

Description

Background of the Invention

This invention relates to arc discharge devices such as segmented plasma excitation and recombination (SPER) devices and, in particular, to low voltage arc formation between adjacent electrodes of such devices.

In *Applied Physics Letters*, Vol. 36, No. 8, pages 615—617 (1980), W. T. Silfvast, L. H. Szeto and O. R. Wood II describe a new electric discharge device developed for producing laser action in the atomic spectra of a number of metal vapors by a segmented plasma excitation and recombination (SPER) mechanism. This laser includes a number of narrow metal strips (of the lasing species) positioned end-to-end on an insulating substrate in such a way as to leave a small gap between each pair of adjacent strips. The strips are surrounded by either a buffer gas (preferably) or a vacuum and typically are 0.1—1 mm thick, 2 mm wide, and 10 mm long. When a high-voltage, high-current pulse is applied to the end strips of this arrangement, a high-density metal-vapor ion plasma is formed in each gap. Once formed, these plasmas (consisting primarily of vaporized strip material) expand essentially hemispherically into a laser cavity, cool in the presence of the background gas (e.g., helium) at low pressure and recombine.

The SPER laser is simple to construct, can be easily scaled in length and volume, has been shown to be capable of long life, and has the potential for high efficiency. It is the subject matter of U.S. Patent 4,336,506 issued on June 22, 1981.

The excitation means utilized in the prior known segmented plasma arc discharge apparatus typically includes a high voltage supply and a low voltage supply connected in parallel. The high and low voltages are applied sequentially to the device. Illustratively, the high voltage (a few kilovolts) serves to breakdown the gaps between adjacent electrodes. Thereafter, the low voltage (20 V D.C. at a few amperes) serves to sustain the arc discharge (i.e., the plasma).

Summary of the Invention

We have found that arc discharge devices according to the precharacterised part of Claim 1 can be operated without the need for a high voltage supply to break-down the gap(s). In accordance with our invention, a thin film bridges the gap between adjacent electrodes thereby reducing the voltage of said signal required to initiate said plasma. Thus a low voltage supply alone is sufficient to generate the plasma and to sustain operation. For example, 20—30V batteries have been used to operate SPER lasers.

Brief Description of the Drawing

FIG. 1 is a schematic of an illustrative embodiment of a continuous wave SPER laser which is exemplary of the configuration of SPER devices in general;

FIG. 2 is a schematic of a SPER device with a thin film deposited in the gap between a pair of electrodes in accordance with one embodiment of our invention;

FIG. 3 is a schematic of another embodiment of our invention in which a pair of electrodes are placed on top of the thin film which bridges the gap between them;

FIG. 4 is an isometric view of still another embodiment of our invention for incorporating a liquid metal as part of the cathode electrode; and

FIG. 5 is a cross-section taken along line 5—5 of FIG. 4.

Detailed Description

Apparatus used for continuous wave or pulsed operation of a SPER laser in a metal vapor is shown in FIG. 1. A plurality of strip electrodes 101—106 are positioned in tandem on an electrically insulating substrate 120 in such a manner as to leave a small gap between each pair of adjacent strips. This electrode arrangement is then installed in a Pyrex® cross-shaped gas cell comprising a longitudinal glass tube 125 and a transverse glass tube 126. In prior usage, a high voltage supply 130 and a low voltage supply 132 are connectable in series across the first (101) and last (106) electrodes via switches 134 and 136, respectively. The high voltage supply, which typically provides a high voltage pulse (e.g., a few kV) to break-down the gaps, is no longer necessary to the operation of SPER devices as discussed hereinafter. After break-down initiates the discharge, low voltage supply 132 provides a lower voltage (e.g., 20 V D.C.) signal suitable for continuous wave or pulsed operation. In general, a signal which is longer in duration than a few milliseconds would be suitable for continuous wave operation. For operation longer than about 1 sec, well-known cooling means (not shown) should be incorporated to prevent the electrodes from overheating and melting. This excitation produces a bright vapor plasma of electrode material in each gap. Areas 141—145 in FIG. 1 depict the shape of the plasmas after they have expanded essentially hemispherically outward from the gaps into a background gas.

