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Sadleir

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(54) **SUPERCONDUCTING TRANSITION EDGE SENSORS AND METHODS FOR DESIGN AND MANUFACTURE THEREOF**

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(51) **Int. Cl.**
G01K 1/00 (2006.01)

(52) **U.S. Cl.** **374/100**

(58) **Field of Classification Search** .... None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,880,468 A * 3/1999 Irwin et al. 250/336.2
6,239,431 B1 * 5/2001 Hilton et al. 250/336.2
2002/0171040 A1 * 11/2002 Goldie et al. 250/336.2
2010/0304977 A1 * 12/2010 Sadleir 505/470
2012/0065072 A1 * 3/2012 Hays 505/162

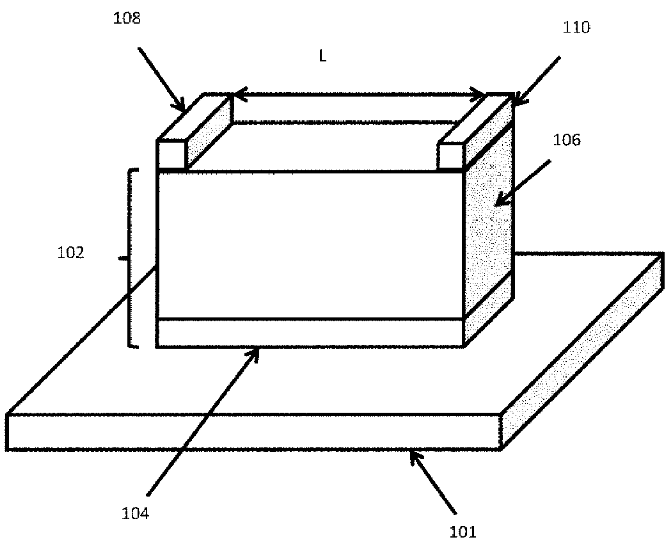
* cited by examiner

Primary Examiner — Andre Allen

(57) **ABSTRACT**

Methods for forming sensors using transition edge sensors (TES) and sensors therefrom are described. The method includes forming a plurality of sensor arrays includes at least one TES device. The TES device includes a TES device body, a first superconducting lead contacting a first portion of the TES device body, and a second superconducting lead contacting of a second portion of the TES device body, where the first and second superconducting leads separated on the TES device body by a lead spacing. The lead spacing can be selected to be different for at least two of the plurality of sensor arrays. The method also includes determining a transition temperature for each of the plurality of sensor arrays and generating a signal responsive to detecting a change in the electrical characteristics of one of the plurality of sensor arrays meeting a transition temperature criterion.

10 Claims, 8 Drawing Sheets



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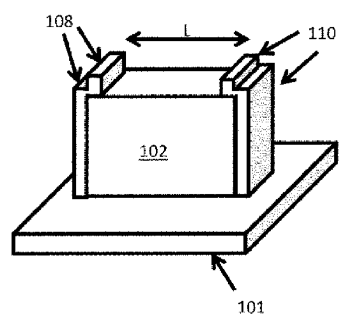


