Dec. 8, 1970 C. N. BERGLUND 3,546,491

SOLID STATE SCANNER UTILIZING A THERMAL FILAMENT

Filed Nov. 16, 1967 2 Sheets-Sheet 1

FIG. 1

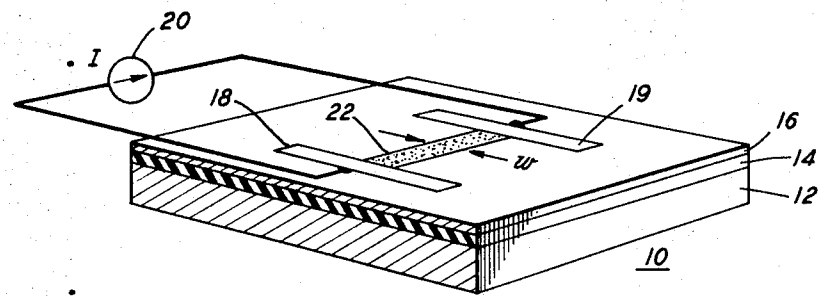


FIG. 2

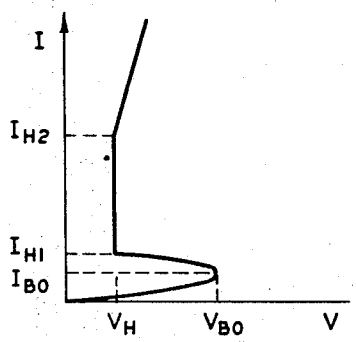


FIG. 3

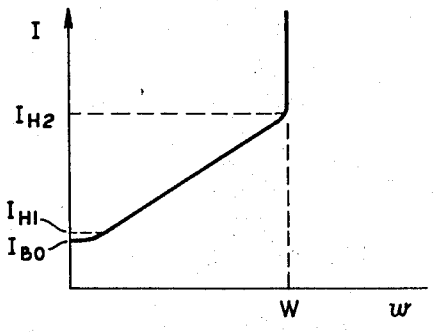


FIG. 4

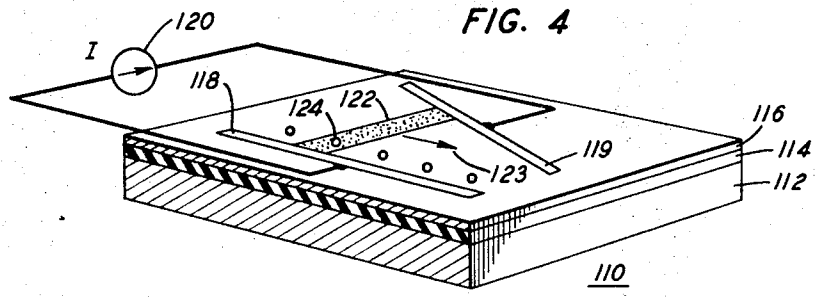
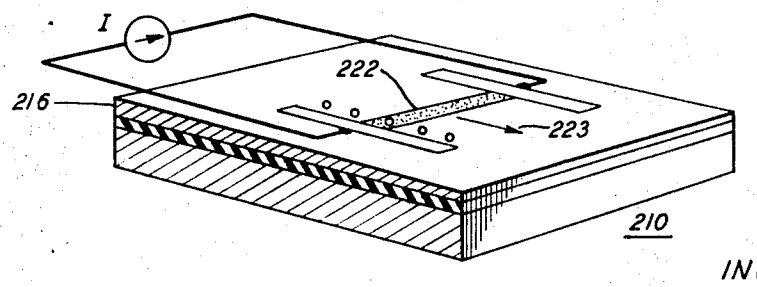