The entirety of each strip need not constitute a material (e.g., a metal) which is vaporizable into a plasma. It is sufficient if the cathode ends constitute such a material and that the anode ends constitute a nonvaporizable material under the operating condition of the device. Moreover, strips of different vaporizable materials can be mixed within a single device so as to yield a multi-color source.

Two dielectric spherical mirrors 150 and 151 are coated for maximum reflectivity as the desired lasing wavelength to form a resonator for the laser radiation. Illustratively, these mirrors are mounted near the ends of longitudinal tube 125 which contain windows 127 and 128. The optical axis 160 of this resonator is positioned parallel to and slightly above the row of electrodes. The output from this resonator, shown as arrow 170,

is focused through suitable filters onto a suitable photodetector (not shown).

A gas inlet 170 and a gas outlet 172 are provided in end plates 129 and 131, respectively, at opposite ends of transverse tube 126. For continuous wave operation, background gas, such as helium, is coupled from a source (not shown) through inlet 170 and is made to flow relatively rapidly (e.g., 500 l/min) across electrodes 101—106 to outlet 172 and then to a gas pump (not shown). For pulsed operation, gas flow across the electrodes is not necessary. For continuous wave operation gas flow is necessary and serves to move the ions in the plasma away from the arc discharges in the regions of the gaps and to cool the plasma. Arrows 174 show an illustrative direction of gas flow (e.g., transverse to resonator axis 160) which acts to cool the electrodes and allows for continuous wave operation. To this end, the gas flow should at least be in the vicinity of the gaps.

To enhance this effect it may be desirable to provide apertures 180 (e.g., slots) in substrate 120 between the electrodes; i.e., in the gaps. Background gas would thus flow not only around substrate 120 but also through it, thereby increasing the cooling interaction of the gas and the electrodes.

In accordance with our present invention, the need for the high voltage supply to break down the gap(s) of an arc discharge device is obviated by providing at least one thin film, illustratively metallic, which bridges the gap(s) between adjacent electrodes. Illustratively, each film is only a few micrometers thick (e.g., $<10\ \mu\text{m}$) and preferably has a resistance in the range about $5\ \Omega$ to $1000\ \Omega$, which is higher than the dynamic impedance of the arc between adjacent electrodes once the arc is established. Typically, the gaps are 1—3 mm wide and the background gas is He at about 6.65 mbar (5 Torr). As depicted in FIG. 2, a thin film 200 may be formed on the substrate 220 in the gap between adjacent electrodes 201 and 202. In this case, the electrodes are in contact with the substrate. Alternatively, as shown in FIG. 3, a thin film 204 may be formed to cover a larger area of substrate 220, and then separated electrodes 201 and 202 may be placed thereon.

The thin films 200 or 204 may be formed by any of numerous well-known processing techniques (e.g., evaporation, sputtering). In addition, for the embodiment of FIG. 2, we have used a short duration, high voltage pulse from high voltage supply 130 (FIG. 1) to evaporate material from electrode 201 (primarily). The evaporated material deposits itself as thin film 200. Note, the high voltage supply 130 is used only to form the film 200. Thereafter, the plasma is initiated and operation sustained with excitation provided only by low voltage supply 132.

The following examples are provided by way of illustration only. Device parameters and operating conditions, unless otherwise stated, are only intended to be alternative ways of carrying out the invention.

Example I

This example describes the application of our invention to the initiation of an arc discharge between a pair of Cd electrodes at low breakdown voltages (about 30 V). As shown in FIG. 2, these electrodes 201 and 202 were 10 mm diameter hemispherical rods which were 8.2 mm long, and were separated by a gap of approximately 1.5 mm, and were mounted on an Al_2O_3 substrate 220. Although not shown in the drawing, the facing ends of the two electrodes were tapered toward one another. The background gas was He at a pressure of about 6.55 mbar (5 Torr).

