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L. O. GRONDAHL ET AL
LIGHT SENSITIVE APPARATUS

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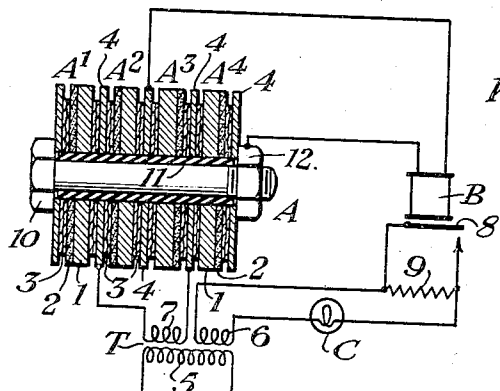


Fig. 1.

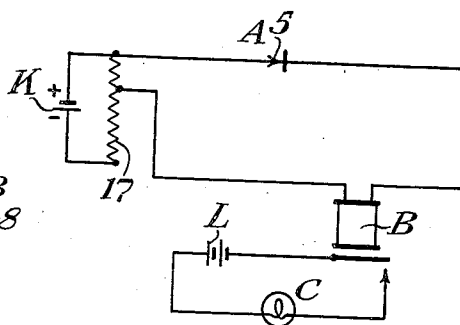


Fig. 2.

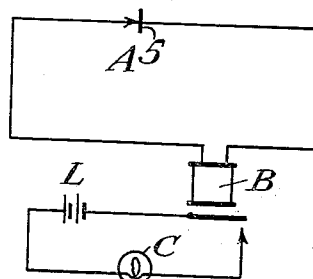


Fig. 3.

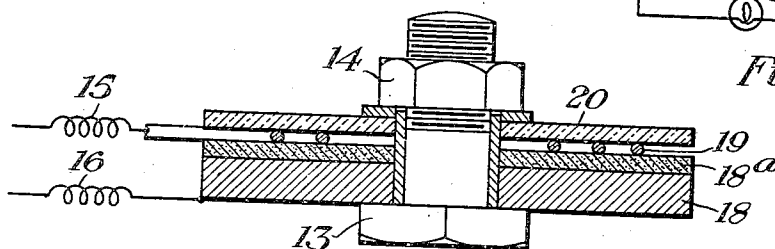


Fig. 4.

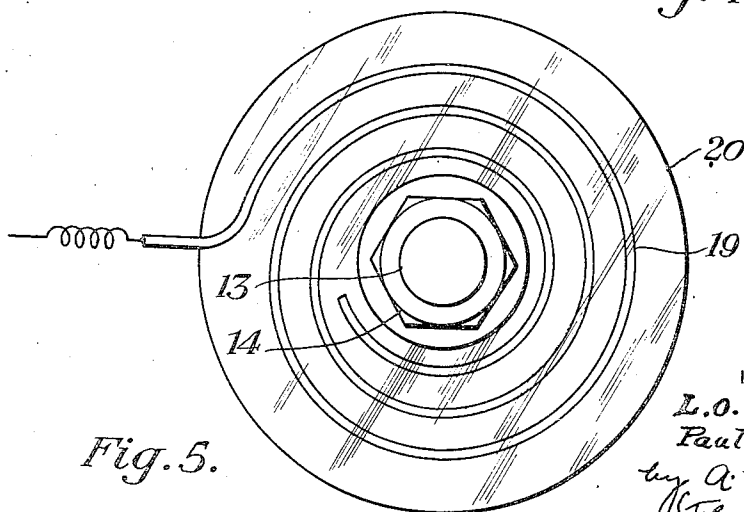


Fig. 5.

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LIGHT SENSITIVE APPARATUS

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Application January 23, 1928, Serial No. 248,852

19 Claims. (Cl. 136—89)

Our invention relates to light sensitive apparatus, that is, to apparatus which responds to variations in intensity of light.