FIG. 6



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FIG. 7

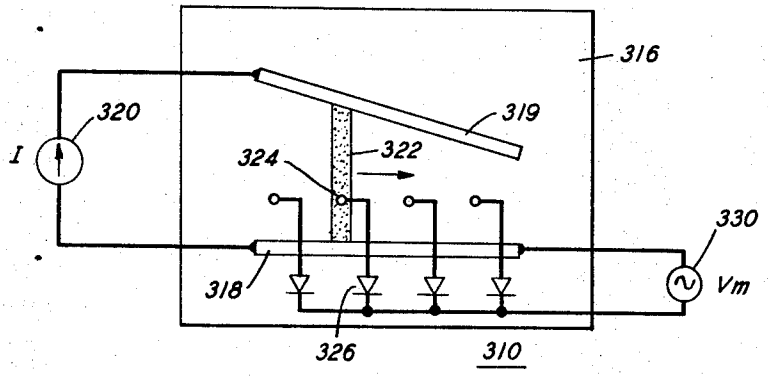


FIG. 8

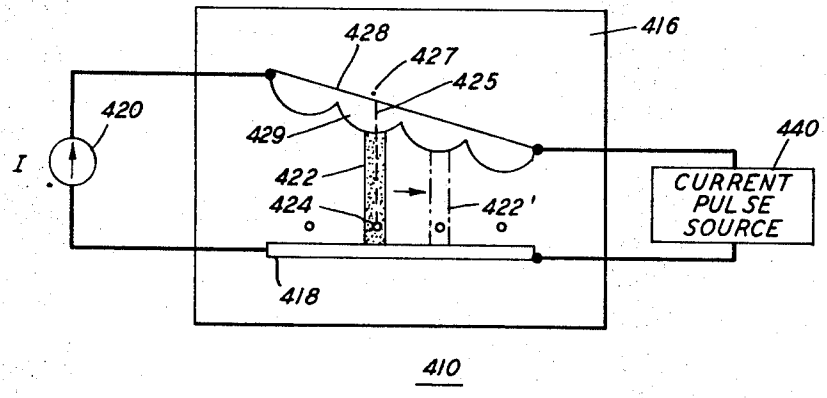
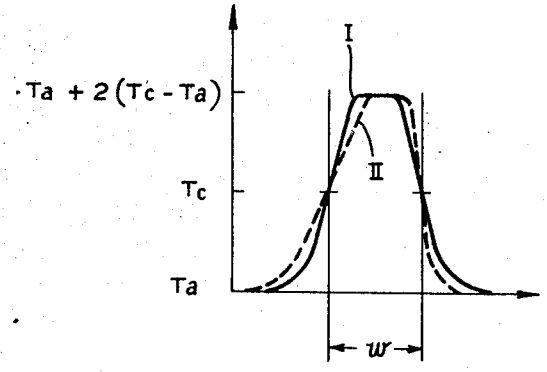


FIG. 5



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3,546,491

SOLID STATE SCANNER UTILIZING A THERMAL FILAMENT

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Int. Cl. H03k 17/56
U.S. Cl. 307—298 11 Claims

ABSTRACT OF THE DISCLOSURE

A scanning device includes a thin film of a material characterized by a negative temperature coefficient of resistivity (e.g. a thermoresistive material such as VO_2) upon which have been deposited a pair of spaced electrodes. A current source connected across the electrodes heats the thin film, but, because the current is maintained between a pair of critical values, produces only a narrow filament of heated material extending betweeen the electrodes. The filament is above the transition temperature and therefore in a low resistivity state, whereas the remainder of the thin film is below the transition temperature and therefore in a high resistivity state. The filament is made to move laterally between the electrodes in the direction of a power gradient created in the thin film by disposing the electrodes at an angle to one another or by grading the thickness of the thin film. The traveling filament is then made to scan contacts (located between the electrodes) to which might be connected the electroluminescent diodes of a display panel, for example.

BACKGROUND OF THE INVENTION

This invention relates to scanners utilizing materials characterized by a negative temperature coefficient of resistivity and in which can be established a low resistivity thermal filament, and more particularly to scanners for use in conjunction with optoelectronic display panels and the like.

With the advent of optoelectronic solid state display panels as a means of visually displaying information, it has become desirable to devise new means for scanning the display panel. The display panel generally includes an array or matrix of optoelectronic elements which form the crosspoints of the matrix. The function of a scanner is to address selectively the optoelectronic elements causing each to emit light in such a manner as to convey information.

Access to an element at a crosspoint is typically accomplished by connecting a horizontal and vertical control lead to each optoelectronic element. All of the horizontal control leads are connected to one scanner and all vertical leads to another. Thus, each crosspoint in the array is addressed by pulsing, through the scanners, an appropriate pair of control leads.

