219-121 CROSS REFERENCE SEARCH ROOM

Feb. 14, 1967 W. W. CARGILL, JR., ETAL 3,304,460

MEANS FOR PRODUCING RADIANT ENERGY

Filed April 27, 1964

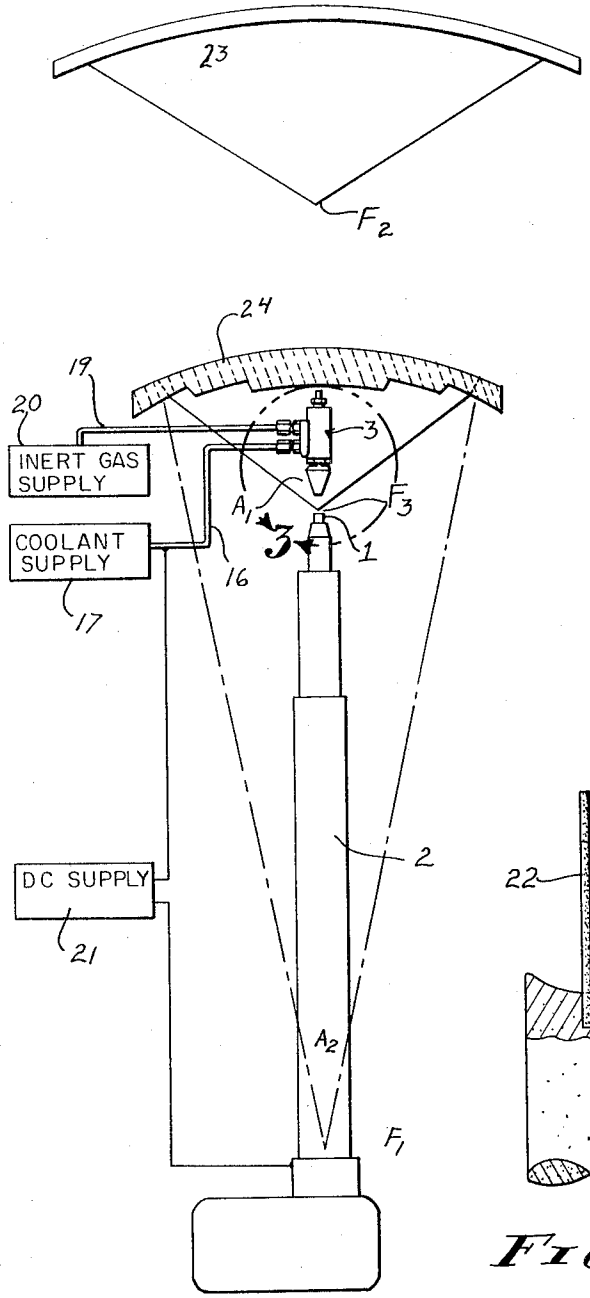


FIG. 1

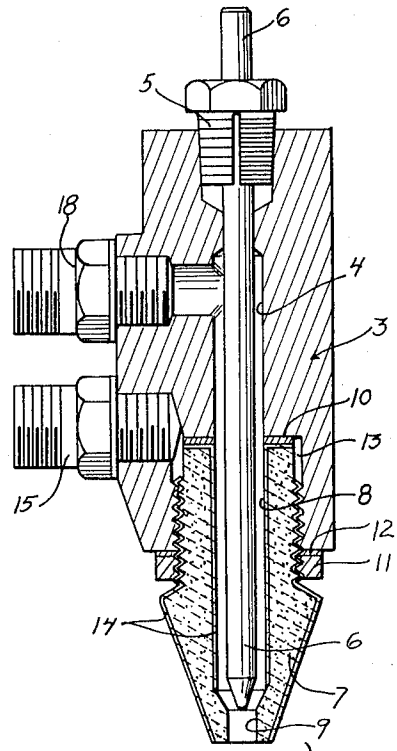


FIG. 2

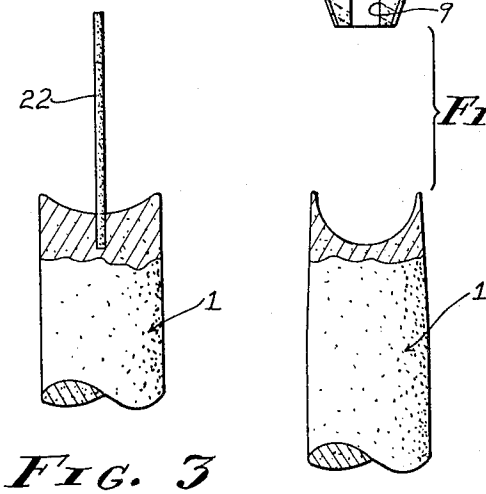


FIG. 3

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United States Patent Office 3,304,460
Patented Feb. 14, 1967

