(12) UK Patent Application (19) GB (11) 2 074 369 A

(21) Application No **8109820**
(22) Date of filing **30 Mar 1981**
(30) Priority data
(31) **140390**
(32) **14 Apr 1980**
(33) **United States of America (US)**
(43) Application published **28 Oct 1981**
(51) INT CL[3] **H01J 17/02 17/50 45/00**
(52) Domestic classification **H1D** 12A 12B13Y 12B2 12C 13A2 13A5A 13A5Y 13B6B 13B6Y 17A4 17AY 1D12 1D4 1J2 1J3 1K 31 32 34 7A1E7 7A1EY 9G 9Y
(56) Documents cited
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GB 1035067
GB 987627
(58) Field of search **H1D**

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(54) Apparatus and method for generating high density pulses of electrons

(57) Apparatus for generating high density pulses of electrons thermionically comprises a metallic target 11 in a low pressure caesium vapour atmosphere within a chamber 10. Caesium atoms are adsorbed on and migrate from the target 11 and a laser 17 rapidly heats the target surface to a high temperature in a time which is short compared with the residence time of the caesium atoms adsorbed on the target surface. This rapid surface heating in combination with the adsorbed caesium atoms causes copious quantities of electrons forming a high current density pulse to be emitted from the target 11 which forms a cathode to an anode ring 13. In an example, a 50 megawatt pulse from a Q-switched neodymium-glass laser 17 heats the caesiated surface of W-Re emitter 11 to 2000°K within the 20 nanosecond laser pulse duration; the residence time of adsorbed Cs atoms being given as 100 nanoseconds. Arrangements in which the apparatus functions as a fast-acting switch, or as a thermionic energy converter, are disclosed.

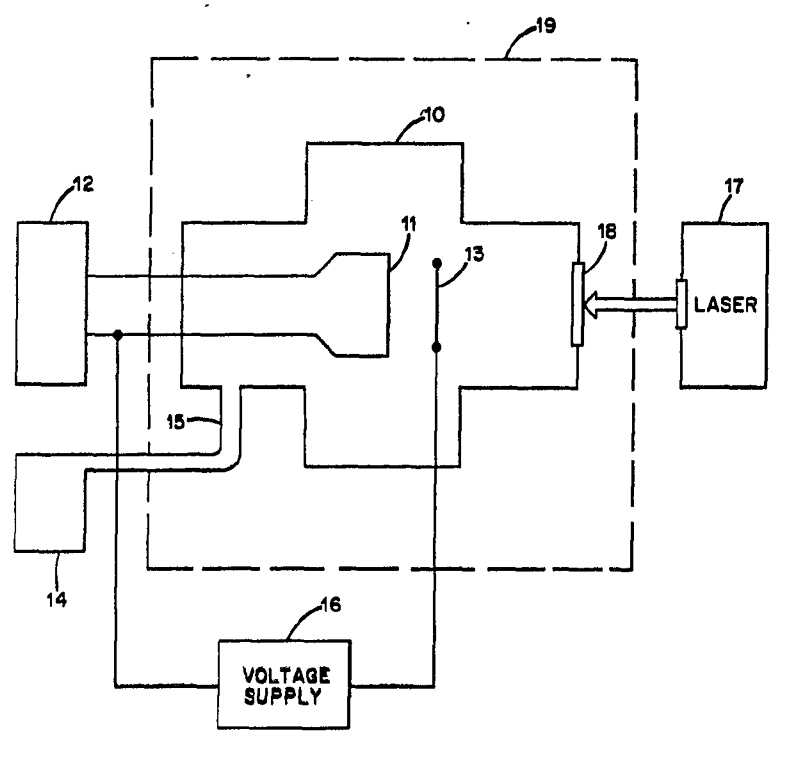

Fig. 1.

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This print embodies corrections made under Section 117(1) of the Patents Act 1977.