130

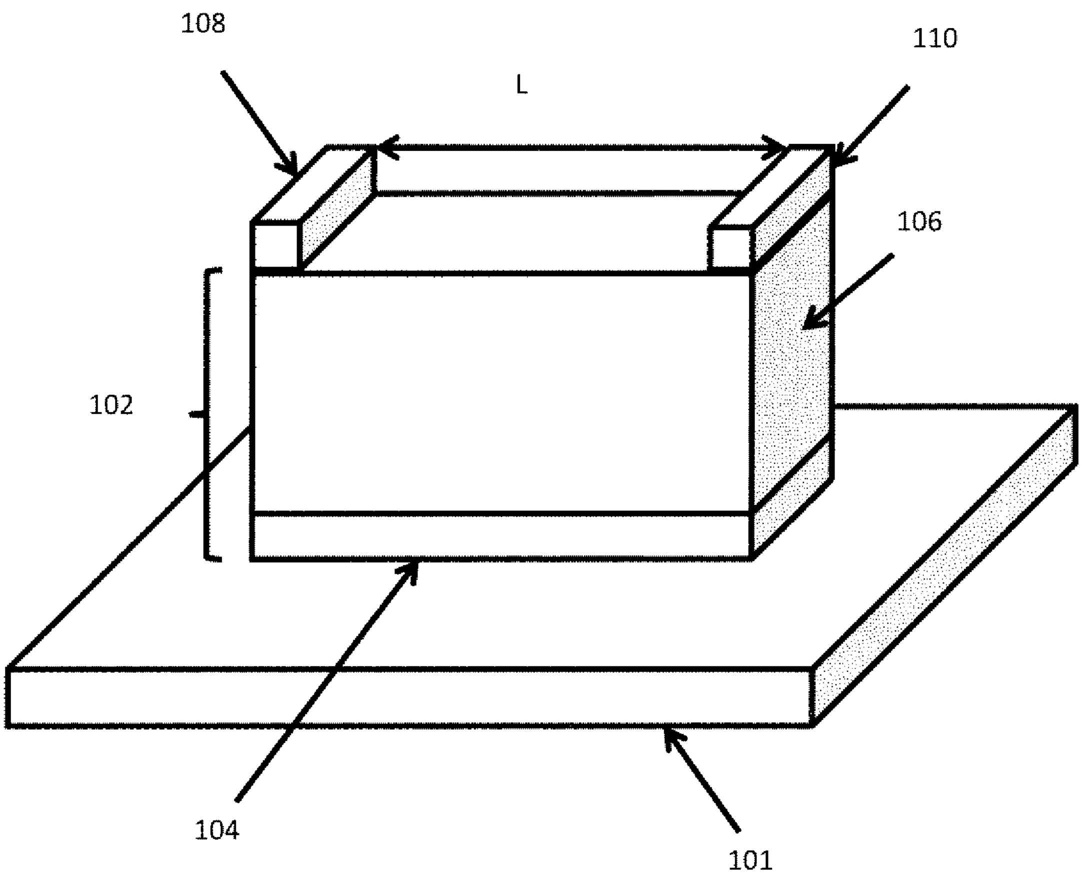


FIG. 1A
100

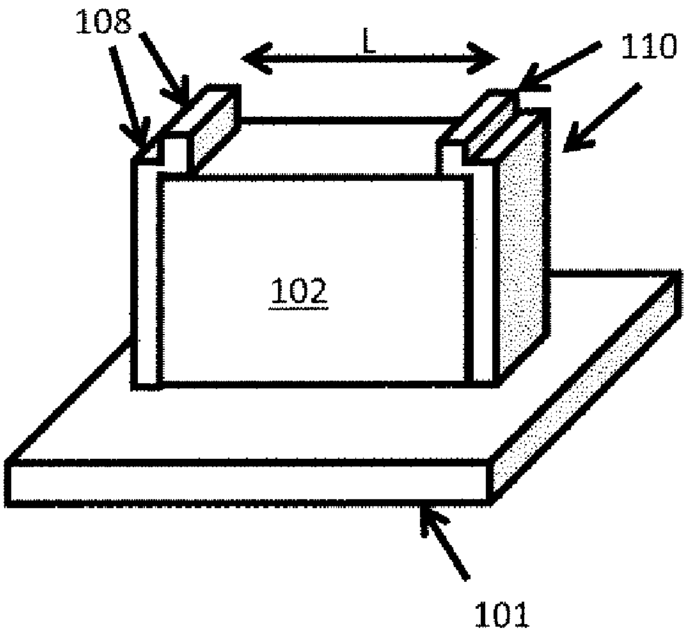


FIG. 1B
130

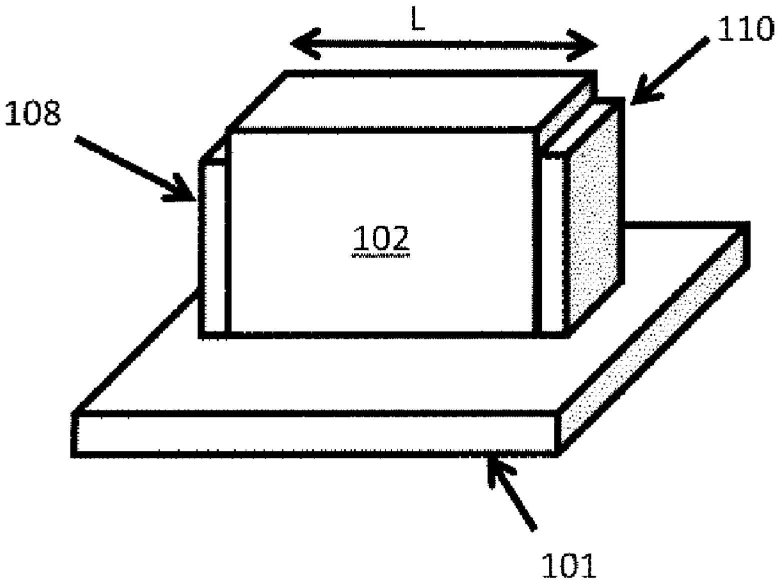


FIG. 1C
140

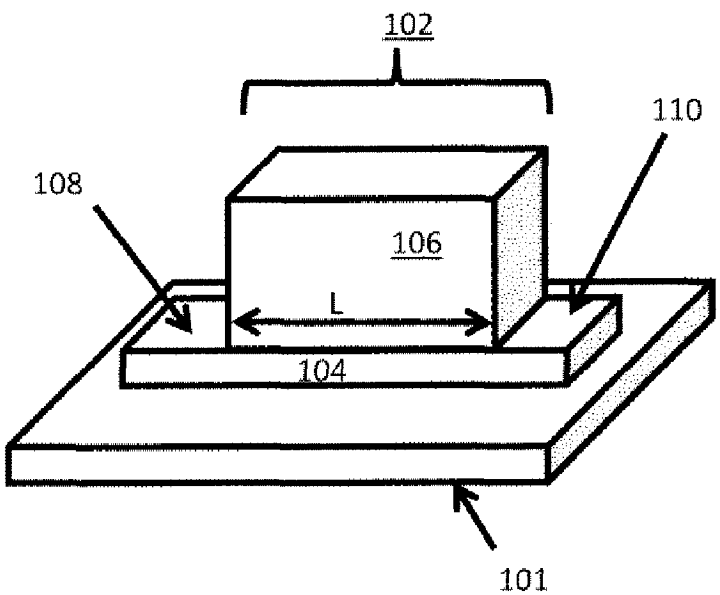
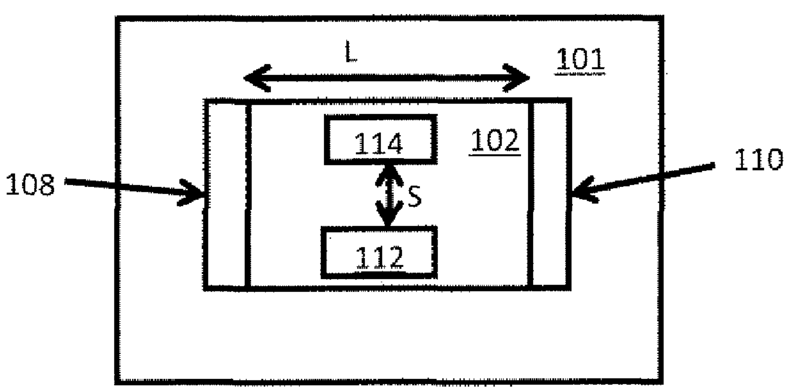
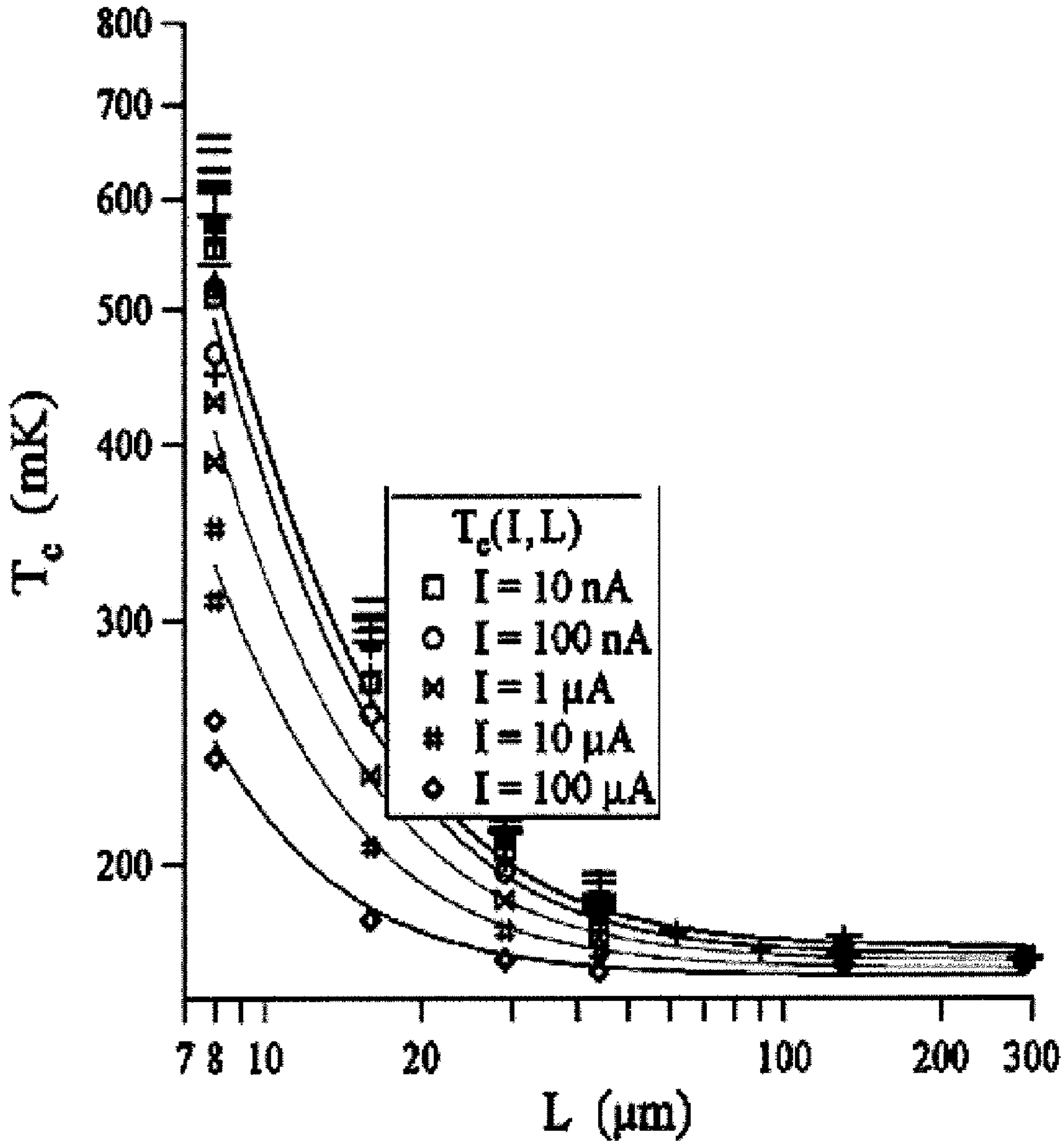


