United States Patent

[11] 3,621,458

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[21] Appl. No. **865,789**
[22] Filed **Oct. 13, 1969**
[45] Patented **Nov. 16, 1971**

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[54] **FLASHTUBES AND METHOD OF PROVIDING SAME**
8 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **331/94.5,** 313/198, 313/217, 313/201
[51] **Int. Cl.** **H01j 17/12,** H01j 61/10, H01s 3/00
[50] **Field of Search** 313/198, 217, 231, 309, 351, 182–186, 192; 331/94.5

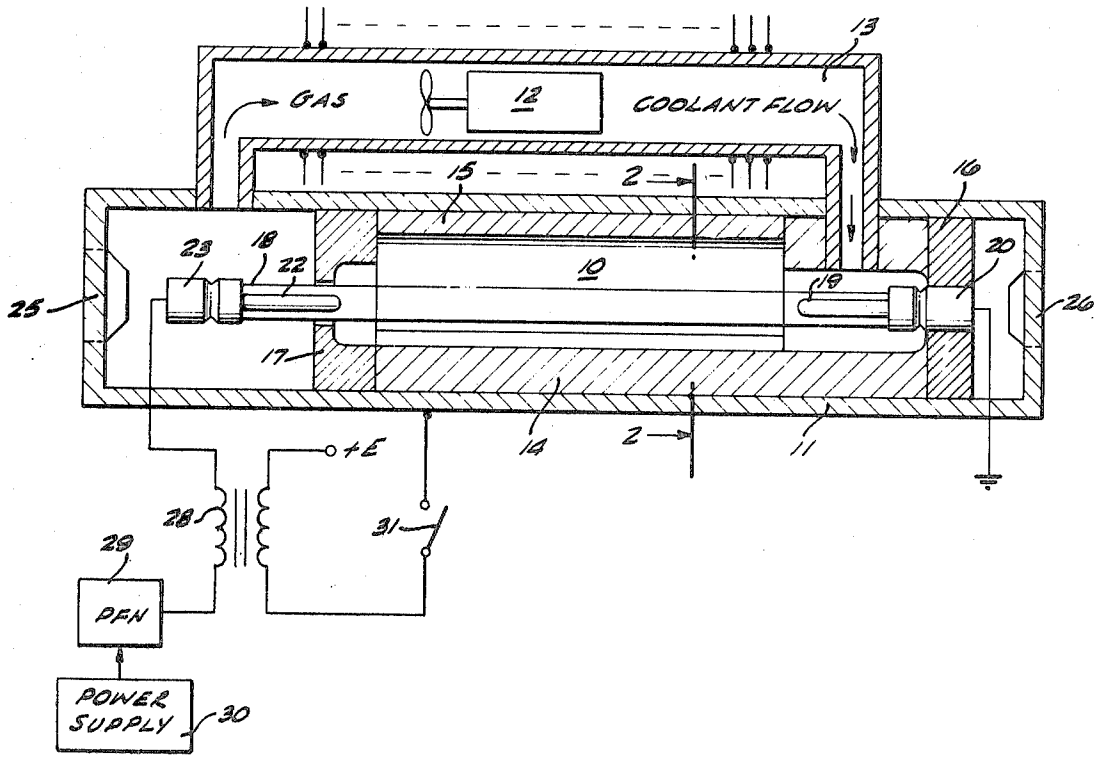
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ABSTRACT: Uniformly low trigger levels are achieved for a flashlamp operated in a chamber filled with a cooling gas at high pressure or at atmospheric pressure by roughening the anode. A technique for roughening consists of firing the flashtube in reverse a sufficient number of times to alter the finish of the anode tip from a bright high polish to a dull gray by sputtering.



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FIG. 1.