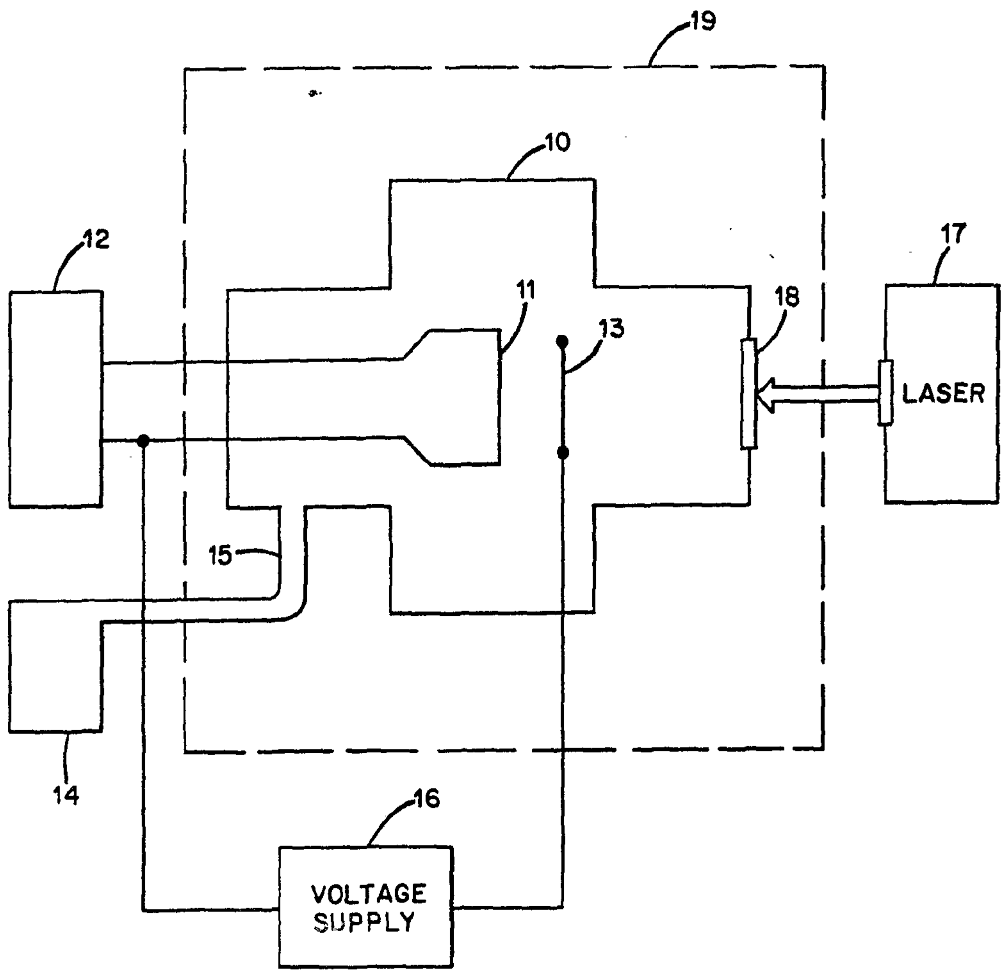

Fig. 1.

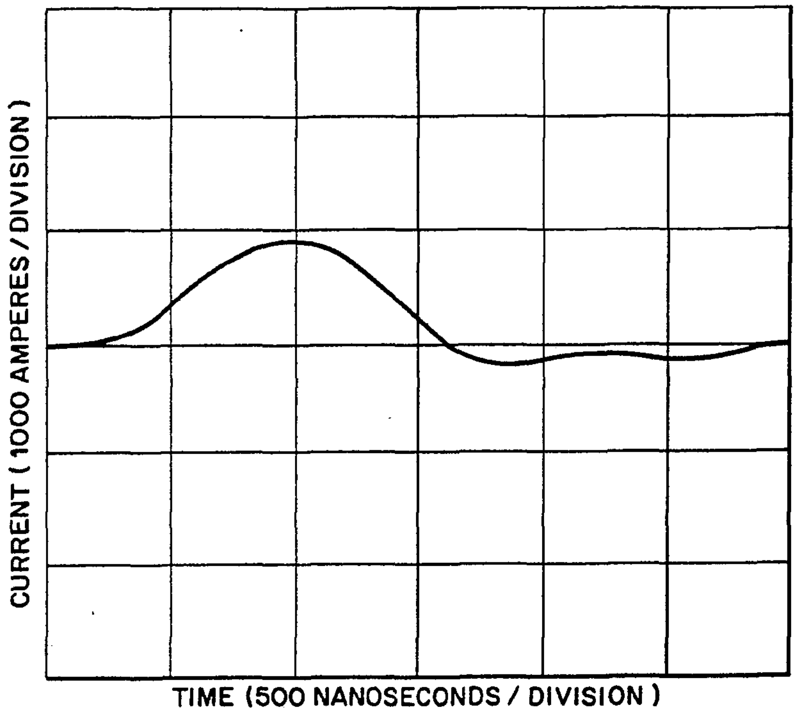
CURRENT (1000 AMPERES / DIVISION)
TIME (500 NANOSECONDS / DIVISION)

Fig. 2.