Various complex shift registers and switching circuits have been devised in the art to perform the basic scanning function. Advanced designs utilize a series of field effect transistor gate circuits; some even require transformers to couple to each optoelectronic element.

For simplicity, size and cost considerations, it is desirable that the scanner be fabricated in integrated circuit form. To this end it is also desirable that both the optoelectronic display panel and its associated scanners be formed on the same substrate. Although prior art transistorized designs can be manufactured in integrated circuit form, the necessity of fabricating semiconductor junctions increases cost by reducing percent yield. Of course, those designs employing transformers have not as yet been manufactured as integrated circuits at all.

SUMMARY OF THE INVENTION

The present invention generally employs materials which exhibit a negative temperature coefficient of resistivity and, more specifically, thermoresistive materials in which it has been found that resistivity is highly dependent on the temperature of the material. Such materials are typically characterized by a metal-semiconductor phase transition. That is, there is some transition temperature below which the material is a semiconductor and has a high resistivity and above which it is metallic and has a low resistivity. At this transition temperature, the resistivity of material decreases abruptly by a factor typically ranging from 10^3 to 10^4. The temperature of the material is raised to the transistion temperature by application thereto of heat energy supplied directly, as by current flow in the thermoresistive material, or indirectly, as by current flow in a heating resistor thermally coupled to the material. Thermoresistive materials include, for example, vanadium monoxide, vanadium dioxide, vanadium sesquioxide and titanium trioxide which have respective transition temperatures of approximately —148° C., 68° C., —95° C. and 327° C.

The prior art, whether employing samples of thermoresistive materials in bulk or thin film form, has generally resorted to inducing a phase transition in the entire sample. It has been discovered, however, that it is possible to induce a phase transition in selected regions of a thermoresistive material by maintaining the current flow through, or in general the power supplied to, the material between a pair of critical levels. It has further been discovered that such a region once created can be made to move in the direction of a power density gradient established in the material.

These phenomena are utilized in a scanner in accordance with an illustrative embodiment of the present invention. The scanner comprises a thin film of a thermoresistive material, for example, upon which have been deposited a pair of spaced electrodes. A current source connected across the electrodes produces a current of a magnitude lying between the pair of critical levels and thereby produces a narrow heated filament of material extending between the electrodes. The filament is above the transition temperature and therefore in the low resistivity state, whereas the remainder of the thin film is below the transition temperature and therefore in the high resistivity state. The filament is made to move laterally between the electrodes in the direction of a power gradient established in the thin film. The power density gradient may be produced in any of several ways including disposing the electrodes such that the longitudinal axes of their adjacent edges are at an angle to one another, grading the thickness of the thermoresistive thin film or by using resistive electrodes. The traveling low resistivity filament is then made to scan contacts (located between the electrodes) to which might be connected, for example, the matrix or elements of a memory or of a display panel. The filament functions as a propagating switch which sequentially creates a low impedance path between successive contacts and the electrodes.

The scanner may be utilized in conjunction with an optoelectronic display panel by connecting one terminal of each optoelectronic element to a separate contact and the other terminal to one side of a modulating voltage source. The other side of the source is connected to one of the electrodes. As the filament propagates, it sequentially connects each optoelectronic element across the modulating source by creating a low resistivity path between the corresponding contact and the electrode to which the source is connected. A visual display is created by the synchronization of the modulating voltage and the propagating filament in such a manner as to activate

the optoelectronic elements in accordance with information to be displayed.

