United States Patent

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[72] Inventor Richard S. Walton
Lancaster, Pa.
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[73] Assignee Hamilton Watch Company
Lancaster, Pa.

[54] **SOLID STATE TIME PIECE HAVING ELECTRO OPTICAL TIME DISPLAY**
24 Claims, 11 Drawing Figs.

[52] U.S. Cl. 58/50, 58/23
[51] Int. Cl. G04b 19/30
[50] Field of Search 58/50, 23; 340/334

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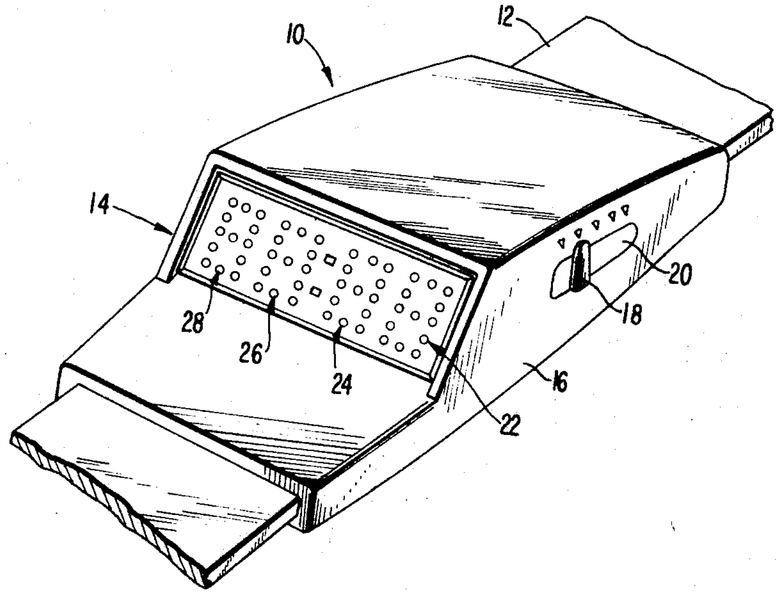
Primary Examiner—Richard B. Wilkinson
Assistant Examiner—Edith C. Simmons
Attorney—LeBlanc and Shur

ABSTRACT: There is disclosed herein an electronic solid-state time piece having an electro-optical display such as an integrated semiconductor light emitting diode structure. The display is provided by four or six digit forming display indicators giving a digital readout of hours, minutes and, if desired, second. The device includes electronic time signal generating circuitry, display drive circuitry and display interrogation and scanning means. A time setting mechanism is also provided.



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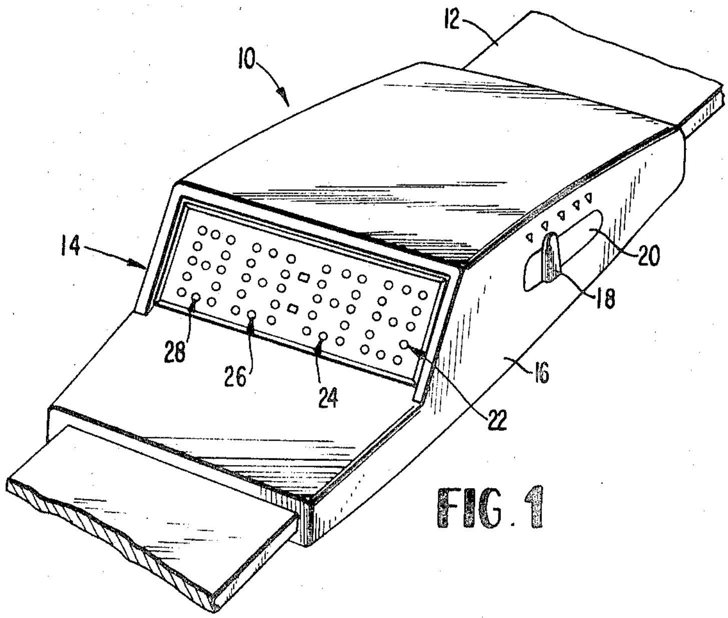