We will describe several forms of apparatus embodying our invention, and will then point out the novel features thereof in claims.

The present application covers the inventions disclosed and claimed in the following co-pending applications: Lars O. Grondahl, Serial No. 748,442, filed Nov. 7, 1924, for Light sensitive apparatus, and Paul H. Geiger, Serial No. 135,481, filed Sept. 14, 1926, for Light responsive generators of electric current.

In the accompanying drawing, Fig. 1 is a view, partly diagrammatic, showing one form of apparatus embodying our invention. Figs. 2 and 3 are views showing modifications of the apparatus illustrated in Fig. 1 and also embodying our invention. Fig. 4 is a view showing in section another modified form of apparatus embodying our invention. Fig. 5 is a top plan view of the apparatus shown in Fig. 4.

Similar reference characters refer to similar parts in each of the three views.

Referring first to Fig. 1, the reference character A designates a rectifier comprising four rectifying units A¹, A², A³ and A⁴, each comprising a member of metal with a compound of the metal formed thereon. As here shown each of these units comprises a member 1 of copper with a coating 2 of cuprous oxide formed directly thereon. The rectifying units are disc shaped and are provided at their centers with holes to receive a bolt 10 from which each of the units is insulated by a sleeve 11. Contact plates 4 are arranged between each two adjacent units and adjacent the outside surface of each end unit for the purpose of making connections with outside circuits. A washer 3 of soft conducting material such as tin foil or lead foil is interposed between each unit and the adjacent contact plate 4 to insure good electrical contact. The various parts are assembled in proper relation and clamped together by a nut 12 threaded on bolt 10. It will be noticed from the drawing that units A¹ and A² are assembled with the oxide coating 2 toward the left, whereas units A³ and A⁴ are assembled with the oxide coating 2 toward the right. The units A¹, A², A³ and A⁴ have the property of offering a comparatively high resistance to electrical currents flowing from the copper to the oxide, and a comparatively low resistance to currents flowing in the opposite direction, that is, from the oxide to the copper.

A source of alternating current, here shown as a secondary winding 7 of a transformer T, has

one terminal connected with the contact plate 4 between units A¹ and A², and the other terminal connected with the contact plate 4 between units A³ and A⁴. Primary 5 of transformer T is constantly supplied with alternating current from a source not shown in the drawing. A relay B has one terminal connected with plate 4 between units A² and A³, and the other terminal connected with bolt 10. Since bolt 10 is connected with the outside faces of units A¹ and A⁴, it will be seen that the device comprises a double wave rectifier which changes the alternating current supplied by secondary 7 of transformer T into direct current which is supplied to relay B.

We have discovered that, when the alternating current input remains constant, and the current supplied to the rectifier is small with relation to its capacity, the output of rectifier A varies between wide limits in response to variations in the intensity of the light incident thereupon; the greater the intensity of light the lower the direct current output of the rectifier. This variation is apparently due entirely, or almost entirely, to an electromotive force which is generated within each rectifier unit at or very close to the junction of the copper and the cuprous oxide, which electromotive force is in such direction as to oppose the unidirectional output current of the rectifier. As the intensity of the light increases, the electromotive force generated in the rectifier increases, so that the greater the intensity of the light, the lower is the direct current output of the rectifier. We have found that the rate of variation of the rectifier output is much greater than that which would be due solely to the change in the resistance of cuprous oxide in response to change in the intensity of light.

In the apparatus shown in Fig. 1 we make use of this characteristic of the rectifier to control an electro-responsive device, such as an electric lamp C, in accordance with the intensity of the illumination of rectifier A. For this purpose we provide lamp C with a circuit including a source of energy, such as a secondary 6 on transformer T, and an impedance 9. The parts are so proportioned that the current through this circuit is sufficient to light lamp C to only a fraction of its normal brilliancy. When relay B is de-energized, however, a low resistance path is closed around impedance 9, shunting current around this impedance and lighting lamp C to its full brilliancy.

