United States Patent [19]
Ace

[11] **3,814,964**
[45] **June 4, 1974**

[54] EXTERNAL PHOTODETECTOR COOLING TECHNIQUES

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[22] Filed: **Jan. 19, 1973**
[21] Appl. No.: **324,922**

[52] **U.S. Cl.** **313/39,** 313/94, 60/3
[51] **Int. Cl.** **H01j 1/02**
[58] **Field of Search** 313/39, 94

[56] **References Cited**
UNITED STATES PATENTS

3,064,440	11/1962	Waller	313/39

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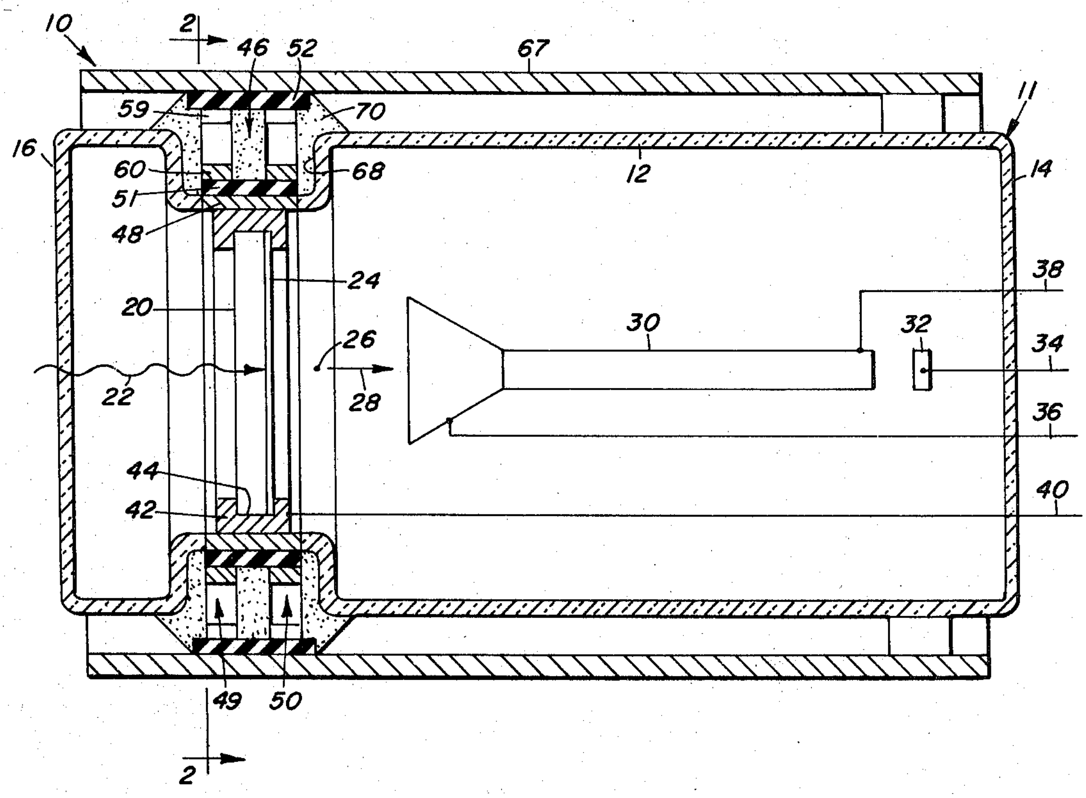
Assistant Examiner—Darwin R. Hostetter
Attorney, Agent, or Firm—Jones and Lockwood

[57] ABSTRACT

A technique is disclosed for improving the performance of photoemissive devices such as the photocathode of a photomultiplier tube by reducing thermal electron emission noise and thus increasing the signal to noise ratio. A thermoelectric cooler is positioned outside the evacuated envelope of the photoemissive device but in thermal communication with the device through a thermally conductive link arranged within and extending through the wall of the envelope. This conductor places the photoemissive device in direct heat exchange relationship with the external thermoelectric cooler while isolating the cooler from the remainder of the tube structure whereby the device is efficiently cooled without the need for cooling the remaining elements of the tube. This permits efficient cooling while at the same time avoiding the expense and bulk of conventional cryostatic coolers.