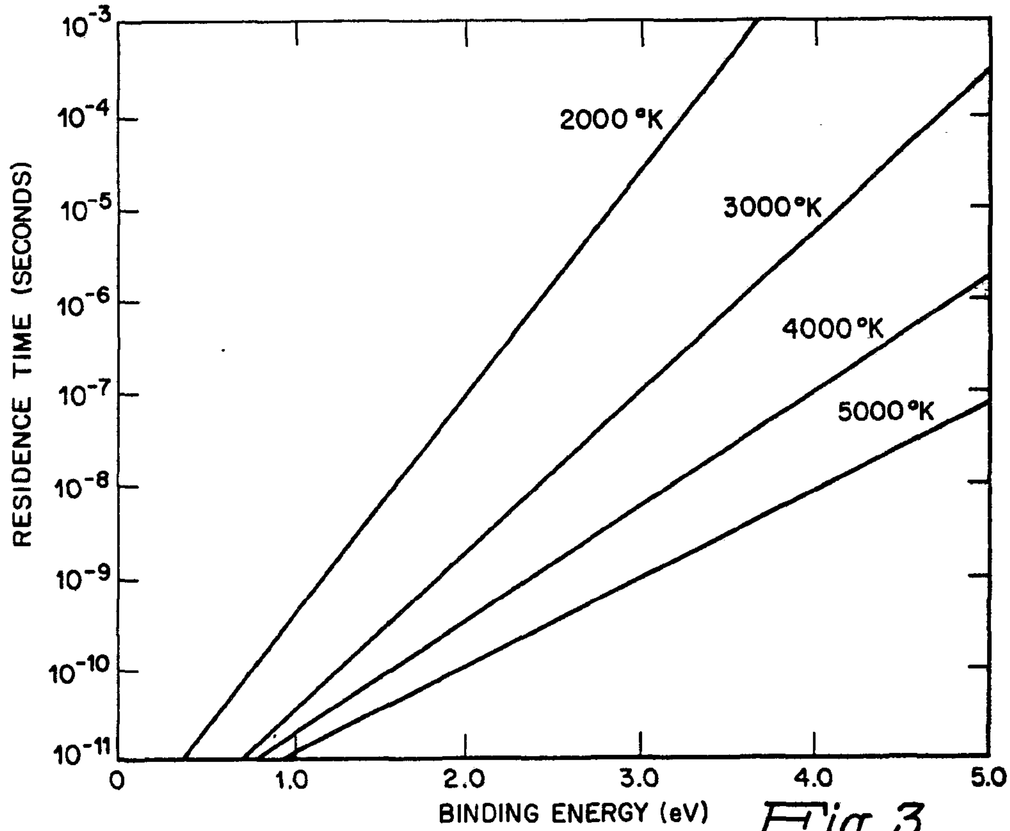
RESIDENCE TIME (SECONDS)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
2000 °K
3000 °K
4000 °K
5000 °K
0
1.0
2.0
3.0
4.0
5.0
BINDING ENERGY (eV)

Fig. 3.

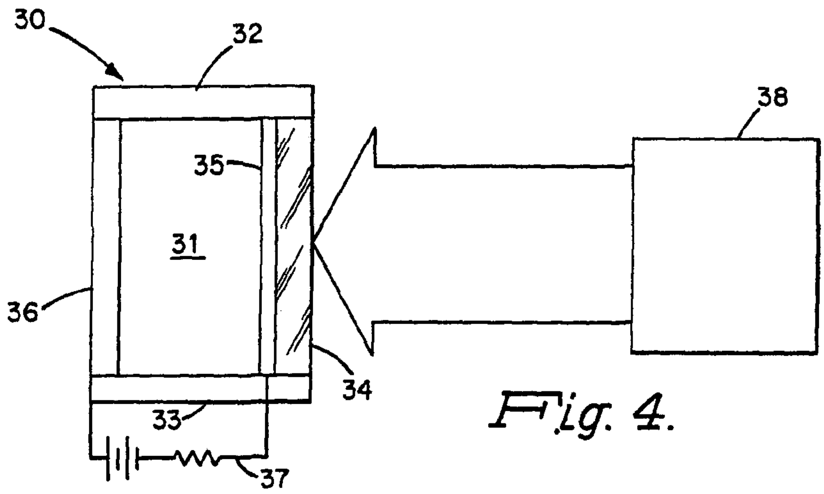

Fig. 4.

