NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: GP

MAY 1 1974

TO: KSI/Scientific & Technical Information Division
Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,806,756

Government or Corporate Employee : Bendix Research Lab. Bendix Center, Southfield, MI

Supplementary Corporate Source (if applicable) : ———

NASA Patent Case No. : GSC-11,602-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES [X] NO [ ]

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ..."

Bonnie L. Woerner

Bonnie L. Woerner
Enclosure

United States Patent [19]

Low et al.

[11] **3,806,756**

[45] **Apr. 23, 1974**

[54] **IMAGE TUBE**

[76] Inventors: **George M. Low,** Administrator of the National Aeronautics and Space Administration with respect to an invention of; **Kenneth L. Hallam,** Washington, D.C.; **Charles Bruce Johnson,** Southfield, Mich.

[22] Filed: **Oct. 16, 1972**

[21] Appl. No.: **298,157**

[52] **U.S. Cl.** **315/10,** 315/11, 315/12

[51] **Int. Cl.** **H01j 31/26**

[58] **Field of Search** .... 315/10, 11, 12; 313/65 R

[56] **References Cited**

UNITED STATES PATENTS

2,248,977	7/1941	Flory et al.	313/65 R X
2,258,728	10/1941	Bedford	313/65 R X
3,478,216	11/1969	Carruthers	313/65 R X
3,662,104	5/1972	Nordseth et al.	315/10 X
2,731,560	1/1956	Krawinkel	315/12 X
2,788,452	4/1957	Sternglass	315/11 X
2,853,648	9/1958	Theile	315/11
3,396,305	8/1968	Buddecke et al.	315/12
3,622,104	5/1972	Nordseth et al.	315/10 X

Primary Examiner—Leland A. Sebastian
Assistant Examiner—P. A. Nelson
Attorney, Agent, or Firm—R. F. Kampf; John R. Manning

[57] **ABSTRACT**

An optical image is projected onto a planar surface of a photocathode that derives an electron beam replica of the image. A target electrode displaced relative to the photocathode so that it does not obstruct the optical image includes a planar surface for receiving and deriving an accurate replica of the electron beam image. The two planar surfaces are parallel. The electron beam image is focused on the target electrode by providing throughout a region that extends between the planar surfaces of the photocathode and receiving electrode, constant, homogeneous d.c. electric and magnetic fields that are canted relative to each other. The electric field extends in a direction perpendicular to the planar surfaces while the magnetic field extends along a straight line that intersects the photocathode and target electrode at an acute angle.