18 Claims, 6 Drawing Figures



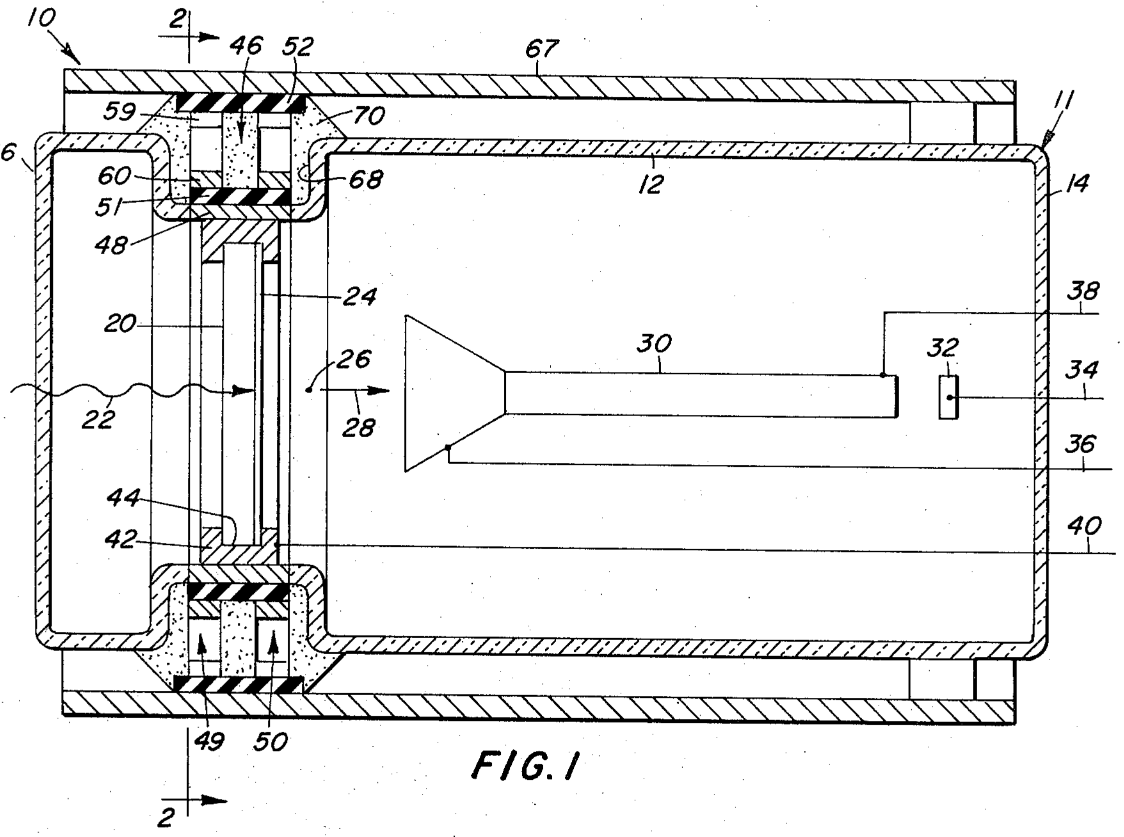

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FIG. 1

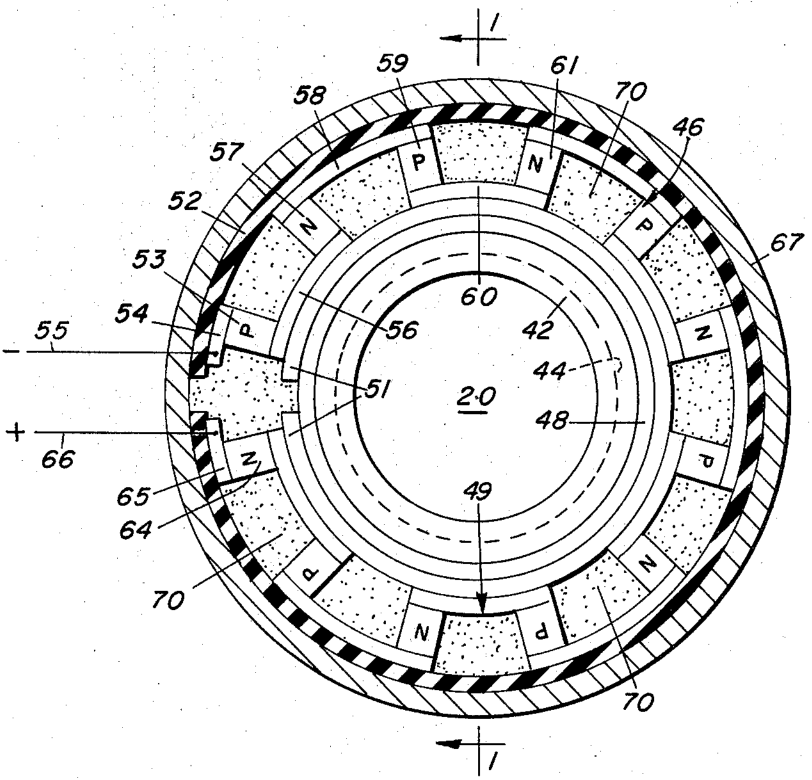
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FIG. 2

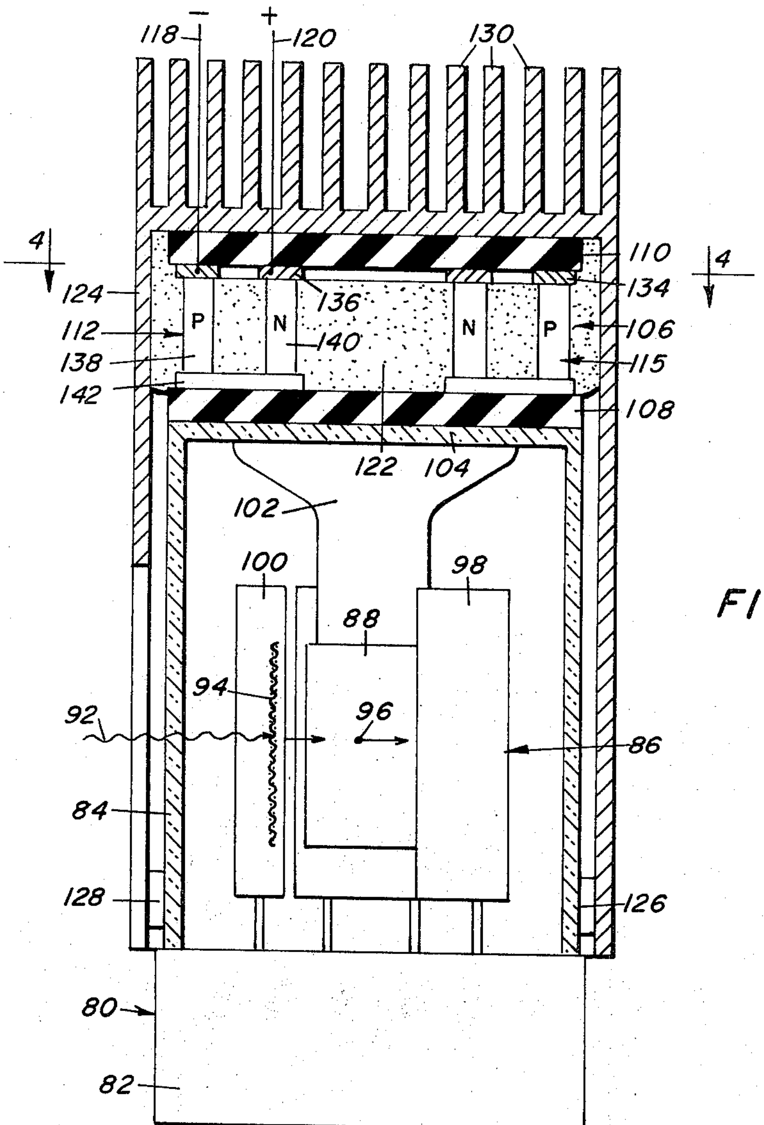
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FIG. 3

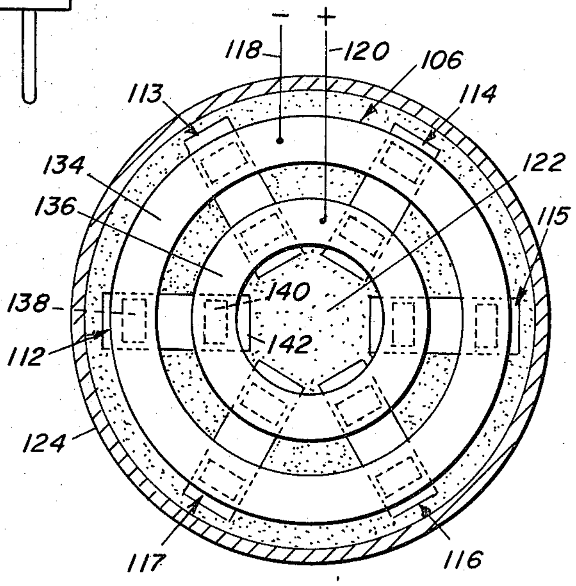
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FIG. 4