3,304,460

MEANS FOR PRODUCING RADIANT ENERGY

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Filed Apr. 27, 1964, Ser. No. 364,356
15 Claims. (Cl. 314—21)

This invention relates to a source of radiant energy and more particularly relates to a source for producing stable, high intensity radiant energy having a desirable spectral distribution.

This is a continuation-in-part application of our co-pending application, now abandoned, Serial Number 181,-377, filed March 21, 1962, and entitled "Means for Producing Radiant Energy."

There are many applications for high intensity radiant energy sources. For example, the commercial projection of motion pictures requires an extremely intense, well concentrated source for use with the conventional optical system. Because of the optical system, the source must be extremely stable in a positional sense so that proper focusing is not detrimentally affected. Similar considerations are present in almost all uses of a high intensity source, as they are almost always the focal point of some optical system. Carbon arcs are the most commonly used source for such purposes and are generally quite satisfactory up to a point. At the high power levels often required by the nature of the application or the inefficiency of the optical system, a carbon arc begins to become unstable and distorts the image projected. Xenon lamps have been used as substitutes for carbon arcs but also are subject to stability limitations at high power levels.

Another important application in which carbon arcs are used is in the simulation of the solar spectrum. Solar simulators are used to determine the effects of undistorted and unfiltered solar radiation on objects to be positioned in outer space. The solar spectrum has been calculated to have a radiation distribution approximating that of a 6000° K. black body radiator. Since this is a higher color temperature than is attainable with the conventional carbon arc, cored electrodes have been developed that contain a mixture of various rare earths and carbon. The contributions of the various elements result in a composite spectrum that is very similar to that of the sun.

Such cored electrode arc systems have two major disadvantages: first, the rare earths, when volatilized, form compounds that deposit on and cloud the system optics; and second, the period of operation is limited to the length of the consumed cathode, as it has been found that the arc is extinguished when a cathode joint is reached. The maximum operational time of an arc of this type is presently about 24 hours, a period much shorter than that usually required in tests of devices to be used in space.

It is therefore an object of the present invention to provide a source of high intensity radiant energy that remains stable at extremely high power levels.

It is also an object of the present invention to provide such a source utilizing a constricted, transferred arc.

It is another object of the present invention to provide such a source in which the maximum color temperature obtainable is far in excess of those heretofore available.

It is a further object of the present invention to provide such a source which can be operated over extended periods of time.

It is a still further object of the present to provide such a source whose total output is variable during operation.

It is yet another object of the present invention to provide such a source whose color temperature is variable during operation.

It is a further object of the present invention to provide

such a source whose output characteristics can be closely controlled during operation.

It is a still further object of the present invention to provide such a source having an energy distribution closely approximating the solar spectrum.

It is a yet further object of the present invention to provide a method of producing high intensity radiant energy.

According to the present invention, these objects are accomplished by providing an arc producing system having a carbon anode, a tungsten cathode, a source of electrical energy for causing an arc to be struck and maintained between the electrodes, and means for constricting the arc in a well defined column. The intensity of the arc produced by this system has been found to be directly related to the voltage as well as to the current and thus its power handling capacity is greatly increased over conventional carbon arcs which are essentially responsive only to changes in current. By use of a constricted, transferred arc in a system having a carbon anode, it has been found that extremely high color temperatures can be attained, temperatures appreciably higher than the sublimation temperature of carbon.

Color temperatures approaching 6000° K. have been reached and maintained and consequently the arc of the present invention makes a very satisfactory solar simulator without the necessity of providing expensive cored carbon electrodes. Since only the anode is replenished, there is no limit to the operating period of the system and thus the most exhaustive tests may be conducted. The arc, being extremely stable at high power levels, is readily adaptable for use with even the most demanding optical systems.

