Sept. 21, 1965 F. P. STROTHER 3,206,832

MINIATURE PHOTOCELL ARRAY AND METHOD OF MAKING THE SAME

Original Filed Jan. 4, 1960

FIG.3.

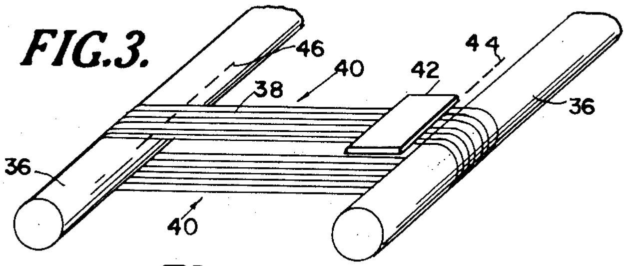


FIG.2.

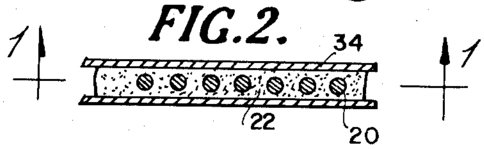


FIG.4.

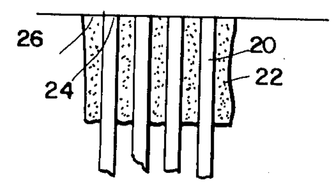


FIG.1.

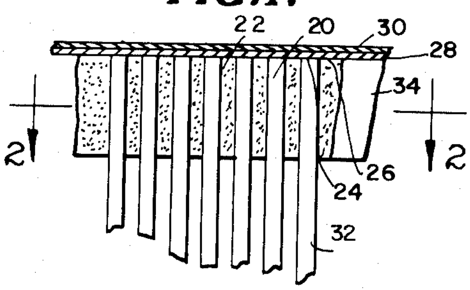


FIG.5.

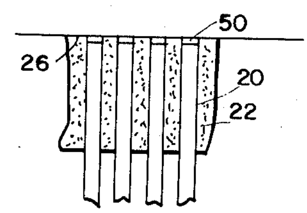


FIG.6.

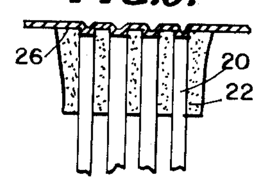


FIG.9.

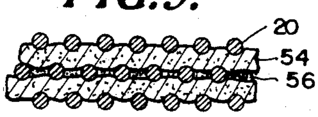


FIG.7.

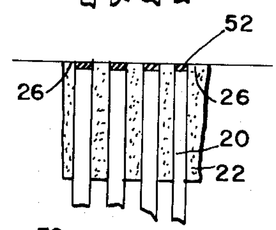


FIG.10.

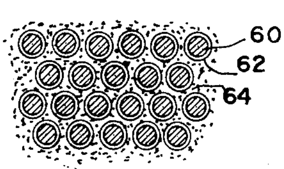
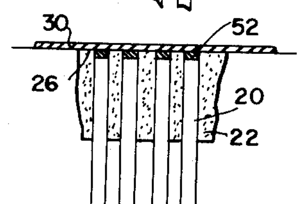


FIG.8.



INVENTOR

FRED P. STROTHER

BY

Cushman, Darby & Cushman
ATTORNEYS.

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MINIATURE PHOTOCELL ARRAY AND METHOD OF MAKING THE SAME

Fred P. Strother, Shawmut, Ala., assignor to West Point Manufacturing Company, West Point, Ga., a corporation of Georgia

Original application Jan. 4, 1960, Ser. No. 404. Divided and this application Apr. 28, 1961, Ser. No. 111,890
3 Claims. (Cl. 29—155.5)

This application is a division of my copending application, Serial No. 404, filed January 4, 1960, now abandoned, and is entitled to the filing date thereof.

This invention relates to photocells, and in particular to groups of miniature photocells arrayed in close order. The invention relates also to methods of making miniature photocell arrays.

The principal object of the invention is the provision of multiple photocells of miniature size, adapted for use in automation, data reduction, process control and the like where operation or control by means of a number of closely spaced and individual photocells is desired. Another object of the invention is to provide a compact photocell unit comprising large numbers of closely spaced and individual photocells, which may be arranged in line or in two-dimensional arrangement. In accordance with the present invention, for example, it is possible to provide a photocell array comprising more than 250,000 individual photocells per square inch.