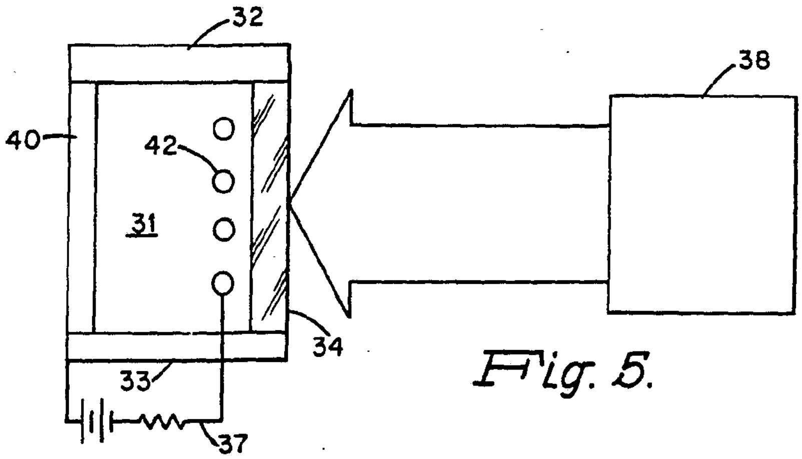

Fig. 5.

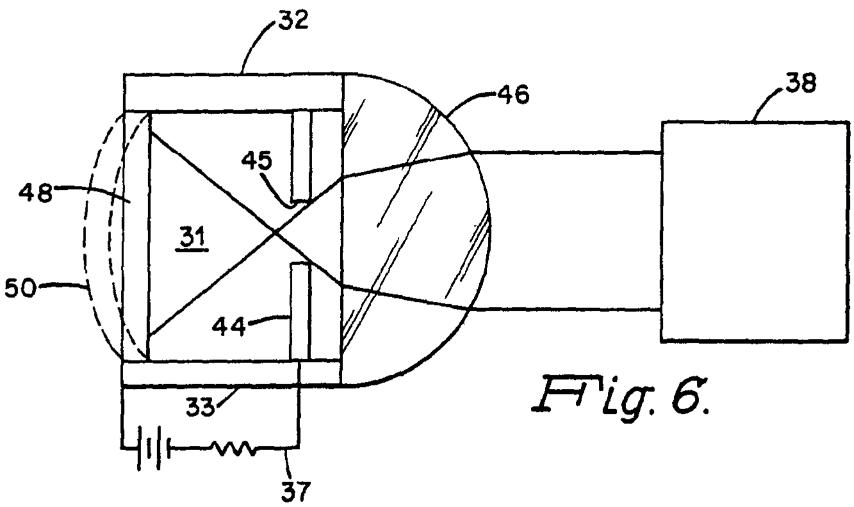

Fig. 6.

SPECIFICATION

Apparatus and method for generating high density pulses of electrons

This invention relates to apparatus and methods for the production of high density pulses of electrons by the employment of a laser energized emitter.

Pulsed sources of electrons of high current density are of value for many purposes, for example for welding and metal working devices, high resolution electron microscopy, intense short burst x-ray emitters, high current switches, electronic beam systems, microwave generators and free electron lasers. It is well known to generate pulses of electrons thermionically, i.e., by heating to a high temperature a suitable metallic cathode with an intense laser beam to drive off electrons. The currents so generated have, however, generally been limited to tens of amperes. Furthermore, these electron emissions were achieved typically with focused incident laser beams which caused target surface damage through vaporization and ionization and hence were not purely thermionic processes. In other known attempts to create high density pulses of electrons the laser flux densities were kept below the destruction level of the metallic target. However, in these cases, very low peak current densities were achieved.