FIG. 1

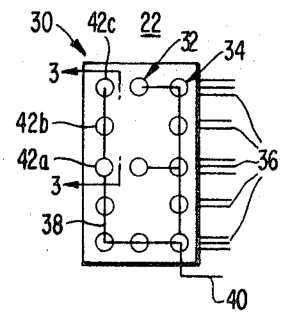

FIG. 2

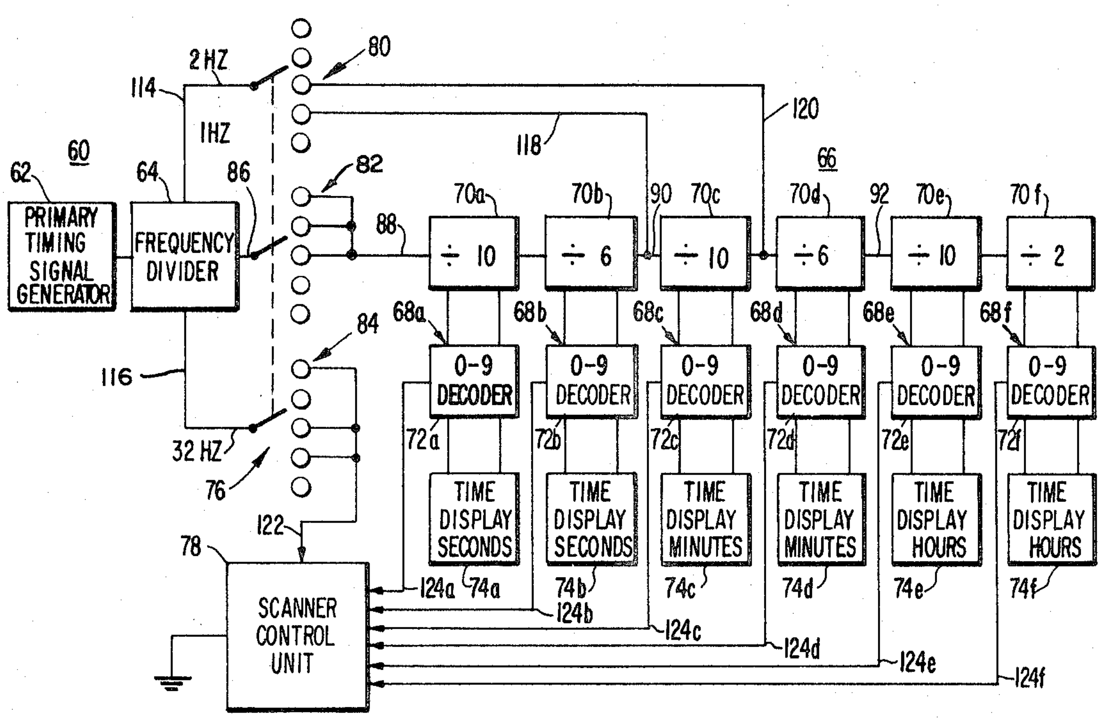

FIG. 4

INVENTOR
RICHARD S. WALTON

BY Le Blanc & Shur
ATTORNEYS

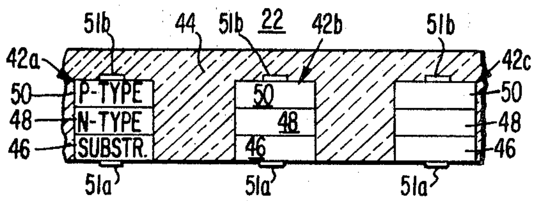

FIG. 3a

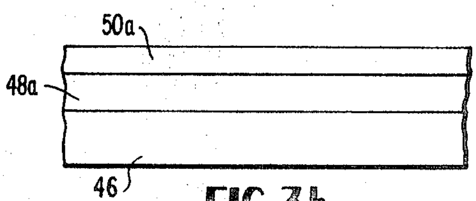

FIG. 3b

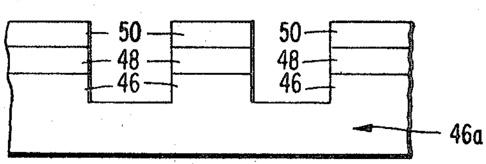

FIG. 3c

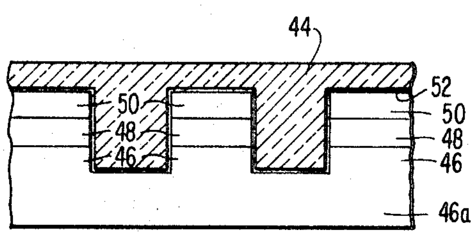

FIG. 3d

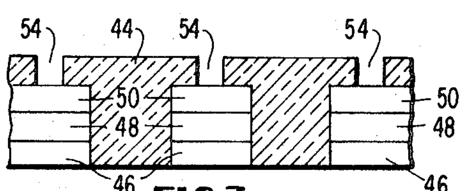

FIG. 3e

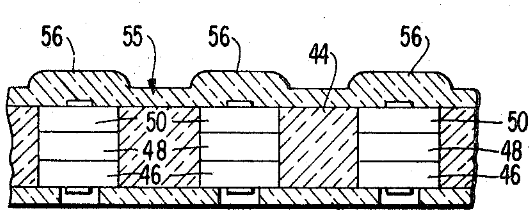

FIG. 3f

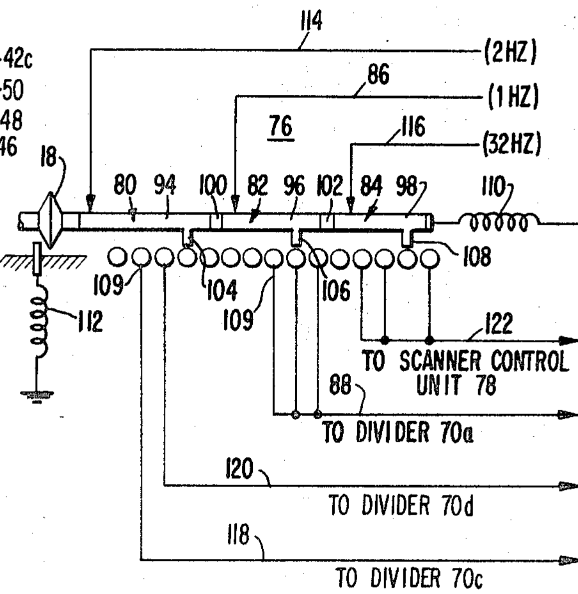

FIG. 5

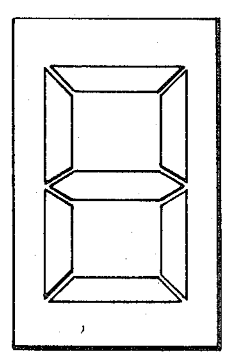

FIG. 6

INVENTOR
RICHARD S. WALTON

BY LeBlanc & Shur

ATTORNEYS

SOLID STATE TIME PIECE HAVING ELECTRO OPTICAL TIME DISPLAY

BACKGROUND AND BRIEF DESCRIPTION

The present invention relates to electronic timekeeping devices, and more particularly to timepieces such as wristwatches and the like having electro-optic displays which are readily perceivable under variable light conditions, with realistically low power consumption.

In spring driven timepieces, or currently available electric watches various electromechanical energy converters are employed as the time display. To enhance the visibility of the display under low light conditions, watch or clock dials are commonly formed with luminous numerals displayed against a nonluminous background, or vice versa. Sometimes, watch and clock dial faces are provided with auxiliary light sources to illuminate the dial for visibility under low light conditions. It is also known to provide clocks utilizing fluorescent materials adapted to be made visible upon irradiation by ultraviolet rays.

In general, all of the foregoing arrangements have been employed with varying degrees of success in timepieces having a mechanically driven display. On the other hand, attempts to develop fully electronic time keeping devices without mechanically driven displays have resulted in significantly different problems, both with regard to effectiveness of the display under variable lighting conditions, and also in creating an optically efficient display having low power consumption to permit practical use in wristwatches.