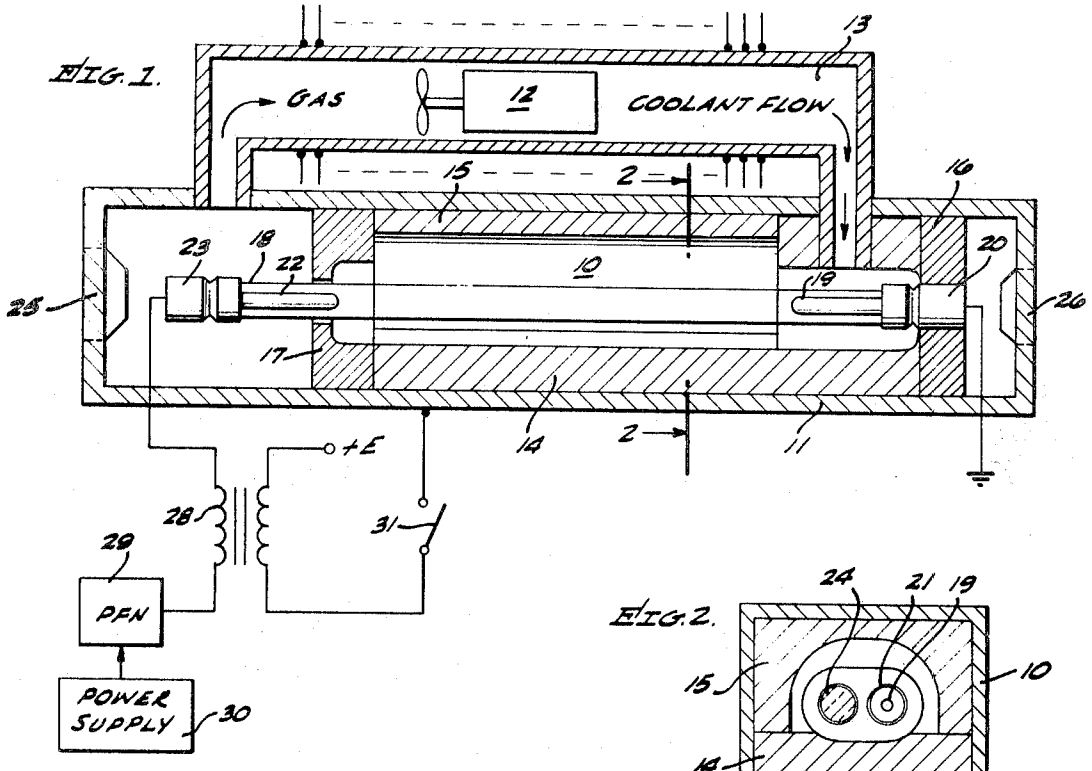


FIG. 2.

FIG. 3.

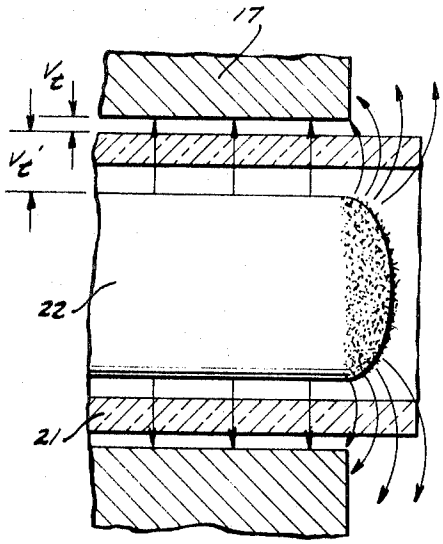
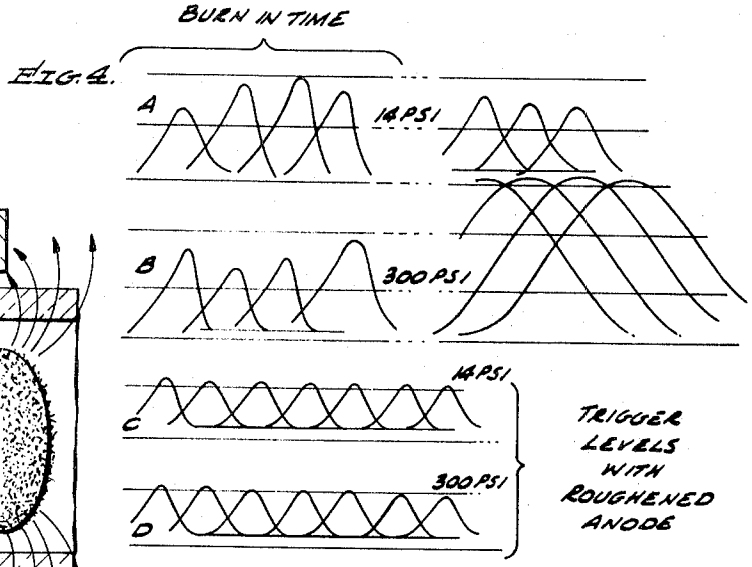


FIG. 4.