7 Claims, 3 Drawing Figures

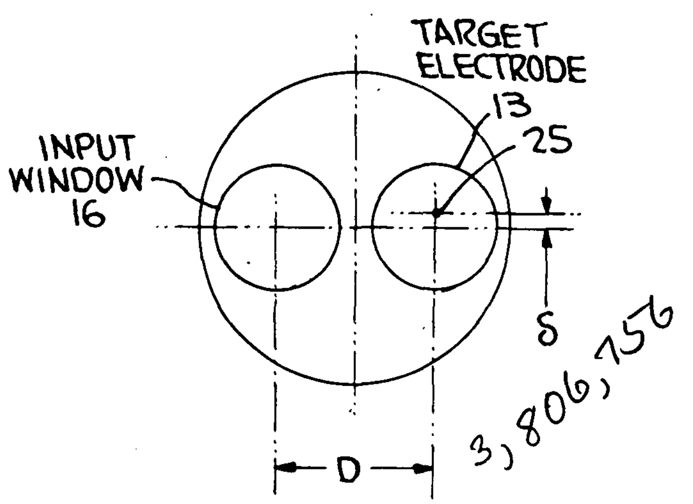

FIG. 1

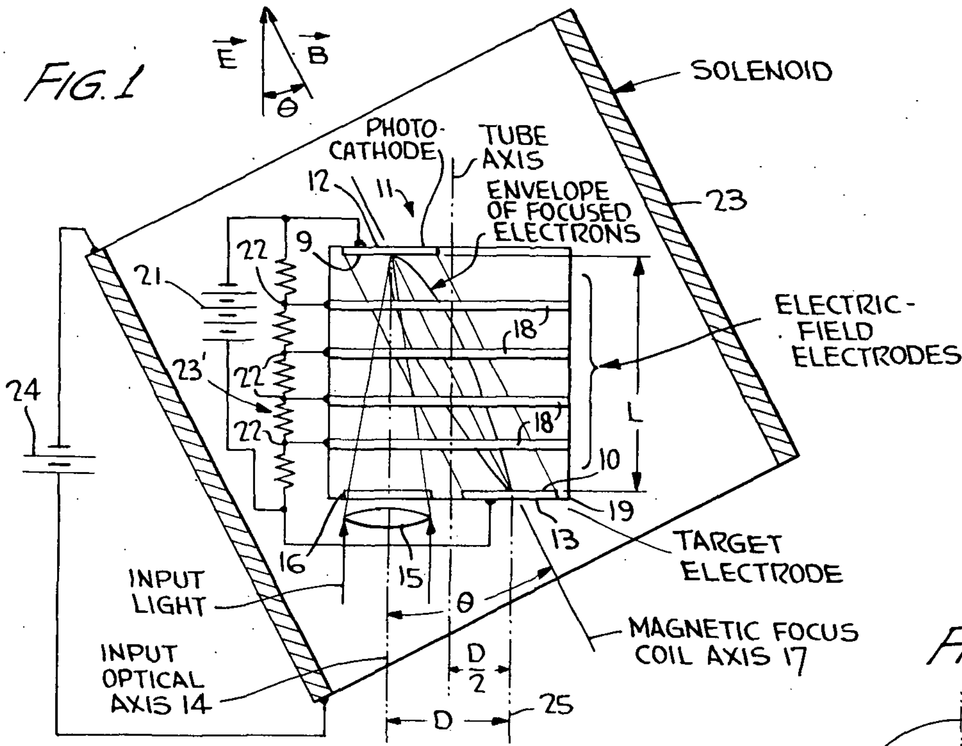

FIG. 2

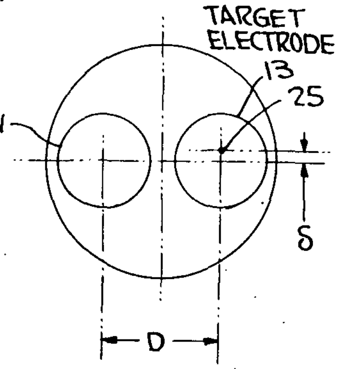

FIG. 3

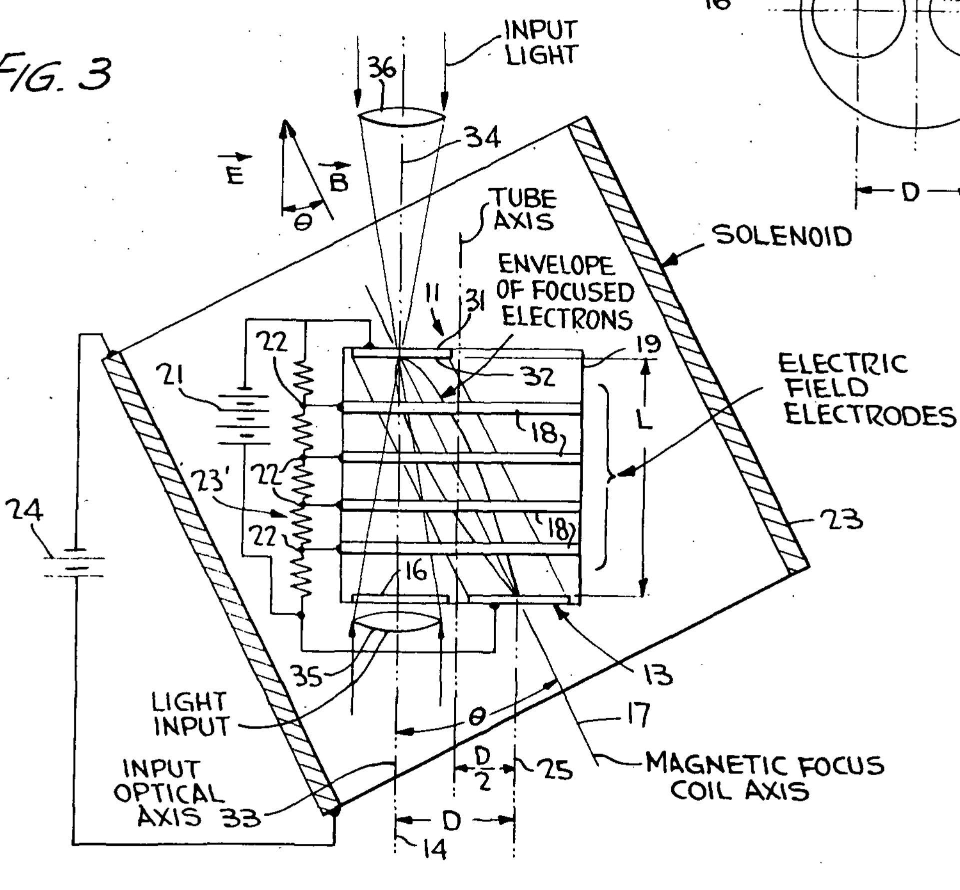

IMAGE TUBE

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 U.S.C. 2457).

FIELD OF INVENTION

The present invention relates generally to devices for converting an optical image into an electron image and more particularly to such a device including constant, non-colinear, homogeneous electric and magnetic fields.

BACKGROUND OF THE INVENTION

For many applications, it is desirable to convert an optical image to an electron beam image such that the electron beam image is derived from the same side of a photocathode as is irradiated by the optical image, and the electron beam image is a reflected replica of the optical image. The optical image may contain energy in the infrared, visible or ultraviolet spectrums. Image converters of this type, herein referred to as reflective image converters are particularly advantageous with opaque photocathodes. Opaque photocathodes are advantageous over the now generally utilized semi-transparent photocathodes because they have increased efficiency, are easier to fabricate, utilize compounds from Group III-V that are responsive to wavelengths between ultraviolet (approximately 100 nanometers) and the near-infrared (approximately 1,200 nanometers), and are highly sensitive to vacuum ultraviolet range wavelengths. Reflective image converters also enable a semi-transparent photocathode to be responsive to optical images directed onto the photocathode from opposite directions, whereby a first optical image can be focused to impinge directly on an electron emitting surface of the photocathode and a second optical image can, if desired, be simultaneously focused to impinge on the electron emitting surface via a transmission path through the photocathode.

Practical prior art reflective image converters have generally employed optical reflectors to direct the optical image onto the photocathode. The photocathode or a target electrode for receiving the electron beam image of the photocathode is usually in the path of the optical image so that a portion of the optical image is obstructed thereby and a blank area in the image occurs, usually in the image center.

Although reflective image converters have been proposed wherein a photocathode does not obstruct the optical image, apparently none of these converters has been adopted. Analysis indicates that these prior art proposals result in target electron images that do not appear to be acceptable, reproducible replicas of the optical image. In general, the resolution and/or magnification of the electron beam image striking the target electrode would appear to vary from one area to another on the target electrode or be unpredictable from one unit to another.

In one proposed type of prior art converter, an electron beam is derived from an opaque, planar photocathode in response to an impinging optical image. The derived electron beam is accelerated and focused by

colinear, constant and homogeneous electric and magnetic fields. After the electron beam has passed out of the region where the fields are constant and homogeneous, it is bent by a deflecting magnet system to a target electrode that is out of the line of sight of the optical image. Because the electron beam is bent in a region where the focus and accelerating fields are no longer homogeneous and constant, the electron beam has a tendency to diverge and an accurate replica of the originally derived beam would not appear to be provided on the target electrode.