In attempting to eliminate the electromechanical display, efforts have naturally been directed toward utilization of electro-optic devices providing an illuminated display. For such devices, the problems have been essentially the reverse of those previously encountered in that the electro-optic devices provide a display much more readily visible under low light conditions than under conditions of ordinary daylight. Providing a sufficiently bright display for satisfactory daylight visibility without excessive power consumption has been an extremely serious obstacle to the development of an electro-optic watch display.

Excessive power consumption has manifested itself as a problem in other areas of electronic watch development as well. For the most part, integrated transistor circuitry has been recognized as the only feasible approach to electronic time keeping for wristwatches due to inherent space limitations. Nevertheless, attempts to devise an all solid-state timekeeping device of high accuracy, small size, and low power consumption, yet compatible with electro-optic time displays has also proven to be a serious obstacle to the development of a completely solid-state wristwatch.

Many of the aforementioned difficulties have been resolved by employment of circuit techniques such as those disclosed in applicant's copending U.S. Pat. application, Ser. No. 768,076, filed Oct. 16, 1968, and commonly assigned herewith. The techniques disclosed in the aforementioned copending application allow construction of compact solid-state timekeeping circuitry with adequately low power consumption levels for incorporation in an electronic wristwatch.

In accordance with the present invention utilization of electronic circuitry like that disclosed in applicant's aforementioned copending application, together with an integrated electro-optic display are incorporated in a timekeeping system capable of providing an effectively visible display under daylight conditions without excessive power consumption.

Briefly, the improved electronic timekeeping device of the present invention comprises an integrated light emitting diode display, an integrated circuit for generating a timekeeping signal, a display drive unit, adapted to be manually interrogated, and a suitable time setting mechanism. The electro-optic display may be provided in one of several forms, with the preferred arrangement being a 13-element array for each of the time digits to be presented. Alternatively, a seven bar segment array for each time digit may be substituted.

The timekeeping signal generating unit comprises a primary timing signal generator operating at a frequency which is high in relation to the highest frequency required for time keeping, and a series of frequency dividers responsive to the primary timing signal to generate the low frequency timing signal to generate the low frequency timing signal actually required for operating the display. The display drive unit includes suitable counting and other digital logic and memory circuitry which operates in response to the low frequency output of the frequency divider to actuate the time display indicators in the proper manner to present an accurate time display.

In order to assure minimum power consumption, the display drive unit includes an interrogation and scanning mechanism to eliminate power consumption when the time display is not actually being consulted. When the user wishes to determine the time, an actuator is manually operated and power is provided to the display indicators. For additional power conservation, the display is periodically interrupted, but at a sufficiently rapid rate to exceed the time of persistance of human vision thereby providing the view with an illusion of a continuous display.

The time setting function is accomplished by selectively adjusting the memory states of the display drive unit to produce gross variations in the indicated time.

Accordingly, it is an object of the present invention to provide a fully electronic timekeeping device suitable for wristwatch use.

A further object of this invention is to provide an electronic wristwatch having a completely nonmechanical time display.

It is yet a further object of this invention to provide a wristwatch with an electro-optical time display and with solid-state integrated circuitry to provide timekeeping signals and display actuation.

It is yet a further object of this invention to provide a completely nonmechanical wristwatch with an illuminated digital time display in the form of a plurality of integrated arrays of light emitting diode elements selectively actuated to present an illuminated time display.

It is also an object of this invention to provide a wristwatch having an electro-optical time display including a plurality of selectively illuminated elements and circuitry for periodically interrupting the illumination of the display at a rate sufficiently rapid to present an illusion of a continuous display.

It is another object of the invention to provide a timekeeping device having such an interrupted electro-optical timekeeping display which is normally inactivated to reduce the power consumption of the display.

It is a further object of this invention to provide an electronic timekeeping device providing a nonmechanical digital timekeeping display in the form of a plurality of integrated arrays of solid-state light-emitting diode elements selectively activated by an electronic translating circuit responsive to periodic timekeeping pulses and having means for periodically interrupting the illuminated display at a rate sufficiently rapid to provide the illusion of a continuous display together with means for maintaining the display in normally inactive condition and subject to interrogation on demand to provide the time display readout and having semiautomatic means for resetting the time display to maintain accurate timekeeping.

The exact nature or this invention, as well as other objects and advantages thereof will be apparent from consideration of the following detailed description in conjunction with the drawing in which:

FIG. 1 is a perspective view of an electronic timekeeping device having a digital time display and constructed in accordance with the present invention;

FIG. 2 is an enlarged view of a portion of the display face illustrating the preferred 13-element digital display devices;

FIGS. 3*a*—3*f* are enlarged fragmentary cross-sectional views showing the construction of the integrated light-emitting diode dot matrix of FIG. 2, taken generally along line 3—3 in FIG. 2;

FIG. 4 is a block diagram showing the construction and operation of the timing signal generating unit, the display interrogation and scanning unit, the display drive unit and the time setting mechanism;

FIG. 5 is a representation of a combined setting control and display interrogating mechanism; and

FIG. 6 is an enlarged view showing a digital display indicator in the form of a 7- bar-segment array.

DETAILED DESCRIPTION OF INVENTION

With reference now to the drawings, particularly to FIG. 1, there is illustrated a wristwatch generally indicated at **10**, having a watchband **12**, and a time display face, generally indicated at **14**. Wristwatch **10** includes a casing **16** for housing the time display unit, and an electronic system including a time signal generating unit circuitry for translating the time signal into numerical form for the electro-optical display, a setting mechanism, and display interrogation and scanning means described in more detail hereinafter. A slide actuator **18** is mounted in a slot **20** in the side of casing **16** to actuate the setting mechanism also as hereinafter described.

In the embodiment shown, four digital display indicators **22**, **24**, **26** and **28** are provided for presenting the time display in digital form. Face **14** inclines upwardly at an angle from housing **16** to be readily viewable by the wearer of the watch when the wearer's arm is naturally raised to bring the watch into view.