Our invention is well adapted for the control of the signal lamps in a railway signaling system when it is desirable that the lamps should

be more brilliantly lighted during daylight than at night. For this purpose rectifier A is exposed to the light of the sun. During the day time when the rectifier is illuminated the direct current output is considerably less than at night when the rectifier is not illuminated. The parts are so proportioned that in daylight relay B is de-energized, thus closing the shunt around impedance 9 and lighting lamp C to full brilliancy. At night, however, no light will fall upon rectifier A and the output of the rectifier will be increased. Relay B will then become energized, opening the shunt around impedance 9 and decreasing the brilliancy of lamp C.

Referring now to Fig. 2, a rectifier unit A⁵, similar to one of the units illustrated in Fig. 1, is connected in series with a battery K and a relay B, the connections being such that the current from battery K flows freely through rectifier unit A⁵. Inasmuch as the phenomenon referred to in the present application takes place only at relatively low energization of the rectifier, it is necessary to apply a lower potential than even the potential delivered by one cell of battery. For this reason a resistance 17 is connected across the terminals of battery K, and the terminals of the circuit for rectifier A⁵ and relay B are connected with two points on this resistance. When the rectifier A⁵ is not illuminated, current flows through this rectifier in the low resistance direction to energize relay B. When the rectifier is illuminated, however, the electromotive force produced in the rectifier in the high resistance direction partially neutralizes the current in the low resistance direction due to the battery, and relay B then opens. Relay B may be used for any suitable purpose; as here shown, a back contact of this relay controls a circuit including a lamp C and a battery L, so that this circuit is closed only when relay B is open.

Referring now to Fig. 3, the apparatus shown in this view is the same as that shown in Fig. 2, except that the battery K is omitted. When the rectifier A⁵ is not illuminated, no current flows through relay B. When the rectifier is illuminated, the electromotive force produced in the rectifier creates a current which energizes relay B. It follows that in this view the relay is energized when the rectifier is illuminated, whereas with the apparatus shown in Fig. 2, the relay is energized when the rectifier is dark.

Referring now to Figs. 4 and 5, the apparatus illustrated in these views comprises a metal disc 18 having formed thereon a compound of the metal as indicated at 18^a. For example, the disc 18 may be of copper and the compound 18^a may be cuprous oxide. The free surface of the cuprous oxide 18^a is exposed to the source of light to which the device is to respond. An electrode 19 is placed in electrical contact with the compound 18^a in such manner as to absorb only a portion of the light which falls on the device. As here shown, the electrode 19 is a spiral of wire. The electrode 19 and the compound 18^a are preferably protected by a glass plate 20, and the parts are securely held together by a bolt 13 and a nut 14. One terminal 15 is connected with the electrode 19 and another terminal 16 is connected with the metal disc 18, the function of these terminals being to connect the electrode in an electric circuit.

We have found that when light falls on the compound 18^a, a difference of potential is created between the terminals 15 and 16, and that when

the intensity of the light is varied, the difference of potential varies. The variations in the difference of potential may be amplified, if necessary, and used to operate any suitable electro-responsive device. For example, if the illumination is made to vary in accordance with a train of sound waves, the electromotive force produced across the terminals 15 and 16 can be amplified and the sound waves can thereby be reproduced.

One feature of our invention is that little fatigue is noticeable even after constant illumination for a considerable number of hours. No saturation value of the light electromotive force is reached up to several thousand foot candles, and so the devices can be designed to be affected only by very strong illumination. There is little, if any, time lag between a change of illumination and the resulting change of electromotive force; when a sector disc is rotated between the device and a source of light at a speed to give over 150 breaks per second, there is no noticeable time lag.

Although we have herein shown and described only a few forms of apparatus embodying our invention, it is understood that various changes and modifications may be made therein within the scope of the appended claims without departing from the spirit and scope of our invention.

