

Nov. 7, 1972

S. E. CUMMINS
ELECTRON BEAM CONTROLLED BISTABLE FERROELECTRIC
LIGHT VALVE

3,702,215

Filed March 8, 1971

4 Sheets-Sheet 1

Fig-3

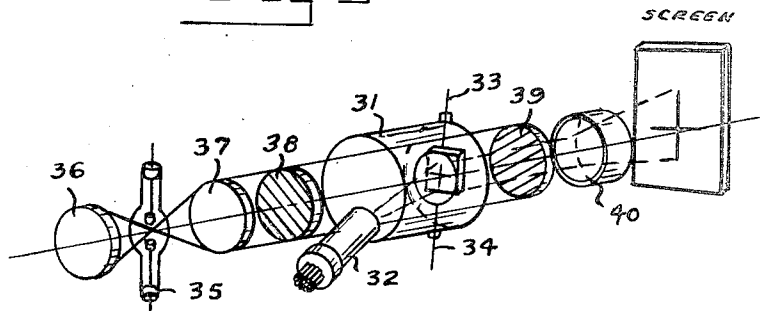


Fig-1

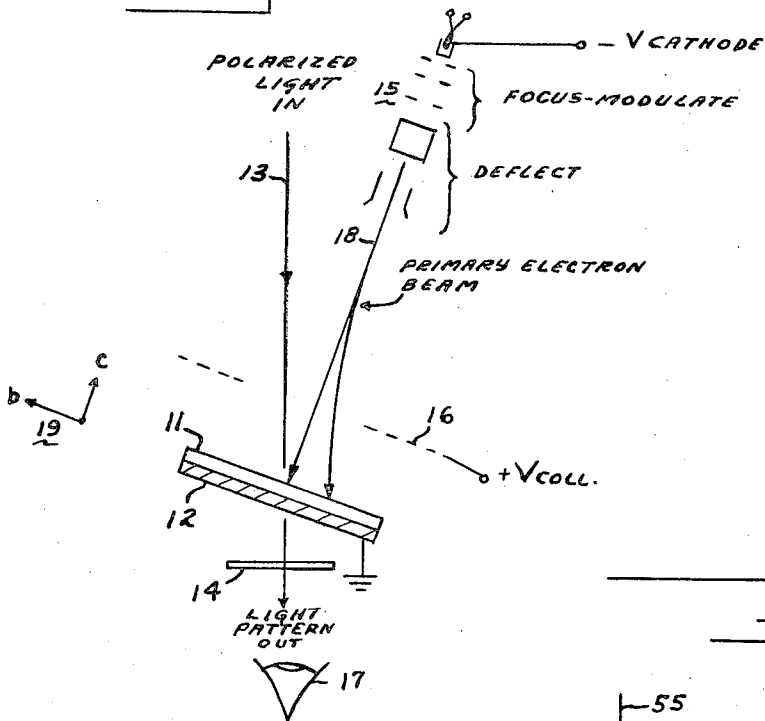
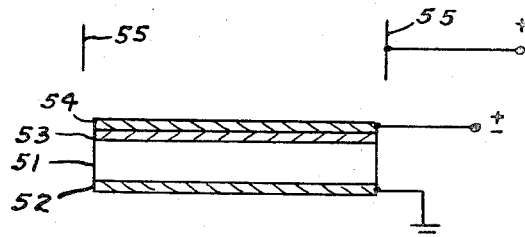


Fig-5



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4 Sheets-Sheet 2

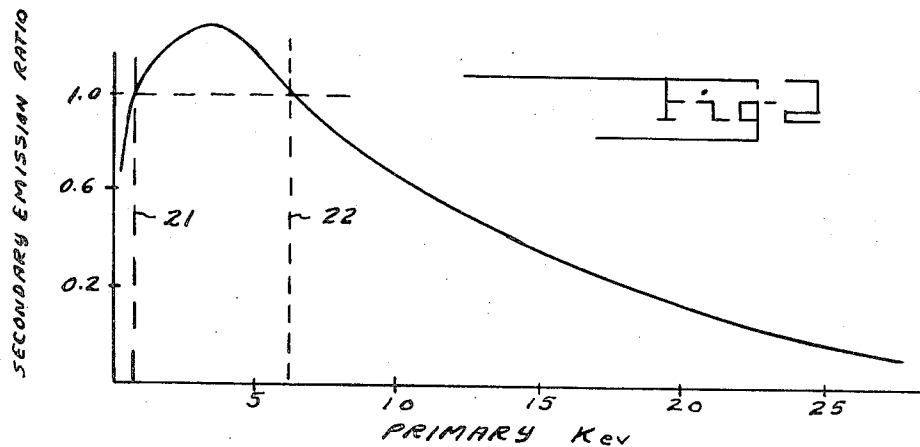
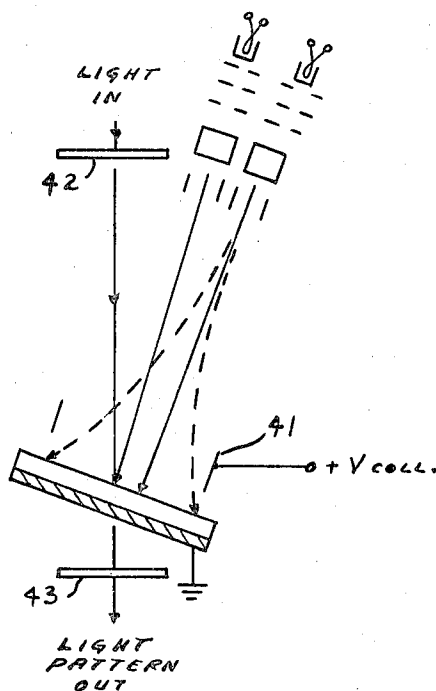