The basic simplicity of the invention allows it to be readily fabricated in integrated circuit form by well-known thin film sputtering or evaporation techniques (although, the aforementioned filaments can be established in bulk materials as well as in thin films). In fact, it is feasible to utilize a separate scanner disposed along each horizontal (or vertical) row of crosspoints. Such an arrangement advantageously reduces capacitive coupling inherent between the control leads of a matrix, a problem inherent in prior art devices utilizing only a single vertical and a single horizontal scanner.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with its various features and advantages, can be easily understood from the following more detailed description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a perspective view of a structure in which a high temperature, low resistivity filament can be created;

FIG. 2 is a graph of an I–V characteristic which illustrates the primary electrical features of the structure of FIG. 1;

FIG. 3 is a graph of current versus filament width for the structure of FIG. 1;

FIG. 4 is a perspective view of a free running scanner in accordance with one embodiment of the invention;

FIG. 5 is a graph of the temperature distribution in a thermoresistive thin film and its associated filament;

FIG. 6 is a perspective view of a free running scanner in accordance with a second embodiment of the invention;

FIG. 7 is a top view of a free running scanner used in conjunction with an optoelectronic display in accordance with another embodiment of the invention; and

FIG. 8 is a top view of controlled scanner in accordance with still another embodiment of the invention.

DETAILED DESCRIPTION

Before discussing the structure and operation of scanners in accordance with the present invention, it may be helpful to consider with reference to FIGS. 1, 2 and 3 the properties of a filamentary device in which a low resistivity filament is created.

Turning now to FIG. 1, there is shown a filamentary device **10** comprising a heat sink **12** upon which have been deposited an insulator **14** and a thermoresistive (TR) thin film **16** in that order. A pair of parallel electrodes **18–19** are deposited in spaced relation to one another on the TR film **16**. The deposition may be accomplished by evaporation as any other technique well known in the art. Across the electrodes is connected a current source **20**. As shown on the graph of FIG. 2, as the current I is increased from zero, the voltage V across the electrodes increases until breakover occurs at current level I_{B0}. Above I_{B0} a further increase in current results in an abrupt decrease in voltage until a first critical current level I_{H1}, termed the holding current, is reached. In the range of current between zero and I_{B0} the entire film **16** is in a low temperature-high resistivity state and power is dissipated in the entire TR film **16** between the electrodes, causing the film between the electrodes to heat up uniformly. Consequently, as the transition temperature is reached, the resistivity of the TR film decreases abruptly, causing a corresponding abrupt decrease in the power dissipated in the TR film **16**. This lower power dissipation is insufficient to support the entire TR film **16** in its high temperature-low resistivity state because the power density would be too low, but is sufficient to support a narrow filament **22** extending between the electrodes **18–19** as shown in FIG. 1, inasmuch as the power density in the narrow filament **22** would be proportionally higher. The filament **22** is in a high temperature-low resistivity state, whereas the remainder of the film **16** is in a low temperature-high resistivity state. As the current increases beyond I_{B0} the width w of the filament increases nonlinearly until the first critical level I_{H1} is reached (FIG. 3). Beyond I_{H1}, the width of the filament increases approximately linearly with increasing current, but the voltage remains fixed at the holding voltage V_H (FIG. 2) until the filament encompasses the entire portion of the TR film **16** between the electrodes at a second current level I_{H2}. It is to be noted that the magnitude of I_{H2} is determined solely by the length of the electrodes **18–19** and is not a characteristic of the TR film. For further increases in current beyond I_{H2} the width of the filament remains fixed at W, the width of the electrodes **18–19**, but the voltage across the electrodes no longer remains constant, rather it increases with increasing current.

A qualitative explanation of the current voltage characteristic shown in FIG. 2 is as follows. Between the current levels zero and I_{B0} the TR thin film has a fixed high resistivity and therefore a fixed high resistance. Thus, increases in current produce increases in voltage in accordance with Ohm's law. At I_{B0} a low resistivity-low resistance filament is formed between electrodes **18–19** as previously described. The abrupt decrease in resistivity of the filament causes the voltage across the electrodes to decrease abruptly as the current flows through the path of least resistance; that is, through the filament.

Further increases in current beyond I_{B0} cause increased power dissipation of the TR film **16**. The filament width increases in order to compensate for the increased power dissipation, increases in width thereby maintaining the power density constant. Increased width in the filament, however, represents a decrease in resistance of the filament (the resistivity being fixed at the low value of the TR film). Thus, when the current is being increased beyond I_{H1}, the resistance of the filament decreases resulting in the vertical slope-constant voltage characteristic shown in FIG. 2. When the width of the filament can increase no longer; that is, when it equals the width of the electrodes **18–19** at current level I_{H2}, the resistance of the filament is fixed so that increases in current beyond I_{H2} again results in increases in voltage.