Having thus described our invention, what we claim is:

1. A generator of electric current comprising copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith, said combination constituting a unit having a unidirectional current carrying characteristic, a source of light arranged to strike said oxide and to be transmitted therethrough to the junction of the copper and the oxide whereby an electric current is caused to flow across such junction the value of which depends upon the intensity of the light received by the oxide from said source, and a metallically conducting electrode applied to the free surface of said oxide arranged to make distributed electrical contact with portions only of such surface whereby a short average distance exists between any illuminated portion and said electrode.

2. A generator of electric current comprising copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith, said combination constituting a unit having a unidirectional current carrying characteristic, a source of light arranged to strike said oxide and to be transmitted therethrough to the junction of the copper and the oxide whereby a potential difference is produced across such junction the value of which depends upon the intensity of the light received by the oxide from said source, and a metallically conducting electrode applied to the free surface of said oxide to make electrical contact with portions only of such surface and so to obstruct only a portion of the light which is directed upon such surface from said source.

3. A generator of electric current comprising copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith, said combination constituting a unit having a unidirectional current carrying characteristic, a source of light arranged to strike said oxide and to be transmitted therethrough to the junction of the copper and the oxide whereby an electric current is generated the value of which depends upon the intensity of the light received by the oxide from said source, and an electrode in the form of a wire of electroconductive material ap-

plied to the free surface of said oxide to make distributed electrical contact therewith and arranged to provide alternate illuminated and obscured portions over the entire surface.

4. A generator of electric current comprising copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith, said combination constituting a unit having a unidirectional current carrying characteristic, a source of light arranged to strike said oxide and to be transmitted therethrough to the junction of the copper and the oxide whereby an electric current is generated the value of which depends upon the intensity of the light received by the oxide from said source, and a metallic electrode permeable to light and applied to the free surface of said oxide.

5. A generator of electric current comprising an element made up of copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith and a metallically conducting electrode permeable to light applied to the free surface of said oxide, said element having a unidirectional current carrying characteristic, and a source of light arranged to illuminate said oxide through said light permeable electrode whereby a difference of potential is produced between said copper and said electrode the value of which depends on the intensity of said light.

6. A generator of electric current comprising copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith, said combination constituting a unit having a unidirectional current carrying characteristic, a source of light arranged to strike said oxide and to be transmitted therethrough to the junction of the copper and the oxide whereby an electric current is generated by the liberation of electrons from the cuprous oxide at said junction and their passage into the copper, the value of said current depending upon the intensity of the light received by the oxide from said source, and a metallically conducting electrode permeable to light and applied to the free surface of said oxide.

7. A generator of electric current comprising copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith, said combination constituting a unit having a unidirectional current carrying characteristic, a source of light arranged to strike said oxide and to be transmitted therethrough to the junction of the copper and the oxide whereby an electric current is generated at said junction, the value of which depends upon the intensity of the light received by the oxide from said source, and a metallically conducting electrode permeable to light conductively applied to the free surface of said oxide.

8. A generator of electric current comprising copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith, said combination constituting a unit having a unidirectional current carrying characteristic, a source of light arranged to strike said oxide and to be transmitted therethrough to the junction of the copper and the oxide whereby a difference of potential is produced between said oxide and said copper across said junction the value of which depends upon the intensity of the illumination received by said oxide from said source, and a light permeable electrode through which said oxide is illuminated and between which and said copper said potential difference is made evident.

9. In a photo-electric generator of current an

element comprising copper with cuprous oxide formed thereon and a light permeable metallic electrode applied to make electrical contact with the free side of said oxide, said element having greater conductivity from its light permeable electrode to the copper than in the opposite direction, and a source of light arranged to illuminate said element through its light permeable electrode, whereby a potential difference is produced between said copper and said electrode in such a direction as would produce a current therein, if an external circuit were connected, in a direction opposite to the direction of greater conductivity.