Fig-4



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4 Sheets-Sheet 3

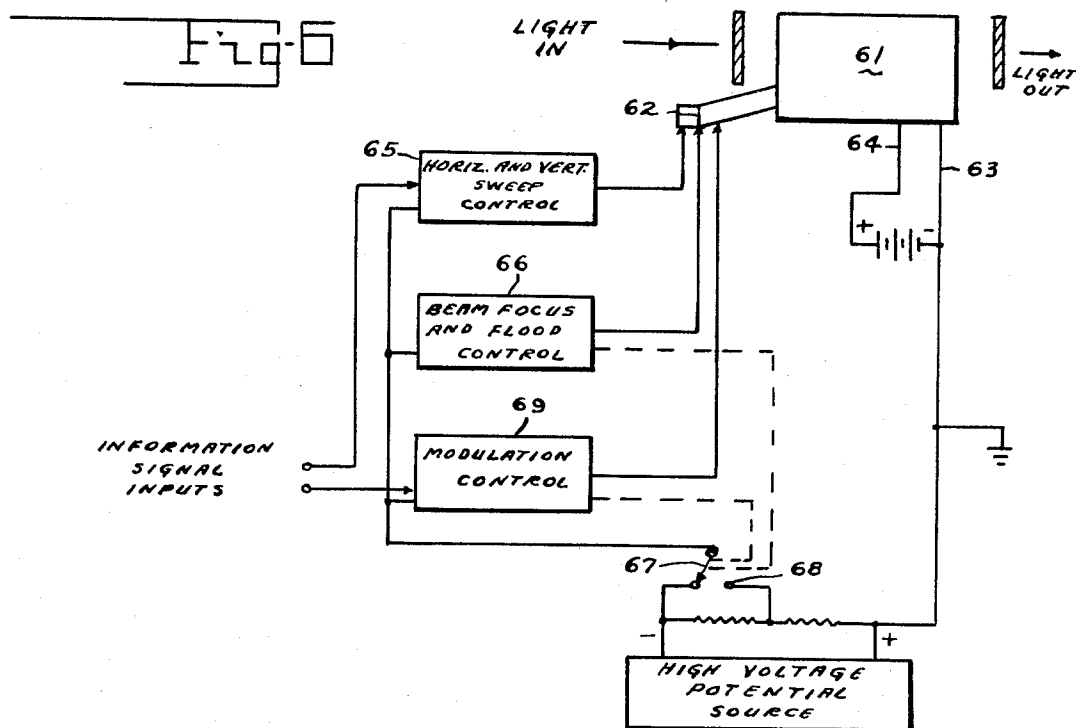
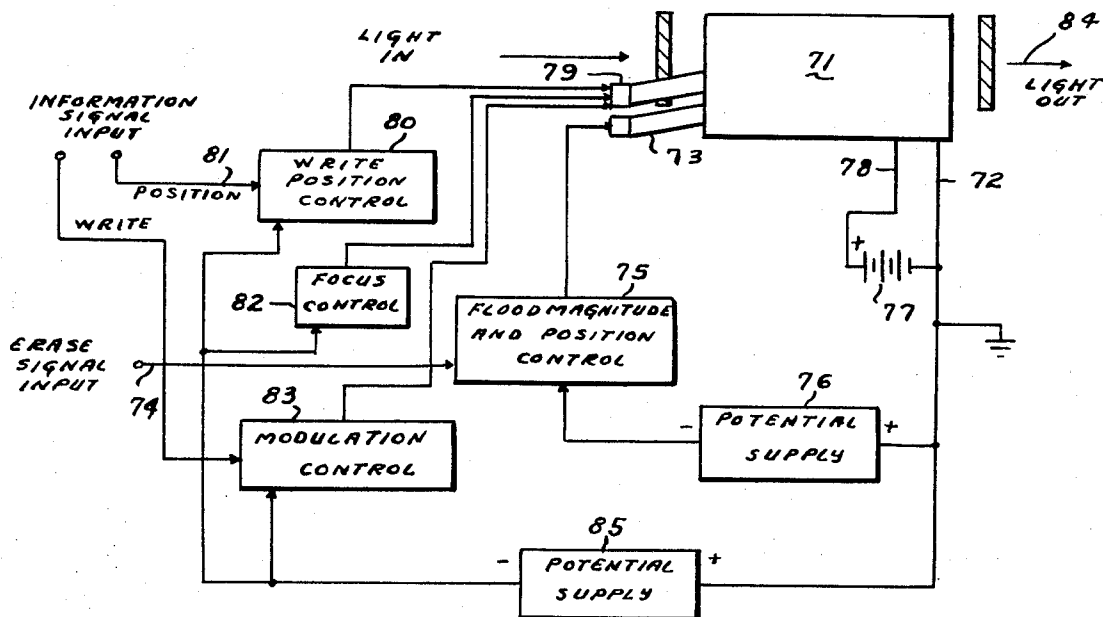


