April 28, 1970 W. S. BOYLE ET AL 3,509,348

OPTICAL MEMORY DEVICE UTILIZING METAL-SEMICONDUCTOR PHASE TRANSITION MATERIALS

Filed Sept. 18, 1967 2 Sheets-Sheet 1

FIG. 1

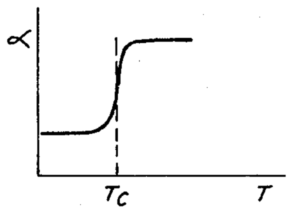


FIG. 2

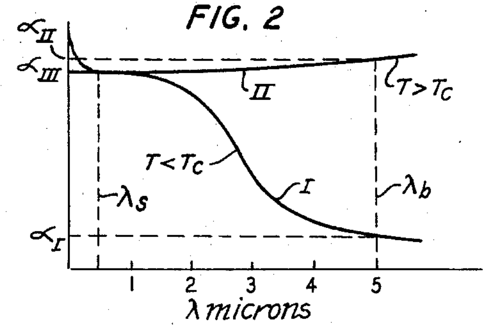


FIG. 3

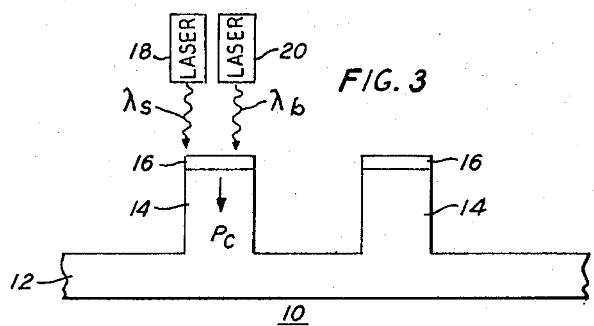


FIG. 4

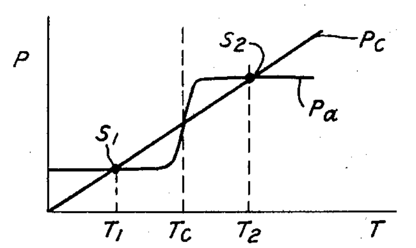


FIG. 5

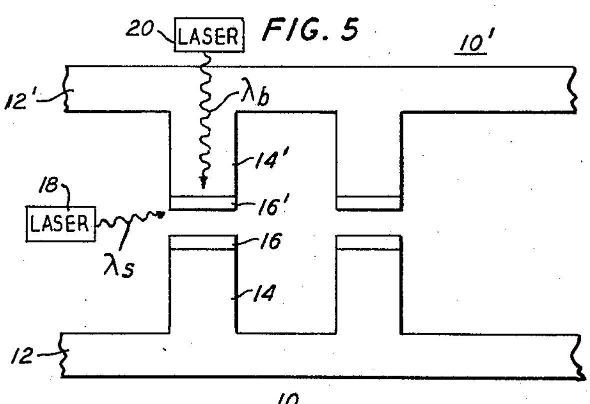


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FIG. 6

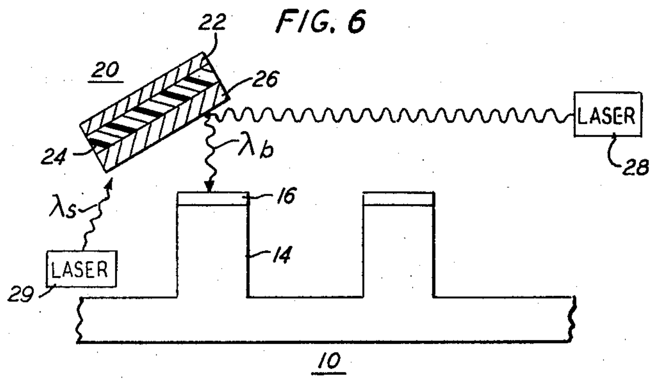



FIG. 7

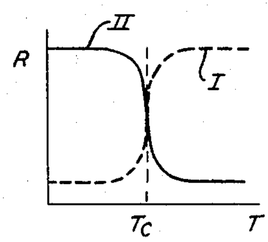



FIG. 8A

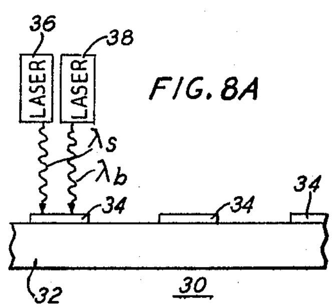
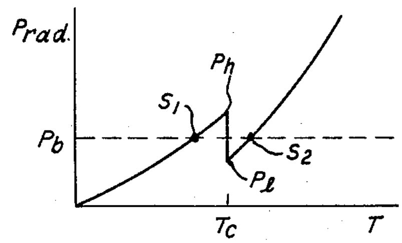



FIG. 8B



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## OPTICAL MEMORY DEVICE UTILIZING METAL SEMICONDUCTOR PHASE TRANSITION MATERIALS

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**U.S. Cl. 250—211** **8 Claims**

### ABSTRACT OF THE DISCLOSURE

An optical memory device utilizes the variable absorptivity characteristics of materials which undergo a metal-semiconductor phase transition. The power versus temperature characteristic of the material, when the material is coupled to an appropriate heat sink, exhibits two stable temperature states, one above and one below the transition temperature. The device is accessed by two light beams.

### BACKGROUND OF THE INVENTION

This invention relates to memory devices and more particularly to optical memory devices which utilize the variable absorptivity property of materials which are characterized by a metal-semiconductor phase transition.

Recent advances in technology, notably the development of the laser, have brought feasible optical communication systems nearer to reality. As with most communication systems, however, a memory is needed to store information, and methods must be developed to access that information. In particular, in an optical memory system it is desirable to have a bistable optical memory device which can be controlled by light beams. In order that large quantities of information might be stored in a small area the memory device should be small in size and readily fabricated.

The basic functions performed by any memory system include writing, read out, erase and, of course, memory. In the optical memory in accordance with the present invention, the writing, read out and erase functions may be performed by one or more light beams and the memory function is performed by utilization of the variable absorptivity property of materials which are characterized by a metal-semiconductor phase transition. In these materials it has been found the the absorption of light (i.e., radiation, in