FIG. 1D
150

FIG. 1E
160





800
700
600
500
400
300
200
T_c (mK)
$T_c(I,L)$
I = 10 nA
I = 100 nA
I = 1 μA
I = 10 μA
I = 100 μA
7 8 10
20
100
200 300
L (μm)

FIG. 2

200

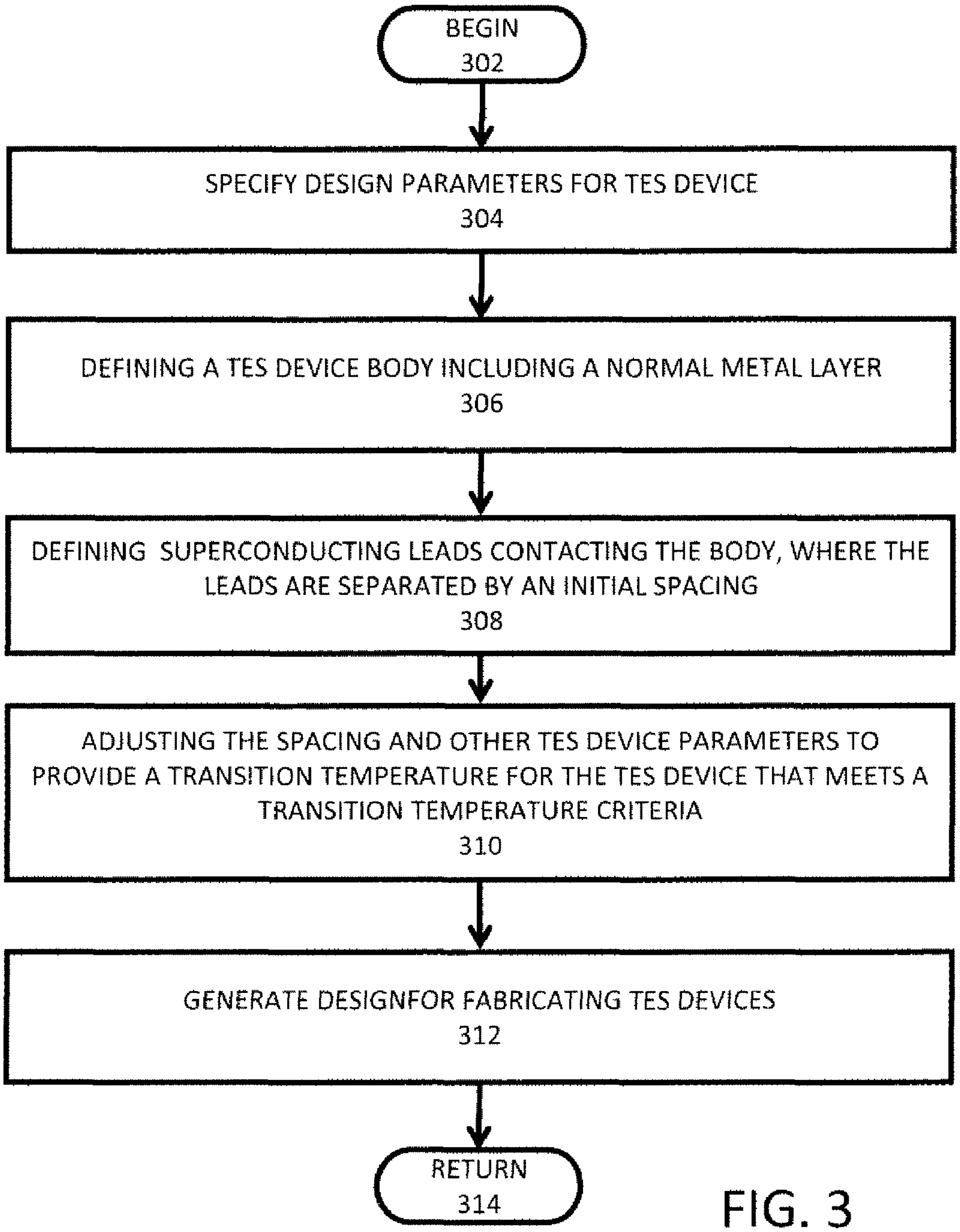

BEGIN
302
SPECIFY DESIGN PARAMETERS FOR TES DEVICE
304
DEFINING A TES DEVICE BODY INCLUDING A NORMAL METAL LAYER
306
DEFINING SUPERCONDUCTING LEADS CONTACTING THE BODY, WHERE THE LEADS ARE SEPARATED BY AN INITIAL SPACING
308
ADJUSTING THE SPACING AND OTHER TES DEVICE PARAMETERS TO PROVIDE A TRANSITION TEMPERATURE FOR THE TES DEVICE THAT MEETS A TRANSITION TEMPERATURE CRITERIA
310
GENERATE DESIGNFOR FABRICATING TES DEVICES
312
RETURN
314