Digital display indicators **22** through **28** are preferably formed of a plurality of display elements selectively actuable to provide a readily visible time display. In the preferred arrangement, the indicators each comprise an array of 13 properly arranged semiconductor light-emitting diodes. As illustrated, the four display indicators are arranged across face **14**, to present a 4-digit display of hours and minutes, but it should be understood that a six unit display including two seconds digits may be provided.

The nature and construction of the light-emitting diode arrays will be described more fully hereinafter in connection with FIGS. *3a*—*3f*. However, as illustrated in FIG. 2, each array is formed of three columns of diodes **30**, **32**, and **34**. Left and right columns **30** and **34** each comprise five diodes, while center column **32** comprises three diodes.

Each diode is provided with a separate path for electrical actuation. The thirteen individual leads **36** are connected respectively to one of the diode elements, e.g. on the reverse side as indicated in FIG. 2. A common return path **38** connects all the diodes, and terminates as shown in a single return path **40**. By selectively actuating various combinations of diodes over leads **36** and **40**, all of the digits between zero and 9 may readily be synthesized. Thus, to represent the numeral zero, all of the diodes would be illuminated except that at the center, i.e., the middle element of column **32**. Likewise, to display the numeral **1**, all of the elements in either of columns **30** or **34** would be illuminated. Other numerals would be represented in a similar fashion.

It should be pointed out that light-emitting solid-state diodes, and even 13-element display indicators as described above are known for alphanumeric display purposes and it should therefore be understood that the use per se of such an arrangement does not constitute part of this invention. However, employment of an integrated solid-state matrix of light-emitting diodes having certain carefully selected properties as hereinafter detailed, in conjunction with the electronic system disclosed herein has been found to be quite important to successful practice of the invention.

As mentioned above, display indicator **22** comprises a 13-element array coupled to suitable logic and memory circuits to display minutes in units from zero to 9. The adjacent indicator **24** is arranged to display tens of minutes from zero through 5. By selective actuation of indicators **22** and **24**, the full range of minutes from zero to 59 may be displayed.

Correspondingly, display indicator **26** is arranged to display hours in selected units from zero to 9, while indicator **28** is arranged to display selected tens of hours in units from zero through 2, whereby the hours from 1 through 24 may be displayed.

It should be appreciated, however, that it may be preferable to provide only a 12 hour time cycle. In that event, indicator **28** need not comprise an entire 13-element array. Rather, it may be formed of a column of five diode elements such as column **30** or **34** (in FIG. 2). In that case, all of the elements are illuminated to display the hours **10**, **11**, and **12**, but are otherwise not illuminated. Accordingly, for the hours 1 through 9, only a three-digit display is necessary.

FIGS. *3a*—*3f* shown the construction of one of the 13-element display indicators such as indicator **22**. As previously mentioned, each of the indicators comprises an integrated array of 13-light emitting semiconductor diodes. As illustrated in FIG. *3a*, individual diode elements denoted at **42***a*, **42***b* and **42***c* are supported in a matrix **44** of transparent insulating material such as glass or plastic having suitable dielectric properties. Each of the diodes **42***a*—**42***c* is formed of a substrate layer **46** of semiconductor material having substantially intrinsic properties, and two layers **48** and **50** of P-type and N-type semiconductor material respectively which actually form the diode. Electrical connections for leads **36** and **38** to each diode are made to substrate layers **46** and P-type layers **50** at **51***a* and **51***b*, respectively. The actual conductors are omitted from FIG. *3a* in the interest of clarity, but it should be appreciated that the required connections may be made in any suitable fashion. For example, thin conductive leads are evaporated onto the P-type layer **50** to provide the desired common return path **38**. Similarly, individual conductors **38** are evaporated on the reverse side of the indicator in an appropriate pattern to lie on the dielectric matrix **44** with contact only to one of the substrate areas **46** for each lead.

As will be appreciated by those skilled in the art, several techniques are available for manufacturing the above-described integrated display indicators. The manufacturing technique per se does not constitute a part of this invention, and therefore only a brief description is presented in the interest of brevity. With reference therefore to FIG. *3b*, the manufacturing process begins with a composite diode element in the form of a monolithic substrate **46***a* having epitaxially deposited N-type and P-type layers **48***a* and **50***a*. The composite structure constitutes a single diode approximately equal in size to the ultimately manufactured 13-element array.

Individualizing the diode elements is accomplished as shown in FIG. *3c* by transforming the epitaxially deposited N-type and P-type layers into an array of 13 mesas or lands in the required configuration e.g., by use of a commercially available ultrasonic cutting tool. As illustrated in FIG. *3c*, substrate **46***a* is partially cut away leaving upwardly extending substrate bodies **46** of approximately the same thickness as the N-type and P-type layers **48** and **50**.

After cutting, a thin layer **52** of Silicon Dioxide is applied to the array as a passivation layer, and the transparent supporting matrix **44** is provided. (See FIG. *3d*) This may be done in several ways. For example, a glass blank may be heated, and the partially processed display indicator pressed into the glass so that the latter fully occupies the interelement spacing resulting from the cutting operation. Alternatively, suitable transparent polymer material having appropriate dielectric properties may be used to encapsulate the partially processed structure.

At this point, the partially finished array is ready for the final processing steps and attachment of electrical contacts. As shown in FIG. *3e*, a series of small openings **54** are formed in the surface of supporting matrix **44** directly above each of the diode elements. Then, the remaining portion of the monolithic substrate **46***a* is removed, e.g., by lapping to the lower surface of the matrix **44**. This provides a flat surface with substrate bodies **46** only in the areas of the 13-diode elements. Then, the electrical connectors are attached, as previously noted. The openings **54** may then be filled if desired to produce the integrated display indicator array shown in FIG. 3*a*.

An alternative finishing technique is illustrated in FIG. 3*f*. Here, instead of providing openings **54** in matrix **44**, the latter is lapped down to expose the tops of P-type layers **50**, and the thin conductive path **38** applied as before. Then, a unitary lens array **55** of epoxy or the like, is formed, e.g., by molding on the upper surface of matrix **44**. Lens array **55** includes **13** raised lens elements **56** axially aligned with the diode elements to concentrate the light output for more efficient operation.