A further object of the invention is the provision of novel miniature photocell arrays wherein electrical connection to each individual photocell may be readily made in simple, quick fashion. The photocell arrays, further, lend themselves to simplified and inexpensive manufacture, by mass production methods.

Another object of the invention is to provide novel methods of manufacturing miniature photocell arrays, by simple and economical procedures. Further objects of the invention will be in part evident, and in part pointed out hereinafter.

The invention and the novel features thereof may best be made clear from the following description and the accompanying drawings, in which

FIGURE 1 is an elevational sectional view of an exemplary embodiment of the present invention, on greatly enlarged and exaggerated scale, taken on the line **1—1** of FIGURE 2;

FIGURE 2 is a transverse sectional view taken on the line **2—2** of FIGURE 1;

FIGURES 3–8 are a series of views illustrating exemplary procedures for manufacturing photocells in accordance with the invention. FIGURE 3 is a diagrammatic view illustrating the initial arrangement of wires for incorporation into a rigid matrix;

FIGURE 4 is a sectional elevational view illustrating the relationship of the wires embedded in the matrix, after the assembly has been faced off flush in a plane perpendicular to the wire axes;

FIGURE 5 is a view corresponding to FIGURE 4, but illustrating the assembly after the wire ends have been recessed;

FIGURE 6 illustrates the assembly of FIGURE 5, after the face end thereof has been coated with photosensitive material;

FIGURE 7 illustrates the condition of the FIGURE 6 assembly, after removal of all photosensitive material except from the recessed wire ends;

FIGURE 8 illustrates the completed array, wherein the face end has been coated with a transparent conductive coating;

FIGURE 9 is a transverse sectional view of a two-dimensional array, wherein adjacent rows of wires are separated and insulated from each other by mica sheets, which have been incorporated in the matrix, and

FIGURE 10 is a transverse sectional view of another two-dimensional array, wherein insulated wires are embedded in the matrix.

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In the drawings, FIGURES 1 and 2 illustrate a simple embodiment of the present invention, wherein a plurality of uninsulated wires **20** are arranged in closely spaced parallelism and embedded in an insulating matrix **22**. The wires **20** may be commercial copper wire of small diameter, for example .001 inch diameter, and spaced apart from each other about .001 inch, whereby there may be 500 wires to the lineal inch, or 250,000 to the square inch. It will be understood that wires of smaller diameter may be employed, with less spacing therebetween, whereby arrays with 1,000 or more wires to the inch may be constructed. The matrix **22** may be inorganic, for example ceramic cement, or organic, such as an aldehyde or an epoxy resin.

In the embodiment illustrated, corresponding ends **24** of the wires **20** terminate flush with the surface **26** of the matrix **22**, the surface **26** being preferably normal to the wire axes. As will be understood, the surface **26** may be planar, curved or otherwise.

The matrix surface **26** and the wire ends **24** are coated (see FIGURE 1) with a layer **28** of photosensitive material, and a transparent electrically conductive coating **30** overlies the photosensitive layer **28**. The free wire ends **32** may be of any desired length, and are adapted to be separated from their fellows and individually connected to different circuits. The conductive coating **30** serves as a common terminal, and an electrical connection thereto may be made in conventional fashion, for example by soldering a wire thereto. In FIGURE 2, metal plates **34** laterally confine the matrix **22**, and if the conductive coating **30** overlies a portion of the metal plates, they may serve as ready means of connection to the conductive coating, as well as for mounting the array. As will be understood, each free wire end **32** constitutes the other terminal of an individual photocell, and may be connected to its own circuit.

The wires **20** may be arranged in closely spaced parallelism, and then maintained or fixed in such relationship and mutually insulated from each other, by means of an insulating matrix, clamp or the like, in many ways. One simple procedure for arranging the wires is illustrated in FIGURE 3, wherein rods **36** are mounted in spaced parallelism, and a continuous wire **38** wound thereabout with desired spacing between adjacent convolutions. The spacing may be readily effected by using appropriately grooved or threaded rods, or two wires **38** may be wound simultaneously side by side, and one subsequently removed to leave the other in desired spaced relationship. If insulated wire is used, no spacing is necessary, and the convolutions may be wound and maintained side by side. The rods **36**, for example, may be an inch or two in diameter, and arranged with axes spaced apart 10 or 12 inches, whereby the wire layers **40** are each disposed with adequate working space thereabout.