Fig-7



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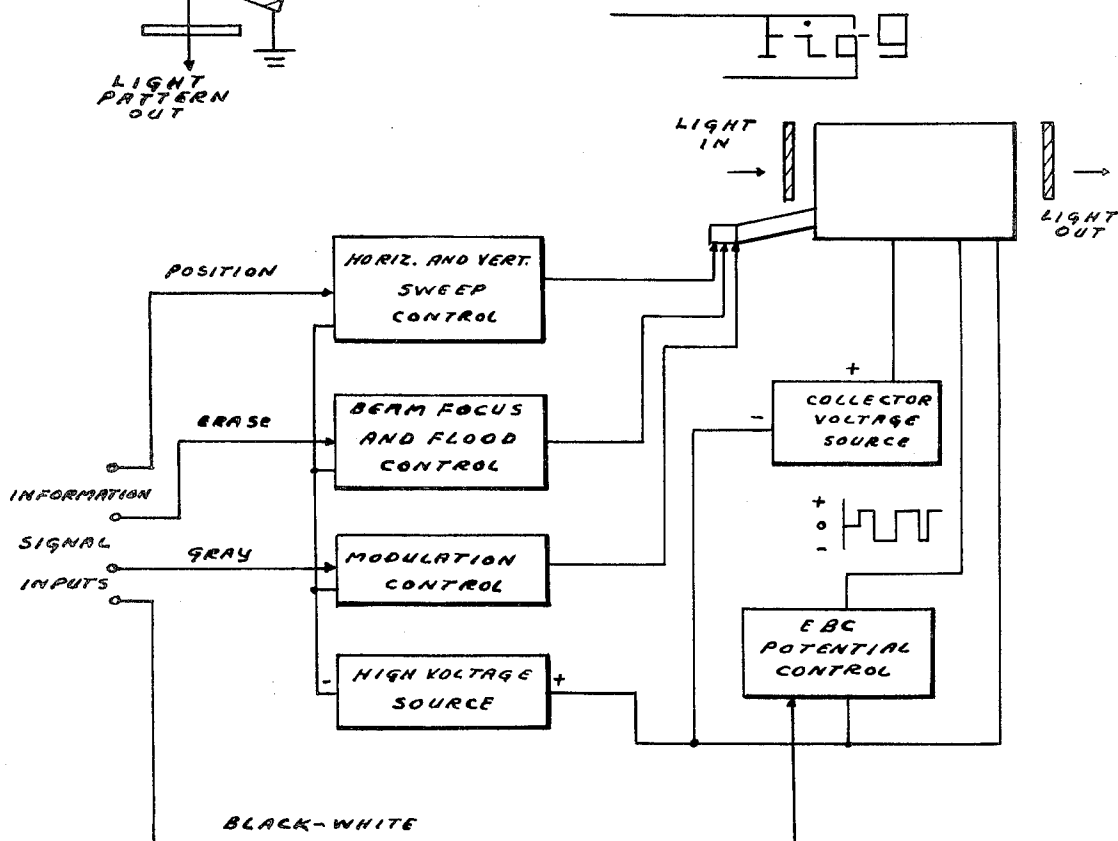
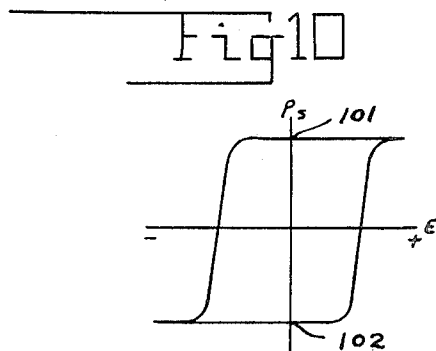
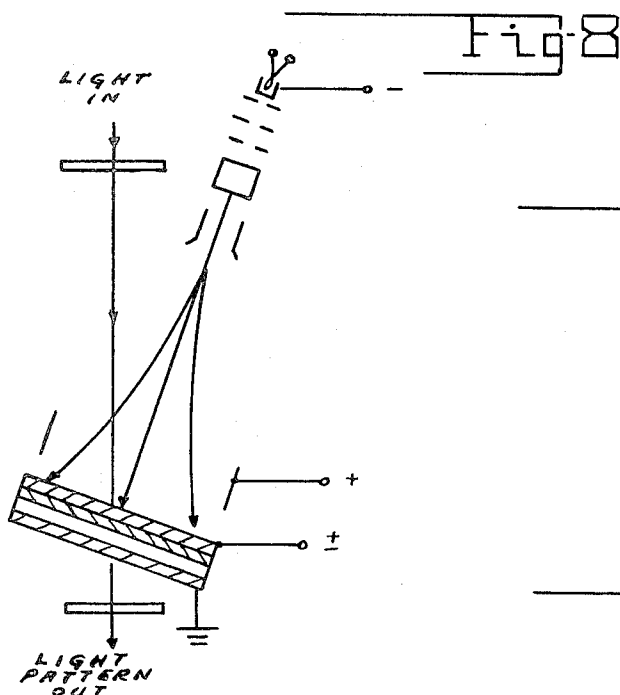
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4 Sheets-Sheet 4