FIG. 5

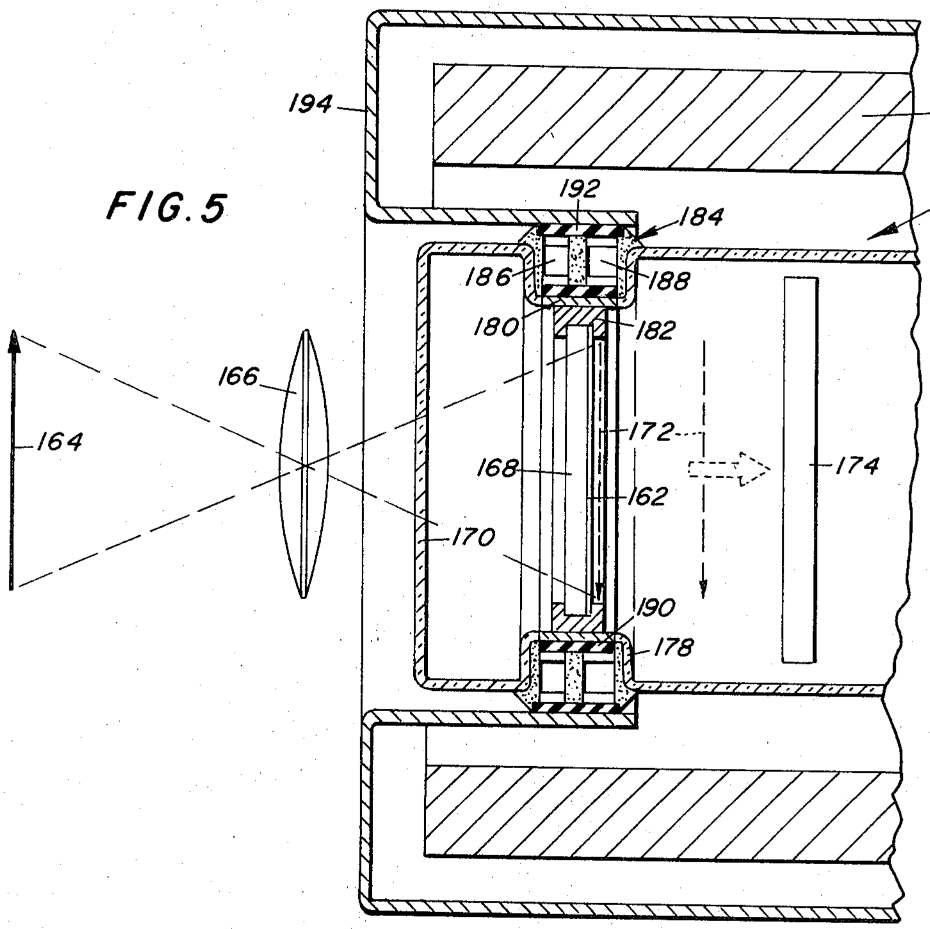
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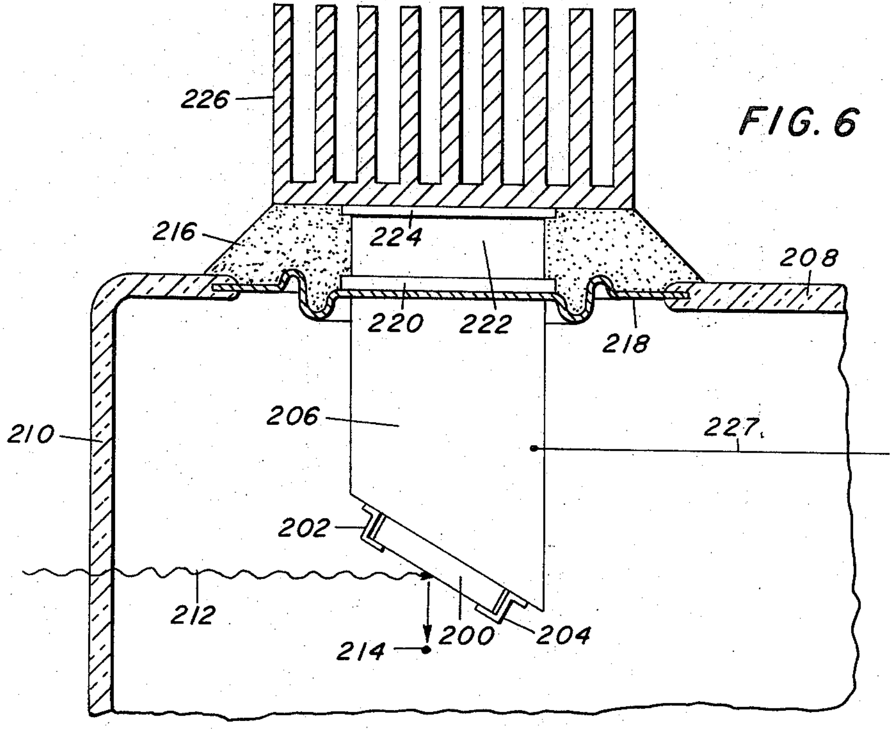
FIG. 6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EXTERNAL PHOTODETECTOR COOLING TECHNIQUES

BACKGROUND OF THE INVENTION

The present invention relates, in general, to a method and apparatus for improving the signal to noise ratio of photoemissive devices, and more particularly to an improved apparatus for reducing the temperature of the photocathode in a photoemissive device such as a photomultiplier tube, image intensifier, or the like, by placing in direct thermal contact with the photocathode a thermoelectric cooler. The cooler is in heat exchange relationship with the photocathode through the wall of the evacuated envelope of the tube by way of a suitable thermally conductive link.

It is presently common practice to cool photomultiplier tubes in order to reduce their temperatures and thus decrease the amount of "dark current" which occurs by reason of thermal emission of electrons from the photocathode material. Such cooling would also be desirable for other photoemissive devices used for detecting small quantities of light, but this has not been generally done since the methods and apparatus for cooling used in the prior art have been prohibitively expensive, as well as being so bulky and awkward that they have fallen into the category of "last resort" devices to be avoided if at all possible. Since the primary application to date has been limited to such devices, the present invention will be described in the context of a photomultiplier tube; however, it will be understood that the present invention may be utilized in combination with other photoemissive devices where the detection of light and its conversion to corresponding electric signals to be accomplished, and it will be seen that photodetectors in general may be cooled by the method and apparatus of the present invention without departing from the scope thereof.

Photoemissive detectors, which are devices used to detect and measure very small quantities of light, or photons, are sensitive to, and are capable of measuring, light of various wavelengths, ranging from beyond the X-ray region through the visible wavelengths and into the infrared regions, depending upon the active materials used on the photoemissive surface. All photosensitive devices take advantage of the fact that under certain conditions a given photocathode material will emit one or more free electrons per incident light photon. By means of this photoelectric effect, the light photon is transduced into an equivalent number of photoelectrons which constitute an equivalent electrical signal. In a photomultiplier tube, the emitted photoelectrons undergo high multiplication, or amplification, in a series of dynode stages, each of which releases secondary electrons upon impact by a primary electron. By appropriate selection of the dynode material, numerous electrons are emitted by each impact from a primary electron, whereby the small number of photoelectrons emitted by the photocathode is multiplied. This increased number of secondary electrons is ultimately received at the output anode of the tube to provide an electrical pulse, or count, whereby the light received by the photomultiplier tube produces an analogous output signal.

Although photoemissive devices of this type are remarkably sensitive, at their lower limits, they are found to exhibit electrical noise which is indistinguishable from photon-produced signals, and such noise prevents accurate measurement of very small quantities of light. There are, of course, additional sources of noise within the various devices utilizing the photoemissive phenomena, but such other noise can be obscured electronically. Since, however, the photocathode-generated noise is indistinguishable from the desired photoelectron current, this noise cannot be filtered out or otherwise removed from the detector output signal. This is because photocathode noise and photoelectrons both occur naturally as single electron events, with the noise producing a dark current which renders the detection of weak light signals nearly impossible. The present invention recognizes the fact that if very minute quantities of light are to be measured, it is essential that thermal emission from the photocathode of a photosensitive detector be eliminated and that this can be accomplished by maintaining a reduced temperature on the photocathode.

The prior art has recognized that spurious emissions, or dark counts, can be reduced in photoemissive devices by utilizing various techniques. But after all of the known electronic and optical techniques have been exhausted, designers usually resort to cooling the entire device in order to achieve the very best signal to noise ratio. The advantages of cooling photoemissive devices can, in some cases, be very significant. Under some conditions, photocathode noise can be reduced by factors greater than 10,000 and because this advantage is so worthwhile, many device users purchase cooled housings, known as cryostats, at prices which are often much greater than the tube that it is intended to cool. Although a cryostat is capable of reducing a photoemissive device to a temperature sufficiently low to produce a significant reduction in the photocathode noise events, the use of cryostats has not generally been a satisfactory solution to the problem. Not only is a cryostat costly, but its size and weight nearly always dwarfs that of the photodetector and size and weight are important considerations in many applications of these devices. Thus, the total size and weight of present day photoemissive detectors and their cooling systems is usually a prohibitive deterrent to designers.