FIG. 3
300

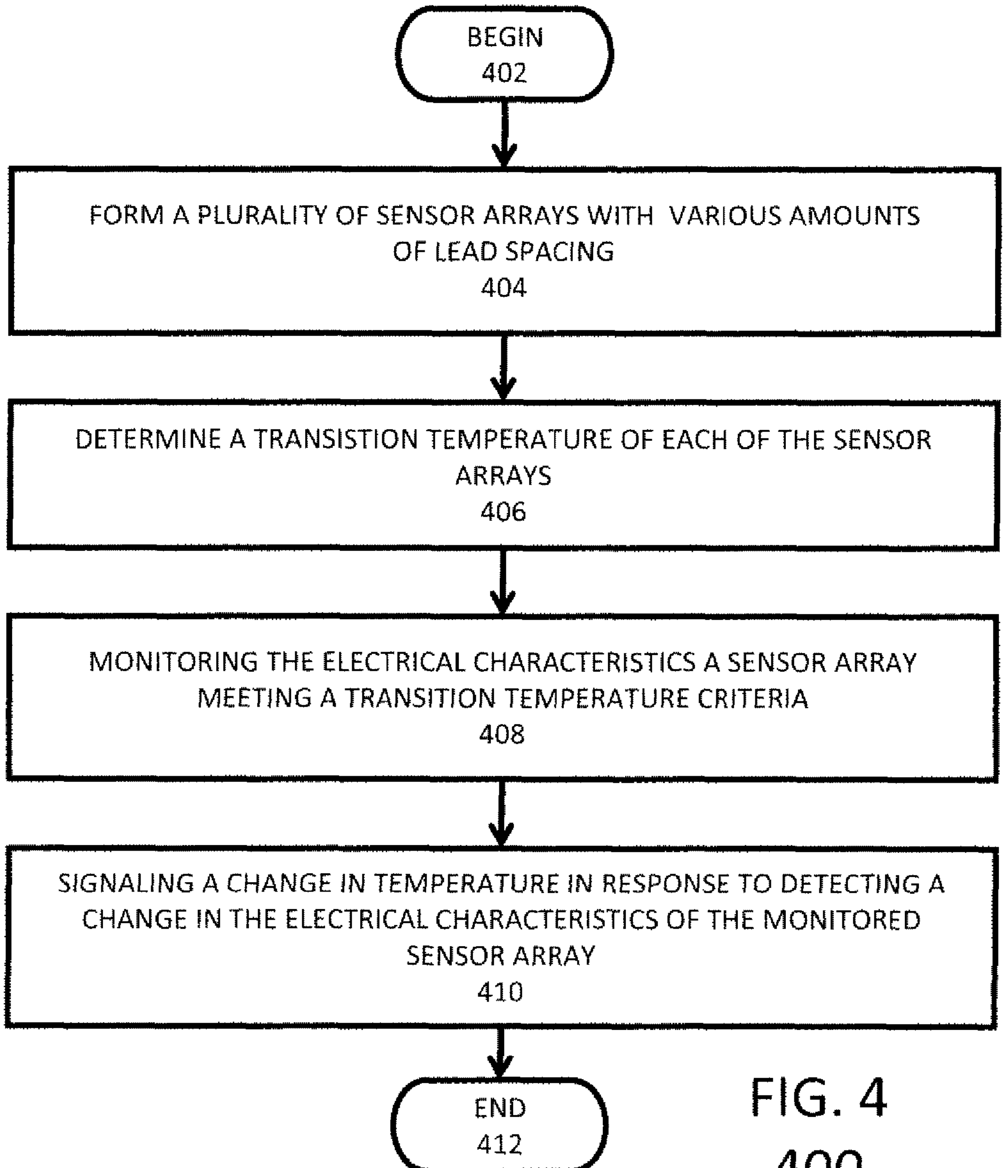

BEGIN
402
FORM A PLURALITY OF SENSOR ARRAYS WITH VARIOUS AMOUNTS OF LEAD SPACING
404
DETERMINE A TRANSISTION TEMPERATURE OF EACH OF THE SENSOR ARRAYS
406
MONITORING THE ELECTRICAL CHARACTERISTICS A SENSOR ARRAY MEETING A TRANSITION TEMPERATURE CRITERIA
408
SIGNALING A CHANGE IN TEMPERATURE IN RESPONSE TO DETECTING A CHANGE IN THE ELECTRICAL CHARACTERISTICS OF THE MONITORED SENSOR ARRAY
410
END
412