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1

3,702,215

ELECTRON BEAM CONTROLLED BISTABLE

FERROELECTRIC LIGHT VALVE

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Filed Mar. 8, 1971, Ser. No. 122,012

Int. Cl. G02f 1/26

U.S. Cl. 350—150

2 Claims

ABSTRACT OF THE DISCLOSURE

Ferroelectric domains in a crystal of ferroelectric bismuth titanate ($\text{Bi}_4\text{Ti}_3\text{O}_{12}$) are switched between two stable states, by a controlled electron beam. One state provides optical transparency and the other optical opacity, in a polarized light system. The bistable action of the ferroelectric domains in the crystal provides a multi-cell memory device with nondestructive optical read-out.

BACKGROUND OF THE INVENTION

The field of the invention is in the art of nondestructive ferroelectric light valve (gate) memory devices.

Ferroelectric light valves are well known. Prior art is well set forth in the article "Ferroelectric Ceramic Light Gates Operated in a Voltage-Controlled Mode," by J. R. Maldonado and A. H. Meitzler in "IEEE Transactions on Devices," vol. ED-17, No. 2 for February 1970 commencing at page 148, and in Chapter Ten, "Light Valves, Lasers, and Electroluminescent Devices" of the text "Display Systems Engineering," edited by H. R. Luxenberg, and Rudolph L. Kuehn. A ferroelectric light valve having memory was disclosed in prior Patent No. 3,374,473 entitled "Bistable Optically Read Ferroelectric Memory Device." The use of electron beams to write information into solid state storage devices is also well known. Patent No. 2,872,612 entitled "Non-Volatile Barium Titanate Storage Tube" to R. B. De Lano, Jr. et al. and Patent No. 2,869,111 entitled "Electron Beam Switch Tube Operation of Ferroelectric Matrix" to D. R. Young typify the prior art of these devices. One form of laser beam modulation by electron beam write in on a solid state device is disclosed by Charles E. Baker in the article entitled "Laser Display Technology" appearing in the IEEE "Spectrum" for December 1968 commencing at page 39. An electron beam controlled light valve (without memory) is disclosed by T. H. Moore and J. Don Pace, in "IEEE Transactions on Electron Devices" vol. ED-17, No. 5 for May 1970 commencing at page 423.

Multigun bistable (memory) electron beam viewing tubes are well known as set forth diagrammatically in FIG. IV-5, page 244 of the text "Electronic Image Storage" by B. Kazan and M. Knoll. This same text also discusses bombardment-induced conductivity (BIC) and electron-bombardment conductivity (EBC) commencing at page 33.

For some early work in connection with this invention reference is made to the article "Electron-Beam Writing of Ferroelectric Domains in $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ Single Crystals" by Cummins and Hill in "Proceedings of the IEEE" for June 1970.

SUMMARY OF THE INVENTION

Information storage in a ferroelectric crystal by the switching of the domains within the crystal by an electron beam provides a bistable light valve for polarized light. Information may be read into the device at television scanning rates to provide a high resolution display that may be viewed directly or projected. The information may be stored indefinitely, repeatedly read, or erased either with the same electron beam gun or with a separate "focused" or "flood" gun.

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The controlled switching of ferroelectric domains by means of an electron beam is novel and distinguished from the prior art electron beam switching devices which employ a temporary charging of electro-optic crystals by means of an electron beam. The invention provides a new device having very high-density random access information storage suitable in the fields of memory, electro-optical display, transducer, and correlation functions.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a pictorial view showing an embodiment of the fundamental apparatus of the invention;

FIG. 2 is a typical plot of the secondary emission ratio of a crystal of bismuth titanate with respect to the primary beam energy;

FIG. 3 is a pictorial representation of a complete projection system using a single gun electron beam controlled bistable ferroelectric light valve for both "write-in" and "erase";

FIG. 4 is a representative pictorial view of an embodiment of the invention in which a separate electron gun is used for erasing the stored information;

FIG. 5 is a pictorial representation of a ferroelectric crystal having an EBC layer;

FIG. 6 is a representative block diagram of a single gun information storage system;

FIG. 7 is a representative block diagram of a two-gun information storage system having a separate information erase gun;

FIG. 8 is a pictorial view showing an embodiment of the invention having an EBC layer on the surface of the ferroelectric crystal;

FIG. 9 is a representative block diagram of a display-memory system having an EBC layer cooperating with the electron beam for switching the memory status of the crystal; and

FIG. 10 is a representative plot of the hysteresis characteristics of the ferroelectric material $\text{Bi}_4\text{Ti}_3\text{O}_{12}$.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the prior Patent No. 3,374,473 it was disclosed that the spontaneous polarization vector of a monoclinic crystal of ferroelectric bismuth titanate ($\text{Bi}_4\text{Ti}_3\text{O}_{12}$) can be switched between two stable directions with an accompanying switching of the optical indicatrix between two stable angular positions about the crystallographic b axis by the momentary application of an electric field normal to the a - b plane. Nondestructive optical read-out is accomplished by placing the crystal between crossed polarizers with the crystal oriented such that one of its two stable positions of the indicatrix is oriented for extinction of the light from the last polarizer.