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FLASHTUBES AND METHOD OF PROVIDING SAME

BACKGROUND OF THE INVENTION

This invention relates to improved flash tubes and more particularly to flashtubes employed in a laser pump cavity filled with a coolant under high pressures, and a method for processing such flashtubes in order to reduce the trigger level thereof.

In some applications, temperature control is required for extended operation of a laser. Accordingly, it has become the practice to sometimes operate lasers in a pressure chamber filled with a coolant gas, such as nitrogen, that is recirculated under high pressure, such as 300 p.s.i. However, it has been discovered that such a cooling system inhibits the triggering of the flashtube such that the trigger level is 50 to 200 percent higher than the trigger level at ambient pressure (14 p.s.i.) depending upon the particular flashtube. An increase in trigger voltage from typically 10 kv. to about 20 kv. is then required.

Although this "pressure effect" can be overcome by, for example, providing a higher trigger voltage, in some systems the trigger voltage cannot be increased because undesired arcing will occur for voltages in excess of typically 12 kv. due to the compact packaging of the total system, and the resulting short distances between the high-voltage cables, and connections, and the grounded metal parts of the high pressure chamber. Moreover, a higher trigger voltage would require a larger trigger transformer, thereby adding both weight and volume to the system. What is required is a solution to the "pressure effect" to enable standard flashtubes, such as flashtubes filled with xenon gas to be triggered at low levels in the presence of a high pressure cooling gas without any modification of the pressure system or the trigger system comprising a pulse forming network and a trigger transformer.

SUMMARY OF THE INVENTION

In accordance with the present invention, the anode of a flashtube is provided with a rough surface to decrease its operating trigger level, particularly in systems employing cooling gases at high pressures. A rough surface is provided on the anode of an assembled flashtube by firing the flash tube in reverse (grounded anode) with sufficient energy to cause sputtering of the anode, and for a sufficient number of times to produce the desired rough surface. However, in its broadest aspect, the technique contemplated for providing an improved flash tube includes any roughening of the anode. The present invention also contemplates use of such an improved flashtube in a laser system cooled by a gas recirculated under high pressure through a chamber surrounding the laser pump cavity.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a laser pump cavity in a chamber schematically shown through which a gas coolant is recirculated under pressure.

FIG. 2 is a cross section of FIG. 1 taken along a line 2—2.

FIG. 3 illustrates the anode section of the laser in FIG 1 enlarged to show the roughened surface of the anode.

FIG 4 illustrates in waveforms A, B, C and D the improved operation of a flashtube having a roughened surface.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, a laser pump cavity 10 is shown disposed in a pressure chamber 11 through which a gas coolant, such as nitrogen, is recirculated at a high pressure (typically 300 p.s.i.) by a pump 12. Fins on a pump manifold 13, or an equivalent heat exchange unit, transfers sufficient heat to the atmosphere to maintain the laser system at the desired operating temperature. In practice, a second pump or air blower is provided to circulate air over the fins.

The pump cavity 10 is electrically connected to the pressure chamber 11 which in turn is connected to ground. In practice, the cavity 10 is made of four parts for ease of assembly namely a base section 14, a cover section 15, a cathode clamp 16 and a tube clamp 17 which also functions as a trigger electrode. The clamps 16 and 17 support a flashlamp 18 comprising a cathode 19 protruding from a cathode cap 20 into a tubular quartz envelope 21 filled with xenon. An anode electrode 22 protrudes from an anode cap 23 into the envelope 21.