In a further proposed prior art system, a planar, opaque photocathode responds to an optical image to derive an electron beam that is accelerated by a constant d.c. electric field to a planar target which is positioned so it does not obstruct the optical axis, a result achieved by canting the accelerating electric field relative to the optical image axis. A relatively thin solenoid provides a magnetic field having relatively short, straight lines of flux in a portion of the region between the photocathode and target electrode. The angular position of the solenoid axis relative to the electric field axis between the photocathode and target electrode is variable, as are the magnitudes of the magnetic field produced by the solenoid and the electric field between the photocathode and receiving electrode. The position of the solenoid, and strengths of the magnetic and electric fields are varied depending upon the geometry of the situation, and apparently cannot be easily and predictably determined before a particular unit is built.

BRIEF DESCRIPTION OF THE INVENTION

In accordance with the present invention, the aforementioned problems of the prior art reflective image converters are avoided by utilizing an electron lens system wherein the entire region between an electron emissive surface of a photocathode and an electron receiving surface of a target electrode responsive to electrons emitted from the photocathode includes constant, homogeneous electric and magnetic fields having longitudinal vectors that are canted relative to each other. The longitudinal magnetic field vector extends along an axis between the photocathode and target electrode. The magnetic field axis intercepts the emissive and receiving surfaces of the photocathode and target at an acute angle greater than zero so that the target can be laterally displaced relative to the photocathode and there is no obstruction of the optical image. The electric field longitudinal vector extends in a direction along an axis that extends at right angles between the parallel, planar emitting and receiving surfaces of the photocathode and target electrode. The electron lens system enables the emissive and receiving surfaces of the photocathode and target to be flat, a feature which enables the device of the present invention to be easily fabricated.

The separation between the planar surfaces of the photocathode and target electrode is such that the electron image of the photocathode is focused on the target electrode. In particular, the separation equals the distance whereby one cyclotron oscillation period exists between the photocathode and target electrode. The homogeneous, uniform, canted magnetic and electric fields combine to provide constant radial velocity in planes parallel to the parallel planar surfaces and perpendicular to the plane containing the two fields. The electric field provides constant acceleration for electrons as they travel between the photocathode and target electrode along and parallel to the magnetic field axis, and cyclotron motion about the magnetic field axis. These three separate conditions of motion, together with the defined spacing between the photocathode and receiving electrode, result in an accurate replica of the electron image derived from the photocathode to be formed over a substantial area of the receiving electrode.

It is, accordingly, an object of the present invention to provide a new and improved optical to electron image converter.

A further object of the present invention is to provide a new and improved reflective image converter wherein an optical image impinges unobstructed on a photocathode.

A further object of the present invention is to provide a new and improved reflective image converter wherein an accurate electron beam replica of an optical image is predictably provided.

A further object of the invention is to provide a new and improved device for forming an electron beam image that is a composite of optical images received by a semi-transparent photocathode from opposite directions.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of several specific embodiments thereof, especially when taken in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a planar, schematic view of one embodiment of the invention utilizing an opaque photocathode;

FIG. 2 is a front view of the embodiment illustrated in FIG. 1; and

FIG. 3 is a plan view of a second embodiment of the invention, utilizing a semi-transparent photocathode.

DETAILED DESCRIPTION OF THE DRAWING

Reference is now made to FIGS. 1 and 2 of the drawing wherein there is illustrated an embodiment of the invention wherein a vacuum electron tube 11 includes an opaque photocathode electrode 12 at one end and an electron beam target electrode 13 at its other end. Target 13 may be a phosphorous screen to provide direct optical readout of the electron beam image derived from photocathode 12 or a storage electrode that is readout by an electron beam, such as disclosed in FIG. 5 of Bedford, U.S. Pat. No. 2,258,728. Electrodes 12 and 13 include planar, parallel facing surfaces 9 and 10 that are in line of sight relationship with each other for respectively emitting and receiving an electron beam. The planar faces of electrodes 12 and 13 are laterally displaced relative to each other, whereby an optical image having optical axis 14 may be focused by lens 15 and propagated through optically transparent window 16 of tube 11 onto the emitting face 9 of the photocathode, without being obstructed by target 13. In response to the optical image focused on surface 9, the photocathode 12 emits an electron beam that is focused by the electron-lens of the present invention onto the facing surface 10 of the phosphorous screen 13.