In this invention instead of switching the crystal spontaneous polarization, P_s , by a voltage applied to electrodes on the crystal, incremental elements of the crystal are switched by changing the charge on the crystal elements with an electron beam. It has been found that very high resolution (10 μm .) may be obtained. The switching action is bistable, that is, the elements of the crystal retain the optical characteristic determined by the electron beam after the beam has been removed. Thus, information may be written into the crystal and read-out optically either by direct viewing, or by projection, with polarized light. Repeated readouts may be made at various time intervals without affecting the information stored. The non-destructively read light valve, with memory, as herein disclosed may be used for information storage, information display, image conversion, and electro-optical information processing.

The basic principles and apparatus of the invention are shown in FIG. 1. The bismuth titanate crystal 11 has

been previously poled in the conventional manner for uniform polarization to provide the usable optical properties as described in previous Pat. No. 3,374,473. The crystal 11 has a bare top surface and a conventional transparent back electrode 12. Such electrodes of tin oxide and thin semitransparent layers of metals (such as aluminum) are well known. The optically polarized light 13 is passed through the crystal and then through a polarizer 14, positioned at 90 degrees from the direction of polarization of the incoming light 13. Either the crystal 11, or the polarization of the incoming light is rotated to the proper relative orientation to give optical contrast as the crystal is switched to opposite domains. The conventional electron gun 15 provides a focused electron beam that is scanned and modulated in the conventional manner to provide the write-in information.

The energy in the electron beam as it is scanned over increments of the crystal essentially determines the domain state existing in the crystal under each respective incremental area. This may best be understood by referring to the typical hysteresis characteristic plot of $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ shown in FIG. 10 and the curve of FIG. 2 showing the secondary emission ratio (i.e., the ratio of the electrons emitted from the surface of the crystal over the incident electrons from the gun arriving on the surface of the crystal) plotted with respect to the kiloelectron volt energy in the electron beam from the electron gun. FIG. 10 shows that the spontaneous polarization, P_s , in an element of the crystal is determined by the electric field E , resulting from the charge deposited on that element of the crystal by the electron beam. Thus, after a sufficient charge in the positive direction is placed across an element of the crystal, and the electron beam supplying the charged removed, the spontaneous polarization of the element resides in a direction (that may be termed positive) represented at 101. Likewise a negative charge will leave a spontaneous polarization in the other direction as represented at 102.

The polarity of the charge across incremental elements of the crystal is determined by the energy in the electron beam impinging on the crystal. This may best be understood by referring to FIG. 2 which is a representative plot of the ratio of secondary electrons emitted from the crystal to the primary electrons in the incident beam (from the electron gun) striking the crystal plotted with respect to the energy in kiloelectron volts in the beam. This energy in the incident beam is determined by the potential difference between the electrode 12 on the back of the crystal 11 and that of the cathode of the electron gun. It is usually desirable to electrically position the crystal at ground potential (as shown) and operate the cathode at a negative potential. It is to be observed that for the potential region between the dotted lines 21 and 22 (FIG. 2) that the ratio of secondary electrons emitted from the crystal to the primary electrons striking the crystal is greater than one, and hence although the surface is bombarded with negative electrons, even more electrons are emitted from the surface and the net charge remaining on that part of the crystal is positive. When the energy of the beam is in the region below line 21 or above line 22 of FIG. 2, the ratio is less than one and the net charge on the portion of the crystal struck by the beam is negative. Thus, by changing the magnitude of the cathode potential the surface charge on the crystal may be controlled, and consequently the polarity of the ferroelectric domains produced in the crystal. The secondarily emitted electrons from the crystal are attracted to and returned to the electrical circuit by a collector 16 which may be either a screen electrode (with, or without, a center hole for the incident beam) as shown in FIG. 1 or a ring electrode as shown in FIG. 3 and at 41 in FIG. 4. Generally the ring type electrode is preferred.

By changing the energy in the electron beam it gives both write and erase capability to the same electron beam. When the write situation provides a minimum amount of light emerging through the last polarizer representing an

incremental element of the crystal, the erased condition could provide the maximum amount of emerging light. The energy level of the focused electron beam may be controlled to provide "spot" erase, or the electron beam may be defocused to a "flood" beam to effect a complete simultaneous erase of all the stored information in the crystal. Typical values of suitable operating parameters for $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ crystals have been found to be approximately a 20 kev. write potential and a 1000 ev erase potential. A typical potential value for the collector 16 (41 of FIG. 4 and 55 of FIG. 5) has been found to be a positive potential of approximately 200 volts (not critical) with respect to the crystal electrode potential (conventionally, ground potential as shown).

The crystal is generally oriented with respect to the polarized light beam such that write-in (at the higher beam potential) produces minimum light output through the polarizer 14 to the observer 17, and the lower electron beam potential provides the erase or maximum light out to the observer. The light and dark areas of the read-out pattern can be easily reversed if desired by simply rotating the polarization directions of the optical polarizers. This makes possible for example, read out of both optical positives and negatives of stored images without altering the stored pattern in the crystal. It is also to be observed that the writing and erase beam energies may be reversed, i.e., the high potential beam may be used for the erase and the lower potential beam used in writing. This allows for arranging the writing format so that a minimum area of the crystal is switched.