In order to form the thin film 200 which bridges the electrodes 201 and 202, the high voltage supply 130 of FIG. 1 was employed to generate an arc discharge between the electrodes. Illustratively, the high voltage supply provides 10 kV through a $3.5\ \mu\text{F}$ capacitor connected to ground and a $300\ \Omega$ resistor and spark gap connected in series with the electrodes 201 and 202. The current pulses from supply 130 evaporated Cd from the electrodes 201 and 202. A large fraction of the evaporated Cd was deposited on the surface of substrate 220 as a thin film 200 between the electrodes 201 and 202. This Cd film 200 was in electrical contact with the Cd electrodes 201 and 202.

After typically 5—20 current pulses the high voltage supply 130 was removed (switch 134 was opened), and the arc discharge was subsequently established using only the low voltage D.C. supply 132 with an output voltage of approximately 30 V applied for as short a time as 1 msec.

Although these observations occurred in a He gas of 6.65 mbar (5 Torr), similar low voltage breakdown occurred at higher and lower pressures in the observed range of 0.33—106 mbar (0.25—80 Torr).

The low voltage breakdown of the gap between electrodes 201 and 202 depends on the characteristics of the Cd film 200. It has been observed to occur when the resistance between the electrodes was approximately 5— $1000\ \Omega$ as measured when the power was off.

From a theoretical standpoint, the low voltage breakdown of the gap between electrodes 201 and 202 is believed to occur by the following mechanism. Initially, with the application of the low voltage pulse of about 30 V, current is established between the electrodes in the Cd film 200, and a voltage exists across the electrodes 201 and 202. Because the Cd film 200 is relatively thin ($\leq 10\ \mu\text{m}$), joule heating rapidly produces Cd vapor and electrons, resulting in Cd ions and additional electrons between the electrodes. These species provide between the electrodes a conducting filament which carries an increasing fraction of the current. Additional heating of the film due to increased current flow increases the conductivity of the filament so that the impedance of the filament drops below that of Cd film 200. The majority of the current is then carried by the filament and results in the observed arc discharge.

It is believed that the lowest voltage for which an arc discharge may be formed depends on gap width and on the electrode material employed. For gaps of 1—3 mm and Cd electrodes, the lowest voltage necessary is 20—25 V, which is in agreement with the experimental values of the voltage of 23—25V.

Example II

This example describes a pulsed Cd SPER laser operating at 1.433 μm . A 30 V transistor battery was utilized to initiate the arc discharge as described in Example I. The propulation inversion occurred in the Cd plasma as it expanded and recombined into a He background gas at a pressure of about 2.66—6.65 mbar (2—5 Torr). Laser action occurred during the delay of the input current pulse.

This SPER laser utilized a two electrode configuration (of the type shown in FIG. 2) which was substituted for the six electrode SPER device of FIG. 1. In addition, because only pulsed operation was utilized, the transverse flow 174 of the He gas was not necessary. In this experiment the 30 V transistor battery was utilized to charge a 500 μF capacitor through a 1 k Ω resistor. The charged capacitor was then discharged through the gap between electrodes 201 and 202 as previously described. As a result, an arc formed between the electrodes with a peak current of about 25 A, decaying to 1/e of that value in about 250 μsec . Laser action occurred during the decaying stage of the input current pulse after sufficient cooling of the expanding plasma had occurred. The laser pulse duration was about 200 μsec .

The laser action was observed for He pressures in the range of about 2.65—13.3 mbar (1.5—10 Torr) with the optimum value depending upon the distance of the arc discharge from the axis 160 of the resonator. Peak output power was estimated to be less than 1 mW and probably greater than 0.1 mW. No attempt was made to optimise the output.

In nearly identical experiments, the input voltage was reduced to 22.5 volts under different operating pressures and distances d between the arc and the resonator axis. For example, this lower voltage operation was achieved at a pressure of 3.33 mbar (2.5 Torr) with $d = 10$ mm and at a pressure of 4.65 mbar (3.5 Torr) with $d = 7.5$ mm.