The electron lens includes means for establishing a constant, d.c. homogeneous electric field having a longitudinal vector in tube 11 that extends along and parallel to optical axis 14 and means for providing a constant, d.c. homogeneous magnetic field having a longitudinal vector that extends between photocathode 12 and screen 13 along and parallel to axis 17 that is displaced or canted by an angle θ from the optical axis.

The constant, homogeneous electric field is preferably established by providing a plurality of spaced, parallel, annular, metal rings 18 on the inner circumferential wall of dielectric envelope 19 of tube 11. Preferably, adjacent ones of rings 18 are equidistant from each other and the planar surfaces 9 and 10 of electrodes 12 and 13. Negative and positive terminals of d.c. power supply 21 are respectively connected to electrodes 12 and 13 and a different intermediate potential is established on each of electrodes 18 by taps 22 of resistive voltage divider 23'. The voltage at each of taps 22 is proportional to the distance of the particular electrode 18 to which it is connected between electrodes 12 and 13. To provide uniform, constant electric fields in the region between electrode 12 and its adjacent electrode 18 and in the region between electrode 13 and its adjacent electrode 18 in the region through which the electron beam propagates, electrodes 12 and 13 are made sufficiently large so there is no substantial fringing field in the region traversed by the electron beam. In the alternative, the end walls of envelope 19 can be provided with metallic coatings which are connected to supply 21. In such a configuration, window 16 is an optically transparent, metal coating or a metal mesh to establish optically transparent equipotential planes at either end of envelope 19.

To attain the uniform, homogeneous magnetic field along axis 17 throughout the region between the planar, parallel faces of electrodes 12 and 13, a relatively long solenoid 23 having a longitudinal axis parallel with axis 17 and a length that extends beyond the planar electron emitting and receiving faces 9 and 10 is located outside of envelope 19. Opposite ends of the solenoid 23 are connected to a suitable d.c. source 24 to establish the d.c. constant, homogeneous magnetic field along and parallel to axis 17 throughout the volume of tube 11. It is to be understood that a similarly dimensioned and positioned permanent magnet may be substituted for the solenoid and its d.c. excitation or that a permanent magnet and an electric magnet may be used in combination.

In operation, the optical image on axis 14 is focused by lens 15 on the planar surface of photocathode 12 which emits an electron beam that is accelerated by the homogeneous constant electric field and focused by the magnetic field produced by solenoid 23 along axis 17. The electron beam is uniformly accelerated along and parallel to axis 17 because of the combined actions of the homogeneous, constant electric and magnetic fields. The magnetic field also imparts cyclotron motion to electrons of the beam in a direction at right angles to axis 17. To provide the correct focus for the electron beam image at one or more integral cyclotron periods (N) or nodes of electron beam rotation (360° × N of electron beam rotation due to cyclotron action), the separation along axis 14 between the planar surfaces of target 13 and photocathode 12, L, and the cant angle θ, between the electric and magnetic field axes 14 and 17 are related by:

$$L = \pi N \cos\theta / B \sqrt{2V/\eta} \quad (1),$$

where:

η = charge to mass ratio of an electron,

V = d.c. potential difference between electrodes 12 and 13, and

B = magnitude of magnetic flux density produced by solenoid 23.

The electric and magnetic fields combine to provide constant, radial velocity in all planes parallel to surfaces 9 and 10 perpendicular to the plane common to axes 14 and 17. It can be shown mathematically that the electron beam has a constant velocity, $\vec{V}_c$, in planes perpendicular to the plane containing axes 14 and 17 and parallel to the planar surfaces 9 and 10 in accordance with:

$$\vec{V}_c = \vec{E} \times \vec{B}/B^2 \quad (2),$$

where:

$\vec{E}$ = electric field vector parallel to axis 14, and

$\vec{B}$ = magnetic field vector parallel to axis 17.

It can also be shown that there is a constant acceleration of an electron in a direction parallel to axis 17 in accordance with:

$$\vec{v}_1/\eta = \vec{E}_1 \quad (3),$$

where:

$\vec{v}_1$ = acceleration vector of an electron in a direction parallel to axis 17, and

$\vec{E}_1$ = electric field vector in a direction parallel to axis 17.

