θ_1 and θ_2 decrease, the intensity of light **104** increases because the angle of incidence is smaller and the light receiving region is smaller. In general, earthboring tool component **105** is casehardened more in response to more intense light because the temperature of surface **106** is increased more. Further, earthboring tool component **105** is casehardened less in response to less intense light because the temperature of surface **106** is increased less.

[0041] The area of the light receiving region is related to the power density of light **104** on surface **106**. Hence, the amount of casehardening provided to earthboring tool component **105** can be controlled by controlling the power density of light **104**. The area of the light receiving region depends on the angle of incidence, as discussed above. As the area of the light receiving region decreases, the power density increases and, in response, the temperature of surface **106** increases more. Further, as the area of the light receiving region increases, the power density decreases, and, in response, the temperature of surface **106** increases less. In this way, the angle of incidence of light **104** can be adjusted, with mechanical arm **101**, to control the amount of casehardening provided to earthboring tool component **105**.

[0042] Semiconductor light emitting device **100** generally has many different modes of operation. For example, light emitting device **100** can be operated in a pulsed mode or a continuous mode of operation. In the continuous mode, the output power of device **100** is substantially continuous and, in the pulsed mode, the power output of device **100** is alternately increased and decreased. In general, more power is provided to surface **106** when light emitting device **100** is operated in a continuous mode of operation and less power is provided to surface **106** when device **100** is operated in a pulsed mode of operation. In this way, the amount of casehardening provided to earthboring tool component **105** can be controlled by controlling the mode of operation of semiconductor light emitting device **100**.

[0043] It should be noted that the amount of casehardening provided by light emitting device **100** to earthboring tool component **105** can be controlled in many other ways. For example, in some embodiments, light **104** can flow through a lens before it reaches surface **106**. The optical properties of the lens are chosen to provide light receiving region **107** with a desired intensity and area. In other examples, the properties of light **104** are chosen to provide a desired amount of casehardening, as will be discussed in more detail presently.

[0044] Light **104** emitted by semiconductor light emitting device **100** can have many different wavelengths. However, light **104** is generally infrared light because infrared light was found to be useful in casehardening surface **106** sufficiently. Infrared light generally has a wavelength between about 900 nanometers and about 1450 nanometers, although the wavelength can be outside of this range.

[0045] As the wavelength of light **104** decreases, it has more energy so the temperature of surface **106** increases more and more casehardening is provided. Further, as the wavelength of light **104** decreases, it is less capable of penetrating into light receiving region **107** so the case depth is less. As the wavelength of light **104** increases, it has less energy and the temperature of surface **106** increases less and less casehardening is provided. Further, as the wavelength of light **104** increases, it is more capable of penetrating into light receiving region **107** so the case depth is more. In this way, the amount of casehardening provided to earthboring tool component **105**, as well as the case depth, can be controlled by controlling the wavelength of light **104**.

[0046] FIG. **2***a* is a perspective view of a rotary earth bit **110**, in accordance with the invention. There are many different types of rotary earth bits, and examples are provided in the references discussed above in the description of the related art. In this embodiment, rotary earth bit **110** is a tri-cone earth bit having an earth bit body **120** which carries three lugs **111** and corresponding cutting cones **112**.

[0047] FIG. **2***b* is a cross-sectional view of lug **111** and cutting cone **112** taken along a cut-line **2***b*-**2***b* of FIG. **2***a*. FIG. **2***c* is a more detailed view of cutting cone **112** and a hub unit **113** included with rotary earth bit **110** and FIG. **2***d* is a more detailed view of cutting cone **112** of FIG. **2***c* with hub unit **113** removed from it.

[0048] In this embodiment, hub unit **113** is attached to lug **111** and received by a channel **135** (FIG. **2***d*) of cutting cone **112**. In this way, lug **111** and cutting cone **112** are coupled together with hub unit **113**. Cutting cone **112** is rotatably mounted to hub unit **113** with ball bearings **118***a* and **118***b*, as well as roller bearings **116***a*, **116***b*, **116***c* and **116***d*, so that cutting cone **112** is rotatable about an axis **119**. In operation, lug **111** rotates in response to the rotation of earth bit body **120**. As lug **111** rotates, cutting cone **112** rotates around hub unit **113** in response, and cuts into the earthen annulus it contacts.