The lower surface of the array may be finished as before. Alternatively, it may be coated with a phosphorescent layer **58** as illustrated in FIG. 3*f* to permit s shorter duty cycle during scanning as later explained.

While the foregoing represent suitable techniques for manufacturing the diode indicator arrays, it should be understood that other techniques may also be employed. In addition, it might be noted that the above description pertains to manufacture of a single indicator. However, an integrated structure of the four or six required indicators constituting the entire time display for the watch could also be provided.

As pointed out above, light-emitting diodes are well know. However, it has been found that most such diodes are totally unsuitable for use in a display indicator for an electronic wristwatch. It is also found that the nature of the semiconductor materials employed, the doping, etc. are the primary factors in determining suitability.

More specifically, satisfactory operation requires utilization of semiconductor materials and constructions yielding a satisfactory brightness level at an appropriate wavelength and with reasonable power consumption. Thus, it has been found that the semiconductor material employed should be such that the emission spectrum of the diode is centered at a wavelength between about 4500 Angstroms and about 6500 **Angstroms and preferably centered between** 5000 Angstroms and about 6300 Angstroms. Such materials would exhibit band gap energies varying between 1.9 and 2.75 electron volts, and preferably varying between 2.0 and about 2.5 electron volts.

Satisfactory operation under varying lighting conditions requires not only attention to the primary emitted wavelength, but also to the brightness level at a realistic level of current excitation. As will be appreciated, a brightness level sufficient for satisfactory perception under relatively dark conditions may be insufficient for visibility in full daylight. Accordingly, it has been found that the diode elements should produce a brightness level on the order of at least about 30 foot Lamberts for a current flow of between about 1 ma. and 5 ma. at about 1.5 volts to about 2.5 volts. Diode elements exhibiting a lower brightness may be employed depending upon the primary wavelength of emission as long as satisfactory visual stimulation is achieved.

To meet the foregoing requirements, it has been found that several different semiconductor materials may be utilized. These include gallium phosphide which produces a green emission in the vicinity of 5500 Angstroms. Silicon carbide, which is capable of producing emissions varying in wavelength between about 4100 and about 5600 Angstroms may also be employed. Further, certain semiconductor alloys, particularly gallium phosphide-aluminum arsenide or gallium arsenide-phosphide can be employed. This latter, for example, may be employed to produce light-emitting diodes having a peak emission at about 6300 Angstroms with good radiation efficiency. The required P-N junction can be formed by depositing the semiconductor alloy on an appropriate substrate such as gallium arsenide. The junction is formed by diffusion of a suitable acceptor material such as zinc. The 13-element display indicator as described herein may be formed in the manner described in connection with FIGS. 3*a* through 3*f* above.

With reference now to FIGS. **4** and **5**, there is shown an electronic timekeeping system employing the 13-element integrated display indicator previously described.

As illustrated in FIG. **4**, the timekeeping system includes a time signal unit **60** including a primary timing signal generator **62** and a frequency divider **64**. A display drive unit generally noted **66** includes six separate drive channels **68***a* through **68***f*, each including a digital counter **70***a* through **70***f* and a decoding or translating unit **72***a* through **72***f* functioning in the manner hereinafter described. Each of display drive channels **68***a* through **68***f* is coupled to an individual time display indicator **74***a* through **74***f*, preferably of the type described in connection with FIGS. **2** and **3***a* through **3***f* above.

Associated with display drive unit **66** is a time setting-display interrogation switch **76** and a scanner control unit **78**. Switch **76** is a three stage five position switch described in detail hereinafter. A first stage **80** provides an interconnection between frequency divider **64** and counters **70***c* and *d* to reset the time display. A second stage **82** provides an interconnection between frequency divider **64** and counter **70***a* and serves as the input for the timekeeping drive signal. Switch stage **84** provides an interconnection between frequency divider **64** and the scanner control unit **78** to periodically interrupt the display during interrogation whereby substantial saving in power consumption may be effected.

Time signal unit **60** serves to generate the display drive signal, the time setting signal, and the interruption control signal for scanner control unit **78**. To permit display of time to the nearest second, a timekeeping signal at a frequency of 1 Hz. is needed. This is provided by frequency divider **64** over lead **86**. For time display setting, it is found that a faster drive rate may be employed, e.g. 2 Hz. This is provided by frequency divider **64** over lead **114**.

As noted the display is scanned or interrupted at a rapid rate during viewing, to conserve power. However, if the interruptions are frequent enough, and the duty cycle or "on time" is sufficient, an illusion of continuous display can be produced. For this purpose, an interruption rate of at least 30 Hz. is preferred in a binary counting chainlike frequency divider **64**, a signal at 32 Hz. (2^6) is available, and is provided on lead **116**. The signals on leads **86**, **114**, and **116** are provided through switch **76** for the various purposes as herein described.

Because several frequencies are needed, it will be appreciated that the two stage arrangement shown including primary timing signal generator **62** and frequency divider **64** should be employed. In addition, it is found that the frequency of generator **62** should be substantially in excess of the frequencies needed for operating the display. This is because it has been found that production of a low frequency timing signal generator having a sufficient level of accuracy, and meeting the necessary size and power consumption requirements is quite difficult. In contrast, employment of a high frequency ultrastable multivibrator, for example, such as that shown and described in applicant's aforementioned U.S. Pat. application, Ser. No. 768,076 or in copending U.S. Pat. application, Ser. No. 802,571 filed Feb. 26, 1969 in the name of C. H. Rahell and commonly assigned herewith, produces excellent results.

Frequency divider **64** may be of any suitable and desired circuit configuration, but preferably employs circuitry of the type disclosed in applicant's aforementioned patent application, Ser. No. 768,076. In a preferred embodiment, primary timing signal generator **62** is a free running multivibrator pulse generator operating at a frequency of 524,288 (2^{19}Hz., while frequency divider **64** comprises **19** stages of complementary MOS integrated circuit frequency dividers. This provides the output signal on lead **86** at the required 1 Hz. frequency.