These and other objects and advantages of the present invention will become more apparent upon reference to the accompanying description and drawings in which:

FIGURE 1 is a substantially diagrammatical view showing a source of radiant energy according to the present invention arranged in conjunction with an optical system for concentrating the energy;

FIGURE 2 is an enlarged, fragmentary, sectional view within circle 2 of FIGURE 1;

FIGURE 3 is a fragmentary view showing the carbon anode in its original state with a starting pencil for the purpose of initiating the arc.

The source of producing radiant energy includes an anode 1 formed of carbon. The anode may be pure graphite or it may contain various additives, such as the salts of various metals, which modify the spectrum of the arc produced in the well known manner. As used in this application, the term "carbon anode" is therefore intended to include anodes formed of pure carbon and those formed of carbon and minor portions of such metallic salts. The anode 1 is supported at the end of an anode feeding means 2 which, for the purposes of this application, may be considered as conventional. The feeding means 2 is arranged to move the anode 1 forwardly at its tip is consumed.

Disposed in coaxial relation with the anode 1 and spaced forwardly therefrom is a cathode holder 3 essentially in the form of a cylinder having a central bore. The end of the bore 4 remote from the anode 1 is constricted and is provided with a clamping collet 5 for the purpose of securing a cathode 6 in concentric relation with the bore 4. The cathode 6 is substantially smaller in diameter than the bore 4 so as to form therewith an annular passage. The anode is positioned relative to the cathode such that when an arc is established the arc attachment area of the anode will be substantially normal to the arc column.

The cathode 6 is preferably formed of tungsten or tungsten alloy, although in some instances other refractory metals may be used.

The end of the cathode holder 3 confronting the anode 1 is provided with a tip member 7, preferably formed of a porous ceramic material capable of withstanding high temperatures. The tip member 7 is provided with a bore 8 forming a continuation of the bore 4. The bore 8 is constricted at the extended end of the tip member 7 to form a nozzle port 9. The tip of the cathode 6 preferably terminates within the bore 8 adjacent the nozzle port 9, but may extend outwardly therefrom.

The tip member 7 may be screw-threaded into the holder 3 and a gasket 10 interposed between the inner end of the tip member 7 and the holder 3. The tip member 7 is also provided with a sealing nut 11 and gasket 12 to seal the tip member 7 at its plane of emergence from the cathode holder 3. Adjacent the inner end of the tip member 7 the tip member defines an annular coolant chamber 13.

The interior and exterior surfaces of the tip member 7 are provided with an impervious coating 14 except for the extreme end of the tip member confronting the anode 1, and if desired the walls of the nozzle port 9. The porous nature of the tip member 7 permits a coolant to flow therethrough and effect transpiration cooling of its extreme end confronting the anode 1. The tip member 7 is preferably tapered externally so as to present a minimum surface to the radiant energy generated at the anode 1. Alternatively, a sealed coolant chamber may be formed within the holder and tip member through which a coolant is circulated in a conventional manner.

The cathode holder 3 is provided with a lateral opening which communicates with the coolant chamber 13 and receives a coolant supply fitting 15 connected with a coolant supply line 16 which in turn is connected with a coolant supply 17. The cathode holder 3 is also provided with a lateral opening communicating with the bore 4 and provided with an inert gas supply fitting 18, which is connected through a supply line 19 with an inert gas supply 20.

A D.C. source 21 is electrically connected to the anode 1 through the anode feeding means 2 and with the cathode holder 3 and cathode 6 through either or both of the supply lines 16 or 19.

Operation of this system is as follows:

For establishing an arc between the cathode 6 and anode 1, a small carbon starting pencil 22 may be extended initially from the anode 1 into close proximity with the cathode 6. Other conventional starting means such as a high frequency starter may also be used to initiate the arc. Prior to arc initiation, an inert gas, such as helium, argon, or nitrogen, or mixtures thereof, is introduced through the supply line 19 so as to form a laminar gas flow from the nozzle port 9 toward the anode 1.

