Dec. 17, 1929. I. LANGMUIR 1,740,252

PHOTO ELECTRIC DEVICE

Filed Nov. 13, 1923

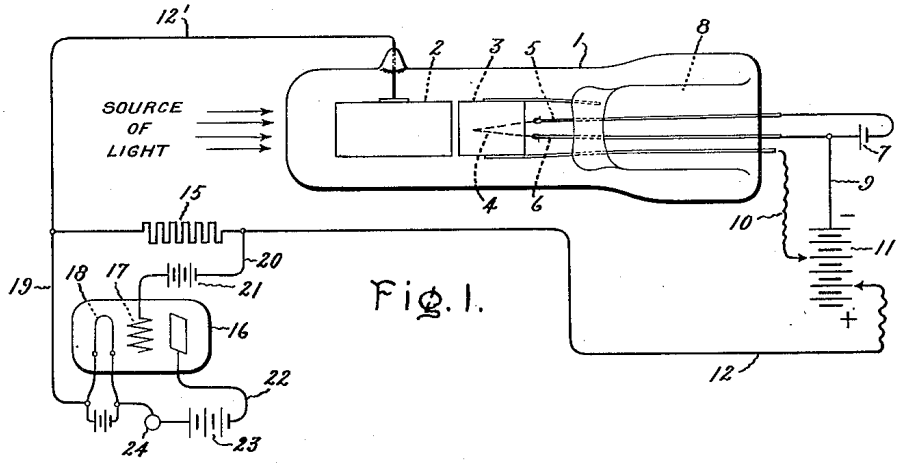
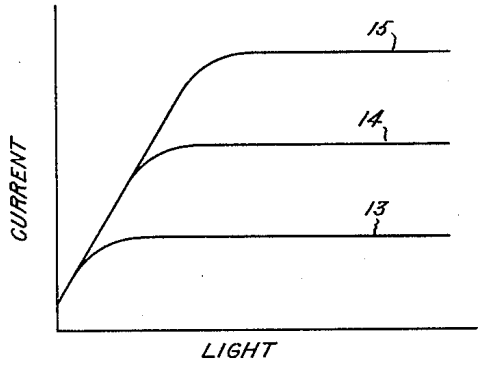


Fig. 1.

Fig. 2.



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UNITED STATES PATENT OFFICE

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PHOTO-ELECTRIC DEVICE

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My present invention relates to photo-electric action and involves the control of an electric current by light in accordance with a new principle.

Heretofore, electric conductivity in a photo-electric device has been produced by the illumination of a light-sensitive surface which constituted the negative electrode of an electric circuit, the electrons liberated by the action of light flowing to the positive electrode of the device. This effect will be referred to as the primary photo-electric effect.

In accordance with my present invention, I have provided a device wherein an electric current is caused to flow to an electrode by the reflection under the influence of light of electrons from another electrode which is coated with an active material, the electrons being generated independently. As will be described in greater detail later, light directed upon the surface of the coated electrode modifies this surface in such a way that it becomes capable of reflecting electrons. The number of electrons which thus can be reflected is proportional to the intensity of the light. This new phenomenon has been called herein the photo-reflection effect.

The accompanying drawing illustrates in Fig. 1 an apparatus embodying my invention, together with suitable circuit connections, and Fig. 2 is a diagram of electrical characteristics of the new device.

The photo-reflection device illustrated in the drawing comprises a highly exhausted container 1 in which are mounted hollow cylindrical electrodes 2, 3 consisting of nickel, for example. These cylinders are aligned end to end along the longitudinal axis and are but slightly separated one from another. Inside the electrode 3 is mounted a small V-shaped filament 4 which is connected to conductors 5, 6, so that a heating current may be conducted thereto from a suitable source 7. The filament 4, preferably consists of thoriated tungsten, as described in Langmuir Patent 1,244,216 of October 23, 1917. After a thorough exhaust of the container, an alkali metal, for example, pure metallic cæsium is introduced. The cæsium may be derived from a side tube (not shown) containing a mixture of cæsium chloride and calcium, or magnesium turnings. Other alkali metals, for example, potassium, may be used. The alkali metal forms an adsorbed film upon the surface of the electrodes 2 and 3. To prevent short circuiting due to the condensation of alkali metal on the glass between leading-in conductors, the envelope adjacent the stem 8 preferably is maintained at a temperature sufficiently high to prevent condensation of cæsium, or whatever alkali metal may be used.

Connected to the cylinder 3 and the filament 4 is a circuit 9, 10, which is connected to a source of current, as for example, part of the cells of a battery 11, making the electrode 3 positive. The electrodes 2 and 3 are connected by the conductors 10, 12, 12′ to a source of current which is also represented by the battery 11. The drawing shows a connection which will give a higher positive voltage on the electrode 2 than on the electrode 3. This arrangement although desirable is not essential as good results may be obtained by making the electrode 2 much less positive with respect to the cathode 4 than the electrode 3.

Neglecting for the present the electrode 4, light falling upon the electrode 3 will produce some electron emission by the primary photo-electric effect and will cause a current to flow between electrodes 2 and 3 in the circuit 10, 12, providing a current source is provided as in the present case. The direction of this current will depend upon the direction of the potential difference between the electrodes 2 and 3.