Cryostats suffer additional disadvantages in that they are relatively inefficient, and require periodic maintenance of the cooling refrigerants, which may be dry ice, liquid nitrogen, or the like. Where the cryostat is thermoelectrically powered, it usually will require water or forced air cooling of the thermoelectric pile and and this in itself produces problems in that there must be continuous maintenance of the circulating pumps and fans, water filters, and the like. Thus, all of these cooling systems requre constant attention. In addition to the foregoing deterrents to the use of photoemissive devices and their coolers is the fact that cryostats, although presumably sealed and operating with very dry air, are often plagued with the problem of condensation, forcing the user periodically to open the device for defogging and/or defrosting the system, thus possibly exposing the photosensitive device to bright lights which can be harmful to the photoemissive surfaces. Still another deterrent to the use of cryostats is the fact that they usually do not incorporate provisions to prevent a too rapid temperature change in the detector device. Since these devices usually are enclosed in metal and glass envelopes, a too rapid change in temperature can and often does fracture the envelope near the pins of the tube or at other glass to metal seals. The uneven thermal shock and resultant stress from such cooling has destroyed many valuable detectors inadvertently in attempts to cool the whole tube too fast. This problem is particularly acute where the multiplier tube must be exchanged periodically, or where the tubes are cooled, allowed to return to room temperature, and subsequently recooled. To avoid thermal shock during this procedure, it is necessary to reduce the temperature gradually and it is often inconvenient to have to wait for many hours while the system gradually reaches thermal equilibrium; however, it is equally inconvenient to have to leave the cryostat in operation at all times so that the tube can be used occasionally. Because of these major difficulties with the cooling of photoemissive devices, it has long been evident that improved techniques for cooling such devices were needed.

A step forward in the direction of improving the cooling of photoelectric devices was provided by the invention disclosed in copending application Ser. No. 279,922, filed on Aug. 11, 1972, and entitled "Internal Cooling for Photodetectors." That application recognized that the only portion of a photosensitive device that needed cooling was the photocathode, and that a cryostat accomplishes this cooling with a "shotgun" approach which is inefficient since it cools portions of the devices which do not need cooling. Accordingly, the application was directed to a method of cooling solely the photoemissive structure in an efficient manner, with a lightweight, inexpensive thermoelectric cooler located within the evacuated envelope of the photoemissive device. However, although that prior application produced numerous advantages over the prior methods of cooling photoemissive devices, several difficulties were encountered, caused by the fact that the processing of ultrahigh vacuum devices such as photoemissive detectors usually require high bakeout temperatures; in some manufacturing processes, the bakeout temperatures may exceed 600°C. Unfortunately, some of the most desirable thermoelectric cooler materials such as Bismuth telluride semiconductors and alloys cannot easily be raised to such a demanding temperature, for they either melt before reaching such a temperature, or the temperature creates intolerable vapor pressures. In order to produce photodetectors using high temperature curing techniques, thermoelectric devices such as Lead Telluride semiconductors and alloys capable of withstanding such temperatures have to be used if they are to be incorporated within the tube envelope. However, such higher temperature devices have lower efficiencies and are less desirable. Accordingly, if the best possible thermoelectric efficiencies are to be utilized in cooling photoemissive devices, other techniques must be used.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to overcome the difficulties inherent in prior art cooling systems for photoemissive devices by providing an inexpensive, easy to use cooling system which completely eliminates the bulk and expense of prior art cryostats by locating a thermoelectric cooler in heat exchange relationship with only the photoemissive surface of the device.

It is a further object of the invention to provide means for cooling photoemissive devices located within sealed, high vacuum envelopes quickly and efficiently while at the same time reducing the cost and time delays inherent in prior devices.

It is a further object of the present invention to provide means for reducing the temperature of a photoemissive surface by close thermal contact between the surface and a thermoelectric cooling element.

It is another object of the present invention to provide efficient, inexpensive, cooling of the photocathode area of a photoemissive device to enhance the signal to noise ratio of the electrical signals produced by the device in response to impinging light by providing means for rapid and accurate temperature control of the photocathode.

It is another object of the present invention to provide cooling means for a photodetector device which has low power consumption and increased cooling efficiency due to the provision of means for cooling only the photoemissive surface of the photodetector.

Briefly, the present invention accomplishes the foregoing and other objects by positioning a thermoelectric cooling element of the type exhibiting the Peltier effect adjacent the exterior surface of the envelope enclosing a photoemissive detector device. The thermoelectric element is secured in intimate heat transfer relationship with the photoemissive surface through the medium of a thermally conductive material such as tungstan, aluminum, various other metals, ceramics, and even some glasses, in the wall of the envelope and within the envelope, which material forms a thermally conductive link between the cooler and the element to be cooled.

Because of the large variety of photosensitive devices, such as photomultipliers and image intensifiers, and the more common imaging pick-up devices such as image orthicons, silicon intensifier tubes, and secondary electron conduction tubes used in the television industry, and becuase of the variety of configurations which they take, the particular manner in which the cooling surface of ther thermoelectric cooler is secured to the exterior surface of the envelope, and the particular arrangement by which the photoemissive surface is placed in heat exchange relationship with the thermoelectric element will vary. However, the primary advantage of any present arrangement is that the thermoelectric cooling elements will be positioned on the outside of the envelope of the photosensitive device after heat tratment of the envelope, thus eliminating any possible contamination inside the envelope and preventing possible destruction of the thermoelectric cooling apparatus. Thus, the very best thermoelectric cooling materials, such as Bismuth Telluride and similar alloy semiconductors exhibiting the Peltier effect, may be chosen as coolers without concern for problems such as the temperature limitations of such materials during manufacturing processes.

The present invention differs from other external cooling arrangements by its ability efficiently to cool the photocathode area only, without cooling the entire photodetector envelope. This arrangement permits high efficiency, since there is a relatively low heat load presented to the cooler, the heat load being a function of the relatively small cooled area and the associated thermally insulating properties of the vacuum within the envelope in which the photoemissive surface is located.

In a preferred form of the invention, the envelope for the photosensitive device is formed with a heat transfer segment such as a metal band, plate or disc, which may be secured in the envelope wall by conventional metal glass seals. This heat transfer segment of the envelope is so located as to be as near as practicable to the photoemissive cathode located within the tube, and a thermal link is provided to place the photocathode in direct thermal contact with the segment. For example, the photocathode may be physically secured within the envelope by means of a support structure which is thermally conductive but electrically insulating, the support structure being secured to a heat conductive band in the envelope wall. Alternatively, a thermally conductive link may be positioned in the tube to contact the photocathode, which may be supported by other elements within the tube, the thermally conductive link merely serving to transfer heat from the photocathode to the exterior of the envelope. The metal plate or band secured in the envelope wall and the thermally conductive link contacting the photocathode are of materials which are capable of withstanding the high curing temperatures required in the manufacture of such devices. Upon completion by a conventional manufacturing process of a photoemissive device having an envelope incorporating a heat transfer segment, the thermoelectric cooling element may be secured to the exterior surface of the heat transfer segment, with the cold surface of the thermoelectric device in contact with the envelope segment and the hot surface of the device in contact with the suitable heat sink outside the tube. Because of the low heat load of such a device, the heat sink need not be water cooled, and is formed in accordance with known heat exchange techniques to provide the required cooling surface.