When connected to frequency divider **64** through switch stage **82**, display drive channels **68***a* through **68***f* respond to the 1 Hz. timing signal to provide an accurate second, minutes and hours display on time indicator units **74***a* through **74***f*. From comparison of FIGS. **1** and **4**, it will be noted that the timekeeping device of FIG. 4 makes provisions for a seconds display while that of FIG. 1 does not. However, it will be appreciated that the seconds time display provided by indicators 74*a* and 74*b* may be added to the wristwatch of FIG. 1 (or removed from that of FIG. 4) without any significant departure from the techniques described herein.

Referring still to FIG. 4, the 1 Hz. drive signal is connected through stage 82 of switch 76 and through lead 88 to the input of counter stage 70*a* which operates as a scale of 10 divider (i.e., mod 10). The output of counter stage 70*a* is connected to the input of counter stage 70*b* which operates mod 6. Accordingly, counters 70*a* and 70*b* together operate mod 60, whereby the 1 Hz. input signal on lead 88 is divided down to produce an output signal from stage 70*b* on lead 90 at a frequency of 1 pulse per minute.

The latter signal is connected through a third counter stage 70*c* operating mod 10, and a fourth stage 70*d* operating mod 6 to produce a second mod 60 divider having an output signal on lead 92 at the rate of 1 pulse per hour. This signal in turn is connected to a fifth counter stage 70*e* operating mod 10, and sixth stage 70*f* operating mod 2 to control the hour portion of the time display.

Appropriate output connections are made from the internal stages of counters 70*a* through 70*f* to produce a unique binary code output assemblage for each second of the 12 or 24 hour timing period. For example, the output code may be in the form of binary coded decimal in an 8-4-2-1 code, or in any other appropriate code. These 12 in turn are transformed by decoders 72*a* through 72*f* including appropriate logic circuitry into a multielement output code for actuation of the display indicators 74*a* through 74*f*. In the case of the 13-element display indicators described in connection with FIGS. 2 and 3*a* through 3*f*, decoder units 72*a* through 72*f* each provide a 13-element output code to the respective display indicators. However, the details of the logic circuitry incorporated in counters 70*a* through 70*f* and the coders 72*a* through 72*a* do not constitute a portion of this invention per se, and therefore are omitted in the interest of brevity.

In FIG. 5, there is shown a specific representation of the time setting-display interrogation switch 76 shown in FIG. 4. Switch 76 comprises an elongated composite slide member formed of three electrically conducting portions 94, 96 and 98 with insulating spacers 100 and 102 separating conductive portions 94 and 96 and 96 and 98 respectively. Contact projections 104, 106 and 108 extend from conductive portions 94, 96 and 98 respectively to engage with various ones of a plurality of fixed contact members generally denoted 109. A nonconductive actuator portion 18 extends from the end of conductive portion 94 out through the housing 16 as illustrated in FIG. 1. A compression spring 110 is secured in electrical isolation to conductive portion 98 to maintain slide switch 76 normally in the position shown. This corresponds to the normal operating position as hereinafter explained. Also, spring 110 allows switch 76 to be moved to the right as illustrated in FIG. 5 against the compressive spring force, and to return to the normal position when the switch is released. This corresponds to the interrogate position for the time display. In contrast, a detent mechanism 112 cooperates with actuator 18 when switch 76 is moved to the left making such motion relatively difficult in comparison to movement to the right. These positions are used for the timesetting functions or to stop the watch completely.

As illustrated, the electrical input for switch stage 82 is provided by lead 86 from the 1 Hz. output of frequency divider 64 through switch conductive portion 96. A suitable sliding contact mechanism provides the electrical connection. Switch stages 80 and 84 are energized by signals over leads 114 and 116 respectively from outputs of frequency dividers 64 at frequencies of 2 Hz. and 32 Hz. Again, suitable sliding contact mechanisms provide the electrical interconnection.

The first five fixed contact members 109 (from the left) are associated with switch stage 80, the second five fixed contacts are associated with switch stage 82, and the last five fixed contacts are associated with switch stage 84. As illustrated, for stage 80, the rightmost position, the normal position, and the leftmost position are electrically unconnected while the second position from the left, and the center position are connected by leads 118 and 120 to the input of divider stages 70*c* and 70*d* respectively. For switch stage 82, the two left-hand positions are electrically unconnected, while the three right-hand positions are connected in common by lead 88 to the input of divider stage 70*a*. In switch stage 84, the leftmost position and the normal position are unconnected, while the center position, the rightmost position and the second position from the left are electrically connected in common to an input of scanner control unit 78 by a lead 122.

Referring back to FIG. 4, scanner control unit 78 is an electronic logic circuit whose purpose is to actuate decoders 72*a* through 72*f* in synchronism with the input drive signal on lead 122. The circuitry itself may be of any suitable form, for example, it may be a six input "inhibit" circuit which completes the power supply path for decoders 72*a* through 72*f* over signal leads 124*a* through 124*f* respectively. When switch stage 84 is in the rightmost center and second from left positions as shown in FIG. 5, the 32 Hz output of frequency divider 64 is connected over lead to periodically actuate scanner control unit 78. This periodically actuates decoders 72*a* through 72*f* which in turn periodically actuate time display indicators 74*a* through 74*f* with a changing pattern of drive signals to effect the desired time display. In other words, the input code provided by dividers 70*a* through 70*f* periodically is converted into the desired actuating code for the display indicators to produce the required time display, but only when switch 76 is actuated to the interrogate position or during setting as later explained.

As will be appreciated, the persistence of human vision may be utilized to substantial advantage here since a relatively slow scanning rate may be employed with good perception while effecting a drastic reduction in power consumption. For example, an interrogation rate of 25 times per day for a period of about 5 seconds each may be assumed. In that case, with the 13-element display drawing about 1 ma. per diode for a brightness of 38 foot Lamberts a scanning rate of 32 times per second with an "on time" of approximately 4 milliseconds may be employed. This would produce an approximate power consumption of 25 ma. hours per year. In contrast, a continuously operating display using the same elements but without interrogation and scanning would result in a power consumption on the order of 50 ampere-hours per year. Since marketability and consumer acceptance of battery operated timepieces appear to require a battery replacement rate not exceeding approximately 1 per year, it should be appreciated that the power consumption reduction affected by the interrogation and scanning is a substantial factor in achieving success in accordance with this invention.