FIG. 4
400

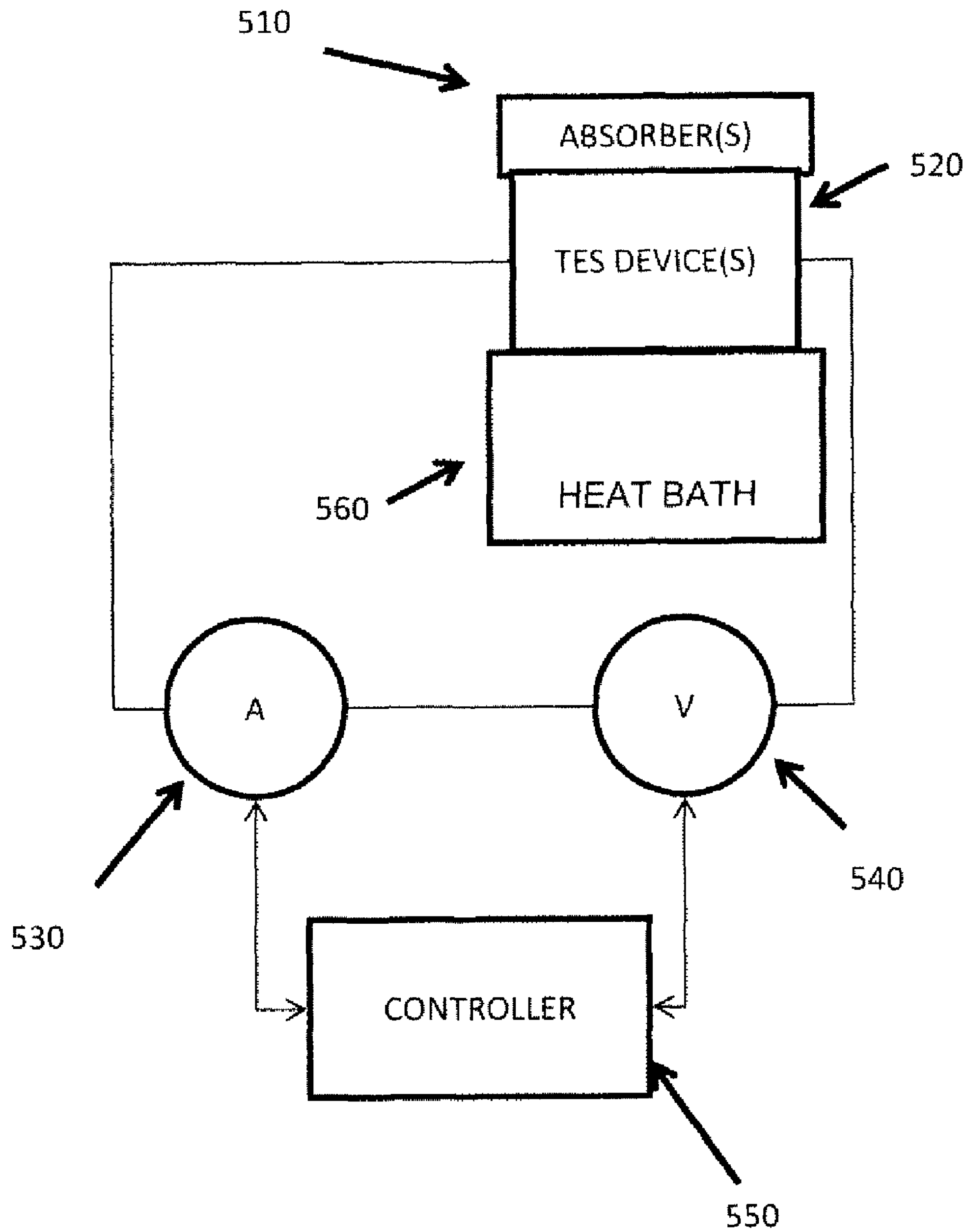

510
ABSORBER(S)
520
TES DEVICE(S)
560
HEAT BATH
A
V
530
540
CONTROLLER
550

FIG.5
500

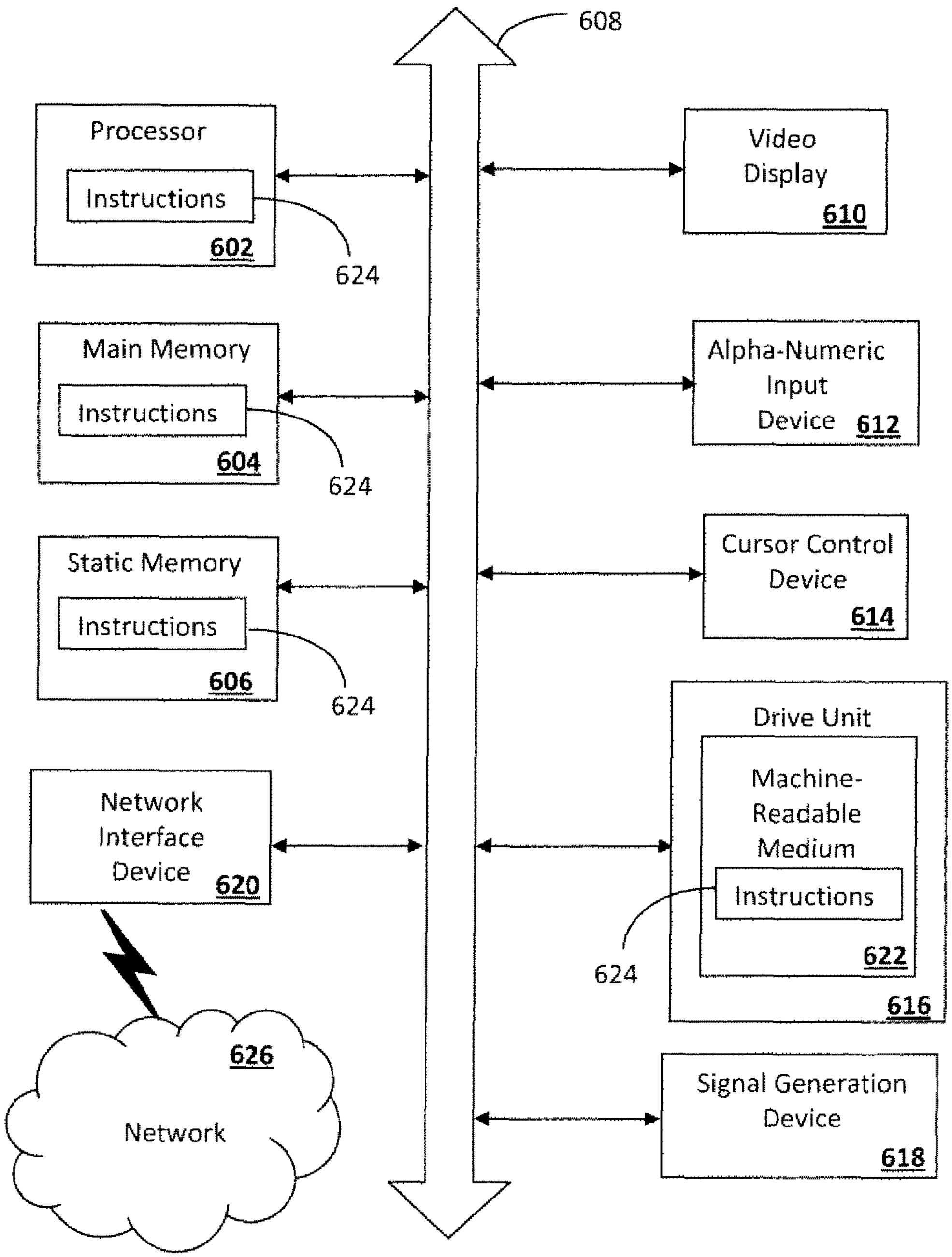

608
Processor
Instructions
602
624
Main Memory
Instructions
604
624
Static Memory
Instructions
606
624
Network
Interface
Device
620
626
Network
Video
Display
610
Alpha-Numeric
Input
Device
612
Cursor Control
Device
614
Drive Unit
Machine-
Readable
Medium
Instructions
622
624
616
Signal Generation
Device
618

FIG. 6 600

SUPERCONDUCTING TRANSITION EDGE SENSORS AND METHODS FOR DESIGN AND MANUFACTURE THEREOF

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Patent Application Ser. No. 61/182,782, entitled "NOVEL SUPERCONDUCTING TRANSITION EDGE SENSOR DESIGN," filed Jun. 1, 2009, which is herein incorporated by reference in its entirety.

This application is related to co-pending U.S. patent application Ser. No. 12/789,937, entitled "SUPERCONDUCTING TRANSITION EDGE SENSORS AND METHODS FOR DESIGN AND MANUFACTURE THEREOF," filed concurrently herewith.

BACKGROUND

1. Technical Field

The present disclosure relates to sensors, and more specifically, to superconducting transition edge sensors and methods for design and manufacture thereof.

2. Introduction

A wide variety of particle detectors, energy detectors, and other devices can be made using a superconducting transition edge sensor (TES) as a thermal energy sensor, thermometer, bolometer, or microcalorimeter. By operating the device such that the TES is in the superconducting transition temperature region (i.e., the temperature region in which the material switches from normal conducting properties to superconducting properties) any heat deposited in the TES can be precisely measured due to the strong dependence of its conductivity (or conversely electrical resistance) on the temperature. Thus, very precise measurements of temperature changes and/or detection of an incident particles providing even minute heating, can be performed. The device can also be used as a high resolution spectrometer with the energy of the absorbed particle determined by the measured heat pulse in the detector (when used as a microcalorimeter) or a change in absorbed power when a flux of particles are detected (when used as a bolometer). Manifestation of devices include a single TES thermally connected to a single particle absorbing material, a single TES thermally connected to multiple absorbers, or multiple TESs thermally connected to a single absorber body, it is also possible for the TES sensor to act as both the thermistor and absorber. Considerations when selecting an absorber material and absorber design is chosen such that it efficiently absorbs the particle of interest, has a sufficiently fast thermalization time to meet timing requirements, is compatible connecting with the TES body, and a heat capacity large enough such that heat pulses from particles of highest energy do not saturate but no so large that the energy resolution is sufficiently degraded.