In general keeping with good high-vacuum photodetector design techniques, high vapor pressure materials must be kept out of the detector envelope in order to reduce the possibility of condensates being deposited on sensitive surfaces such as the electron multipler or photocathode surfaces. Such deposits are particularly a problem if the photocathode structure is cooler than the remainder of the tube components, for the condensates tend to collect on such a cooler surface. Fortunately, excellent construction materials for photodetectors do exist that provide a very low vapor pressure level for most of the tube components. Materials such a Berilium or Berilium-Copper, for example, may be used for the electron multiplier structure, and thus reduce this problem. No particular precautions need to be taken with respect to the vapor pressure of the material used for the photocathode, on the other hand, since the cathode is the main component being cooled and thus encourages its own vapor, if any, to condense on itself.

Since the cooled portion of the tube is limited to the photocathode and to a relatively small portion of the envelope surface at the metal band heat exchange area, fogging and frost build-up on the optical and electrical surfaces is not a problem with the present invention, because these surfaces are never cooled in the presence of moist air. The photocathode is located entirely within the vacuum envelope, and the optical surface of the tube is insulated from the photocathode by the vacuum of the tube. Because of the low heat load, cool down time to equilibrium is significantly reduced compared to that of presently available systems, and the problem of thermal fracturing is greatly reduced. With the thermoelectric device, the cooling rate can be fully and easily controlled, and by selection of appropriate heat exchange geometries the device is cooled in a symetrical, stress relieving manner.

The rugged, lightweight cooling system of the present invention is well suited for nearly all of the present day applications of photosensitive devices. These applications range from photomultiplier devices and image intensifiers to more common imaging pick-up devices such as image orthicon tubes, silicon intensifer tubes, and secondary electron conduction tubes used in the television industry. In general, any photoemissive device can be markedly improved by the cooling techniques disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and additional objects, features and advantages of the present invention will be apparent to those skilled in the art from the following detailed description of preferred embodiments thereof, taken with the accompanying drawings, in which:

FIG. 1 is a diagrammatic view of a conventional "end on" photomultiplier tube utilizing a thermoelectric cooler in accordance with the present invention;

FIG. 2 is a cross-sectional view of the tube of FIG. 1, taken along line 2—2 thereof;

FIG. 3 is a diagrammatic sectional view of a conventional "side on" photomultiplier tube utilizing the external thermoelectric cooling system of the present invention;

FIG. 4 is a cross-sectional view of the tube of FIG. 3, taken along line 4—4 thereof;

FIG. 5 is a partial sectional diagrammatic view of an image pick-up tube utilzing the thermoelectric cooling techniques of the present invention; and

FIG. 6 is a partial sectional diagrammatic view of another version of a conventional photomultiplier tube utilizing the external thermoelectric cooling system of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENT

In order to cool efficiently the photocathode area of a photosensitive device, a suitable thermal conduction path must be established between the photocathode and the cold surface of a thermoelectric cooler. In accordance with this invention the cooler is external to the envelope of the photosensitive device, but in initimate heat exchange relation with the photocathode thereof. Because of the extremely wide variety of photoemissive devices presently available, the present invention is illustrated with a variety of representative devices which may be utilized in combination with this invention. Referring more particularly to the drawings, there is illustrated in FIG. 1 a photomultiplier tube generally indicated at **10** which may be of the conventional end-on type wherein the photocathode is a thin semitransparent semiconducting film such as CS_3Sb, (Ca)-Na_2KSb, $(CS)Na_2KSb$, or the like, deposited on the glass window through which light enters the device. The photomultiplier tube **10** includes an evacuated envelope **11** having a sidewall **12**, base **14** and a face plate **16**, the face plate being of an optically transparent material such as glass and the sidewall and base perferably being of glass or other conventional materials of low thermal conductivity. Mounted within an evacuated chamber **18** defined by the tube envelope **11** is an optically transparent substrate **20** which is mounted so as to be parallel to face plate **16** and closely spaced therefrom to receive light in the form of photons **22** which is to be detected, and which passes through the face plate. A thin film coating **24** of photoemissive semiconducting material is supported by the substrate **20** and forms a photocathode, whereby the entering photon **22**, upon passing through substrate **20**, interacts with the photoemissive material to produce a free electron, diagrammatically indicated at **26.** The photoelectron, after emission, is caused to follow a substantially straightline path **28** to the multiplier stage of the tube. In the illustration of this figure, the miltiplier is diagrammatically shown to be that of a commercially available multiplier device known as a Channeltron, generally indicated at **30.** The Channeltron, which is manufactured by the Bendix Corporation, is functionally similar to other known photomultiplier devices, although it is of smaller size and by reason of its configuration is relatively immune to stray magnetic fields.

As is known in the photomultiplier art, the photoelectron **26** strikes the surface of the Channeltron device **30** at its input end and causes the release of secondary electrons. Each emitted electron is then drawn to a second portion of the Channeltron device, in the manner of electrons striking succeeding dynodes of a conventional photomultiplier tube, thereby producing the output of the Channeltron a corresponding packet of secondarily emitted electrons, which are collected on an output anode **32,** and apeear on an output pin **34** for the tube as a small electrical pulse, or single count, which is analogous to the input photon. Power supply leads **36** and **38** are provided for the Channeltron device **30** to provide the required biasing, and these leads also extend through the base **14** of the tube in the form of pins for easy connection to external circuitry, in known manner. As electrical lead **40** is provided for the photocathode, this lead also extending through the base **14** of the tube in the form of a pin.

The substrate **20** which carries the photocathode **24** may be secured within the tube envelope by means of an annular support base **42** which is formed with an interior peripheral channel **44** to receive the edge of the disc-shaped substrate. The support base **42** firmly clamps the edge of the substrate to provide not only strong mechanical support but a good thermal contact so that there will be adequate heat transfer between the substrate and the base support element. Support base **42** is constructed of a material which has good thermal conduction characteristics, and its outer circumferential surface is secured to the sidewall of the envelope to hold the substrate and photocathode in the proper location within the tube envelope and to serve as a thermal link between the photocathode and the exterior of the envelope. This unit may be secured in place by a pressure fit, by soldering, or by any other convenient means in such as way as to provide a good thermal contact between the annular support base and the sidewall **12** of the tube. Since in the illustrated embodiment the power is supplied to the cathode **24** by way of lead **40** connected to the support base **42,** it is apparent that the base must only by thermally, but electrically, conductive in this case.

As has been indicated, there are numerous sources of noise within a photomultiplier tube of the type illustrated in FIG. **1,** but most sources produce signals which can be identified and eliminated either electronically or optically from the resultant output signal. However, spurious electrons emitted by the photocathode in the absence of an incident light photon cannot be distinguished from a photoelectron emitted in response to a photon, and both will produce secondary emission in the Channeltron device which will produce a resultant output signal. Accordingly, if the operational characteristics of the tube are to be improved, the noise signal generated by such spurious electrons must be eliminated. This is accomplished in the present invention by means of a thermoelectric cooling system generally indicated at **46,** which is located adjacent the exterior surface of a selected heat transfer segment **48** of the sidewall **12** of the tube and is in intimate heat exchange relationship with that portion of the envelope wall to which the photocathode is secured by the support base **42,** the support base and the wall segment thus forming a thermal link between the photocathode and the cooler.