It is, therefore, an object of this invention to provide apparatus and a method for generating thermionically pulses of electrons of appreciable spatial erea and high current density, for example, current densities of from four to six kiloamperes per square centimetre and currents in the range of from two to three kiloamperes with pulse widths varying from nanoseconds to tens of microseconds.

To this end, according to one aspect of this invention, apparatus for generating high density pulses of electrons comprises a metallic target, means for causing caesium atoms to be adsorbed on and to migrate from a surface on the target, and laser means for heating the surface on the target in a time interval, which is short compared with the residence time of the caesium atoms on the surface between adsorption and migration, to an electron emitting temperature below the melting point of the target to cause the emission of the high density pulses of electrons from the target.

The metallic target may be pre-coated with caesium atoms, but preferably it is exposed to caesium vapour so that the surface is continually replenished with caesium atoms to effet a "self-healing" condition. Suitable metallic targets may be composed of tungsten or a tungsten-rhenium alloy.

In a preferred embodiment, the apparatus includes a chamber filled with caesium vapour under low pressure, and a metallic cathode forming the target is disposed in contact with the caesium vapour. An anode is also disposed within the chamber at a suitable spacing from the cathode. A voltage is applied across the anode and the cathode and the laser means provides a pulsed beam for periodically heating the cathode rapidly. By this means, high electron current pulses flow between the cathode and the anode. The caesium vapour pressure within the chamber is preferably between 10^{-6} and 10^{-3} torr.

The invention also consists, according to another of its aspects in a method of generating a high spatial density pulse of electrons comprising the steps of:

1) providing a chamber containing caesium vapour under low pressure;

2) disposing a metallic target within the chamber in contact with the caesium vapour and thus causing caesium atoms to be adsorbed on and to migrate from a surface on the target; and,

3) rapidly heating the surface on the target with a laser in a time interval, which is short compared with the residence time of the caesium atoms on the surface between adsorption and migration, to an electron emitting temperature below the melting point of the target to produce the high spatial density pulses of electrons from the target.

The invention may also be embodied in a high current, high voltage, fast response switch. In this embodiment, a pulse of electrons is generated by the impingement of a pulse laser beam on the front or back side of the target. The resulting pulses of electrons establish a conduction path which serves to close the switch.

Some example of apparatus and an example of a method in accordance with the invention will now be described with reference to the accompanying drawings in which:–

Figure 1 is a diagrammatic representation of one example of the apparatus for producing high density pulses of electrons;

Figure 2 is a graphical representation of a typical electron pulse;

Figure 3 is a graphical representation of caesium residence time as a function of atomic binding energy and temperature; and

Figures 4, 5, and 6 are diagrammatic representation of three examples of fast-acting switches incorporating apparatus in accordance with the invention.

The basis for the electron generation apparatus amd method lies in pulsed high density irradiation of a caesiated metallic target, i.e., a target having a coating of caesium atoms adsorbed onto its surface. A laser beam rapidly heats the surface of the metallic target in a time interval which is short compared to the residence time of the adsorbed caesium atoms on the surface.

When a metallic element is exposed to caesium vapour, an equilibrium is established in which caesium atoms are continually being adsorbed onto the surface of the metallic element and are migrating away from the surface. The adsorbed electropositive atoms interact electrically with the metal surface to form dipoles which facilitate the emission of electrons, i.e., reduce the work function of the metal surface. The residence time of caesium atom on the surface is the average length of time that the atoms remain on the surface of the metallic element. If the surface of the element is heated rapidly enough, i.e., in a time interval short compared with the residence time of the caesium atoms, the heating will be accomplished while the caesium atoms remain bound to the surface. This transient combination of high surface temperature and lowered work function of the metallic element allows the emission of an abundance of electrons which form a high current density source.

A preferred embodiment of the apparatus for generating a high density pulses of electrons is shown in Fig. 1. This apparatus comprises a ceramic vacuum chamber 10 housing a tungsten-rhenium foil target emitter 11 which may have a thickness of about 25 microns. The emitter 11 can be separately resistance-heated by a power supply 12 to a preselected temperature.

Disposed within the chamber 10 is a ring collector anode 13 which is spaced approximately one centimetre in front of the emitter 11. A caesium vapour reservoir 14 is connected to the chamber 10 by a conduit 15. the caesium vapour reservoir 14 is independently thermally controlled for adjusting the caesium vapour pressure in the chamber 10. A suitable temperature for the caesium reservoir 14 is 350°K. A voltage source 16 applies a voltage between the emitter 11 and the ring collector anode 13.