Example III

In this experiment we measured the contact resistance and the thin film resistance of a SPER device of the type shown in FIG. 2. As described in Example I, both the electrodes and the thin film were made of Cd. We found that the Cd thin film 200 had a thin film resistance of 0.75 Ω . We measured no contact resistance between the anode electrode 202 and the thin film 200, but we measured a 3.5 Ω contact resistance between the cathode electrode 201 and the thin film 200.

Example IV

In this experiment we utilized a glass substrate on which were mounted three Cd electrodes each measuring 19 mm (0.75 in.) long by 3 mm wide by 1 mm thick. They were separated from one another by 1 mm gaps so that two gap regions were defined. After the application of 50 current pulses each 0.3 seconds long from a 80 V D.C. supply, suitable thin films were deposited in the gaps. That is, we were able to generate an arc discharge across the gaps utilizing a 45 V battery. The resistance of the SPER device, as measured between the first and third electrodes, was found to be 2.5 Ω .

Contact to the first and third electrodes was made by aluminum foils placed between these electrodes and the substrate.

Example V

In this example we plated a Cd film 204 on a glass substrate 220 as shown in FIG. 3. Cd electrodes 201 and 202 were then mounted on the film 204. However, in the actual experiment the thin film 204 did not extend completely under both electrodes. Rather, the thin film 204 extended part way under each electrode, with the contact area under the cathode electrode 201 being larger than that under the anode electrode 202. The Cd film 204 had a thin film resistance of about 10 Ω and a thickness less than about 1 μm . The resistance between the electrodes with power off was approximately 15 Ω . This SPER device generated a plasma arc discharge between the electrodes with the application of a pulse from a 30 V battery as previously described.

Example VI

This experiment was similar to that described in Example V except that the cathode electrode 201 was made of Al and the anode electrode 202 was made of Cd. The thin film 204 was again made of Cd. This SPER device also generated a plasma arc discharged with the application of a voltage pulse from a 40 V D.C. supply. The plasma comprised a mixture of Al and Cd ions.

Example VII

This experiment was also similar to that described in Example V except that the gap between the Cd electrodes was 1 cm instead of 1 mm. The application of at least 50 V D.C. resulted in two Cd plasmas, one near each electrode.

Example VIII

This experiment was similar to that described in Example I except that two Al electrodes each 25 mm long by 3 mm wide by 1 mm thick were separated by a 1 mm gap when mounted on a glass substrate, as shown on FIG. 2. The thin film 200 of Al was formed as described in Example I by the application of approximately 10 pulses each of 1 sec duration from the high voltage supply 130 (FIG. 1). Thereafter, the SPER device was capable of initiating an arc discharge from a 75 V D.C. supply.

Example IX

This experiment describes the generation of low voltage arc discharge in a SPER device which includes a composite Cd-Hg cathode and a Cd anode mounted on a glass substrate. As shown in FIGS. 4 and 5, a glass block 322 was mounted on a glass substrate 320. The block 322 had cut therein a channel 324 which was adapted to receive a cathode electrode 326. A step 328 was formed at one end of cathode electrode 326 so that when the cathode 326 was placed in the channel 324, the step 328 formed a recess 330 into which the liquid Hg could be placed. (Alternative configurations for confining the liquid are, of course, possible including for example forming a well in the cathode electrode 326.) The anode electrode 332 was mounted to the top of the glass block 322 in axial alignment with the cathode electrode 326 and spaced slightly from the recess 330.

Before the Hg was inserted in recess 330, this SPER device was processed as described in Example I in order to plate a Cd thin film 334 on the vertical and horizontal surfaces of the glass block 332 between the cathode and the anode, i.e., on the corner of block 332 at the closed end of channel 324. The thin film 334 enabled a plasma arc discharge to be struck at low voltages between the electrodes without the liquid Hg in the recess. Then, a pool of liquid Hg was placed in recess 330 making contact with the Cd cathode electrode 326 and the Cd thin film 334, but not with the Cd anode electrode 332. Utilizing this configuration on a background gas of He at 3.99 mbar (3 Torr), a plasma arc discharge was initiated and sustained utilizing a 22.5 V battery. The plasma was primarily Hg vapor which generated ultraviolet radiation primarily at a wavelength of 253.7 nm (2537 Å). The procedure was reproducible for only a few pulses but could be reproducibly operated after reprocessing from a D.C. power supply (e.g., 30 V pulses of 1 msec duration) or from two series connected 22.5 V batteries.