The thermoelectric cooling system **46** incorporates a pair of thermoelectric elements **49** and **50** which are generally annular in shape and are secured to a common internal circumferential cold junction surface defined by a ring **51** and to a common external circumferential hot junction, defined by a ring **52.** The thermoelectric elements **49** and **50** are each made up of one or more couples—each of which may comprise a pair of a great variety of materials which exhibit the Peltier effect, such as Bismuth Telluride and Lead Telluride, all of which have a heat pumping ability and thus are capable of producing a temperature differential between two spaced surfaces when connected electrically in series, upon application of an appropriate electrical current. Peltier effect devices may be constructed in virtually any geometrical configuration, and thus the exact size and shape of the device utilized with the photomultiplier tube **10** will depend upon the me chanical construction of the tube, of the photocathode, of the support elements for the photocathode, and of the mechanical arrangements of elements.

An example of suitable thermoelectric cooling elements for application in the device of the present invention may be found in the publication of the Thermoelectrics Department of the Borg-Warner Corporation, Des Plaines, Ill. This publication is entitled "The Where and The Why of Thermoelectric Cooling" by G. F. Boesen, C. J. Phetteplace, and L.J. Ybarrondl, and was copyrighted in 1967. Another publication describing suitable thermoelectric devices is the "Thermoelectric Manual" published by the Cambridge Thermonic Corporation, 445, Concord Ave. Cambridge, Mass.

As noted in the Borg-Warner publication identified above, a thermoelectric cooler utilizes semiconductor materials with dissimilar characteristics connected electrically in series and thermally in parallel, so that two junctions are created. The semiconductor materials are N and P-type and are so named because with they have more electrons than necessary to complete a perfect molecular lattice structure (N-type) or not enough electrons to complete a lattice structure (P-type). The extra electrons in the N-type and the holes left in the P-type material are called carriers, and they are the agents that move the heat energy from the cold to the hot junction. Heat absorbed at the cold junction is pumped to the hot junction at a rate proportional to the carrier current passing through the circuit and the number of couples. Good thermoelectric semiconductor materials such as Bismuth Telluride impede conventional heat conduction from hot to cold areas, yet provide an easy flow for the carriers. In addition, these materials have carriers with a capacity for carrying more heat. In practical use, a plurality of couples are combined in a module which can be tailored to the exact requirements of the user. These modules come in a great variety of sizes, shapes, operating currents, operating voltages, number of couples, and ranges of heat pumping levels, although the present trend is toward a larger number of couples operating a low current.

In the illustrated embodiment of FIGS. **1** and **2** the thermoelectric elements **49** and **50** each consist of a plurality of thermocouples arranged in series to form an annular ring adapted to fit around the envelope **11** of the photodetector **10**. As shown in FIG. **1**, the rings are arranged in parallel, coaxial, side-by-side relationship and are in thermal contact with cold and hot junction rings **51** and **52**.

As shown in FIG. **2**, the thermoelectric element **49** is made up of a series of couples which extend in an annular ring about the axis of the tube. Thus, for example, a first couple consists of a block of P-type material **53** connected at its upper end of an electrically conductive plate **54** which is connected in turn to an electrical lead **55**. The lower end of block **53** is connected to an electrically conductive plate **56** which interconnects the block with the bottom of an N-type semiconductive block **57**. Plate **56** thus forms the junction between the P and N-type materials of this couple. The upper end of the semiconductive block **57** is connected by way of a conductive plate **58** to the upper end of block **58** which is the P-type material of a second couple in the series. The lower end of block **58** is connected by a conductive plate **59** to the lower portion of its corresponding N-type semiconductive block **60** to complete the second couple. In similar manner, the upper end of block **60** is connected to the next couple in the series by way of electrically conductive plate **63**. Successive couples are similarly connected to each other in series around the thermoelectric element **49**, with the N-type material **64** forming the last portion of the last couple in the series. The upper end of block **64** is connected by way of conductive plate **65** to an electrical lead **66**. A direct source (not shown) having its positive terminal connected to line **66** and its negative terminal connected to line **55** causes a current to flow in series through the plurality of couples, creating a pumping action which produces a heat flow away from the conductive plates **56**, **59**, etc. and toward the conductive plates **54**, **58**, **63**, etc. whereby heat is pumped from the cold junction ring **51** to the hot junction ring **52** in known manner.

The rings **51** and **52** are electrically non-conductive, but are of a material having a good thermal conductivity to which the thermocouples can be secured by any convenient means, such as by soldering, epoxy bonding, or the like. The inner surface of cold junction ring **51** is in intimate heat conductive contact with the heat transfer segment **48** of the sidewall **12** of the tube, while the outer surface of the hot junction **52** is similarly in intimate heat conductive contact with a surrounding heat sink **67**, which, as may be seen in FIG. **1**, extends substantially the length of the tube envelope to provide the required surface contact with the ambient atmosphere.

The thermoelectric element **50** may be substantially identical to element **49**, but preferably has one difference. The difference is that the element **50** is so constructed as to provide the desired heat pumping with a current flow which is the reverse of that shown in FIG. **2** for element **49**. That is, if the current is flowing from the positive source terminal through element **49** to the negative source terminal in a counter-clockwise direction to produce the desired heat pumping, then element **50** preferably is constructed to produce the desired direction of heat pumping with a clockwise flow of current as viewed in FIG. **2**. Since photosensitive devices are, in general, Sensitive to magnetic fields, the provision of two parallel but oppositely sensed thermopile loops **49** and **50** as illustrated in FIG. **1** is particularly advantageous. The magnetic field generated by the net clockwise current flow through one series of thermocouples tends to be cancelled by the magnetic field generated by the net counterclockwise current in the oppositely sensed parallel loop of thermocouples, all of the thermocouples being in series electrical connection. This geometrical configuration reduces the effect of the thermoelectric cooling current on the electrical operation of the tube. In addition, suitable shielding, the use of coaxial power lines, and the use of low current, high voltage series arrays in the thermopiles further reduce the problem of magnetic interference. Since the Channeltron device illustrated in FIG. **1** is particularly immune to stray magnetic fields. the use of the foregoing techniques with such a device insures that there will be virtually no problem of magnetic interference.

It will also be noted that in some applications the production of a magnetic field by the thermopile loops illustrated in FIG. **1** can be useful in controlling the flow of the photoelectrons **26**. For example, a magnetically focused photomultiplier tube could utilize the magnetic field of the thermopile to limit an electron imaging aperture, with a corresponding reduction in the size of the effective photocathode area. This procedure results in further reduction of photocathode noise.

The thermoelectric elements **49** and **50** are firmly secured to the cold and hot junction rings **51** and **52** which preferably are of a thin flexible material to enable the cooling elements to be flexed for positioning about the sidewalls of the envelope **11**. Alternately, the cooling device may be formed in semicircular pieces which may be placed about the envelope and secured by a suitable clamp or by soldering the abutting ends of the rings together. Alternatively, or in addition, the inner junction ring **51** may be soldered or epoxy bonded to the tube segment **48** to insure a good conductive relationship and the outer ring **52** may similarly be soldered or otherwise bonded to the heat sink.

As illustrated in FIG. **1**, the envelope may include an annular depression or channel **68** formed in the side wall **12**. The interior surface of this annular channel may provide a supporting surface for the photocathode substrate **20** and its support base **42**, and thus may define the segment of the envelope where the thermoelectric device is to be located. It will be evident that the sidewall **12** may be made cylindrical throughout its length, with the thermoelectric device fitting around the outside, but the illustrated construction is preferred since it enables the envelope sidewall to provide a protective housing for the thermoelectric elements. As has been indicated, the thermoelectric elements are secured in place around the tube sidewall by any suitable means, and thus may be clamped, soldered together or to the sidewall, or otherwise firmly fastened in such a manner as to provide a good thermal connection, with or without the use of thermal compounds such as silicon grease or the like, with the sidewall. The heat transfer segment **48** of the tube sidewall may form the bottom of channel **68**, and may be positioned there by suitable metal to glass seals in accordance with methods known in the art.