Several conventional methods for fabricating TES-based detectors are available. For example, a TES device with a body consisting of a uniform superconductor material, having a target superconducting transition temperature (T_c) corresponding to the temperature of interest can be fabricated. In another method, the superconducting materials can be doped with magnetic impurities. In such devices, the concentration of magnetic particles is used to modify the T_c of the superconducting material being used for the body. In another method, the body of the TES device can be formed using a bilayer structure consisting of a normal metal layer (i.e., a metal layer that is not superconducting at the operating temperatures of interest when in isolation) disposed on a superconductor layer formed on a supporting substrate. Such devices take advantage of the proximity effect. That is, when a clean interface is provided between a superconducting film and a normal metal film, and the films are thinner than their coherence lengths, the bilayer acts as a single superconducting film with a transition temperature suppressed from that of the bare superconductor. Consequently, the superconducting transition temperature (T_c) and the heat diffusion properties of the TES device can be modulated by careful selection of the thickness of the layers. However, precisely achieving a target T_c is typically difficult, principally due to the process variations typically associated with conventional TES device manufacturing processes.

SUMMARY

Additional features and advantages of the disclosure will be set forth in the description which follows, and in part will be obvious from the description, or can be learned by practice of the herein disclosed principles. The features and advantages of the disclosure can be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features of the disclosure will become more fully apparent from the following description and appended claims, or can be learned by the practice of the principles set forth herein.

Disclosed are systems, methods, and non-transitory computer-readable storage media for forming sensors using transition edge sensors (TES) and their form are described. In one exemplary embodiment, a method includes funning a plurality of sensor arrays including at least one transition edge sensor (TES) device. The TES device includes a TES device body, a first superconducting lead extending over a first portion of the TES device body, and a second superconducting lead extending of a second portion of the TES device body, where the first and second superconducting leads are separated on the TES device body by a lead spacing, where the lead spacing is selected to be different for at least two of the plurality of sensor arrays. The method also includes determining a transition temperature for each of the plurality of sensor arrays and generating one or more signals responsive to detecting a change in the electrical characteristics of one of the plurality of sensor arrays meeting transition temperature criteria.

In another exemplary embodiment, a transition edge sensor (TES) is provided. The TES includes a substrate having an electrically insulating surface, a normal metal layer disposed on the electrically insulating surface, and a first superconducting lead disposed on a first portion of the normal metal layer. The TES also includes a second superconducting lead disposed on a second portion of the normal metal layer and separated on the normal metal from the first superconducting lead by a lead spacing, where the lead spacing is 20 times or less the normal metal coherence length for the normal metal layer for a target transition temperature.

In another exemplary embodiment, a computer-implemented method of designing a transition edge sensor (TES) sensor array is provided. The method causes a computing device to perform steps including defining a body for a TES device, the body includes a normal metal layer. The method also includes causing the computer device to define first and second superconducting leads for contacting the body, the first and the second leads separated by a lead spacing on the normal metal layer. The method further includes causing the

computer device to adjust at least the lead spacing to provide a transition temperature for the TES device meeting transition temperature criteria.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to describe the manner in which the above-recited and other advantages and features of the disclosure can be obtained, a more particular description of the principles briefly described above will be rendered by reference to specific exemplary embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only exemplary embodiments of the disclosure and are not therefore to be considered to be limiting of its scope, the principles herein are described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIGS. **1**A-**1**D show a perspective view of TES device;

FIG. **1**E shows a plan-view of a TES device;

FIG. **2** shows a log-log plot of measurements of effective T_c for different currents as a function of lead spacing (L);

FIG. **3** is a flowchart of steps in an exemplary method for designing a TES device in accordance with an exemplary embodiment of the invention;

FIG. **4** is a flowchart of steps in an exemplary method for fabricating a sensor using a TES device in accordance with an exemplary embodiment of the invention;

FIG. **5** is an exemplary configuration of a sensor, including a TES device designed in accordance with the various exemplary embodiments of the invention; and

FIG. **6** is a schematic diagram of a computer system for executing a set of instructions that, when executed, can cause the computer system to perform one or more of the methodologies and procedures described herein.

DETAILED DESCRIPTION

Various exemplary embodiments of the disclosure are discussed in detail below. While specific implementations are discussed, it should be understood that this is done for illustration purposes only. A person skilled in the relevant art will recognize that other components and configurations may be used without parting from the spirit and scope of the disclosure.

As described above, TES devices can be used as sensors across much of the electromagnetic spectrum. As such, TES-based sensors are useful in a variety of fields, including materials microanalysis, mass spectroscopy of biomolecules, nuclear nonproliferation, synchrotron experiments, atomic physics, quantum information, dark-matter searches, and astrophysics, to name a few. However, to achieve high energy resolution for these applications, it is important to control both the T_c and transition width (ΔT_c) in a TES device. A transition width is generally used in lieu of transition edge to emphasize the fact that the transition is not instantaneous but rather requires a finite temperature range.

In general, since the energy resolution of calorimeters improves with decreasing temperature, many TES devices are typically designed to operate at temperatures around 0.1 K. For a TES, this requires a superconductor with T_c in that range. While a few suitable elemental superconductors have a T_c in this range, the best results have been achieved using proximity-coupled bilayers, as described above, in which T_c is tuned by selection of the thicknesses of the superconducting (S) and normal metal (N) layers. However, as described above, a primary issue with TES-based detectors is that fabrication of TES devices is generally non-trivial with respect to obtaining a desired T_c. For example, process variation during the fabrication of TES devices can result in final layer thicknesses that deviate from target thicknesses. In most TES devices, even slight variations in layer thickness can significantly affect the resulting T_c of a bilayer structure and render the TES device unusable for at least some types of particle detectors. In another example, it is generally difficult to produce a bilayer TES device in which the interface between the normal metal layer and the underlying superconductor layer is completely free of contaminants. Such contaminants have been found to introduce noise or alter the T_c of bilayer TES devices. Chemical processes between the layers or interdiffusion of species at the interface can also cause problems in controlling T_c, ΔT_c, uniformity and device behavior. Variation in intrinsic or extrinsic film stress is also known to cause changes in the resistive transition including T_c.

Efforts to improve the performance of such TES devices have generally focused on reducing noise, improving absorption characteristics, and improving the interface or boundary between the normal metal layer and the underlying superconducting film. As a result, the parameters for adjusting T_c in bilayer and other TES structures during fabrication are still generally limited to selection of types of materials, doping of materials, transmissivity of the interface, film stress, and thicknesses of layers. However, control of such parameters is generally difficult in most conventional TES device fabrication processes. As a result, fabrication yields for TES-based detectors are generally low.

Therefore, in order to overcome the limitations of conventional TES devices and fabrication thereof, the various exemplary embodiments of the invention provide a novel methodology for fabricating TES devices by providing an additional degree of freedom for selecting T_c. In particular, exemplary embodiments of the invention provide a design methodology in which the spacing between the superconducting leads of TES devices over the TES device body is selectively adjusted to further modulate T_c. Thus, lead spacing provides an additional degree of freedom for designing TES devices. Furthermore, since lateral spacing targets are typically easier to achieve in monolithic processes typically used for fabricating TES devices, this degree of freedom can be adjusted with a relatively high degree of accuracy. Thus, target T_c's are significantly easier to achieve, improving yield of TES device manufacturing processes.