A laser 17 is provided for illuminating and heating the emitter 11 through a sapphire window 18 in the vacuum chamber 10. The chamber 10 itself is situated inside an oven 19 which maintains a virtually uniform internal temperature.

The operation of the apparatus shown in Fig. 1 will now be described with reference to a specific example of operating conditions. The ceramic vacuum chamber 10 is initially evacuated by conventional means, not shown, to a pressure of approximately 10^{-8} torr. Caesium vapour is then introduced from the caesium reservoir 14 into the chamber 10 to a pressure of about 10^{-4} torr. The oven 19 surrounding the chamber 10 is maintained at a temperature of 400°K. The voltage source 16 applies a voltage across the emitter 11 and the ring collector anode 13. It is preferred that this voltage be maximised consistent with restricting the intra-chamber leakage current to a few micro-amperes. This maximum voltage is approximately inversely proportional to the caesium vapour pressure. For a vapour pressure of caesium of 10^{-4}, as in this example, the maximum voltage is approximately 770 volts. The laser 17 is a Q-switched neodymium-glass oscillator with two amplifying stages. This laser can emit single mode pulses with a potential power level of 500 megawatts and pulse durations of approximately 20 nanoseconds. In this example, a 50 megawatt laser pulse has been used. The laser 17 generates an unfocused circular beam of approximately 9 millimetres diameter. This unfocused beam is directed through the sapphire window 18 in the chamber 10 onto the emitter 11. In this example the caesium reservoir 14 is maintained at a temperature of approximately 350°K. The 50 megawatt pulse from the laser 17 heats the emitter 11 to approximately 2,000°K within the 20 nanosecond pulse duration. With the emitter 11 thus heated to 2,000°K, the residence time of adsorbed caesium atoms on the emitter 11 is approximately 100 nanoseconds, a time much longer than the 20, or up to 30, nanoseconds needed for heating the emitter 11. Thus, caesium atoms remain adsorbed on the emitter 11 surface during the whole heating operation so that the work function is lowered, as has been explained above. The work function under these conditions is approximately two electron volts. Residence time of the caesium atoms on the emitter versus temperature and binding energy will be discussed below in conjunction with Fig. 3. A peak current of 2500 amperes in the electron pulse emitted by the emitter has been measured in this example in whch the emitter 11 was heated to approximately 2,000°K within 20 nanoseconds. Because the beam of emitted electrons is approximately 9 millimetres in diameter (the diameter of the illuminating and heating laser beam), the 2500 amperes translates onto a current density of 3930 amperes per square centimetre.

Lowering the caesium pressure in the chamber 10 to approximately 5×10^{-5} torr raises the maximum voltage which can be sustained across the emitter 11 and the collector 13 to about 1000 volts. The peak current attained at this pressure is about 1000 amperes which results in a current density of 1560 amperes per square centimetre for a 9 millimetre diameter beam. An oscillogram of such a pulse is shown in Fig. 2. It will be noted that the duration of the current pulse is on the order of one microsecond, which is many times longer than the 20 nanosecond laser pulse which heats the emitter 11. The current pulse is much longer than the laser pulse because of the diffusion of the electrons and caesium ions from the target to collector and reflects the ion transit time between these electrodes.

Although the neodymium glass laser 17 is restricted to pulse repetition rates of only several pulses per minute, higher repetition rate lasers are suitable for use in the apparatus and method in accordance with the invention. Generally, the maximum rate at which current pulses can be generated with the apparatus of Fig. 1 is limited by the adsorption characteristics of the caesium on the target. Specifically, the time required between pulses for sufficient cooling of the surface dictates the maximum pulse repetition rate, i.e., the emitter 11 cannot be allowed to get so hot by repeated laser pulses that the residence time of the caesium atoms adsorbed on the emitter is less than the duration of the laser pulse. This pulse rate limitation can be circumvented by heating different areas of the target with successive laser pulses. Very high repetition rates can thus be achieved either by rotating rapidly a disc or drum target or by directing the laser beam onto different target areas. It is anticipated that kilohertz repetition rates can be attained using this technique.