general) by the material is highly dependent on the temperature of the material. The metal-semiconductor phase transition is characterized by a transition temperature below which the material is a semiconductor and above which it is metallic. At this temperature the absorptivity (and absorption coefficient) of the material increases abruptly as the temperature increases. Materials included in this class are vanadium monoxide, vanadium dioxide, vanadium sesquioxide and titanium trioxide which have respective transition temperatures of about —148° C., 68° C., —95° C. and 327° C. In addition, the absorptivity of these materials has been found to be frequency dependent, the absorptivity for temperatures below the transition temperature typically being less in the near infrared than in the visible portion of the spectrum. Both the temperature and frequency dependent properties are utilized in the optical memory device in accordance with the present invention.

### SUMMARY OF THE INVENTION

A memory module in accordance with one embodiment of the invention comprises a thin layer of variable absorptivity material deposited on a pedestal-like heat sink.

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The power versus temperature characteristic of the structure exhibits two stable temperature states, one above and one below the transition temperature $T_c$ of the variable absorptivity material. Two light beams are used to control the state of the module. One of the light beams is typically infrared and is used to bias the module in its low temperature state, whereas the other beam is visible, and is used to switch (i.e., the writing function) the module to its high temperature state. When $T<T_c$ and only the bias beam is incident upon the module, the absorptivity of the material at infrared wavelengths is low and, consequently, little energy is obsorbed from the infrared bias beam and the module is in its low temperature state. When, however, the visible switching beam is also made incident upon the module, energy is absorbed from that beam to heat the material since the absorptivity at visible wavelengths is high. When sufficient heat is absorbed, the temperature of the material exceeds $T_c$, the absorptivity abruptly increases, and the module switches to its high temperature state. In this state the absorptivity of the material at the infrared wavelength of the bias beam is high and sufficient energy is absorbed from the bias beam alone to maintain the module in its high temperature state. Thus, the module performs a memory function by remaining in its high temperature state even in the absence of the switching beam.

### BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. 1 is a graph of absorptivity versus temperature for a variable absorptivity material;

FIG. 2 is a graph of absorptivity versus wavelength for a variable absorptivity material;

FIG. 3 is a schematic of one embodiment of the invention;

FIG. 4 is a graph of power versus temperature for the embodiment of the invention as shown in FIG. 3;

FIG. 5 is a schematic of another embodiment of the invention;

FIG. 6 is a schematic of still another embodiment of the invention;

FIG. 7 is a graph of reflectivity versus temperature for a portion of the invention as shown in FIG. 6;

FIG. 8A is a schematic of yet another embodiment of the invention; and

FIG. 8B is a graph of power versus temperature for the embodiment of the invention as shown in FIG. 8A.

### DETAILED DESCRIPTION

As discussed previously, the absorptivity of a typical variable absorptivity material is both temperature and frequency dependent. Turning now to FIG. 1, there is shown a graph of absorptivity $\alpha$ versus temperature for such a material. The material undergoes at the temperature $T_c$ a metal-semiconductor phase transition which is characterized by an abrupt increase in absorptivity at $T_c$. FIG. 2, on the other hand, is a graph of absorptivity $\alpha$ versus the wavelength of incident light $\lambda$. When $T<T_c$ the absorptivity decreases with increasing wavelength, as shown by cure I. For $T>T_c$, the absorptivity is more nearly constant between $0.5\mu$ and $5\mu$ wavelength, but the values of $\alpha$ are greater for $T>T_c$ than for $T<T_c$ as shown by curve II.

Both of these characteristics are utilized in a memory module in accordance with one embodiment of the invention as shown in FIG. 3. The module **10** comprises a heat sink **12** upon which have been formed a plurality of pedestal-like members **14**. On each pedestal **14** is deposited a thin film **16** of a variable absorptive material.

The power versus temperature characteristic of the module **10** is shown in FIG. 4. The curve label $P_a$ represents the power absorbed by the variable absorptivity material. Curve $P_a$ exhibits an abrupt increase at $T_c$ to correspond with the abrupt increase in $\alpha$ as shown in FIG. 1. The curve labeled $P_c$ represents the power conducted by the pedestal **14**. Curve $P_c$ varies linearly with temperature and intersects curve $P_a$ in three points corresponding to the stable temperature states $S_1$ and $S_2$ at temperatures $T_1$ and $T_2$, respectively, and one unstable state at the transition temperature $T_c$.

Two light beams, a bias beam and a switching beam, typically generated respectively by lasers **18** and **20**, are used to control the state of the memory module **10**. The bias beam is used to maintain the module in its low temperature state $S_1$ and is at a wavelength $\lambda_b$ (e.g., $5\mu$ for $VO_2$) as shown in FIG. 2, such that the corresponding absorptivity is low for $T<T_c$ ($\alpha_I$, curve I) and high for $T>T_c$ ($\alpha_{II}$, curve II). The switching beam is used to switch the module to its high temperature state $S_2$ and is at a wavelength $\lambda_s$ (e.g., $0.5\mu$ for $VO_2$) such that the corresponding absorptivity $\alpha_{III}$ is high for both $T<T_c$ and $T>T_c$.

The memory and writing functions of the device are performed as follows. With $T<T_c$ and only the bias beam incident upon the thin film **16**, little energy is absorbed from the beam inasmuch as the absorptivity is small at $\lambda_b$ ($\alpha_I$, FIG. 2). The beam is transmitted through the member **14** which is transparent at both $\lambda_b$ and $\lambda_s$. The module is therefore in its low temperature state $S_1$ (FIG. 4). When the switching beam is also made incident upon the thin film **14** (i.e., the writing function) it is highly absorbed inasmuch as the absorptivity is high at $\lambda_s$ ($\alpha_{III}$, FIG. 2). The energy absorbed from the switching beam heats the thin film thereby increasing its temperature above the transition $T_c$ and causing an abrupt increase in absorptivity, most notably at wavelength $\lambda_b$ (curve II, FIG. 2). The module is therefore switched to its high temperature state $S_2$ (FIG. 4). Sufficient energy is now absorbed from the bias beam alone so that when the switching beam is removed the module remains in its high temperature state $S_2$ (i.e., the memory function).