The polarized light 13 directed on the crystal may be light from any conventional light that is passed through a polarizer to establish a direction of polarization to the light. Quite frequently, in the use of two polarizers, the first or input polarizer is termed the "polarizer" and the second or output polarizer, set at 90 degrees to the first, is termed the "analyzer." This would be elements 42 and 43, respectively, of FIG. 4. The direction of light through the system is immaterial, that is, equivalent operation is obtained with the light entering the electrode side of the crystal.

The invention is quite suitable for use with a laser light source, which generally is polarized at the output of the laser. The angle of the incident primary electron beam 18 (FIG. 1) with the surface of the crystal 11 is not critical, however normal incidence is preferred. Likewise the angle between the electron beam 18 and the polarized light 13 are not critical; values between 15 to 20 degrees have been found to be quite suitable in the operation of the invention. The bistable crystal is operated in the commonly termed extinction mode with the crystal axes as represented at 19 (the a axis is directed out of the paper).

A typical embodiment of the invention for the projection of stored images is shown in FIG. 3. The ferroelectric light valve as shown in FIG. 1 is enclosed in the evacuated envelope 31 with the conventional electron gun contained at 32, the connection 33 is to the transparent back electrode, and the connection 34 is to the collector ring. The light from the conventional light source 35 is concentrated and collimated by the conventional mirror 36 and lens 37. Polarizer 38 and analyzer 39 are positioned at 90 degrees with respect to their relative polarization directions, and conventional projection lens system 40 focuses the image on the screen. In this embodiment a single beam electron gun is used for both writing in the information on the crystal and removing it in the manner previously described.

It is well to realize the distinction between electron beam energy and electron beam intensity. This was mentioned briefly, previously. In the electron gun the intensity of the beam (including the on and off conditions) is determined by the potential applied to the control grid (usually designated g_1) of gun. The energy contained by the electrons in the beam is determined by the potential difference through which the electron moves, i.e., the

potential difference between the cathode of the gun (the source of the electrons) and that of the back electrode on the crystal (the target). The beam energy determines whether the charge across the element of the crystal struck by the beam tends to be charged positive or negative in accord with FIG. 2, as previously explained. The establishment of the charge, Q , across the incremental elements of the crystal under the beam is a function of beam current i , and time t . It is apparent that with high beam currents faster sweeps may be employed and still switch essentially all the elements of the crystal, at the expense of larger amounts of heat dissipation within the crystal. (Partial switching produces shades of gray as will be further explained.) The following specifically enumerated parameters in connection with a particular embodiment will aid in understanding and practicing this invention. They are not to be construed as limiting the scope of the disclosure.

For $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ the typical value of spontaneous polarization P_s as represented by position 101 on the hysteresis curve of FIG. 10 is 4×10^{-6} c./cm.² (coulombs per square centimeter). Thus, to switch from points 101 to 102 or from on to off requires twice this value, or 8×10^{-6} c./cm.². Typical crystals used in embodiments of the invention are approximately 1 cm. by 1 cm. or 1 sq. cm. in area. To achieve approximately the resolution used in the television art of 500 lines per frame and a frame time of $\frac{1}{30}$ second requires the following beam current;

$$i_{\text{beam}} = \frac{Q}{t} = \frac{8 \times 10^{-6}}{\frac{1}{30}} = 240 \mu\text{a.}$$

for complete switching of the 1 sq. cm. crystal, and a line width of 2×10^{-3} cm. or 20 $\mu\text{m.}$ with a spot size of approximately 4×10^{-6} sq. cm. The current density J of the beam then becomes;

$$J = \frac{240 \times 10^{-6}}{4 \times 10^{-6}} = 60 \text{ amperes per sq. cm.}$$

At the present state of the electron gun art it requires from 1000 to 5000 volts to achieve this current density. Hence in the embodiment being described, the minimum amount of power into the crystal is approximately $\frac{1}{4}$ watt ($240 \times 10^{-6} \times 10^3$) to effect a complete change of spontaneous polarization, i.e., from light to dark or vice versa. Actually, for full switching it has been found that beam currents must be somewhat greater than 240 $\mu\text{a.}$, since the net deposited charge depends on the secondary emission ratio. For negative charging low secondary emission ratios give best use of the beam. For positive charging high secondary emission ratios give best use of the beam. Coatings to increase the secondary emission ratio in the positive charging region can then be used to advantage.

One approach that reduces the required beam current (simplifies the gun design, and permits lower accelerating potentials, thus reducing power dissipation in the crystal) is to make the writing operation take place over a period of several frames. This may be done by using a separate flood-erase gun that runs continuously and to erase the domains in a time equivalent to several frames. Thus, in each $\frac{1}{30}$ second scan a picture is written. In those areas of the picture which do not change over several frames, the maximum build up occurs. In this type of operation when the beam is turned off the picture would gradually fade out over several frame times due to the continuous operation of the erase beam. It is to be emphasized that these problems of high beam currents only occur when high writing speeds are used, and for normal information storage they are not a problem. The crystal may also be mounted in or attached to the face plate of the tube to aid in cooling the crystal.