A ruby crystal rod 24 is supported in the pump cavity 10 in a conventional manner with its axis parallel to the axis of the quartz envelope 21 of the flashlamp as shown in FIG. 2. Pressure windows 25 and 26 are provided at each end of the pressure chamber 11 to transmit the laser beam to a Q-switch module at one end and an output reflector at the other end, neither of which is shown. An optical bench holds the Q-switch module in proper alignment with the laser rod and output reflector. Alternatively, the flashtube, ruby laser rod, pump cavity, and the optical components may be mounted on an optical bench located in a pressure chamber through which a coolant gas is recirculated. In that case only one pressure window is required at one end of the chamber.

It should be understood that although reference is made to a high-power laser employing the Q-spoiling technique, such reference is only by way of example, and not by way of limitation.

It should also be understood that the configuration of the pump cavity is also by way of example, and not by way of limitation. All that is important is the cathode clamp 16, or similar supporting member, provide an electrical ground connection to the cathode cap 20 in order to ground the cathode 19, and that the tube clamp 17 surround the tip of the anode 22. The pressurized cooling gas will flow through the cavity to remove the heat generated by the flashtube. Passage for the cooling gas is through ports near the tube clamp 17 and the cathode clamp 16. In practice, the ports may be apertures aligned with the axis of the ruby rod 24, as in the case of the tube clamp 17, or passages through the wall of the base section 14, as in the case of the return port over the cathode 19.

Triggering the flashlamp consists of ionizing the xenon gas within the quartz envelope 21 and is accomplished by the injection of a very high-voltage pulse through a step-up trigger transformer 28 having its secondary winding in series with a pulse forming network 29. The latter accumulates energy from a power supply 30 in a conventional manner until a switch 31 is closed in the primary circuit of the trigger transformer 28 for a series triggering arrangement using the tube clamp 17 as a trigger electrode. A shunt triggering arrangement may be provided instead by including in the cavity a trigger electrode positioned along the axis of the flashtube. The secondary winding of the trigger transformer is then connected between that trigger electrode and ground, and the pulse forming network 29 is connected directly to the anode cap 23. In either case, once the pulse forming network 29 is charged from the power supply 30 to the desired voltage level (typically 10 kv.), and the switch 31 is closed, the tube will flash.

The primary current through the trigger transformer 28 induces a high potential pulse to initiate ionization of the xenon gas in the flash lamp. The pulse forming network 29 then discharges its energy through the flashlamp. Under normal operational conditions, the flashtube is fired at a repetition rate of two pulses per second. The problem is initiating ionization which has been more difficult in a laser having a pressurized cooling system and has been more acute with the series trigger arrangement shown than with the shunt trigger arrangement having a trigger electrode disposed along the length of the tube. Accordingly, the present invention will be described with specific reference to the series triggering arrangement, after which application of the present invention to the shunt triggering arrangement will be described.

The problem referred to is that the trigger level for the flashtube in a pressurized system (300 p.s.i., nitrogen) is 50 to 200 percent higher than the trigger level at ambient pressure (14 p.s.i.) depending upon the particular flashtube employed. This requires an increase in the trigger voltage from 10 kv. to about 20 kv. As noted hereinbefore, this is referred to as the "-

pressure effect" which has been discovered in pressure cooled systems.

To understand the mechanism causing the pressure effect, reference is made to FIG. 3 showing the anode section of the laser in a fragmentary enlarged view. When the trigger pulse is applied to the anode **22**, an electric field is established between the anode **22** and the tube clamp **17**, which is made in two parts fitted together loosely around the quartz envelope **21** of the flashtube in order that the envelope not be damaged in assembly. Accordingly, the electric field established between the anode **22** and the clamp **17** must pass not only through the xenon gas surrounding the anode **22** in the envelope **21**, and the envelope **21** itself, but also through a small space filled with pressurized gas between the envelope **21** and the tube clamp **17**. Thus initial breakdown inside the flashtube will occur in the xenon gas surrounding the anode electrode, but the discharge path for the trigger voltage includes a gap between the tube envelope **21** and the tube clamp **17**. This gap is typically one-fiftieth to one-hundredth of an inch since allowance for temperature expansion and for the different outside diameters of flashtubes has to be made. Any voltage developing across the gap outside the envelope **21** lowers the field strength inside the envelope.