Laminar flow in this connection means a flow of gas which is essentially undisturbed by turbulence. The gas molecules all move along substantially parallel lines with all radial motion components eliminated and thus form layers of gas. The transferred arc is established in the center or core of this laminar gas flow and causes the gas adjacent the arc to become ionized and form a plasma. The laminar flow of gas surrounding the arc constricts the arc and prevents it from rapidly broadening into a bell shape as occurs in a conventional carbon arc. The degree of constriction can be varied by varying the parameters of the nozzle structure, flow rate, etc. In any event, the arc column is relatively well defined and has a generally uniform cross-section along its length. If desired, other means of constricting the arc may be used. For example, the arc may be constricted by suitably established magnetic fields, or turbulent gas flow may be substituted for laminar flow.

In the formation of a plasma, the arc is believed to act on the surrounding gas to generate ionized particles and free electrons in the same vicinity. The plasma may be compressed to form a stream and may be used as a conductor, as in the case of a transferred plasma arc. When the ionized particles regain the electrons lost in the ionization process, they release the energy required to effect the separation in the first place. This energy appears as heat and if confined to a constricted zone results in the production of very high temperatures. This characteristic is presently taken advantage of in plasma arc torches and similar devices. Such devices have metallic anodes, generally constructed of copper.

As previously stated, the anode of the present invention is constructed of carbon. Carbon has many characteristics which make it the best substance generally for a source of radiant energy. It has an emissivity of about 78% of that of a black body (the highest of any known substance). It does not melt, but sublimates, and at the highest temperature any material is known to exist in the solid form, approximately 4000° K. Also carbon is a conductor and is relatively inexpensive, and has high thermal shock resistance. It is easily molded, formed, and machined. It actually gains in physical strength with increased temperatures.

The precise mechanism involved in the operation of the present invention is not completely understood; however, the following commentary appears to be a logical and probable explanation of the phenomena.

In the conventional carbon arc, the arc assumes a bell shape due to a scattering effect caused by collisions between the electrons leaving the cathode and gas particles interposed between the cathode and anode. The mean free path of the electrons is quite short, and consequently they are at a relatively low energy level when they reach the anode. By constricting the arc, as by use of a laminar gas flow, the path of the electrons moving from the cathode toward the anode will be substantially cleared of particles and consequently the probability of collisions will be greatly decreased as will the effects of any other external forces tending to displace or widen the arc.

As the probability of collisions decreases, the mean free path of the electrons increases with the result that an electron, when it does have a collision, will be at a high enough energy level to cause the interfering particles to move completely out of the path of following electrons through an increase in its thermal energy activity. After the arc has been established, almost all particles will be removed from the path of the electrons, and any that happen to drift into the path will be rapidly caused to leave by the electrons on the fringe of the arc column. The core of the column will thus be traversed solely by electrons having extremely long mean free paths and very high energy levels.

When these high energy electrons first hit the surface of the carbon anode, they impart sufficient energy to the surface atoms to free monoatomic carbon particles which tend to form a sheath or shield across the face of the anode in the path of the electrons. As a result of transfer of energy from the electrons, these carbon ions are in a highly excited state and will pick up even more energy as they intercept further electrons from the cathode and their valence electrons absorb the further energy from the cathode's electrons. The presence of the carbon particles thus creates a region of energy exchange that acts to detain the cathode electrons sufficiently to affect a space charge whose equilibrium conditions provide cathode electrons to the carbon surface with just sufficient energy to maintain the rate of flow of carbon particles through which this equilibrium is maintained. Thus any additional energy imparted to the electrons between the cathode and sheath is largely transferred to the carbon particles at the sheath region and then converted to radiant energy.

When an atom of any substance receives additional energy beyond its minimum necessary or ground state, it is considered to be excited. Such an excited atom tries to lose its excess energy and return to the ground state. It does so by emitting quanta of radiant energy, the frequency of which is dependent upon the energy drop in-

volved. Ultimately, equilibrium exists between input and output for the atom, and this macroscopically is generally expressed in degrees Kelvin. The recombination of the electrons and ions in the plasma also appears to contribute to the radiant energy output.