As is illustrated in FIGS. **1** and **2**, the thermoelectric cooling elements **49** and **50** secured within the channel **68** are surrounded by a thermally insulating foam **70** which fills the voids around the thermoelectric loops and between the semiconducting blocks of each of the thermocouples in order to increase cooling efficiency.

Although a highly thermally conductive path of metal, ceramic, or the like is usually desirable between the thermoelectric cooler and the cathode structure, a relatively poor path can still be used where a larger temperature differential, between the cold junction and the photocathode, with its consequent reduction in efficiency, produces acceptable operational characteristics. Thus, in some cases, it may be satisfactory to utilize the glass wall of a glass envelope, thus obviating the need for multiple glass to metal seals and thereby simplifying the device and reducing its cost. However, since the thermal emissions which generate noise signals in a photomultiplier tube occur even at temperatures well below room temperature, the cooling apparatus must operate to reduce considerably the temperature of the photocathode in order to minimize this source of noise. A typical temperature for photocathode operation is −25°C., although some may be operated at temperatures as low as −200°C. It is evident that where a photocathode material need not be reduced in temperature to the lowest ranges, a glass wall may provide a satisfactory degree of thermal conductivity. However, where the material of the thermal link is the same as that of the envelope, there will be some loss of efficiency due to the tendency of the cooler to also cool the envelope. This problem together with other factors such as the relative cost and the temperatures involved must be taken into consideration when determining whether to utilize an existing glass envelope construction or to modify the photoemissive device to accomodate a metal, ceramic, or similar material in a section of the envelope wall for maximum thermal conductivity.

Turning now to FIG. **3**, there is illustrated another embodiment of the present invention, wherein a thermoelectric cooler is applied to a conventional side-on version of the photomultiplier tube. The conventional photomultiplier tube generally indicated at **80** is provided with a base **82** and glass envelope **84** in which is mounted the conventional electron multiplier array **86**. In this figure, the multiplier array is illustrated as including a photocathode **88**, which may again be a thin film of photoemissive material supported on a suitable substrate (not shown), mechanically supported in a suitable manner within the tube envelope. The substrate may be of metal to provide a uniform distribution of the support voltage to the photocathode material. Again, suitable supply voltages are supplied to the tube elements by way of a plurality of pins **90**.

A photon of light, indicated diagrammatically at **92**, enters the photomultiplier tube **80** through the glass envelope **84**, passes through a grid **94**, and impinges on the surface of the photocathode **88**. The photoemissive surface emits a photoelectron, diagrammatically illustrated at **96**, which is attracted by the potential on a first dynode element **98**. When the electron strikes element **98**, that element emits a number of secondary electrons, which are, in turn, attracted to a second dynode (not shown) and so on through the dynode array. Electrons emitted by the last unit in the array are attracted to an anode **100** to produce an output which corresponds to the input photon.

The cooling of the photocathode in the illustrated embodiment is effected by means of a thermally conductive connecter element or link **102**, which is secured in intimate heat conductive relationship with the substrate on which the photocathode is mounted and spans the thermally isulating vacuum between the photocathode and the tube envelope. This thermal link **102** preferably is electrically insulative and serves to provide a heat conductive path between the photocathode and the cap **104** of the tube envelope. This cap or heat transfer disc may be of glass or metal, depending upon the heat transfer requirements of the device. Mounted on top of cap **104** is a generally disc-shaped thermoelectric cooler unit **106** which is comprised of a pair of spaced parallel plates **108** and **110** made up of metalized thermally conductive but electrically insulating material such as Alumina or Berylium Oxide, these plates serving as the cold and hot junctions respectively of the thermoelectric element. Mounted between the hot and cold plates are a plurality of conventional thermoelectric cooling units **112** through **117**, which are suitably energized, as by a pair of electrical leads **118** and **120** to pump heat from the cold plate **108** to the hot plate **110**.

The Peltier effect devices **112** through **117** are surrounded by a thermally insulating material **122** which may be a foam insulator or the like, to improve the efficiency of the device and prevent condensation on the cool elements. In intimate contact with the hot surface **110** is a heat sink **124** which may be in the form of an inverted cup fitting over the top of the tube and spaced from it at the sidewalls by spacers such as those indicated at **126** and **128**. The heat sink may be provided with cooling fins **130**. and is designed to dissipate the heat from the photocathode by way of the heat conductive thermal link **102**, the cold plate **108**, the Peltier effect devices **112** through **117**, and the hot plate **110**. This heat sink includes an opening **132** aligned with the photocathode **88** and grid **94** to admit light into the interior of the tube.

As illustrated in FIG. **4**, which is a top view of a modified form of the photomultiplier of FIG. **3** with the cooling fins **130**, the top of the heat sink **124**, and the hot plate **110** cut away, the thermoelectric cooler is seen to comprise a pair of concentric electrically conductive rings **134** and **136** between which are connected the several thermocouples **112** through **117**. As illustrated in FIGS. **3** and **4**, each thermocouple, **112** for example, includes a block of P-type semiconductive material **138** and a block of N-type semiconductive material **140** joined at the bottom surfaces by an electrically conductive plate **142**.

A current applied to line **120** is fed by way of ring **136** through the N-type material, plate **142**, and P-type material **138** to ring **134**, this current flow providing a heat pumping action to cool the plate **142**, and thus the cold junction plate **108**, transferring the heat by way of rings **134** and **136** to the electrically insulating but thermally conductive hot junction plate **110**. In similar manner, each of the other thermocouples **113** through **117** pump heat away from plate **108** toward plate **110** to effect cooling of the upper end **104** of the envelope and thus of the thermal conductor **102**, whereby the photocathode of the tube is reduced in temperature. It will be noted that the current flow through the thermocouples of this arrangement produces a very limited magnetic fied which has a minimal effect on the operation of the photomultiplier tube. Other geometrical arrangements and locations of the thermoelectric cooling elements and their corresponding heat transfer elements for use with the side-on type of photomultiplier or other photoemissive devices will be apparent.

This tube as indicated at **160**, is generally similar to that of the conventional end-on photomultiplier tube illustrated in FIG. **1**, except that an optical image is focused on the photoemissive cathode **162** from which it is translated into an equivalent electron image. This, an object **164** is focused by means of suitable optics **166** onto the photocathode **162** which is supported by an optically transparent substrate **168**, the image passing through the optically transparent face plate **170** of the tube **160** before striking the cathode. The electron image **172** is accelerated in known manner to a target array, or intensifier stage, **174**, and is maintained in an "unscrambled" condition during this transfer by means of an external field magnet **176**. The image may be stored, intensified on target **174** or read out in the usual way, as by electron beam scanning, or the like.