In a particular example, I_{H1} is about 4 ma. and I_{H2} is about 400 ma. for the following parameters with reference to FIG. 1: a silicon heat sink **12**, a 1μ thick SiO_2 insulator **14**, thermal conductivity of insulator **14** of 2×10^{-2} watts/cm. ° C., resistivity of the TR film **16** in the high temperature state of 2×10^{-4} ohm.-cm., and electrode length of about 140μ.

These properties may be utilized in several solid state devices including a bipolar voltage regulator, a solid state inductor, a latching relay and a negative resistance oscillator, as described in applicant's copending application, Ser. No. 683,549, filed concurrently herewith. The application of the aforementioned properties to scanners is explained in the following discussion.

A scanner in accordance with an illustrative embodiment of the invention is shown in FIG. 4, the numerals corresponding to those of FIG. 1 increased by **100**. The scanner **110** comprises a heat sink **112** upon which have been deposited an insulating layer **114** and a thermoresistive thin film **116**. A pair of electrodes **118–119** are deposited on the TR film **116** in spaced relation to one another and such that the longitudinal axes of their adjacent edges are at an angle to one another. A current source **120** is connected across the electrodes and a plurality of contacts such as **124** are deposited on the TR film **116** between the electrodes. As described previously a narrow, high temperature-low resistivity filament **122** extending between the electrodes may be created in the thin film by maintaining the current applied from source **120** between the pair of critical current values I_{H1} and I_{H2}. The filament **122** is made to move laterally between the electrodes by a power density gradient established in the TR film **116** in the direction of the desired motion.

As long as the current is maintained constant, the filament width remains fixed while the filament moves. The moving filament scans the contacts sequentially creating a low resistivity electrical connection between the contacts and the electrodes as, for example, between contact **124** and the horizontal electrode **118**. The power density gradient in this instance is established by disposing the electrodes **118–119** at an angle to one another, the power density in the TR film **116** being greatest where the electrodes are closest together, and being least where the electrodes are farthest apart. The filament **122** moves laterally between the electrodes in the direction of the power density gradient from the region of lower power density toward the region of higher power density; that is, in the direction of the arrow **123**.

The operation of the scanner **110** can be understood more fully with reference to FIG. 5 which shows the temperature distribution in a TR film and its associated filament. The filament width is designated by the interval w which indictaes that the temperature at the edges of a filament are at the transition temperature T_c, whereas the temperature of the interior of the filament increases to a maximum of approximately $T_a+2(T_c-T_a)$ at the center of the filament, where T_a is the ambient temperature. Outside the interval corresponding to the filament width w the temperature decreases rapidly to the ambient temperature T_a, but at no point outside that interval is the temperature of the TR film at or above the critical temperature T_c. Curve I of FIG. 5 shows a temperature distribution which is symmetrical about the center line of the filament and represents the distribution for a stationary filament (as, for example, the filament **22** described with reference to FIG. 1). The filament must be stationary inasmuch as the slope of the temperature distribution at each edge of the filament has the same magnitude. Because the lateral heat flow is proportional to that slope, it too is equal (and opposite in direction) at each edge of the filament and therefore the filament does not move. In comparison, however, curve II exhibits an asymmetrical temperature distribution characterized by unequal slopes at each edge of the filament. The magnitude of the lateral heat flows at each edge are therefore unequal (and again opposite in direction) and produce the requisite power density gradient. Consequently, one side of the filament heats up faster than the other, thereby causing the filament to move in a direction of the higher power density (i.e., to the right with reference to FIG. 5).