As used herein, the term "spacing" or "lead spacing," with respect to the superconducting leads for a TES body refers to the average spacing of the portion of the superconducting leads contacting the device body of the TES device.

In general, a conventional bilayer structure or body in a TES device will have an intrinsic transition temperature T_{ci} prior to attaching any leads thereto. However, when superconducting leads are connected to opposite ends of the body, superconductivity is also induced longitudinally into the body from the ends via a longitudinal proximity effect. In the longitudinal proximity effect model the superconducting order parameter is a maximum in the TES near the leads then decays to a minimum halfway between the leads. Traditionally, it has been believed that in order to induce superconductivity longitudinally in a bilayer structure, the spacing between the superconducting leads needs to be less than two times of the mean free path length of a normal metal layer, typically on the order of order the film thickness when mean free path thickness limited and no larger than a few μm's for bulk superconductor/normal metal/superconductor sandwiches with high a purity normal metal. Further, the effect of such induced superconductivity has generally been a shift in

T_c on the order of 100's of mK, further complicating design of TES-based sensors when superconducting leads are used.

However, the present inventor has discovered that for at least some types of TES device structures, the longitudinal proximity effect still induces superconductivity even when the superconducting leads are separated by 100's of μm. Further, the present inventor has discovered that by providing superconductor lead spacing in the 100's of um, the shift in T_c can be limited to 1 mK or less. Such mK T_c shifts can even occur for lead separations L of over 1000 times the electron mean free path in the TES body. In particular, as described below, the present inventor has discovered that the amount of T_c shift decreases predictably as $\sim 1/L^2$.

Accordingly, the various exemplary embodiments of the invention exploit this property to provide a new design methodology for TES devices. In particular, the various exemplary embodiments of the invention provide for design and fabrication of TES devices in which T_c can be selected by (1) varying the thickness of the layers in the body of the TES device and (2) varying the spacing of superconducting leads over the body of the TES device. Thus, the various exemplary embodiments of the invention allow a desired T_c to be targeted by selection of the thickness of layers in the body and the spacing of the superconducting leads to be used to fine-tune the final T_c. This is conceptually described with respect to FIG. **1**A.

FIG. **1**A shows a perspective view of a TES device **100**. As shown in FIG. **1**A, the TES device **100** includes a substrate **101** having an electrically insulating surface and a body **102** on substrate **101**. In FIG. **1**A, the body **102** includes of a superconducting layer **104** and a normal metal layer **106**. The body **102** in FIG. **1**A therefore forms a S/N structure having superconducting properties. In particular, normal metal electrons in **106** and superconducting order in **104** are diluted in the combined bilayer giving an intrinsic bilayer transition temperature T_{ci} In general, the bilayer structure will have a T_{ci} value that is dependent on the thicknesses of layers **104** and **106**, the conditions at the interface between the layers **104** and **106**, and the Fermi metal properties of **104** and **106**.

Although the body **102** in FIG. **1**A is shown as including a specific bilayer structure, the invention is not limited in this regard. In other exemplary embodiments of the invention, the body can include of a multi-layer structure. That is, a stack of alternating superconducting and normal metal layers on substrate **101**. Further, the body **102** can also be formed by disposing the normal metal layer **106** on substrate **101** and thereafter forming the superconducting layer **104** on normal metal layer **106**. Alternatively **102** may be a uniform superconductor, a magnetically doped superconductor, a normal metal, a semiconductor or semimetal, or a magnetically doped metal.

Substrate **101** is a material which has lower conductivity than the body **102** so that it does not create a conducting path around the body **102**. Further a material for substrate **101** can be selected which is not a source of impurities to the body **102**. In a one exemplary embodiment, the substrate is crystalline silicon substrate coated with a silicon nitride layer formed on its surface. However, the various exemplary embodiments of the invention are not limited in this regard and various other types of materials can be used to provide an electrically insulating surface for the body **102**. The substrate can also be selected to be thermally conductive and can serve as a substrate to provide an absorber. Further, the substrate can be used to support additional circuits or devices coupled to the body **102**.

Superconducting layer **104** and leads **108** and **110** can be made of any metal or metal alloy which is a superconductor at the operating, temperature of the sensor. These superconducting layers can further be selected to be a metal that does not rapidly form a contaminant layer, such as an oxide, so that there are little or no impurities at their surfaces. A few elemental BCS superconductors include aluminum, molybdenum, titanium, and alloys including these metals. However, the invention is not limited in this regard and any other superconducting materials can be used in the various exemplary embodiments of the invention. Additionally, in some exemplary embodiments of the invention, superconducting layer **104** can be magnetically doped superconductors, for example, iron or manganese doped aluminum. However, the invention is not limited in this regard and other combinations of superconductors and magnetic impurities can be used in the various exemplary embodiments of the invention.

Normal metal layer **106** can be made of any metal or metal alloy which is a normal conductor at the operating temperature of the sensor. Layer **106** can be selected to be a normal metal that does not rapidly form a contaminant layer, such as an oxide, so that there are little or no impurities at its surface. Some normal metals include gold, silver, copper, palladium, platinum, gold/copper alloys, and palladium/gold alloys. An advantage of using metal alloys is their high sheet resistance, which is appropriate for some applications. The normal metal can also be a ferromagnetic material such as chromium, manganese, iron, cobalt and nickel, in which case the T_c of the bilayer can be suppressed well below the T_c of superconducting layer **104**. In some cases, the normal metal can be a material such as tungsten which is a superconductor having a T_c below the operating temperature of the sensor, but is a normal conductor at the operating temperature. However, the invention is not limited in this regard and any other normal metals can be used in the various exemplary embodiments of the invention. In some exemplary embodiments of the invention, the normal metal layer can be other types of electrically conductive materials, such as semimetals or semiconductors. Thus, the term "normal metal." as used herein, refers to any metal, semimetal, or semiconductor material lacking superconducting properties at the temperature of interest (i.e., having an intrinsic superconducting transition temperature in isolation T_{ci}=0). Additionally, in some exemplary embodiments of the invention, normal metal layer **106** can be a magnetically doped metal, semimetal, or semiconductor.

In the structure illustrated in FIG. **1**A, when superconducting leads **108**, **110** are disposed on the body **102**, these superconducting leads also induce a superconducting order in **102**. As a result, the TES device is effectively a SN'S structure and the T_c of the TES device is increased above the transition temperature of body **102** in isolation's T_{ci}. TES T_c becomes dependent on the T_{ci} of the superconducting leads **108** and **110**. However, since the order parameter is changing longitudinally in the TES and there is a region of minimum order parameter strength in **102** (in the particular TES designed in illustrated in FIG. **1**A, the minimum is along the line bisecting L halfway between the leads). That is, the path between leads **108** and **110** through layer **102** operates as a superconducting weak link. It follows that the resistive transition and the devices T_c is inherently current dependent and increasingly so as L is decreased. Further, as described above, the effect is strongly dependent on the spacing (L) between the leads **108** and **110**. Thus, as the leads **108** and **110** are brought closer together (i.e., L is reduced), the strength of the order parameter at the minimum along the line bisecting L increases therefore increasing the devices T_c for a given current. Conversely, as the leads **108** and **110** are separated (i.e., L is increased), the strength of the order parameter at the minimum along the line bisecting L decreases therefore decreasing the devices T_c for a given current. Therefore, as the amount of superconductive order induced varies, the shift in T_{ci} will also vary. This shift in T_{ci} as a function of spacing is shown below in FIG. **2**.