Suitable repetition rates can be determined with the aid of the graph shown in Fig. 3. Fig. 3 illustrates the residence time of caesium atoms on a target surface as a function of the binding energy of the adsorbed atoms and the target temperature. For a work function of caesiated tungsten of approximately two electron volts, as discussed in the example above, the binding energy of caesium on the tungsten is expected to be approximately two electron volts. With laser heating of the emitter to 2000°K, Fig. 3 indicates a caesium adsorption residence time of approximately 100 nanoseconds. If, however, the repetition rate were such that the target became heated to 3500°K the residence time of caesium on the target for the same binding energy of two electron volts would be approximately one nanosecond, which is shorter than the 20 nanosecond laser pulse width used in the example above. Thus, if the laser heated the target to a temperature of 3500°K, the caesium atoms would adsorb and migrate from the surface within the duration of the laser pulse, thereby greatly diminishing the current pulse achieved.

Electron emission is not limited to the front or illuminated side of a target exposed to laser light. Thermionic electron emission occurs on the back side of thin metallic foil targets as well. Such back side currents, however, are typically five to ten times lower than the currents from the front side of the target. Nevertheless, electron emission from the back side of a target is useful in construction of high current-high voltage, fast response switches. One such arrangement is shown in Fig. 4. The switch generally designated at 30 includes a chamber containing caesium vapour 31 at a pressure of from 10^{-6} to 10^{-3} torr. The chamber comprises electrically insulating ceramic side plates 32 and 33. The front of the chamber includes a transparent cover plate 34, made for example, of sapphire, and behind that a thin metallic foil target 35 made, for example, of a tungsten-rhenium alloy. The metallic foil 35 should be in the range of from 25 to 75 microns thick. The rear of the chamber is formed by a metallic anode 36. When it is desired to operate the switch to complete the circuit 37, a pulse of laser light from a laser 38 is directed onto the metallic foil 35 through the transparent window 34. The pulse of laser light causes the emission of a high density pulse of electrons from the rear side of the foil target 35 towards the anode 36 thereby completing the circuit 37 which includes means such as a power supply for applying a voltage across the anode and cathode. A switch as described in Fig. 4 has applications in pulse power generators and may be used as a thyristor for switching large currents at high voltages. Furthermore, by placing the anode electrode 36 close to the foil target 35, the arrangement of Fig. 4 may be used as an effective thermionic energy converter. That is, the arrangement of Fig. 4 may be used to convert the energy in an incident laser beam into electrical currents. For example, with a spacing between the foil target 35 and the anode 36 of approximately 10 microns, laser heating of the target to 2500°K will generate thermionically 5.2. watts of electrical power per square centimetre assuming that the target 35 and the anode 36 have work functions of about two electron volts. Although the efficiency of such conversion is low, there may be applications where such power conversion is practical, as, for example, power transmission in space in which the target is located very far from the laser.

Two other configurations of high current-high voltage, fast response switches are shown in Fig. 5 and 6. In these arrangements electron emission occurs from the front or illuminated side of targets 40 and 48, respectively. In order to allow the laser beam to be passed to the target 40, an anode 42 in Fig. 5 is a metallic wire grid or mesh, whereas in Fig. 6 an anode 44 is an annular metal plate having an opening 45. The switch shown in Fig. 6 includes a lens 46 for focusing the incident laser beam so that it passes through the opening 45 to the target 48. Focusing of the laser beam also increases its intensity, which may enhance electron transport from the target 48 to the anode 44 by photoionizing more interelectrode caesium atoms 31 to provide space charge neutralizing positive ions. The path of any reflected light from the incident focused beam bouncing off the target 48 may be controlled by using a concave target 50 as shown by the broken lines in Fig. 6.

The apparatus in accordance with the invention can be made to yield high current densities and currents over an order of magnitude greater than heretofore achieved in laser-target interactions. The emissions described herein are thermionic with no apparent damage to the target surface through vaporization.

CLAIMS

1. Apparatus for generating high density pulses of electrons comprising a metallic target, means for causing caesium atoms to be adsorbed on and to migrate from a surface on the target, and laser means for heating the surface on the target in a time interval, which is short compared with the residence time of the caesium atoms on the surface between adsorption and migration, to an electron emitting temperature below the melting point of the target to cause the emission of the high density pulses of electrons from the target.