Since the energy possessed by the electrons when they reach the anode or the sheath in front of it has an important effect on the energy reached by the valence electrons of the atoms in the sheath, variations in the voltage as well as variations in current density affect the nature of the radiant energy produced. Thus, the length of the arc and the input power can be increased to produce a corresponding increase in intensity. Arc lengths of up to 15 inches and color temperature readings in excess of 5800° K. have been reached without any indications that these values are limits. The response to changes in either voltage or current provide the system with great control versatility.

In producing arcs of great length, it is, of course, necessary to initiate the arc at a shorter distance and then move the cathode and anode away from each other to the desired distance. The longer arc offers wide benefits in that the advantages of transpirational cooling are increased by the greater distance of the cathode holder tip from the carbon crater, and that also the longer arc minimizes optical obscuration in certain applications.

The coolant may be an inert gas, in fact may be identical to the inert gas supplied through the nozzle port **9**. Inasmuch as the pressures required may be different for the coolant and the inert gas, separate lines are desirable. The coolant, however, need not be identical to the inert gas. For example, it may be desirable to use argon or helium as the inert gas which is raised to the plasma state and utilize nitrogen as a coolant, which issues from the pores of the nozzle at a much lower rate and tends to remain outside the zone of extreme temperature.

The amount of commingling of the coolant and the inert gas may be controlled by selecting the surfaces of the nozzle which remain uncoated or pervious. For example, less commingling occurs if the nozzle port **9** as well as the bore **8** are made impervious. Still further, it should be noted that the coolant may be a liquid which vaporizes at or immediately within the pervious surface of the tip member **7**. Still further, either or both of the inert gas and coolant may be introduced to the cathode holder structure in a liquid state.

The system is well adapted for use with optical systems requiring a stable source of high intensity radiant energy. As has previously been pointed out, the radiation of the sun in space approximates that of a 6000° K. black body radiator. The system of the present invention provides a source than can be made to closely approximate this and thus makes an ideal solar simulator. Since a solid carbon anode is used, no compounds are formed that will deposit on and cloud the associated optics. The solid carbon is, of course, much cheaper than the previously used cored carbon electrodes and hence very desirable in this regard. Perhaps the greatest advantage of the present system is that it requires only a replenishable anode and thus may be operated for much longer periods of time than systems that also require a replenishable cathode.

Another example of an optical arrangement with which the arc previously described may be used is shown in FIGURE 1. This system includes an ellipsoidal mirror **23** which is capable of establishing a distal focal point F_1 and a proximal focal point F_2. A Fresnel lens **24** is interposed between these two focal points.

The Fresnel lens **24** intersects the rays originating at F_3 and concentrates them for direction to the mirror **23**, which views them as if they originated at distal focal point F_1. The mirror **23** focuses the image thus produced at proximal focal point F_2. The included angle A_1 between rays originating at the focal point F_3 is substantially greater than the included angle A_2 between corresponding rays if they originated at focal point F_1. Thus a substantially larger proportion of radiant energy originating at focal point F_3 is transmitted by the Fresnel lens to the elliptical mirror **23** than would be the case if the Fresnel lens were omitted and the radiant energy originated at F_1.

More specifically, the cathode **6** and anode **1** are so positioned with respect to the Fresnel lens **24** that the region of greatest radiant energy output, i.e., the anode region, of the arc coincides with the focal point F_3. By reason of the large angle A_1 and the relatively small size of the cathode **3**, the shadow of the cathode has only a negligible effect on the energy transmitted through the Fresnel lens. Thus, by use of the Fresnel lens a substantially greater percentage of the radiant energy emitted by the arc at the focal point F_3 is utilized than would be the case if the Fresnel lens were omitted and the radiant energy was emitted from the focal point F_1.

By utilizing the ellipsoidal mirror **23** an image reduction is obtained. That is, the image of the arc at F_2 is substantially smaller than the arc at its origin, and the radiant energy is correspondingly concentrated and intensified. The diameter of the concentrated image may be as much as one-third the diameter of the arc at its origin or even smaller.

While a particular embodiment of this invention has been shown and described, it is not intended to limit the same to the exact details of the construction set forth, and it embraces such changes, modifications, and equivalents of the parts and their formation and arrangement as come within the purview of the appended claims.