It is worth noting that the temperature at which the penetration of order into **102** is zero (i.e., no superconducting order induced) requires going above the T_c of the superconducting material for lead **108** and **110**. This temperature is typically much higher than the device operating temperature (e.g., lead T_c is often of the order of several Kelvin as compared to a 100 mK T_c device). As a result, this produces at temperatures higher than the sharp resistive transition a gradual decrease in resistance as the temperature is lowered corresponding to a small leakage of superconducting from **108** and **110** into **102**. Therefore, in some exemplary embodiments of the invention, this property of the longitudinal proximity effect on the normal state slope can be used as a design feature in TESs to provide extended spectra range of sub-optimal energy resolution. That is, the detector can then be designed to give the best energy resolution in a specified particle energy window. Thus, this feature is operative to prevent heat pulses from saturating the TES device for particles above this energy range by using these variations in the slope of the transition to measure these particles with sub-optimal energy resolution.

In the various exemplary embodiments of the invention, the interface between the leads **108** and **110** and the body **102** can be formed to provide a "clean" interface (substantially free of native oxide or other impurities). However, in other exemplary embodiments, the amount of impurities at this interface can be modulated to allow at least a thin insulating layer between leads **108** and **110** and body **102**. Such an interface can help in reducing the size of the TES pixels while maintaining narrow transition widths desired for optimal energy resolution performance.

The various exemplary embodiments of the invention are not limited to the structure shown in FIG. **1**A. Rather, other structures can be used, as shown in FIGS. **1**B-**1**E. FIGS. **1**B-**1**D perspective views of alternate configurations for a TES device. In a first configuration, as shown in FIG. **1**B, a TES device **130** is shown. The configuration of device **130** is generally similar to that shown in FIG. **1**A. However, in device **130**, the leads are formed by superconducting leads **108** and **110** overlapping body **102**. Thus, a portion of leads **108** and **110** contacts the sidewall portions of body **102**. However, for purposes of adjusting T_c, the spacing of interest is still the same as in FIG. **1**A, the spacing between the leads on the top of body **102**, as shown in FIG. **1**B.

In another configuration, as shown in device **140** in FIG. **1**C, the leads are formed on at least a portion of the sidewalls of body **102**. In such a configuration, the spacing of interest is then the length of the body **102**. In yet another configuration, as shown in device **150** in FIG. **1**D, rather than forming leads **108** and **110** separately from superconducting layer **104**, they are formed concurrently. In particular, once superconducting layer **104** is formed, normal metal layer **106** is formed over only a portion of superconducting layer **104**. As a result, the portions of superconducting layer **104** having no normal metal material disposed thereon form the leads **108** and **110**, as shown in FIG. **1**D. In such a configuration, the body is defined by the normal metal layer and the directly underlying portion of superconducting layer **104**. As a result, similar to device **140** in FIG. **1**C, the spacing of interest is the length of the normal metal layer **106**.

As described above, in additional to providing a spacing for L to adjust T_c, T_c can also be adjusted by selection of materials, layer thicknesses, and incorporation of magnetic impurities. However, in some exemplary embodiments of the invention, in addition to adjustment of the lead spacing, normal metal features can be disposed on a S/N bilayer (i.e., superconducting/normal metal/substrate) between the leads. This is shown in FIG. **1**E. FIG. **1**E is a plan-view schematic of a TES device **150** in accordance with some exemplary embodiments of the invention. As shown in FIG. **1**E, between the leads **108** and **110**, normal metal features **114** and **116** are formed on the top of body **102**. In the various exemplary embodiments of the invention, the shape of such features can vary. Further, any combination of geometric shapes can be used in the various exemplary embodiments of the invention for features **114** and **116**.

Typically, such features are provided to reduce excess electrical noise in the devices and give detectors an improved energy resolution. However, the present inventor has found that for at least some types of TES device structures, these additional normal metal features can also be used, in conjunction with the spacing L, provide further adjustment of T_c in areas far from leads **114** and **116**. In particular, by changing the separation distance S between features **114** and **116**, a lateral inverse proximity effect is induced countering the effect of L. The size of the reduction in T_c is found to scale as $\sim 1/S^2$. Thus, in exemplary embodiments of the invention including such features, adjustment of both L and S can be used to adjust the effective T_c of the TES device.

As described above, the relationship between the change in T_c and spacing L is related by $\Delta T_c \sim 1/L^2$. This is shown in FIG. **2**. FIG. **2** shows a log-log plot of measurements of effective T_c for different currents as a function of lead spacing (L). The fabricated TES devices were measured using currents of 10 nA, 100 nA, 1 uA, 10 uA, and 100 uA. The data for FIG. **2** was collected by measurements of TES devices having a body including a bilayer of 55 nm molybdenum (Mo) and 21.0 nm of gold (Au), where T_c for Mo ~0.9K and T_{ci} for the body is ~170.9K. The TES devices further include superconducting leads fabricated from a molybdenum/niobium (Mo/Nb) alloy, having a T_c ranging from 3.5-7.1K, with a lead spacing (L) ranging from 8 to 290 um.

As shown in FIG. **2**, the measurements exhibit two characteristics. First, FIG. **2** shows that as electrical current is increased, the overall variation in T_c is reduced. For example, the data points associated with 100 uA current show that T_c goes from about 169.5 mK at a 290 um spacing to 240 mK at a 8 um spacing. In contrast, the measurements associated with 10 nA current show that T_c goes from a little over 171 mK at a 290 um spacing to over 500 mK at a 8 um spacing. Second, FIG. **2** shows that as lead spacing varies, the T_c of the TES device varies approximately as $1/L^2$. Since T_c, of the body is relatively weakly current dependent (–171 the observed variation in T_c thus reflects the change induced in the T_c of the TES device provided by the superconductivity induced by the Mo/Nb leads. Thus, by adjusting the lead spacing from 8 um to 290 um, the T_{ci} of the body can be adjusted as much as ~100's of mK and to less than ~1 mK. Although, the lead spacing can be increased beyond 100's of microns, this results in shifts of less than 1 mK.

Accordingly, since the relationship between lead spacing and T_c is predictable and the range of spacing over which the longitudinal proximity effect is operative induces changes in T_c of 100 mK or less, such adjustment of lead spacing can be used during design and fabrication of high-resolution TES devices with target T_c's in the 100's of mK. Such a design methodology is illustrated in FIG. **3**.

FIG. **3** is a flowchart of steps in an exemplary method **300** for designing a TES device in accordance with an exemplary embodiment of the invention. Although only a limited num-