The read out function requires sensing the state of the memory module **10** and may generally be performed by coupling a photodiode to each module to sense whether the bias beam is being absorbed as transmitted or by merely sensing the reflectivity by a light beam making use of the same beam steering as used for the writing function.

The erase function, which requires switching the module back to its low temperature state $S_1$, may be performed most directly by turning off the bias beam. If, however, it is undesirable to turn off the bias beam, the erase function may be accomplished by either of the structures shown in FIG. 5 or 6. As shown in FIG. 5, a complementary module **10′**, which is disposed opposite the memory module **10**, is substantially identical to the module **10**. It comprises a heat sink **12′** upon which has been formed a pedestal **14′**. A thin film **16′** of a variable absorptivity material is deposited on the pedestal **14′**. The bias beam $\lambda_b$ is transmitted through both the pedestals **14** and **14′** and the thin films **16** and **16′**. Consider the situation with module **10** in its high temperature state $S_2$. It is desired to switch that module to state $S_1$. This may be accomplished by turning off the bias beam, or equivalently by preventing the bias beam $\lambda_b$, typically generated by laser **20**, from being incident upon the thin film **16** by making the switching beam $\lambda_s$, typically generated by laser **18**, incident upon the thin film **16′**. The result is that thin film **16′** is heated by the switching beam and thereby caused to undergo a semiconductor metal phase transition. Its absorptivity increases abruptly and it therefore absorbs substantially all the energy from the bias beam $\lambda_b$. The thin film **16** therefore cools down and switches back to its low temperature state $S_1$.

An alternative erase mechanism is shown in FIG. 6. Use is made of a variable reflectivity device **20** comprising a reflector **22**, a dielectric **24** deposited on one surface of the reflector **22**, and a thermoreflectance layer **26** deposited on the dielectric **24**. The device **20** is disposed at an angle to the module **10** such that the bias beam $\lambda_b$ (typically generated by laser **28**), after being reflected from the thermoreflective layer **26**, is transmitted through the thin film **16** and the pedestal **14** of module **10**. The thermoreflectance layer **26** undergoes a metal-semiconductor phase transistion accompanied by an abrupt increase in reflectivity at a transition temperature $T_c$ (curve I, FIG. 7) in much the same way that the variable absorptivity material undergoes an abrupt increase in absorptivity. In fact, the variable absorptivity materials previously discussed are also thermoreflectance materials. The device **20**, however, undergoes an abrupt decrease in reflectivity at the transition temperature, as shown by curve II of FIG. 7. It is this latter characteristic that makes possible the use of this structure to perform the erase function. Consider the situation again with module **10** in its high temperature state $S_2$. Device **20** is in its high reflectivity state so that most of the energy of bias beam $\lambda_b$ is reflected and made incident upon thin film **16** thereby maintaining module **10** in state $S_2$. When, however, the switching beam $\lambda_s$ (typically generated by laser **29**) is made incident upon thermoreflectance layer **26**, it is absorbed causing the layer **26** to heat up and undergo a phase transition. Consequently, the reflectivity of device **20** decreases abruptly and little of the energy of bias beam $\lambda_b$ is reflected onto thin film **16**. The thin film **16** then cools down and switches the module **10** back to its low temperature state $S_1$.

A memory module which employs only the aforementioned thermoreflective properties is shown in FIG. 8A. The memory module **30** comprises a heat sink **32** upon which have been deposited a plurality of thin films **34** of a thermoreflectance material such as vanadium dioxide. As discussed previously, the reflectivity of a thermoreflectance material increases abruptly at the transition temperature. The emissivity therefore decreases abruptly. Because the power radiated by a body is linearly proportional to emissivity, it too decreases abruptly at the transition temperature $T_c$, as shown in FIG. 8B. Below and above the transition temperature $T_c$ the power radiated follows the well known Stefan-Boltzmann law. The power radiated characteristic exhibits two transition power levels, $P_h$ at a temperature just below $T_c$ and $P_l$ at a temperature just above $T_c$. To switch from $S_1$ to $S_2$ the power is increased above $P_h$ whereas to switch from $S_2$ to $S_1$ the power is decreased below $P_l$.