We claim:

1. A source of radiant energy comprising a carbon anode, a tungsten cathode disposed in spaced relation to said anode, means for establishing an arc between said cathode and said anode, and means for surrounding said arc with flowing gas to constrict said arc in a column having a generally uniform cross-section along its length.

2. The source of claim **1** wherein said anode has a relatively flat arc attachment area and said cathode is disposed relative to said anode such that said arc attachment area is normal to said arc column.

3. A source of radiant energy comprising a tungsten cathode, a holder for said cathode covering said cathode and defining therewith a passage for the flow of gas around said cathode, a carbon anode disposed in spaced relation with said cathode, means for establishing an arc between said cathode and said anode, and means for supplying gas for flow through said passage to produce an envelope of said gas about said arc and constrict said arc in a column having a generally uniform cross-section along its length.

4. The source of claim **3** wherein said carbon anode has a relatively flat arc attachment area and is disposed relative to said cathode such that said arc attachment area is normal to said arc column.

5. A source of radiant energy comprising a tungsten cathode, means for mounting said cathode, a carbon anode disposed in spaced relation with said cathode, means for establishing an arc between said cathode and said anode, a source of inert gas, and means for establishing a laminar flow of said gas around said arc to constrict said arc in a well defined column.

6. A source of radiant energy, comprising a cathode holder having a bore and terminating in a porous ceramic tip, a substantially nonconsumable cathode centered in said bore having an operating end recessed in said ceramic tip, a carbon anode spaced from said cathode, means for establishing an arc between said cathode and anode, means for introducing an inert gas through said bore and axially around said arc whereby said arc is constricted in a well defined column, and means for causing a coolant to flow through said ceramic tip and issue from the surfaces thereof exposed to said arc.

7. The source of claim **6** wherein said means for introducing inert gas and the means for causing flow of a

coolant through said ceramic tip are supplied from a common source.

8. The source of claim 6 wherein said means for introducing inert gas and the means for causing flow of a coolant through said ceramic tip are supplied from different sources.

9. A system for supplying high intensity radiant energy comprising a carbon anode, a metallic cathode disposed in spaced relation to said anode, means for establishing an arc between said cathode and said anode, means for constricting said arc in a well defined column, and optical means optically associated with said column for projecting an image of the anode region thereof.

10. A system for supplying high intensity radiant energy comprising a tungsten cathode, a holder for said cathode covering said cathode and defining therewith a passage for the flow of gas around said cathode, a carbon anode disposed in spaced relation with said cathode, means for establishing an arc between said cathode and said anode, means for supplying gas for flow through said passage to produce an envelope of said gas about said arc and constrict said arc in a column having a generally uniform cross-section along its length, and optical means optically associated with said column for projecting an image of the anode region thereof.

11. A system for concentrating radiant energy, comprising a source of radiant energy, a Fresnel lens positioned to intersect rays diverging from said source, a concave mirror establishing proximal and distal focal points, said Fresnel lens being positioned between said proximal and distal focal points, and oriented to cause the divergent rays from said source of radiant energy to have an apparent origin at said distal focal point thereby to focus at said proximal focal point.

12. A system for supplying high intensity radiant energy comprising a carbon anode, a metallic cathode disposed in spaced relation to said anode, means for establishing an arc between said cathode and said anode, means for constricting said arc in a well defined column, a Fresnel lens positioned to intersect rays diverging from the anode region of said column, a concave mirror establishing proximal and distal focal points, said Fresnel lens being positioned between said proximal and distal focal points, and oriented to cause the divergent rays from said anode region to have an apparent origin at said distal focal point thereby to focus at said proximal focal point.

13. A method of producing radiant energy comprising establishing an arc between a tungsten cathode and a carbon anode, said anode being positioned relative to said cathode such that the area of arc attachment of said anode is normal to said arc, and surrounding said arc with flowing gas to constrict said arc in a column having a generally uniform cross-section along its length.

14. A method of producing radiant energy comprising spacially positioning a tungsten cathode and a carbon anode, establishing a laminar flow of an inert gas from said cathode to said anode and establishing an arc between said cathode and said anode, said arc being generally parallel to said laminar gas flow whereby said gas constricts said arc in a well defined column.

15. The method of claim 14 wherein said anode is oriented relative to said cathode such that the area of arc attachment of said anode is normal to said arc column.

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