After this type of operation, we found that the Cd cathode electrode 326 was completely covered with Hg which could not be readily scraped off.

Example X

A closed quartz tube about 10 mm in diameter and about 11.5 cm (4.5 in.) long contained about 2.54 cm (1 in.) of Hg in the bottom and the remainder was filled with He gas at approximately 53.2 mbar (40 Torr). A tungsten wire, 1 mm in diameter, extended through the bottom of the tube into the Hg pool and served as a negative electrode. A copper strip extended through the top of the tube and served as a positive electrode. A quartz strip extended from the bottom of the copper strip into the Hg pool. By striking a high voltage arc, the quartz strip was coated with Hg, thereby providing a Hg thin film which bridged the gap between the Cu strip and Hg pool in accordance with our invention.

About 12 V D.C. at 6A was applied between the Cu strip and W wire to create and sustain an arc

discharge and thereby to generate UV radiation at 253.7 nm (2537 Å) from the Hg plasma in the gap. Because of the high He pressure employed, the UV radiation was generated primarily by electron-impact excitation rather than by recombination.

Claims

1. An arc discharge light source comprising: excitation means for producing radiation comprising two spaced apart strips (201, 202), the gap therebetween providing an electrical discharge path; and means for applying an electrical signal between said strips;

a portion of said strips between fabricated from a material which is converted into a plasma of ions as a result of the application of said electrical signal, which plasma generates said radiation; characterized in that a thin film (200, 204, 334) bridges said gap, thereby reducing the voltage of said signal required to initiate said plasma.

2. The light source of claim 1, further including an electrically insulating substrate (220) on which said strips are mounted and wherein said thin film is formed on said substrate and underlies a portion of said two strips.

3. The light source of claim 1, further including an electrically insulating substrate (220) on which said strips are mounted and wherein said thin film is formed in said gap and in contact with each of said strips.

4. The light source of claims 1, 2, or 3 wherein said thin film comprises a metal layer.

5. The light source of claim 4 wherein said thin film has a thickness of $\leq 10 \mu\text{m}$.

6. The source of claim 3 wherein one of said strips (326) has a recess (330) therein,

a liquid metal contained in said recess, said thin film (334) being in contact with said liquid metal and the other (332) of said strips so that said plasma comprises ions of said liquid metal.

7. The source of claim 6 wherein said substrate (322) has therein a channel with an interior end wall, said one strip is adapted to be received in said channel and has a step (328) at one end thereof which, together with said end wall, forms said recess when said one strip is inserted in said channel,

said other strip is mounted on said substrate adjacent to said recess, and

said thin film connects said strips and is formed on at least said end wall.

Patentansprüche

1. Bogenentladungslichtquelle mit —einer Anregungseinrichtung zum Erzeugen von Strahlung mit zwei beabstandeten Streifen (201, 202), wobei der Spalt hierzwischen einen elektrischen Entladungsweg bildet, und —einer Einrichtung zum Zuführen eines elektrischen Signals zwischen die Streifen, wobei ein Teil der Streifen aus einem Material hergestellt ist, das als folge der Zufuhr des elektrischen

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2. The light source of claim 1, further including an electrically insulating substrate (220) on which said strips are mounted and wherein said thin film is formed on said substrate and underlies a portion of said two strips.

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Signals in ein Ionenplasma umgesetzt wird, welches seinerseits die Strahlung erzeugt, dadurch gekennzeichnet, daß

—eine Dünnschicht (200, 204, 334) den Spalt überbrückt und dadurch die zur Initiierung des Plasmas erforderliche Spannung des Signals reduziert.