Such image pick-up tubes are very sensitive devices which are limited in their ability to detect light primarily by the quantum efficiency of the photocathode material and by the level of electronic noise. However, photocathode cooling of image tubes can reduce cathode thermal noise by significant amounts in the same manner as previously described with respect to photomultiplier tubes, and with similar efficiencies. This is accomplished by providing a channel portion **178** in the tube envelope and by mounting the photocathode in thermal contact with the base **180** of the channel through the use of an annular support element **182** which serves as a thermal link. The thermoelectric cooling device **184** is mounted within the channel **178** and incorporated a pair of spaced annular thermoelectric elements or thermopiles **186** and **188**, secured between inner and outer circumferential rings **190** and **192** forming the cold and hot junctions,, respectively, of the thermoelectric device. For convenience in assembly, the thermoelectric device may be constructed in two halves in the manner described with respect to the device of FIG. **1**, and may be clamped or otherwise secured around the tube envelope in the manner described hereinabove. Secured to the outer cooling ring **192** is an annular cup-shaped heat sink **194** which fits inside the field magnet in order to contact the cold junction of the thermoelectric device and which extends outside the field magnet in order to provide sufficient contact with the ambient air to produce the required amount of cooling.

As before, where the thermal conductivity of a glass envelope is sufficient, the base **180** of channel **178** may be of glass; however, it is preferred that a band of metal be secured in the envelope in accordance with well-known techniques in order to provide maximum heat transfer from the photocathode to the heat sink **194**. With this metal band construction, the envelope does not provide the electrical insulation between the photocathode and the cooler, and the element **190** must be electrically insulating.

The final embodiment to be illustrated is a modified form of the end-on type of photomultiplier tube shown in FIG. **1**. This modified form is illustrated in FIG. **6**, and utilizes the conventional gallium arsenide photoemissive crystal, which replaces the semitransparent thin film photocathode illustrated in the prior device. As shown in FIG. **6**, the gallium arsenide crystal **200** is supported by means of spring loaded brackets **202** and **204** on a support block **206** which is in turn secured by any suitable means such as spot welding within a photomultiplier tube envelope having a sidewall **208**. Forming the end of the tube is a face plate **210** which is of an optically transparent material such as glass adapted to admit light represented by photon **212**. This light enters the tube and strikes the surface of the gallium arsenide crystal **200**, causing the crystal to emit an electron **214** which is then directed to a series of dynode multiplier stages (not shown) in a commercially known manner.

The support block **206** for the crystal may be electrically conductive to provide energization for the crystal via connector **227**. In this instance, the heat transfer segment may be comprised of a thin, metallic, flexible disc **218** similar to an aquadag connector, secured in a circular opening the sidewall **208** by means of conventional metal to glass seal. The block **206**, and the metal diaphram **218** form a thermal link between crystal **200** and the electrically insulating but thermally conducting cold junction **220** of a thermoelectric cooling module **222**, which may take the form of one of the cooling modules illustrated hereinabove. The module has a hot junction **224** which is secured by any suitable means as previously noted to a heat sink **226**. The embodiment illustrated in this figure has the advantage not only of providing means for effecting cooling of a gallium arsenide photocathode, but also illustrates a method for providing a thermal link through the sidewall of a tube with a minimum effect on the integrity of the tube structure. As before, a suitable foam insulation, **216**, or the like, is place in and around the thermoelectric module in order to increase efficiency.

Although the present invention has been illustrated in terms of preferred embodiments thereof, it will be apparent that numerous variations may be made not only in the physical arrangement of the device, but in he materials used. Thuus, there has been shown an efficient, economical, compact, lightweight, convenient and reliable cooling system for general applicability to photoemissive optical detectors and although numerous variations and modifications will be apparent to those of ordinary skill in the art, it is desired that the foregoing descriptions not be considered limiting but only exemplary of the present invention, and that the true spirit and scope thereof be limited only by the following claims.

I claim:

1. in a photoemissive device, means for reducing the thermal emission of electrons, comprising

an evacuated envelope;

a photoemissive surface within said envelope;

a thermal link between said surface and a portion of said envelope; and

a thermoelectric cooling element outside said envelope and in heat exchange relationship with said portion of said envelope, said cooling element being energizable to pump heat from said thermal link and thus from said surface in order to cool said surface.

2. The photoemissive device of claim **1,** wherein said thermal link comprises a highly thermally conductive element in intimate heat exchange relationship with said photoemissive surface and with said envelope.

3. The photoemissive device of claim **2,** wherein at least said portion of said envelope is of a highly thermally conductive material.

4. The photoemissive device of claim **3,** wherein said envelope is primarily of glass, said portion of said envelope being metal.

5. The photoemissive device of claim **4,** wherein said photoemissive surface comprises a photocathode.

6. The photoemissive device of claim **5,** wherein said thermal link support said photocathode within said envelope.

7. The photoemissive device of claim **5,** wherein said thermoelectric cooling element comprises a Peltier effect device and means for applying electric power to said device for energization thereof.

8. The photoemissive device of claim **7,** wherein said thermal link is an electrical insulator.

9. The photoemissive device of claim **8,** further including a heat sink in thermal contact with said cooling element for dissipating heat pumped from said photocathode.

10. The photoemissive device of claim **9,** wherein said cooling elemnt is in heat exchange relationship with only said portion of said envelope, whereby only said thermal link and said photocathode are cooled.

11. The photoemissive device of claim **10** wherein said portion of said envelope comprises thermally isolated section forming a portion of the wall of said envelope, said thermal link providing a heat conductive path between said photocathode and said wall section, and the vacuum within said envelope thermally insulating said photocathode and said thermal link from the remainder of said envelope, whereby the remainder of said envelope is not cooled by said cooled element.

12. In an electron tube having an evacuated envelope and a photocathode having a photoemissive surface locating within said envelope, means for reducing the thermal generation of free electrons by said photocathode, comprising: a thermoelectric cooling element formed of material exhibiting the Peltier effect and energizable to produce a cold surface and a hot surface;

means for mounting said cooling element adjacent to and exterior of said envelope with said cold surface in heat conductive relationship with the exterior surface of a selected segment of said envelope wall;

a thermal link within said envelope and having a first portion in intimate heat exchange relationship with the interior surface of said selected segment of said envelope wall having a second portion in initmate heat exchange relationship with said photocathode; and

means for energizing said thermoelectric cooling element whereby heat is pumped from said photocathode through said thermal link through said selected segment of said envelope wall to the exterior of said envelope.

13. The device of claim **12,** wherein said thermoelectric cooling element comprises at least one pair of coaxial loops, said loops being oppositely energized whereby any magnetic field produced by current flowing in one of said loops will be opposite to, and tend to cancel, any magnetic field produced by current flowing in the other of said loops, thereby minimizing the effect of said magnetic fields on said electron tube.

14. The device of claim **13,** further including heat sink means mounted in heat exchange relationship with the hot surface of said thermoelectric cooling element for dissipating heat pumped from said photocathode.

15. The device of claim **14,** wherein said selected segment of said envelope is highly thermally conductive, said thermal link providing a heat conductive path between said photocathode and said selected segment and the vacuum within said envelope thermally insulating said photocathode and said thermal link from the remainder of said electron tube, whereby the remainder of said tube is not cooled directly by said thermoelectric cooling element.

16. The device of claim **15,** wherein said selected segment is an annular band in the wall of said envelope, said thermoelectric cooling element being annular and surrounding said tube with its interior circumference forming said cold surface and being in heat exchange relationship with said annular band.

17. The device of claim **12** wherein said selected segment is disc-shaped, said thermoelectric cooling element being generally disc-shaped and having a pair of spaced plates forming said hot and cold surfaces, said cold surface plate being in heat exchange relationship with said disc-shaped segment.

18. The device of claim **17** wherein said thermoelectric cooling element comprises a plurality of thermocouples secured between said spaced plates, said thermocouples being arranged to minimize the production of magnetic fields within said electron tube.

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