An embodiment of the invention utilizing two electron beams, one from each of two separate electron guns is shown in FIG. 4. In some applications it is desirable to have separate write and erase electron beams. By the proper and well known control of the sweeps, the energy

levels, and the focusing or controlled defocusing of the electron beams, information may be written into one part of the crystal while it is being removed from another part, or one gun may be set to flood the crystal and remove all the stored information independent of the writing circuitry.

In the embodiments of the invention shown in FIGS. 1 and 3 the electron beam impinges on the bare face of the crystal. The curve shown in FIG. 2 applies to the electron beam impinging on a bare crystal. Obviously, well known thin film coatings as taught at page seven in the text by Kazan and Knoll, previously referred to, may be used to alter the secondary electron emission properties. For example, a thin film of MgO will greatly increase the secondary emission from the crystal for a given impinging electron beam energy.

Another embodiment of the invention that has greater flexibility in the switching of the crystal may be obtained by depositing a transparent layer of an electron-bombardment conductivity (EBC) material such as cadmium sulfide (CdS) over the surface of the crystal and depositing a transparent electrode over the CdS layer. This is shown in FIG. 5. The $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ crystal 51 has the conventional transparent back electrode 52 as in the previous embodiments. In addition it has the EBC layer 53 and inner electrode 54 to form the semiconducting EBC element. This modification of the invention obviously increases its complexity, but results in improved domain switching characteristics. A discussion of EBC and a listing of suitable semiconducting materials for the EBC layer is given in the text "Electronic Image Storage" by Kazan and Knoll commencing at page 33. The advantage of using an EBC layer is that relatively low electron beam currents may be used and beam energies may be the same for both write and erase. This is true because the charge currents for the crystal elements are supplied from the external power supply through the EBC layer and not the electron beam. The electron beam merely serves as an actuating switch to trigger the portion of the EBC layer under the beam, and the polarity of the voltage across the ferroelectric-EBC combination determines the direction in which the elements of the crystal under the beam are switched.

The EBC layer 53 is a highly insulating, low capacitance, layer when not bombarded, hence the voltage, between the back electrode 52 on the crystal 51 and the top electrode 54 on the EBC layer 53, divides with a very large percentage of the total switching voltage across the EBC layer. Thus, the crystal is not switched in the non-bombarded region. In the bombarded region (the region under an impinging electron beam) carriers are generated in the EBC layer making the EBC layer highly conducting (in that region). This transfers the voltage distribution such that the voltage that had been across the EBC layer now appears across the crystal and the crystal is switched (in that region). The positive and negative voltages between the back electrode of the crystal and the front electrode on the EBC layer must obviously be greater than the coercive field of the crystal. Values of ± 100 volts have been found to be satisfactory for $\text{Bi}_4\text{Ti}_3\text{O}_{12}$ crystals that are approximately 100 $\mu\text{m.}$ thick.

While a continuous write potential may be placed on the EBC layer and the grid of the electron gun turned on and off to write information into the crystal, it is generally desirable to pulse the voltage on the EBC layer in accord with the writing of the electron gun. One preferred mode of operation is to sweep or scan the entire electrode on the top of the EBC layer with a continuous electron beam, and then by pulsing the voltage on the EBC layer electrode + and - in accordance with the information signal and in synchronism with the sweep, light and dark is effectively written into the crystal to form the information pattern in the crystal. It is to be noted that switching of the crystal is no dependent

in this embodiment upon secondary emission from the crystal. However, it is generally desirable to retain the collector ring 55 in the structure to collect any secondary emission that may occur rather than let it return to the EBC layer and possibly degrade the resolution of the information written into the crystal.

A representative schematic drawing of the electron beam optical structure of a light valve having an EBC layer is shown in FIG. 8.

FIG. 6 shows a representative block diagram of a bistable light valve system using a single gun optical storage tube as diagrammed in FIGS. 1 and 3. Tube 61 has a conventional electron gun 62 having conventional deflection elements. The connection 63 is to the back electrode of the crystal and connection 64 is to the collector electrode. The conventional sweep circuit 65 scans the electron beam over the crystal. It is synchronized with the information signal input in the conventional manner. The beam focus and flood control 66 focuses the electron beam or defocuses it to flood the whole surface of the crystal with electrons. These circuits are well known in the art. Two forms of modulation are readily available. The control grid of the electron gun may be modulated in the conventional manner to provide an on-off control of the beam. In this mode of operation when the beam is "on" the unit elements of the crystal struck by the beam change domains to prevent light passage, that is, present a dark appearance when viewed. The information is thus written into the crystal as dark elements when viewed through the second polarizer (analyzer). After the information is written into the crystal by the passing beam of electrons the information remains in the crystal. No further information may be written into the crystal until the previous information is erased. Erasure, in this mode of operation, is provided by defocusing the electron beam forming a well known flood beam in which electrons impinge essentially simultaneously over the complete face of the crystal. At the same time the flood beam is on, the switch 67 is moved to position 68 to provide the proper potential between the cathode and back surface electrode of the crystal as shown in FIG. 2 so that secondary emission from the crystal is greater than the primary emission arriving at the crystal and all the domains in the crystal are switched to the erased condition, i.e., maximum light emerges from the second polarizer. After complete erasure of the stored information the crystal is ready for new information to be written and stored.