If $P(x)$, the power dissipated in the TR thin film per unit volume, is written as

$$P(x)=k_1C_1(1+\beta x) \tag{1}$$

where k_1 is the thermal conductivity of the TR film, C_1 and β are constant and x is distance, then a solution of the heat flow equations yields a velocity for the filament motion given to a good approximation by

$$v=\frac{k\beta w}{(2+\beta w)Ct_1} \tag{2}$$

where w is the width of the filament, C is the specific heat of the insulator, and t_1 is the thickness of the TR film. It is to be noted that βw represents the fractional change in power dissipation per unit volume in the TR film in moving from one side of the filament to the other, (e.g., $\beta=0$ implies there is no variation in electrode spacing). Substituting $k=10^{-2}$ watts/cm. ° C., C=1 joule/cm.^{3} ° C. and $t_1=10^{-5}$ cm., then

$$v=1000\,\frac{\beta w}{2+\beta w}\ \text{cm./sec.} \tag{3}$$

so that for βw large, approaching unity, the velocity of the moving filament approaches 333 cm./sec. For contact spacing of 1μ, this velocity corresponds to a scanning speed of about 0.3 μsec.

A scanner **210** in accordance with a second embodiment of the invention is shown in FIG. 6. The structure of the

scanner is substantially identical to the structure of the device shown in FIG. 1 with the exception that the thickness of the TR film **216** is graded in the direction of the desired filament motion. The graded thickness of the film establishes the requisite power density gradient in the film, the power density being highest in the TR film region of least thickness. Thus, as shown in FIG. 6, the filament **222** moves from a region of higher thickness to a region of lower thickness in the direction indicated by arrow **223**.

Alternatively, the power density gradient may be established by the use of resistive electrodes in lieu of metallic electrodes. The finite resistance of such electrodes produces a potential drop in the electrodes across the filament width, thereby causing the power density to be greater at one edge of the filament than at the other. As before, this difference in power density establishes a power density gradient which causes the filament to move.

A scanner for use in conjunction with an electroluminescent display panel is shown in FIG. 7. Only the top view is depicted. The structure of the scanner **310** is identical to that shown in FIG. 4 except that each diode of the display panel (only four of which are shown) is connected between a separate contact and one side of a modulating voltage source **330**, the other side of the source **330** being connected to the horizontal electrode **318**. As the filament **322** scans the contact **324**, for example, a low resistivity electrical connection is established between contact **324**, which is connected to the anode of diode **326**, and the horizontal electrode **318**, thus connecting the diode **326** across the terminals of the modulating voltage source **330**. The source **330**, by circuit means well known in the art, may be synchronized with the filament motion to produce an appropriate modulating voltage sufficient to cause the electroluminescent diode **326** to emit light in accordance with information to be displayed. At the time diode **326** is activated, however, the other electroluminescent diodes do not emit appreciable light since there exists a high resistivity path between their associated contacts and the source **330**.

The scanners described with reference to FIGS. 4, 6 and 7 are "free running" in that once the filament is started in motion it traverses the electrodes without stopping. By comparison, FIG. 8 shows the top view of a controlled or stepping scanner **410** comprising a TR film **416** upon which have been deposited a horizontal electrode **418** and a scalloped electrode **428** having the longitudinal axis of its scalloped edge disposed at an angle to the adjacent edge of the electrode **418**. The geometrical configuration of the scallops may, for example, be sectors of a circle. Across the electrodes **418** and **428** are connected a current pulse source **440** and, in addition, a current source **420** for supplying a current in the range between the critical current values I_{H1} and I_{H2}.

In operation, a filament **422** positions itself, as shown in FIG. 8, between electrode **418** and one of the scallops of electrode **428**. The filament **422** remains stationary until a stepping pulse from current pulse source **440** is applied across the electrodes **418** and **428**. The pulse increases the width of the filament **422** causing it to move to the next scallop in the position indicated by the dotted filament **422'**. When the pulse has been removed the filament again remains stationary at its new position until the next stepping pulse is applied.

From a qualitative standpoint the operation of the stepping scanner **410** can be explained as follows. The filament **422**, as shown in FIG. 8, positions itself in a region of symmetrical power density distribution; that is, in a region where the power densities (or lateral heat flows) at each edge of the filament **422** are equal. Under these conditions, as described previously, the filament is stationary. That the power densities at each edge are equal is readily seen from the fact that the filament shape and its temperature distribution are symmertical about the line **425** drawn perpendicularly from the center **427** of scallop **429** to the electrode **418**. A stepping pulse applied from source **440**,

however, increases the width of the filament 422 destroying the aforementioned symmetry and thereby making the power density at the right-hand edge of the filament 422 greater than the power density at the left-hand edge of the filament 422. The magnitude and duration of the stepping pulse are chosen so that the filament width overlaps a portion of the next succeeding scallop, thereby causing the filament to move to the right until it reaches the next region of symmetrical power density distribution, even though the stepping pulse in the meantime is removed and the filament has returned to its original width.