Consider the state of module **30** when a bias beam $\lambda_b$, typically generated by laser **38**, is incident upon a thermoreflectance layer **34**. The power $P_b$ of the bias beam establishes two stable temperature states $S_1$ and $S_2$ at temperatures $T_1$ and $T_2$, one above and one below the transition temperature $T_c$. When only the bias beam is incident upon layer **34**, the module is in state $S_1$. When, however, a switching beam $\lambda_s$, typically generated by laser **36**, is also made incident thereon, the layer **34** heats up, sufficient power (i.e., greater than $P_h$, FIG. 8B) being absorbed to switch the module to the high temperature state $S_2$. After the switching beam is removed, and only the bias beam is present, the module remains in state $S_2$ thus exhibiting memory. The erase function is performed by cooling the module below the value $P_l$ as shown on FIG. 8B (i.e., by removing the bias beam).

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.

In particular, all of the access functions (write, read or erase) described above are performed optically by means of light beams. It is clear, however, that any of these functions could readily be performed electrically by sensing the large conductivity changes (analogous to the aforementioned absorptivity and reflectivity changes) associated with the metal-semiconductor phase transition.

What is claimed is:

1. An optical memory device comprising
 a thin film member which undergoes a metal-semiconductor phase transition at a transition temperature,
 means for stabilizing said member in a high or a low temperature state, the high state being above the transition temperature and the low state being below the transition temperature,
 optical means for supplying power to said member to bias said member in the low temperature state comprising means for irradiating said member with optical energy, and
 optical means for switching said member from the low stable temperature state to the high state comprising means for irradiating said member with optical energy thereby causing said member to undergo a metal-semiconductor phase transition.

2. The optical memory device of claim 1 wherein said thin film member comprises a variable absorptivity material having the property that its power absorption versus temperature characteristic exhibits an abrupt increase at the transition temperature, and
 said stabilizing means comprises a heat sink upon which is deposited said thin film member, said heat sink having the property that its power conducted versus temperature characteristic intercepts the power absorption characteristic of said member at the two temperatures of the high and low stable states.

3. The optical memory device of claim 2 wherein
 said variable absorptivity material is further characterized by an absorptivity which, for temperatures below the transition temperature, decreases with increasing wavelength of incident radiant energy, and which, for temperatures above the transition temperature, is approximately constant with increasing wavelength,
 said bias means comprises a first radiant energy beam incident upon said member, said beam having a wavelength such that it is highly absorbed when the temperature of said member is greater than the transition temperature, and highly transmitted when the temperature of said member is less than the transition temperature, and
 said switching means comprises a second radiant energy beam incident at selected times upon said member, said beam having a wavelength such that it is highly absorbed at all temperatures of said member.

4. The optical memory device of claim 3 in combination with means for switching said member from the high to low temperature state comprising means for preventing said bias beam from being incident upon said member.

5. The optical memory device of claim 4 wherein said means for switching said member from the high to the low temperature state comprises
 a second variable absorptivity member disposed between said first member and said bias beam,
 means for causing said second member to undergo a metal-semiconductor phase transition thereby to undergo an abrupt increase in absorptivity.

6. The optical memory device of claim 4 wherein said means for switching said member from the high to the low temperature state comprising a variable reflectivity device comprising
 a reflector,
 a dielectric layer deposited on one surface of said reflector,
 a thermoreflectance layer deposited on said dielectric layer, said thermoreflectance layer being characterized by a metal-semiconductor phase transition and disposed so as to reflect said bias beam onto said member, and
 means for causing the reflectivity of said variable reflectivity device to decrease comprising means for causing said thermoreflectance layer to undergo a metal-semiconductor phase transition.

7. The optical memory device of claim 1 wherein
 said thin film member is characterized by a power radiated versus temperature characteristic which exhibits an abrupt decrease at the transition temperature and further characterized by a first transition power level at a temperature substantially equal to but slightly less than the transition temperature, and a second transition power lever at a temperature substantially equal to but greater than the transition temperature, and
 said switching means comprises means for increasing the power supplied to said member to a value greater than the first transition power level.

8. The optical memory device of claim 7 in combination with means for switching said member from the high to the low temperature state comprising means for decreasing the power supplied to said member to a value less than the second transition power level.


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U.S. Cl. X.R.

250—217; 307—238, 278, 310, 311; 317—235; 350—160