When the filament 4 is heated by the source 7, an electron current will flow to the electrode 3. If no light enters the cell and the filament 4 is heated only to a temperature high enough to produce electrons but at low luminosity, little or no current will flow to the electrode 2 as the electrons tend to leave the cathode in paths normal to the surface, the cathode being substantially linear and being axially arranged within the electrode 3.

When light falls upon the electrode 3, as indicated by arrows, electrons are reflected from the adsorbed film of alkali metal, caus-

ing some of the electrons to be deflected from the electrode 3 to the collecting electrode 2, the deflection of electron current within limits being proportional to the intensity of the light. Within limits of light intensity this photo-reflection current may be several hundred times greater than current due to the primary photo-electric effect. Current due to this effect will continue to flow even when the positive potential of the cylinder 3 is made higher than the positive potential of the cylinder 2, as by moving the contact of circuit 10 toward the positive terminal.

This current increases with the intensity of illumination at first rapidly and then reaches a limiting value at which it remains substantially constant even with higher illuminations. Superimposed on the reflection current is a small current due to the primary photo-electric effect and hence absolute constancy of current at the limiting value is not attainable but the departure from constancy is negligible. The current will slightly rise or fall to a very slight extent with an increase of illumination depending on the relative polarity of the electrodes 2, 3. By changing either the electron emission from the cathode 4, as by changing its temperature or by changing the voltage on either electrodes 2 or 3, a series of curves may be obtained expressing the variation of current with variation of illumination as illustrated by the curves 13, 14, 15 in Fig. 2. The current does not fall to zero in the absence of light as a small electron current may flow from the cathode 4 to the electrode 2. At a higher impressed voltage on the electrode 2 or a higher cathode temperature the current rises to a higher limiting value. Increasing the voltage on the electrode 3 will decrease the limiting value of the current. By plotting these values of current with respect to light for these different conditions a family of curves is obtained which has as an envelope a straight line. This photo-reflection effect disappears when the voltage of either of the electrodes 2 or 3 is brought to zero.

Although the primary photo-electric current reverses in direction when the voltage between electrodes 3 and 4 is made less than the voltage between 2 and 4 by moving the contact 13 toward the negative terminal, the current produced by reflection does not reverse. The primary photo-electric effect is proportional to intensity of the light and it may be caused by light in any part of the visible spectrum, whereas the photo-reflection current is absent in the case of red light, and appears to be brought about most readily by green or blue light.

The variation of current in the circuit 12, 12′ produces a variation of potential at the terminals of a high resistance 15 whereby measurements may be made or indications observed, preferably through the instrumentality of an amplifier 16. The grid 17 and the cathode 18 are connected by the conductors 19, 20 to the terminals of the resistance 15, preferably in circuit with a biasing battery 21. In the plate circuit 22 a source of current 23 and an indicating device 24 are provided. In place of an indicating device other amplifiers may be used together with a relay to control electric devices, as now well known and as shown in my prior Patent 1,297,188 of March 11, 1918.

The variation of light intensity from a given source may be measured electrically, as the photo-reflection current is proportional to the light intensity or the device may be used to close or open a circuit in response to light falling upon the photo-sensitive electrode.

What I claim as new and desire to secure by Letters Patent of the United States, is,—

1. In combination an electrical discharge device comprising an evacuated receptacle, a plurality of electrodes therein, at least one of said electrodes being coated with alkali metal, means for directing electrons upon said coated electrode, and means independent of said first mentioned means for projecting light upon said coated electrode to thereby cause reflection of said electrons from said coated electrode to another electrode.

2. In combination a photo-electric device comprising a sealed receptacle containing a photo-sensitive material, an electrode therein having a surface provided with an adsorbed film of said material, means for directing an electron current upon said film, a second electrode, and means for charging said second electrode to a positive potential with respect to said coated electrode.

3. An electrical discharge device comprising a sealed receptacle, electrodes therein, one of which is provided with a film of light-sensitive material, means for producing therein an electron discharge between said one electrode and another of said electrodes and means for reflecting said discharge to a third electrode by a photo-reflection effect.

4. In combination, an electrical discharge device comprising a sealed evacuated receptacle, a plurality of aligned discharge-receiving electrodes therein, a cathode, means for producing an electron discharge to one of said electrodes, a circuit between said discharge receiving electrodes, and means for charging both of said receiving electrodes positive with respect to said cathode.

5. An electron discharge device comprising a sealed receptacle, a pair of spaced hollow electrodes mounted in alignment in said receptacle, one of said electrodes having a surface provided with a coating of light-sensitive material and a filamentary cathode mounted within said coated electrode.

6. The method of operating a circuit arrangement which includes a source of elec-

trons, a conductive surface in electron-receiving relation with respect to said source and having thereon a surface of light-sensitive material and a second conductive surface in electron-receiving relation with respect to said first conductive surface, which consists in causing electrons to impinge upon the light-sensitive surface and activating the light-sensitive surface to cause the impinging electrons to be reflected by the light-sensitive surface toward the second conductive surface thereby to vary the current flowing in the circuit arrangement.

7. In combination, an electrical discharge device comprising an evacuated receptacle containing a source of electrons and a plurality of electrodes cooperating with said source, at least one of said electrodes being coated with alkali metal and another of said electrodes being hollow and mounted to direct light upon said coated electrode thereby to cause reflection of electrons from said coated electrode to another electrode.

In witness whereof, I have hereunto set my hand this 12th day of November, 1923.

IRVING LANGMUIR.