Each wire layer **40**, preferably adjacent one of the rods **36**, may then be embedded in a matrix. In the figure, **42** indicates the area of application of a matrix cement, resin or the like, which is appropriately set or hardened after application. After hardening of the matrix, the wire layers may be cut along lines such as the lines **44** and **46** in FIGURE 3, each layer thereby yielding a very large number of closely spaced wires embedded at one end in the matrix. The sub-assembly may then be buffed or ground on its surface corresponding to the cut line **44**, whereby the matrix surface **26** and wire ends **24** are made flush and lie in a common plane, as illustrated in FIGURES 1 and 4.

The photosensitive layer **28** is next applied to the surface composed of the matrix and wire ends **24**. Any material having photosensitive characteristics may be employed, including photo-resistive, photo-voltaic and photo-emissive materials. Suitable materials, for example, include cadmium sulphide, cadmium selenide and antimony trisulphide. The coating may be applied in any manner adapted to effect a uniform thin material layer, including by evaporation, settling, spraying and the like. For the purposes of the present invention, it is preferred that the photosensitive layer **28** be so thin as to be light permeable. That is, in use some light must completely penetrate the layer **28** in order to provide requisite electric excitation. The term "light" is used as inclusive of radiation of any wave length, covering the entire range from ultra-violet to infra-red.

The preferred method of applying the photosensitive layer **28** is by sputtering or evaporation in a vacuum. In the case of cadmium selenide, for example, a layer thickness of the order of .0001 inch is useful, and the application may be controlled by evaporating a predetermined quantity of material, or by utilizing a glass plate as a visual control, the proper thickness of coating being detected by color change of the control plate.

If the photosensitive material is applied otherwise than by evaporation, it may be necessary to consolidate or sinter the photosensitive material layer, and this is accomplished advantageously by heating the coated assembly after application of the coating material to appropriate temperature. The photosensitive layer may then be sensitized by any conventional and appropriate method, e.g. by treatment with halogens and copper salts.

After sensitization of the photosensitive layer **28**, the transparent conductive coating **30** is applied thereover. The term "transparent" connotes capability of passing light therethrough, and accordingly includes a degree of translucency. The conductive material may be, for example, titanium dioxide, silver or gold. A convenient method of application of the transparent conductive coating is by evaporation in a vacuum. In the case of gold, for example, a layer 3 or 4 microns thick is suitable, and the thickness of the applied coating may be determined as previously described, by evaporating a predetermined quantity of the material under established conditions, or by visual observation of a glass slide control.

In the case of some photosensitive materials, it is advantageous to subject the material after application to ionic bombardment in a vacuum, to improve or modify the final characteristics of the photocells. Typically, such bombardment may be carried out for a period of from about 30 seconds to about 2 minutes under a pressure of the order of 1 mm. of mercury. In the present case, if the photosensitive material is applied by evaporation, the bombardment may be effected before removal from the vacuum chamber. Similarly, if the overlying conductive coating is applied by evaporation, the ionic bombardment may be carried out in the vacuum chamber prior to the application of the conductive material.

In some applications, it is desirable that the face contact between the photosensitive material and the wires, and/or between the photosensitive material and the overlying conductive coating, be ohmic or non-rectifying in character. This can be effectively accomplished by providing an extremely thin flash coating of indium or gallium therebetween, conveniently in the appropriate vacuum coating step.

This completes the manufacture of the photocell array. If metal plates **34** are provided and the conductive coating **30** extends thereover, the metal plates may be utilized as a common terminal of all cells, each free wire end **32** constituting the other terminal of each individual cell. If metal plates are not incorporated in the device, electrical contact with the conductive coating **30** may be made in any other conventional fashion. While in the example the photosensitive layer **28** is continuous, each wire end **24** and the photosensitive material lying immediately thereover function as an individual photocell, the relative resistance between each cell and adjoining cells being so great that the array functions substantially as if the photosensitive layer were discontinuous between cells.

A more sensitive and efficient construction is illustrated in FIGURES 5 through 8. In this embodiment, the initial assembly of FIGURE 4 is treated to recess the wire ends slightly with respect to the matrix surface **26**. This may be accomplished by selectively building up the matrix surface, as by coating, by mechanically removing the exposed ends of the wires, or most conveniently by subjecting the assembly to electrolysis or etching, as by application of an acid solution to the matrix surface **26**, whereby the wire ends **24** are eroded to terminate slightly below the surface **26**, effecting a shallow recess or pocket **50** above each wire end **24**, as illustrated in FIGURE 5.