Other geometrical configurations of the electrodes are of course possible as long as there are established a plurality of symmetrical power density distribution regions. In general, the requirement of symmetrical power density distribution reduces in an analytical interpretation to the condition that the power density distribution functions at each "stepping point" within the filament width have no linear term since such linear terms are proportional to the velocity of the filament.

It is to be understood that the above-described arrangements are merely illustrative of the many possible specific embodiments which can be devised to represent application of the principles of the invention. Numerous and varied other arrangements can be devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

More particularly, although the invention has been described with reference to thermoresistive materials, it is to be understood that the aforementioned filaments can be established and made to move in materials which exhibit a negative temperature coefficient of resistivity, whether in thin film or bulk form.

What is claimed is:

1. A scanner comprising

a first layer of a material characterized by a negative temperature coefficient of resistivity in which can be established a low resistivity filament,

a heat sink substrate, a thermally insulative layer formed on one surface of said substrate, said first layer of material being deposited on the free surface of said insulative layer,

means for producing a low resistivity filament in said first layer comprising means for passing a current through said first layer at a level between a pair of critical current values, and

means for causing said filament to move in said first layer comprising means for establishing a power density gradient in said first layer in the direction of the motion.

2. The scanner of claim 1 wherein said first layer comprises a thermoresistive material characterized by a metal-semiconductor phase transition.

3. The scanner of claim 1 wherein said means for passing a current first layer comprises

a pair of electrodes deposited on said first layer in spaced relation to one another, said filament extending between said electrodes,

a current source connected across said electrodes, and in combination with at least one contact deposited on said first layer between said electrodes, said moving filament producing a low resistivity electrical connection between at least one of said contacts and at least one of said electrodes.

4. The scanner of claim 1 wherein said means for establishing a power density gradient comprises a pair of electrodes deposited on said first layer in spaced relation to one another and having the longitudinal axes of their adjacent edges disposed at an angle to one another, and wherein said means for passing a current through said first layer comprises a current source connected across said electrodes, said moving filament thereby produced being of substantially fixed width and extending between said electrodes.

5. The scanner of claim 1 wherein the thickness of said first layer is graded in the direction of the motion, thereby to establish said power density gradient, and wherein said means for passing current through said first layer comprises a pair of electrodes deposited on said first layer in spaced relation to one another, said electrodes extending in the direction of the motion, and a current source connected across said electrodes, said moving filament thereby produced being of substantially fixed width and extending between said electrodes.

6. The scanner of claim 1 wherein said means for establishing a power density gradient comprises a pair of resistive electrodes deposited on said first layer in spaced relation to one another, and wherein said means for passing a current through said first layer comprises a current source connected across said electrodes, said moving filament thereby produced being of substantially fixed width and extending between said electrodes.

7. The scanner of claim 1 in combination with means for controllably causing said moving low resistivity filament to stop at least one selected point comprising means for establishing at each selected point a region of symmetrical power density distribution in said first layer.

8. The scanner of claim 7 in combination with means for causing said low resistivity filament to move from a selected point comprising means for establishing an asymmetrical power density distribution in said filament.

9. The scanner of claim 7 wherein said means for establishing a region of symmetrical power density distribution comprises a pair of electrodes deposited on said first layer in spaced relation to one another, at least one of said electrodes having at least one scalloped region disposed opposite said other electrode.

10. The scanner of claim 9 wherein each scalloped region of said scalloped electrode comprises a sector of a circle.

11. The scanner of claim 9 in combination with means for causing said low resistivity filament to move from a selected point comprising means for establishing an asymmetrical power density distribution in said filament comprising means for increasing the width of said filament comprising means for passing a current pulse through said filament of a magnitude and duration sufficient to cause said filament to overlap a portion of the next succeeding scallop.

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JOHN S. HEYMAN, Primary Examiner

U.S. Cl. X.R.

307—299, 307, 310; 3—234