The second mode of operation is that in which the energy level of the beam as well as being controlled in on-off conditions (and shades of gray on the "on" condition by beam intensity), is modulated from the energy level to provide one domain to that providing the other domain. In this mode complete total erasure between changes of stored information is not required, however it is generally desirable to retain the total erase capability. Thus, in the block diagram of FIG. 6 the modulation control 69 may be either grid modulating controlling intensity or a modulator controlling the beam energy or both. For simplicity a mechanical switch 67 is shown for symbolically representing the switching of the energy level of the electron beam. Obviously, for high speed switching, conventional well known electronic switches are used.

An embodiment of the invention having separate write and erase electron guns in combination with typical well known electronic circuitry is shown in representative block form in FIG. 7. The evacuated envelope 71 contains structure such as diagrammed in FIG. 4. As in the previously described embodiments the back electrode of the crystal connected to lead 72 is shown at ground potential. Generally this is desirable, however, it is well understood that the system ground may be at the cathode potential and the crystal a positive potential above ground. This connection does have the advantage that the input

signals which are usually near ground potential may be fed directly into the control circuits without the control circuits providing isolation. The techniques of voltage isolation and level shifts are well known and need not be further described.

In the embodiment shown in FIG. 7, a separate electron gun 73, including focusing and deflecting electrodes, is used for erasing stored information in the crystal. The erase signal input 74 contains the position and erase area information. The flood magnitude and position control 75 applies the spot defocusing potential to the focus electrode of the gun and the potentials to the deflecting plates to control the erase in accord with the input signal. The separate erase potential supply 76 provides the proper energy level to the electron beam to accomplish the erase, as previously described. Thus, the complete crystal may be erased or only a selected portion of the stored information may be removed. Potential 77 applied by connection 78 to the collector ring provides for the collection of the secondary electrons.

Electron gun 79 writes the information to be stored in the crystal. The write position control 80 provides the sweep potentials to the deflecting plates to position the information on the crystal in accord with the position input signal 81. The focus control 82 provides the potential to the focus electrode of the gun. This is normally set to provide the smallest electron beam spot size. The modulation control 83 generally is used to modulate the control grid of the gun to switch the individual elements of the crystal from a light output condition to a dark output condition (or, to shades of gray) for the area in the output 84 represented by the respective crystal elements. The potential supply 85 supplies the required potential for the beam energy to enable it to switch the domains in the crystal. Obviously the modulation control 83 may also switch the beam energy level, as previously described, as well as controlling the grid intensity modulation. These control circuits are all well known and in common usage in the cathode ray tube art.

FIG. 9 shows in simplified block form an embodiment of a system having an EBC layer cooperating with the electron beam for writing information into the ferroelectric crystal. The information signal received by the system for storage and nondestructively read-out at will, may be in the form of a code pattern, operating parameters, or a picture in electrical form such as similar to the conventional television picture. The signal thus contains sweep information that controls the beam position. This beam position signal is synchronized with the signal controlling the intensity of the beam which provides for shades of gray in the pattern, and the black-white signal controls the polarity of the voltage across the EBC layer. The erase signal defocuses the electron beam and in conjunction with a white signal to the EBC layer to provide a complete erase. In the system shown in FIG. 9 shades of gray may also be obtained by lowering the potential (less positive or less negative voltages) placed on the EBC layer.

Shades of gray are readily obtained in all previous embodiments by the partial switching of the crystal elements under the beam. For any incremental area element considered a charge per unit area of 8×10^{-6} coulombs per square centimeter is required for complete switching (e.g., saturation black to saturation white). Partial switching, giving a finely divided domain pattern and intermediate transmitted light values (shades of gray) can be obtained by limiting the charge per unit area to less than that required for full switching. This can also be done by shortening the time that the beam dwells on a given area in addition to the previously explained manner of using reduced beam current. In embodiments having an EBC layer, the power supply to the EBC crystal combination may be modulated to provide shades of gray. Such modulation, in accord with the information in the input signal, may directly control the voltage of the supply or may elec-

tronically control the impedance of the supply so that the EBC crystal drive current is effectively modulated.

What is claimed is:

1. A high resolution electron beam controlled bistable ferroelectric image storage and display system comprising:
 - (a) a single crystal of bismuth titanate having a first and a second parallel surface in the plane of the crystallographic *a* and *b* axes;
 - (b) a transparent electrode positioned on the said second parallel surface;
 - (c) an electron gun providing an electron beam striking the said first crystal surface in substantially normal incidence;
 - (d) means for collecting secondary electron emission from the said first crystal surface;
 - (e) means cooperating with the said electron beam, the said transparent electrode, and the said secondary electron collecting means for controlling and sweeping over the first surface of the crystal the said electron beam in response to the said image being stored;
 - (f) first and second light polarizers having polarization directions at right angles; and
 - (g) means for passing light through the first polarizer, the crystal, and the second polarizer in succession in

a direction at an angle from 15 to 20 degrees to the direction of the said electron beam, providing a display readout of the said stored image.

2. The apparatus as claimed in claim 1 wherein the energy of the said electron beam is controlled by means responsive to the said image being stored for placing a positive or negative charge across incremental elements of the said crystal providing opposite domains in the crystal, and the said polarizers oriented with respect to the said crystal to provide optical contrast between the opposite domains.

References Cited

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