If the system is operated at ambient pressure, the trigger voltage Vt across the gap will be significant as compared to the trigger voltage Vt between the anode **22** and the outside surface of the quartz envelope **21**, but not so large as to appreciably increase the trigger level much above 6 to 7 kv. for a typical xenon flashtube. Accordingly, a pulse delivered by the trigger transformer of 10 kv. will provide somewhat uniform triggering as shown by the waveform A of FIG. **4** which is a facsimile of oscilloscope traces of the trigger level of a flashtube of 14 p.s.i. of nitrogen. The level is not constant and varies between 7 kv. and 11 kv., although after the flashtube is burned in (fired about four times at approximately 150 joules per trigger pulse), the trigger level remains essentially unchanged at a level of approximately 8 kv. Under high pressure (300 p.s.i.), the burn-in characteristics remains substantially the same, but thereafter the trigger level increases to about 17 kv., as can be seen from the waveform B of FIG. **4**. This increase in trigger level is what has been referred to as the "pressure effect" and always sets in after the flash tube has been burned in, i.e., fired a few times. The lower but erratic trigger level during burn-in time is believed to be due to whatever roughening there is on the otherwise highly polished anode of commercial flash tubes resulting from handling in the process of assembly. As the flashtube is burned in, what little roughening exists is effectively fire-polished away.

It has been discovered that extensively roughening the otherwise polished anode will produce uniform triggering at low levels (approximately 6.5 kv.) at both atmospheric pressure and at high pressure during and after the burn-in time as shown in waveforms C and D of FIG. **4**. It is believed that the peaks or high points on the roughened surface of the anode provide high-electric field gradients which lead to low trigger levels for initial ionization of the xenon gas in the envelope **21**. Once the high field gradients between the roughened anode and the tube clamp **17** initiates ionization, the lower electric field gradients extending from the anode through the entire length of the pump cavity **10** causes ionization to extend through the flashtube to the cathode **19**. Thus initial breakdown in the flashtube occurs due to the high field gradients in the transverse field between the anode **22** and the tube clamp **17**, and propagation of the ionization is due to the longitudinal electric field between the anode **22** and the pump cavity. The most rapid propagation of ionization occurs along the inner surface of the tube envelope because, due to polarization of the dielectric material, it has a negative charge to attract ions.

Although roughening the anode **22** is most beneficial if the flashtube is operated at high pressure (because the breakdown voltage of nitrogen at 300 p.s.i. is about 10 times the breakdown voltage of nitrogen at atmospheric pressure,) there is a distinct advantage in roughening the anode of a flashtube operated even at ambient pressure since it provides a lower and more uniform trigger level thus eliminating the usual erratic triggering that characterizes these flashtubes. Thus at low or high pressure, roughening the anode of a flashtube eliminates the burn-in time and provides substantially the same uniform trigger level for both low and high-pressure operation. Such a low and uniform trigger level may be achieved with other cooling gases, such as argon which has about the same breakdown voltage as nitrogen at 40 p.s.i., thus a flashtube with a roughened anode may be produced for universal application with substantially the same advantage as in a system using a high pressure nitrogen cooling gas.

Although a number of methods may be employed to roughen the anode, particularly before assembling the flashtube, such as by sand blasting the anode, it has been discovered that adequate roughening of the anode tip as shown in FIG. **3** may be achieved by sputtering the anode. This is readily accomplished by firing the flashtube in reverse, i.e., by operating the flashtube in a trigger system with the anode grounded. Afterward, the flashtube is operated in the normal manner for laser operation as shown in FIG. **1**.

To sputter a given flashtube, its trigger level (after burn-in in reverse) is first determined. In a typical flashtube, it will be found that the trigger level is in excess of 17 kv. Once the trigger level has been determined, the flashtube is triggered about 50 to 1,000 times at approximately 150 joules per shot. The exact number of times required to roughen the anode will depend upon how quickly the sputtering achieved with each trigger produces the desired roughening. Visual inspection is adequate to determine when the desired roughening has been achieved, which is when all of the anode tip loses its bright finish and presents a dull gray finish characteristic of any electrode which has undergone sputtering.