[0049] Rotary earth bit **110** includes several portions that experience wear during operation. For example, lug **111** includes outer surfaces **111***a*, **111***b* and **111***c* and cutting cone **112** includes an outer cutting surface **117** that experience wear when contacting earthen annulus. Further, cutting cone **112** and hub unit **113** often engage each other in response to external forces applied to cutting surface **117**, so that the interface between cutting cone **112** and hub unit **113** experiences wear.

[0050] FIGS. **2***d* and **2***e* are more detailed views of cutting cone **112** and hub unit **113**, respectively. Hub unit **113** includes surfaces **114***a* and **114***b* (FIG. **2***c*) that face surfaces **115***a* and **115***b* (FIG. **2***d*), respectively, of cutting cone **112**. The outward facing surfaces of bearings **116***a*, **116***b*, **116***c*, **116***d*, **118***a* and **118***b* face surfaces **121***a*, **121***b*, **121***c*, **121***d*, **121***e* and **121***f* (FIG. **2***d*), respectively, of cutting cone **112**. It should be noted that surfaces **115***a*-**115***d* and **121***a*-**121***f* bound channel **135** of cone **112**. Further, the outward facing surfaces of bearings **116***a*, **116***b*, **116***c*, **116***d*, **118***a* and **118***b* face surfaces **123***a*, **123***b*, **123***c*, **123***d*, **123***e* and **123***f* (FIG. **2***d*), respectively, of hub unit **113**.

[0051] The surfaces of bearings **116***a*, **116***b*, **116***c*, **116***d*, **118***a* and **118***b* can engage corresponding surfaces of cutting cone **112** and/or hub unit **113** in response to the external force applied to outer cutting surface **117**. Further, surfaces **114***a* and **114***b*, **115***a* and **115***b*, **121***a*-**121***f* and **123***a*-**123***f*, as well as the outwardly facing surfaces of bearings **116***a*-**116***d* and **118***a*-**118***b*, often experience wear when cutting cone **112** and hub unit **113** rotate relative to each other.

[0052] FIG. **3** is a side view of an earthboring tool embodied as a mechanized boring cutter **150**. In this embodiment, mechanized boring cutter **150** includes a shaft **153** around which a boring cutter header assembly **151** is rotatably coupled. Shaft **153** includes opposed end surfaces **154** and **155** and a side surface **157**. Boring cutter header assembly **151** includes a hub unit **158**, as indicated by an indication arrow **156**, and a tapered cutting cone **152**, wherein tapered cutting cone **152** includes an outer cutting surface **152***a*. In accordance with the invention, any of the components of rotary earth bit **110** and mechanized boring cutter **150** can correspond to rotary earth bit component **105** of FIGS. **1***a* and **1***b*. Hence, any of the components of bit **110** and cutter **150** can be casehardened using an earthboring tool casehardening system, as will be discussed in more detail presently.

[0053] FIG. **4** is a perspective view of an earthboring tool casehardening system **170**, in accordance with the invention. In this embodiment, earthboring tool casehardening system **170** includes a rotary system **160** operatively coupled with a shaft **161**. Earthboring tool casehardening system **170** includes a motor (not shown) that operates to rotate shaft **161**. In accordance with the invention, an earthboring tool component is coupled with shaft **161** so it will rotate in response to the rotation of shaft **161**. In this particular example, the earthboring tool component is embodied as cutting cone **112**, wherein cutting surface **117** faces upwardly and away from rotary system **160**, and channel **135** (FIG. **2***d*) faces downwardly towards rotary system **160**.

[0054] In accordance with the invention, earthboring tool casehardening system **170** includes mechanical arm **101** which carries light emitting device **100**, as described in more detail above with FIGS. **1***a* and **1***b*. In this embodiment, mechanical arm **101** is positioned proximate to rotary system **160** so that the optical axis of light emitting device **100** is directed at cutting surface **117** of cutting cone **112**. Mechanical arm **101** can move light emitting device **100** relative to rotary system **160** and cutting cone **112**. For example, mechanical arm **101** can move light emitting device **100** in directions **102***a* and **102***b*, as shown in FIG. **1***a*. Mechanical arm **101** can also move light emitting device **100** in directions **102***d* and **102***e*, as shown in FIG. **1***b*.