2. Lichtquelle nach Anspruch 1, die des weiteren ein elektrisch isolierendes Substrat (220) aufweist, auf dem die Streifen befestigt sind, und wobei die Dünnschicht auf dem Substrat gebildet und unter einem Teil der beiden Streifen gelegen ist.

3. Lichtquelle nach Anspruch 1, die des weiteren ein elektrisch isolierendes Substrat (220) enthält auf dem die Streifen befestigt sind und wobei die Dünnschicht in dem Spalt und in Kontakt mit jedem der Streifen gebildet ist.

4. Lichtquelle nach Anspruch 1, 2 oder 3, wobei die Dünnschicht eine Metallschicht umfaßt.

5. Lichtquelle nach Anspruch 4, bei der die Dünnschicht eine Dicke kleiner oder gleich ungefähr 10 µm besitzt.

6. Quelle nach Anspruch 3, bei der —einer der Streifen (326) eine Vertiefung (330) besitzt,

—ein flüssiges Metall in der Vertiefung enthalten ist und

—die Dünnschicht (334) in Kontakt mit dem flüssigen Metall und dem anderen (332) der Streifen steht, so daß das Plasma Ionen des flüssigen Metalls enthält.

7. Quelle nach Anspruch 6, bei der —das Substrat (322) einen Kanal mit einer inneren Stirnwand besitzt,

—der eine Streifen dafür vorgesehen ist, vom dem Kanal aufgenommen zu werden, und eine Stufe (328) an seinem einen Ende besitzt, die zusammen mit der Stirnwand die Vertiefung bildet, wenn der eine Streifen in den Kanal eingesetzt ist,

—der andere Streifen auf dem Substrat benachbart der Vertiefung befestigt ist und

—die Dünnschicht die Streifen miteinander verbindet und auf wenigstens der Stirnwand gebildet ist.

Revendications

1. Une source lumineuse à décharge d'arc comprenant:

des moyens d'excitation destinés à produire un

rayonnement, comprenant deux bandes mutuellement espacées (201, 202), l'espace entre elles formant une chemin de décharge électrique; et des moyens destinés à appliquer un signal électrique entre ces bandes;

une partie des bandes étant fabriquée à partir d'une matière qui est convertie en un plasma d'ions sous l'effet de l'application du signal électrique, et ce plasma générant le rayonnement précité; caractérisée en ce que une couche mince (200, 204, 334) forme un pont sur l'espace entre les bandes, ce qui réduit la tension de signal nécessaire pour amorcer le plasma.

2. La source lumineuse de la revendication 1, comprenant en outre un substrat électriquement isolant (220) sur lequel les bandes sont montées, et dans laquelle la couche mince est formée sur le substrat et s'étend au-dessous d'une partie des deux bandes.

3. La source lumineuse de la revendication 1, comprenant en outre un substrat électriquement isolant (220) sur lequel les bandes sont montées, et dans laquelle la couche mince est formée dans l'espace entre les bandes, en étant en contact avec chacune des bandes.

4. La source lumineuse des revendications 1, 2 ou 3, dans laquelle la couche mince consiste en une couche de métal.

5. La source lumineuse de la revendications 4, dans laquelle la couche mince a une épaisseur inférieure ou égale à approximativement 10 µm.

6. La source de la revendication 3, dans laquelle une cavité (330) est formée dans une première des bandes (326),

cette cavité contient un métal liquide, et la couche mince (334) est en contact avec le métal liquide et la seconde bande (332), de façon que le plasma contienne des ions du métal liquide.

7. La source de la revendication 6, dans laquelle une encoche comportant une paroi d'extrémité intérieure est formée dans le substrat (322), la première bande est conçue de façon à être logée dans l'encoche et elle comporte à l'une de ses extrémités une marche (328) qui, en association avec la paroi d'extrémité, forme la cavité lorsque la première bande est introduite dans l'encoche, la seconde bande est montée sur le substrat en position adjacente à la cavité, et

la couche mince connecte les bandes et est formée au moins sur la paroi d'extrémité.