1. In a photo-electric generator of current, an element comprising cuprous oxide and two metallically conducting electrodes therefor with one of which said cuprous oxide forms a rectifying junction, one of said electrodes being permeable to light, and a source of light arranged to illuminate that side of the oxide to which the light permeable electrode is applied.

11. A photo-electric generator of current comprising a cuprous oxide rectifying junction, two metallically conducting electrodes therefor one of which is permeable to light, and a source of light arranged to illuminate said junction through the light permeable electrode whereby a potential difference is produced across said junction.

12. A generator of electric current comprising an element made up of copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith and an electrode permeable to light applied to the free surface of said oxide, said element having a unidirectional current carrying characteristic, and a source of light arranged to illuminate said oxide through said light permeable electrode whereby a difference of potential is produced between said copper and said electrode which is substantially directly proportional to the intensity of said light.

13. A generator of electric current comprising an element made up of copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith and an electrode permeable to light applied to the free surface of said oxide, said element having a unidirectional current carrying characteristic, and a source of light arranged to illuminate said oxide through said light permeable electrode whereby a difference of potential is produced between said copper and said electrode which depends on the intensity of said light and which varies therewith substantially without saturation effect through a wide range of light intensity.

14. A photo-electric generator of current comprising a rectifying junction of the copper-cuprous oxide type, two metallically conducting electrodes therefor one of which is permeable to light, and a source of light arranged to illuminate said junction through the light permeable electrode whereby a potential difference is produced across said junction.

15. A generator of electric current comprising an element made up of a copper plate having a layer of cuprous oxide permeable to light integrally formed thereon over a relatively extended portion of the surface of the plate and an electrode permeable to light applied to the free surface of said oxide, said element having a unidirectional current carrying characteristic, and a source of light arranged to illuminate said oxide through said light permeable electrode whereby a difference of potential is produced between said copper and said electrode which is substantially

directly proportional to the intensity of said light.

16. In a photo-electric generator of current, an element comprising copper with cuprous oxide permeable to light integrally formed thereon over a relatively extended area and a light permeable metallic electrode applied to make electrical contact with the free side of said oxide, said element having greater conductivity from its light permeable electrode to the copper than in the opposite direction, and a source of light arranged to illuminate said element through its light permeable electrode, whereby a potential difference is produced between said copper and said electrode in such a direction as would produce a current therein, if an external circuit were connected, in a direction opposite to the direction of greater conductivity.

17. A device capable of functioning as a generator of electric current comprising copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith, said combination constituting a unit having a unidirectional current carrying characteristic and also characterized by the fact that when light strikes said oxide and is transmitted therethrough to the junction of the copper and the oxide an electric current is caused to flow across such junction the value of which increases and decreases with the intensity of the light received by the oxide, and a metallically conducting electrode permeable to light applied to the free surface of said oxide arranged to make distributed electrical contact with portions only of such surface to produce covered and uncovered portions of such surface so disposed that a short average distance exists be-

tween any uncovered portion and said electrode.

18. A device capable of functioning as a generator of electric current comprising copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith, said combination constituting a unit having a unidirectional current carrying characteristic and also characterized by the fact that when light strikes said oxide and is transmitted therethrough to the junction of the copper and the oxide an electric current is caused to flow across such junction the value of which increases and decreases with the intensity of the light received by the oxide, and a metallically conducting electrode permeable to light conductively applied to the free surface of said oxide.

19. A device capable of functioning as a generator of electric current comprising copper having a layer of cuprous oxide permeable to light formed thereon and integral therewith, said combination constituting a unit having a unidirectional current carrying characteristic and also characterized by the fact that when light strikes said oxide and is transmitted therethrough to the junction of the copper and the oxide an electric current is caused to flow across such junction the value of which increases and decreases with the intensity of the light received by the oxide, a metallically conducting electrode permeable to light conductively applied to the free surface of said oxide, and a light permeable cover applied to the free surface of said electrode.

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