The sputtering technique for roughening the anode of a flashtube is particularly successful with "polarized" flashtubes. These flashtubes have electrodes which consist of different materials. Typically the cathode is made of material which resists sputtering, such as sintered tungsten with barium oxide. The anode which is then not to be connected to ground is made of material not selected to resist sputtering, such as pure tungsten. Purposely connecting the flashtube in reverse then allows sputtering of the anode for the purpose of roughening its tip. When the flashtube is then connected in a laser in its normal (polarized) manner, the cathode which is then connected to ground will resist sputtering.

The sputtering technique for processing unpolarized flashtubes, i.e., flashtubes which have identical electrodes for the anodes and the cathode, is substantially the same. A given electrode is selected as the "anode" and is connected to ground during the sputtering process. Thereafter, that electrode is connected to the pulse forming network of a laser while the other electrode is connected to ground as the cathode normal operation of the flashtube is then with a lower trigger level, but even at a lower trigger level, the cathode will experience some sputtering. Accordingly, life tests of unpolarized flashtubes indicate a total number of shots to be in the order of 50,000 at an energy level of 80 joules per trigger pulse, but without any change in the trigger level throughout the 50,000 shots. The life of a polarized flashtube may be expected to be substantially longer since the cathode material resists sputtering, and consequent darkening of the tube envelope.

The present invention has been described with reference to a laser of the type in which the trigger voltage is reduced from the otherwise extremely high level required (to cause ionization by a field solely between the anode and the cathode) by using as a trigger electrode the grounded tube clamp **17**. However this only reduces the trigger level to about 8 kv. at atmospheric pressure and about 17 kv. at 300 p.s.i. Roughening the tip of the anode reduces the trigger level for both atmospheric pressure and 300 p.s.i. to a level between 6 and 7 kv. In accordance with the present invention, a roughened anode may be used to equal advantage in lasers of the type

which employ a trigger electrode placed along the length of the flashtube, such as the form of a thin wire wrapped around the tube. The end of the trigger electrode thus placed along the tube length extends over the end of the anode so that a transverse field is established between the trigger electrode and the anode in the same manner as the transverse field established by the anode 22 and the tube clamp 17. The roughened anode will then provide high field gradients in that transverse field to produce lower and more uniform trigger levels for firing the flashtube.

What is claimed is:

1. In a laser having a cavity containing a flashlamp for pumping a laser crystal rod disposed therein, said lamp having an elongated envelope filled with a gas to be ionized by an electric field between an anode at one end and a cathode at the other end of said envelope, and having a grounded conductor disposed near said anode for initial ionization of said gas in response to a trigger pulse applied between said anode and said conductor, the improvement comprising a roughened anode.

2. An improvement as defined by claim 1 wherein a cooling gas is circulated through said cavity under pressure.

3. In a system for triggering a flashtube having an elongated envelope filled with a gas to be ionized by an electric field between an anode at one end and a cathode at the other end of said envelope, having a pressure chamber around said envelope and having a trigger electrode, and with a cooling gas circulated through said chamber under high pressure, the improvement comprising

a clamp for holding said tube in said chamber, said clamp being positioned near the tip of said anode outside of said envelope and functioning as said trigger electrode,

and a roughened surface on said anode for reducing the level of a trigger pulse necessary between said anode and said trigger electrode to initiate ionization of said gas.

4. The improvement as defined in claim 3 wherein said roughened surface is on the tip of said anode.

5. The improvement as defined in claim 4 wherein a laser pump cavity is provided around said envelope and within said pressure chamber, and a laser rod positioned within said cavity with its axis parallel to the axis of said envelope.

6. The improvement as defined in claim 5 wherein said trigger electrode is electrically connected to said cathode and said trigger pulse is applied to said anode.

7. A system for providing a source of pumping energy to a laser crystal rod in a laser cavity filled with a cooling gas under pressure comprising

a flashtube having an elongated envelope filled with a gas to be ionized by an electric field between an anode at one position and a cathode at another position along said elongated envelope, said anode having a roughened surface for reducing the level of a trigger pulse necessary between said anode and said trigger electrode to initiate ionization of the gas in said envelope,

and a mounting structure positioned outside of said envelope and near the tip of said anode for providing a trigger electrode.

8. The combination of claim 7 in which said mounting structure is at a reference potential.