[0055] In operation, light emitting device **100** emits light **104** which is incident to surface **117**. Light **104** heats surface **117** within, and proximate to, light receiving region **107**. Hence, portions of cutting cone **112** proximate to and at a depth below light receiving region **107** are heated and casehardened in response to light **104**. As discussed above, the depth below surface **117** that is casehardened is often referred to as the case depth. After surface **117** has been casehardened, it can be treated, such as by sanding, if desired.

[0056] It should be noted that cutting cone **112** can be rotated about axis **119**, if desired, by rotating shaft **161** with the motor of rotary system **160**. As cutting cone **112** rotates, light receiving region **107** moves relative to surface **117** so that the portion of surface **117** that is casehardened is increased. It should be noted that system **170** can caseharden other surfaces of cutting cone **112**, one of which will be discussed in more detail presently.

[0057] FIG. **5** is a perspective view of earthboring tool casehardening system **170**, wherein rotary system **160** carries cutting cone **112** so that channel **135** faces upwardly away from rotary system **160** and cutting surface **117** faces downwardly towards rotary system **160**. In this embodiment, mechanical arm **101** is oriented so that light emitting device **100** is directed to an inner surface **122** within channel **135**, as better seen in a cross-sectional view of cutting cone **112**, which is indicated by an indication arrow **161**. Inner surface **122** can correspond to many surfaces of cutting cone **112**, such as surfaces **115***a* and **115***b* and **121***a*-**121***f* (FIG. **2***d*). Cutting cone **112** can be rotated around axis **119**, if desired, by rotating shaft **161** with the motor of rotary system **160**. As cutting cone **112** rotates, light receiving region **107** moves relative to surface **122** so that a larger portion of it is casehardened.

[0058] It should be noted that mechanical arm **101** can position light emitting device **100** outside of channel **135** so that its optical path **104** is directed at surface **122**. However, in this example, mechanical arm **101** positions light emitting device **100** so device **100** extends into channel **135**. In this way, optical path **104** of light emitting device **100** is directed at surface **122** without using mirrors.

[0059] It should also be noted that system **170** can be used to caseharden many other earthboring tool components and surfaces, such as the outer surfaces of bearings **116***a*-**116***d* and **118***a*-**118***b*, as well as surfaces **114***a* and **114***b* of hub unit **113** (FIG. **2***c*). Further, mechanical arm **101** can be adjusted to move light emitting device **100** in directions **102***a* and **102***b*, as shown in FIG. **1***a*, and directions **102***d* and **102***e*, as shown in FIG. **1***b*. Further, system **170** can be used to caseharden other earthboring tool components, as will be discussed in more detail presently.

[0060] FIG. **6** is a perspective view of earthboring tool hardening system **170**, wherein lug **111** is coupled with shaft **161** so it rotates therewith. In this way, cutting cone **112** (FIGS. **4** and **5**) is replaced with lug **111**. This is useful so that cutting cone **112** and lug **111** can be casehardened separately and provided with different amounts of casehardening. Lug **111** is described in more detail above with FIGS. **2***a* and **2***b*.

[0061] In one example, mechanical arm **101** carries light emitting device **100** so it is directed at surface **111***a* of lug **111**. Lug **111** is rotated so that light emitting area **107** is moved around surface **111***a* to caseharden it. After surface **111***a* is sufficiently casehardened, mechanical arm **101** moves light emitting device **100** in direction **102***b* so it is directed at surface **111***b*. Lug **111** is rotated so that light emitting area is moved around surface **111***b* to caseharden it. After surface **111***b* is sufficiently casehardened, mechanical arm **101** moves light emitting device **100** in direction **102***b* so it is directed at surface **111***c*. Lug **111** is rotated so that light emitting area **107** is moved around surface **111***c* to caseharden it. When casehardening surfaces **111***a*, **111***b*, and **111***c*, light emitting device **100** can also move in direction **102***a*, **102***d*, and **102***e*, if necessary, as discussed above in FIGS. **1***a* and **1***b*.