The operation of time interrogation and setting switch 76 may be described as follows. As illustrated, in FIGS. 4 and 5, the normal operating position for switch 76 is with the moving contact projections 104, 106 and 108 on the second fixed contacts, i.e., the second position from the right as illustrated in FIG. 5. In this position, counters 70*a* through 70*f* continue to operate responsive to the 1 Hz. signals from frequency divider 64 on lead 88. In this way, accurate time continues to be kept even when the display is inactive.

Interrogation is achieved by moving switch actuator 18 to the right to engage the contact projections 104 through 108 on slide members 94 through 98 respectively, with the rightmost fixed contacts 109. Movement to the right is resisted by compression spring 110 which normally biases the switch in the position illustrated, When switch 76 has been moved to the rightmost position, it may be seen that an electrical connection exists between lead 116 from the 32 Hz. output of frequency divider 64 through lead 122 to scanner control unit 78. This actuates decoders 68*a* through 68*f* as previously described thereby allowing the time display to be operated. In order to determine the time, the wearer simply moves the actuator lever 18 to the right. This causes time to be displayed on display indicators 74*a* through 74*f* for the duration of the time that the actuator is maintained depressed. The display is interrupted as previously explained, but the illusion of a constant display is produced by the persistence of human vision. When actuator 18 is released, spring 110 causes slide switch 76 to return to its normal position whereby the timekeeping function produced by divider 70*a* through 70*f* continues but the display is disabled.

Various time setting functions are achieved by moving actuator lever 18 to the three positions to the left of normal in FIG. 5. Detent 112 serves to make movement of actuator to the left somewhat difficult, thereby avoiding inadvertent operation of the setting mechanism, e.g., when time interrogation is intended. The first position to the left of normal for switch 76 provides a coarse time adjustment. Here, an electrical connection exists through switch stage 84 from the 32 Hz. output of frequency divider 64 to scanner control unit 78, from the 1 Hz. output of frequency divider 64 to divider 70*a*, and from the 2 Hz. output of frequency divider 64 to the input of divider 70*d*. Hence, the watch continues to run (via stage 82) the display is actuated (via stage 84) and the time represented by divider 70*d*, vis, the tens portions of the minutes display is changed at the rate of 2 counts per second. In this way, the minutes display may be advanced 20 minutes per second and correspondingly, the hour display may be advanced 1 hour in 3 seconds. This effects a coarse time correction as mentioned, or may be used to advance the watch rapidly during time zone changes.

Movement of slide switch 76 to the second position left of normal provides a fine adjustment of the time display by advancing the unit digit of the minutes display. In this position, an electrical circuit exists through switch stage 80 from the 2 Hz. output of frequency divider 64 over lead 114, and lead 118 to divider stage 70*c*. Also, an electrical path exists between the 32 Hz. output of divider stage 64 through switch stage 84 over lead 116, and lead 122 to scanner control unit 78. This is necessary so the user can observe the time change being effected. However, the watch itself preferably does not run at this time to facilitate accurate setting. Therefore, no electrical connection exists through switch stage 82 from the 1 Hz output of frequency divider 64 to divider stage 70*a* in this mode of operation.

Under these circumstances, the count of frequency divider stage 70*c* is changed at the rate of 2 counts per second whereby the time display may be changed a total of 9 minutes in 4½ seconds and a total of 1 hour in 30 seconds. This alone, or in combination with the coarse adjustment provided in the previously described operating mode, allows rapid and convenient time setting.

Finally, the leftmost position for switch 76 provides no electrical connections between frequency divider 64 and display drive unit 66. Under these conditions, the wristwatch is effectively stopped. This allows the timepiece to be preset and then held in readiness prior to actuation at a precise instant, or permits the watch to be maintained completely inactive if desired for power conservation. (In the latter case, it may also be desirable to provide an additional switch contact or other means for disabling primary timing signal generators 62 and frequency divider 64 whereby a complete shutdown of the timepiece is achieved).

From the foregoing, it will be appreciated that there has been provided a totally electronic wristwatch having no mechanical parts except the interrogation and setting actuator switch. At the same time, various problems encountered in past efforts to design such a wristwatch are overcome by the employment of an electro-optical display of small size and good visibility without excessive power consumption. However, several alternatives to the above-described construction are also possible.

Thus, in addition to variations in the design of the logic circuit elements as previously suggested, in the primary timing signal frequency, and in the corresponding number of stages of frequency divider 64, other display indicator configurations may also be employed. One such configuration is illustrated in FIG. 6 in the form of a seven bar segment indicator comprised of seven relatively elongated light-emitting diode elements formed as an integrated unit in the manner described in connection with FIGS. 2 and 3*a* through 3*f*. In such an arrangement, the diode elements themselves are substantially larger than in the 13-element display indicator, with a correspondingly greater total illumination. On the other hand, an increase in power consumption by a factor of approximately 5 is encountered whereby it will be appreciated that a trade off between low power consumption and increased visibility may be necessary.

A further alternative would be to provide a suitable phosphorus screen in association with the light-emitting diode display indicators. This 5 be applicable either to the configuration of FIG. 2, as noted above, or the configuration of FIG. 6. This could permit a somewhat shorter "on time" for the interrogated display without substantial reduction in the level of visual perception.

As a further alternative, electro-optical display elements of the type disclosed in copending application, Ser. No. 794,551, filed Jan. 28, 1969, in the name of John M. Bergey, and commonly assigned herewith, or miniature incandescent lamps arranged in seven or 13-element arrays may be substituted for the light-emitting diodes herein disclosed. Other modifications within the scope of this invention will likewise occur to those skilled in the art in light of the foregoing description.