2. Apparatus according to Claim 1, in which the target is of tungsten.

3. Apparatus according to Claim 1, in which the target is of a tungsten-rhenium alloy.

4. Apparatus according to any one of Claims 1 to 3, in which the means for causing caesium atoms to be adsorbed on and migrate from the surface comprises a chamber, in which the target, which forms a cathode, is situated, the chamber containing caesium vapour under low pressure in contact with the target, the apparatus further comprising an anode within the chamber spaced from the target, and means for applying a voltage across the anode and the target.

5. Apparatus according to Claim 4, in which the chamber is maintained at a pressure in the range of from 10^{-6} to 10^{-3} torr.

6. Apparatus according to Claim 4 or Claim 5, further comprising a caesium vapour reservoir communicating with the chamber, the reservoir being independently temperature controllable for adjusting the pressure of the caesium vapour within the chamber.

7. A method of generating a high spatial density pulse of electrons comprising the steps of:

1) providing a chamber containing caesium vapour under low pressure;

2) disposing a metallic target within the chamber in contact with the caesium vapour and thus causing caesium atoms to be adsorbed on and to migrate from a surface on the target; and

3) rapidly heating the surface on the target with a laser in a time interval, which is short compared with the residence time of the caesium atoms on the surface between adsorption and migration, to an electron emitting temperature below the melting point of the target to produce the high spatial density pulses of electrons from the target.

8. A method according to Claim 7, in which the target is of tungsten.

9. A method according to Claim 7, in which the target is of a tungsten-rhenium alloy.

10. Apparatus for establishing a conduction path of electrons comprising:

a chanber containing low pressure caesium vapour;

a thin metallic cathode having a first and a second side, the second side being in contact with the vapour;

an anode spaced apart from the second side of the cathode; and

laser means for generating an intense beam of radiation to impinge on said first side of said thin metallic athode, the intense beam being adapted for heating the second side of the cathode in a time interval, which is short compared with residence time of caesium vapour which is adsorbed on the second side of the cathode, to an electron emission temperature below the melting point of said cathode, thereby establishing a conduction path of electrons between the cathode and the anode.

11. A high current, high voltage, fast response switch comprising:

a chamber containing caesium vapour under low pressure;

a thin metallic cathode having a first and a second side, said second side being disposed in contact with the vapour;

an anode spaced apart from the second side of the cathode;

means for applying a voltage across said anode and said cathode; and

laser means for generating an intense beam of radiation to impinge on said first side of the thin metallic cathode, the intense beam being adapted for heating the second side of the thin cathode in a time interval, which is short compared with the residence time of caesium vapour which is adsorbed on the second side of the cathode, to an electron emission temperature below the melting point of said cathode.

12. A switch according to Claim 11, in which the anode comprises a wire grid and the laser means is positioned such that the intense beam passes through the grid and then impinges on the cathode.

13. A switch according to Claim 11, in which the anode comprises a metallic plate having an opening therethrough and further comprising a focusing lens between the laser and the anode, the lens directing the beam through the opening.

14. Apparatus for thermionic energy conversion comprising;

1) a chamber containing caesium vapour under low pressure;

2) a thin metallic target having a first side and a second side, the second side being disposed in contact with the vapour;

3) an electrode closely spaced from the second side of the target; and

4) laser means for generating a beam of radiation to impinge on the first side of said target, the beam being adapted for heating the second side of the thin target in a time interval, which is short compared with the residence time of caesium vapour adsorbed on

the second side of the target, to an electron emission temperature below the melting point of the target, thereby creating an electrical current and voltage between the target and the electrode to generate electrical power.

15. Apparatus according to Claim 14, wherein the electrode is spaced from the second side of the target by a distance of substantially 10 microns.

14. Apparatus according to Claim 1, substantially as described with reference to Fig. 1, or any one of Figs. 4 to 6 of the accompanying drawings.

17. A method according to Claim 7, substantially as described with reference to Figs. 1 to 3 of the accompanying drawings.

18. Apparatus for generating high density pulses of electrons comprising:

a metallic target having a surface coated with adsorbed caesium atoms; and

laser means for heating the surface on the target in a time interval short compared with the residence time of said caesium atoms on the surface to an electron emitting temperature below the melting point of said metallic target to cause the emission of said high density pulses of electrons.

Printed for Her Majesty's Stationery Office
by Burgess & Son (Abingdon) Ltd.—1981.
Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.