[0062] It should be noted that mechanical arm **101** can move light emitting device **100** so it is directed at surface **111***d* so that surface **111***d* is casehardened. Further, it should be noted that surfaces **111***a*, **111***b* and **111***c* can be casehardened in many other orders than the one discussed here. It should also be noted that surfaces **123***a*-**123***f* and surfaces **114***a* and **114***b* of hub unit **113** can also be casehardened, if desired. In this way, the position of light emitting device **100** is moved to direct light **104** to different surfaces of lug **111**.

[0063] After the desired portions of lug **111**, cutting cone **112** and/or hub unit **113** are casehardened, they can be removed from system **170** and coupled together to assemble earthboring tool **110**, as discussed in more detail above with FIGS. **2***a*, **2***b*, **2***c* and **2***d*. For example, surfaces **114***a* and **115***a* of hub unit **113** and cone **112**, respectively, can be casehardened, and then hub unit **113** and cone **112** can be coupled together, as shown in FIGS. **2***c* and **2***d*. In this way, surfaces **114***a* and **115***a* face each other, respectively. In this way, surfaces from two different earthboring tool components are casehardened and positioned so they face each other. This is useful because surfaces **114***a* and **115***a* generally engage each other during the normal operation of rotary earth bit **110**. Hence, by casehardening surfaces **114***a* and **115***a*, the amount of wear they experience is decreased. It should be noted that other surfaces of cutting cone **112** and hub unit **113** that face each other can also be casehardened so they experience less wear.

[0064] FIG. **7** is a flow diagram of a method **200** of casehardening an earthboring tool, in accordance with the invention. In this embodiment, method **200** includes a step **201** of providing a first earthboring tool component and a step **202** of providing a semiconductor light emitting device carried by a mechanical arm. Method **200** also includes a step **203** of directing light emitted by the semiconductor light emitting device to a first surface of the first earthboring tool component.

[0065] In some embodiments, method **200** includes a step of moving, along a predetermined path, the position of the semiconductor light emitting device relative to the first earthboring tool component. Method **200** can also include a step of moving the position of the semiconductor light emitting device to direct the light to a second surface of the first earthboring tool component. Method **200** can include a step of rotating the first earthboring tool component so the optical path of the light emitting device moves along its surface. Method **200** can further include a step of replacing the first earthboring tool component with a second earthboring tool component and repeating one or more of the steps of method **200**.

[0066] In some embodiments, method **200** can also include a step of adjusting, with the mechanical arm, the distance between the semiconductor light emitting device and first surface to adjust the amount of optical power applied to the surface. Method **200** can further include a step of adjusting, with the mechanical arm, the angle of incidence of the light to adjust the case depth, as well as the amount of optical power applied to the first surface. Method **200** can also include steps of adjusting the optical power and/or frequency of the light emitted by the light emitting device. Method **200** can also include steps of adjusting the mode of operation of the light emitting device.

[0067] FIG. **8** is a flow diagram of a method **210** of assembling an earthboring tool, in accordance with the invention. In this embodiment, method **210** includes a step **211** of providing an earthboring tool which includes first and second earthboring tool components and a step **212** of rotating the first earthboring tool component. The first earthboring tool component can be rotated in many different ways, such as with an earthboring tool casehardening system.

[0068] Method **210** also includes a step **213** of directing light from a semiconductor light emitting device to a surface of the first earthboring tool component so it is casehardened. In accordance with the invention, the semiconductor light emitting device is carried by a mechanical arm. In some embodiments, method **210** includes a step of adjusting the distance between the semiconductor light emitting device and the surface by adjusting the position of the mechanical arm. Method **210** can also include a step of adjusting the angle of incidence of the light relative to the surface by adjusting the position of the mechanical arm.

[0069] Method **210** can further include a step of replacing the first earthboring tool component with the second earthboring tool component so that light from the light emitting device is directed at it so it is casehardened. The second earthboring tool component can be rotated, if desired, with the earthboring tool casehardening system. It should be noted that method **210** often includes a step of coupling the first and second earthboring tool components together after they have been casehardened with the semiconductor light emitting device. In some situations, the surfaces of the first and second earthboring tool component that have been casehardened are positioned so they face each other. In this way, they experience less wear when they are engaged together.