The photosensitive layer **28** is then applied as previously described, the resultant coating, as illustrated in FIGURE 6, filling the pockets **50** and overlying the matrix surface **26**. As will be recognized, the depth of the pockets **50** may be predetermined to correspond to the desired thickness of photosensitive material, and the applied layer of photosensitive material may then be buffed or similarly mechanically finished down to the matrix surface **26**, leaving, as illustrated in FIGURE 7, a thin disc **52** of photosensitive material in each pocket **50**.

The assembly may then be coated with a continuous layer **30** of the transparent conductive material, the final product being illustrated in FIGURE 8. Of course, the dots or discs **52** of photosensitive material are sensitized and processed as previously described, prior to application of the conductive coating **30**. The construction illustrated in FIGURE 8 is advantageous in that the matrix walls defining each pocket **50** comprise both a lateral light barrier and an electrical barrier between adjacent photocells. Since the electrically conductive coating **30** is normally employed at ground signal potential, with the circuits normally used with this type of photocell assembly complete isolation between cells is provided.

In the illustrative embodiments described to this point, the photocell array is in line arrangement. Two-dimensional arrangements may be produced in similar fashion. For example, in winding wire layers **40** as described in connection with FIGURE 3, a plurality of layers may be wound, one on another. If uninsulated wires are used, a thin sheet of mica may be interposed between successive layers. As illustrated in FIGURE 9, if the mica sheets **54** approximate in thickness the diameter of the individual wires **20**, a uniformly spaced arrangement may be effected as illustrated. As will be understood, the assembly of wire layers and mica sheets may be embedded in a plastic or ceramic medium, clamped, or otherwise rigidified and fixed in the desired arrangement. The numeral **56** in FIGURE 9 indicates an organic matrix material, such as epoxy resin.

As will be evident, if insulated wire **38** is utilized in winding wire layers **40** in the manner of FIGURE 3, the convolutions may be wound as closely as possible, without any spacing in between other than that incident to irregularities in the wire surface. In accordance with this procedure, successive layers may be wound one upon another without added insulation. FIGURE 10 illustrates a two-dimensional arrangement involving insulated wires **60**, each provided with an insulating coating **62**. As illustrated, the insulated wires **60** are embedded in a matrix **64**.

It will thus be seen that there has been provided by this invention an article and method in which the various objects hereinbefore set forth, together with many practical advantages, are successfully achieved. As various possible embodiments may be made of the novel features of the above invention, all without departing from the scope thereof, it is to be understood that all matter hereinbefore set forth or shown in the accompanying drawings is to be interpreted as illustrative, and not in a limiting sense.

I claim:

1. Method of making a miniature photocell array comprising the steps of winding a wire upon a mandrel to form a helix having a plurality of close fitting substantially parallel convolutes, embedding said convolutes in a hardenable insulating matrix material, hardening said material to provide a rigid insulating matrix, cutting through said convolutes in a direction substantially normal to the direction of wind of said convolutes to provide a matrix surface normal to the wire axis, removing the cut bound convolutes from said mandrel, removing the protruding ends of said cut convolutes so that said convolutes provide a common surface with said matrix surface, applying a thin, light permeable layer of photosensitive material to said common surface, and then applying a transparent conductive coating over said photosensitive material, said conductive coating constituting a common terminal for the individual photocells of the array.

2. Method as defined in claim 1, wherein said wire is wound upon spaced mandrels.

3. Method of making a miniature photocell array comprising the steps of winding a wire upon a mandrel to form a helix having a plurality of close fitting substantially parallel convolutes embedding said convolutes in a hardenable insulating matrix material, hardening said material to provide a rigid insulating matrix, cutting through said convolutes in a direction substantially normal to the direction of wind of said convolutes to provide a matrix surface normal to the wire axis, removing the

cut bound convolutes from said mandrel, removing the protruding ends of said cut convolutes so that said convolutes provide a common surface with said matrix surface, recessing the convolute ends in said matrix by etching, applying a thin layer of photosensitive material to said surface and to the recessed convolute ends, mechanically removing the photosensitive material from the matrix surface to leave a small disc of photosensitive material overlying each recessed convolute end, and then applying a transparent conductive coating over said photosensitive material and said matrix surface, said conductive coating constituting a common terminal for the individual photocells of the array.

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