I claim:

1. A solid-state timekeeping device having sufficiently small power consumption for use as a wristwatch comprising means for generating periodic timekeeping signals, code generator means responsive to said timekeeping signals to establish a multielement code having a unique code word for each unit time interval in a period, a digital display comprised of a plurality of multistate electro-optical indicators responsive to said code words to provide a unique visual display for each time interval in said time period, and a manually operable interrogator switch coupled to said code generator means whereby said digital display is energized by said code generator means only upon operation of said switch.

2. A timekeeping device as defined in claim 1 wherein said digital display includes indicators for minutes between zero and 59, and for hours in a time period of at least 12 hours.

3. A timekeeping device as defined in claim 2 wherein said digital display includes additional indicators for seconds between zero and 59.

4. A timekeeping device as defined in claim 1 wherein each indicator in said digital display comprises a plurality of individually actuatable electro-optical devices disposed in such a configuration that actuation of selective ones of said devices in response to said code words produces said unique visual displays.

5. A timekeeping device as defined in claim 4 wherein each of said display indicators comprises a 13-element array of electro-optical devices.

6. A timekeeping device as defined in claim 4 wherein each of said display indicators comprises a 7-element array of electro-optical devices.

7. A timekeeping device as defined in claim 1 wherein said display indicators are formed of a plurality of semiconductor elements including a layer of P-type and a layer of N-type materials, said elements being characterized by a light emission spectrum under current excitation between about 4500 Angstroms and 6500 Angstroms and a band gap energy between about 1.9 electron volts and about 2.75 electron volts.

8. A timekeeping device as defined in claim 7 wherein said light-emitting semiconductor elements provide a surface brightness of at least 30 foot Lamberts.

9. A timekeeping device as defined in claim 7 wherein said semiconductor elements provide a surface brightness of about 38 foot Lamberts.

10. A timekeeping device as defined in claim 7 wherein the semiconductor material for said P-N junction devices is selected from the group consisting of gallium phosphide, silicon carbide, gallium arsenide phosphide, and gallium phosphide-aluminum arsenide.

11. A solid-state timekeeping device having sufficiently small power consumption for use as a wristwatch comprising means for generating periodic timekeeping signals, code generator means responsive to said timekeeping signals to establish a multielement code having a unique code word for each unit time interval in a period, a digital display comprised of a plurality of multistate electro-optical indicators responsive to said code words to provide a unique visual display for each time interval in said time period, and means coupled to said code generator means for periodically interrupting the energization of said display from said code generator means.

12. A timekeeping device as defined in claim 11 wherein said interruption means comprises scanning means for interrupting the energization of said display at a frequency of at least about 30 Hz.

13. A timekeeping device as defined in claim 11 wherein said generating means includes means for generating a first signal having a lower frequency and a second signal of higher frequency, means coupling said first signal to said code generator means, and means coupling said second higher frequency signal to said interrupting means.

14. A timekeeping device as defined in claim 10 wherein the frequencies of said first and second signals are binarily related.

15. A timekeeping device as defined in claim 14 wherein said first signal has a frequency of 1 Hz. and said second signal has a frequency of at least 32 Hz.

16. A solid-state timekeeping device having sufficiently small power consumption for use as a wristwatch comprising means for generating periodic timekeeping signals including a primary timing signal generator and a frequency divider, code generator means coupled to the output of said divider and including at least hours and minutes display drive channels, a digital display coupled to said drive channels and comprised of a plurality of multistate electro-optical indicators responsive to said drive channels to provide a visual time display in the form of digital numbers to the base 10, first switch means for coupling a signal from said divider having a frequency of at least 2 Hz. to one of said drive channels for coarse time setting, and second switch means coupling said signal to another of said drive channels for fine time setting.

17. A timekeeping device as defined in claim 16 including third switch means for disconnecting said code generator from the output of said divider during fine time setting.

18. A solid-state timekeeping device having sufficiently small power consumption for use as a wristwatch comprising a primary timing signal generator, a frequency divider coupled to the output of said generator, a code generator coupled to the output of said divider and including at least hours and minutes display drive channels, a digital display coupled to said drive channels and comprised of a plurality of multistate electro-optical indicators responsive to said drive channels to provide a visual time display in the form of digital numbers to the base 10, a manually operable interrogator switch coupled to said code generator whereby said digital display is energized by said code generator only upon operation of said switch, and interrupting means coupling said divider to said code generator for periodically interrupting the energization of said display from said code generator at a rate determined by an interrupting signal from said divider.

19. A timekeeping device as defined in claim 18 wherein said signal from said divider is at a frequency of at least 32 Hz.

20. A timekeeping device according to claim 18 wherein said display includes a plurality of light-emitting diodes.

21. A timekeeping device as defined in claim 18 including means coupling a setting signal from said divider to one of said drive channels.

22. A timekeeping device as defined in claim 21 including a first switch for coupling the output of said divider to said code generator, a second switch for coupling said setting signal from said divider to said code generator, and a third switch for coupling said interrupting signal from said divider to said interrupter.

23. A timekeeping device as defined in claim 22 wherein said switches are ganged multiposition switches.

24. A timekeeping device as defined in claim 23 including means for coupling said setting signal through said second switch to different ones of said drive channels for both coarse and fine setting, said first switch being in the open position during fine setting.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,576,099 Dated April 27, 1971

Inventor(s) Richard S. Walton

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Abstract, line 6, "second" should read --seconds--. Column 2, line 7, cancel "to generate the low frequency timing signal". Column 3, line 24, after "Mechanism" insert --and to operate the display interrogation and scanning mechanism--. Column 5, line 24, "know" should read --known--. Column 6, line 66, "(2^{19}Hz.," should read --(2^{19}) Hz-- Column 7, line 28, cancel "12" and substitute --signals--. Column 7, line 36, "72a" should read --72f--. Column 8, line 22, "lead" should read --lead 122--. Column 10, line 15, cancel "5" and substitute --would--. In claim 14, Column 11, line 28, "as defined in claim 10" should read --as defined in claim 13--.

Signed and sealed this 26th day of October 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Acting Commissioner of Patent