[0070] FIG. **9** is a flow diagram of a method **220** of assembling an earthboring tool component, in accordance with the invention. In this embodiment, method **220** includes a step **221** of providing the earthboring tool component and a step **222** of coupling the earthboring tool component to a rotary system. Method **220** includes a step **223** of providing a mechanical arm which carries a semiconductor light emitting device and a step **224** of directing light emitted by the semiconductor light emitting device to a first surface of the earthboring tool component.

[0071] In some embodiments, method **220** includes a step of moving the semiconductor light emitting device along the surface of the earthboring tool component with the mechanical arm. Method **220** can also include a step of rotating the earthboring tool component with the rotary system. Method **220** can further include a step of moving the semiconductor light emitting device, with the mechanical arm, so the light is directed to a second surface of the earthboring tool component.

[0072] It should be noted that, in some embodiments, the earthboring tool component includes a channel and the channel is bounded by the first surface. The semiconductor light emitting device can be positioned, with the mechanical arm, so it is outside of the channel and its optical axis is incident to the first surface. However, the semiconductor light emitting device can be positioned, using the mechanical arm, so that it extends into the channel. In this way, the optical axis of the light emitting device is directed at the first surface without using mirrors. The earthboring tool component, if desired, can be rotated while the semiconductor light emitting device extends into the channel.

[0073] The embodiments of the invention described herein are exemplary and numerous modifications, variations and rearrangements can be readily envisioned to achieve substantially equivalent results, all of which are intended to be embraced within the spirit and scope of the invention.

1. A method of casehardening an earthboring tool, comprising:
- providing a first earthboring tool component;
- providing a semiconductor light emitting device carried by a mechanical arm; and
- directing light emitted by the semiconductor light emitting device to a first surface of the first earthboring tool component.

2. The method of claim **1**, further including rotating the first earthboring tool component.

3. The method of claim **1**, further including adjusting, with the mechanical arm, the distance between the semiconductor light emitting device and first surface to adjust the amount of optical power applied to the first surface.

4. The method of claim **1**, further including adjusting, with the mechanical arm, the angle of incidence of the light incident to the first surface to adjust the amount of optical power applied to the first surface.

5. The method of claim **1**, further including moving, along a predetermined path, the position of the semiconductor light emitting device relative to the first earthboring tool component.

6. The method of claim **1**, further including moving the position of the semiconductor light emitting device to direct the light to a second surface of the first earthboring tool component.

7. The method of claim **1**, further including directing light emitted by the semiconductor light emitting device to a second earthboring tool component.

8. A method of assembling an earthboring tool, comprising:
- providing an earthboring tool which includes first and second earthboring tool components;
- rotating the first earthboring tool component;
- directing light from a semiconductor light emitting device to a surface of the first earthboring tool component.

9. The method of claim **8**, wherein the semiconductor light emitting device is carried by a mechanical arm.

10. The method of claim **9**, further including adjusting the distance between the semiconductor light emitting device and the surface by adjusting the position of the mechanical arm.

11. The method of claim **9**, further including adjusting the angle of incidence of the light relative to the surface by adjusting the position of the mechanical arm.

12. The method of claim **8**, further including replacing the first earthboring tool component with the second earthboring tool component.

13. The method of claim **12**, further including rotating the second earthboring tool component and directing light from the semiconductor light emitting device to its surface.

14. The method of claim **13**, further including coupling the first and second earthboring tool components together.

15. A method of assembling an earthboring tool, comprising:
- providing an earthboring tool component;
- coupling the earthboring tool component to a rotary system;
- providing a mechanical arm which carries a semiconductor light emitting device;
- directing light emitted by the semiconductor light emitting device to a surface of the earthboring tool component.

16. The method of claim **15**, further including moving the semiconductor light emitting device relative to the surface of the earthboring tool component with the mechanical arm.

17. The method of claim **15**, further including rotating the earthboring tool component with the rotary system.

18. The method of claim **15**, wherein the earthboring tool component includes a channel and the surface is bounded by the channel.

19. The method of claim **18**, wherein the semiconductor light emitting device extends into the channel.

20. The method of claim **15**, further including moving the semiconductor light emitting device, with the mechanical arm, so the light is directed to another surface of the earthboring tool component.

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