The cyclotron motion of an electron about axis 17 can be mathematically expressed as:

$$\vec{\omega}_b = -\eta\vec{B} \quad (4)$$

where:

$\vec{\omega}_b$ = cyclotron angular frequency vector of an orbiting electron.

The center of the optical image is shifted by the electron lens of the present invention from a position coincident with optical axis 14 to output optical axis 25 in the plane containing axes 14 and 17, i.e., horizontally, by the distance

$$D = L \tan\theta \quad (5).$$

The output optical axis is shifted vertically, as illustrated in FIG. 3 in the electron receiving plane 10 of target 13 by a distance σ, where

$$\sigma = [\ |\vec{E} \times B\ /\vec{B}^2|]\ (2\pi/\eta B) \quad (6),$$

where:

$\vec{E}$ = total electric field vector, and

$\vec{B}$ = total magnetic field vector.

In response to photocathode 12 being irradiated by monochromatic optical energy, the electrons derived from the photocathode have an emission energy spread which is small compared to their final energy when they strike the target electrode 13; the emission spread is so small that the energy can be considered quasi-monoenergetic. The quasi-monoenergetic electrons provide a substantial replica on target 13 of the electron beam image derived from photocathode 12 regardless of the angle θ between axes 14 and 17.

However, in response to photocathode 12 being irradiated by a relatively wide spectrum of optical energy, whereby electrons with significantly differing initial velocities are emitted by the photocathode, the electrons impinging on target 13 produce a circle of confusion having a finite radius. It has been found that the circle of confusion has a negligible radius for a relatively wide spectrum of incident optical energy if the angle between axes 14 and 17 is limited so that it is no more than approximately thirty degrees.

In one experimental tube fabricated in accordance with the present invention, the separation between the planar, parallel electron emitting and receiving surfaces of electrodes 12 and 13, L, was thirteen centimeters and a voltage of 9.0 KV was applied between the electrodes. A vertical deflection σ, of 4.0 millimeters was observed and the horizontal shift from axis 14 to axis 25, for a deflection angle of $\theta = 15°$, was 3.0 centimeters.

While the present invention is ideally suited for use in conjunction with opaque photocathodes, the principles of the invention are equally applicable to a semi-transparent photocathode. In such a configuration, the optical image is directed at the photocathode from a direction behind the electron emissive surface thereof. The semi-transparent cathode is of particular advantage if it is desired simultaneously to provide an electron beam image of a pair of optical images directed at the photocathode in opposite directions. Such a configuration is illustrated in FIG. 3, wherein semi-transparent cathode 31 is substituted for opaque cathode 12 of FIG. 1.

In FIG. 3, semi-transparent photocathode 31 is simultaneously irradiated by first and second optical images projected onto the photocathode planar electron emitting surface 32 via aligned optical axes 33 and 34. The optical images on axes 33 and 34 are respectively focused on electron emitting surface 32 by lenses 35 and 36, with the latter image being projected through photocathode 31 to surface 32. Electron emitting surface 32 responds to both optical images simultaneously, whereby electrons indicative of the sum of the two impinging images propagate from photocathode 31 to the target planar receiving surface 10 that is parallel to electron emitting surface 32. The image on target 13 is, therefore, a composite of the images focused by lenses 35 and 36 on the electron emitting surface 32 of photocathode 31. In the alternative, only one of the optical images can be focused at a time on cathode surface 32.

While there have been described and illustrated several specific embodiments of the invention, it will be clear that variations in the details of the embodiments specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims. For example, principles of the invention can be used with X-ray image converters and the term optical is to be broadly interpreted to include X-rays and other similar particulate matter, as well as energy from infrared to ultraviolet.

What is claimed is:

1. A device for converting an optical image into an electron beam image comprising a photocathode having a surface responsive to the optical image for deriv-

ing an electron beam in response to the optical image impinging thereon, a target electrode having a surface for receiving the electron beam, said target electrode being displaced relative to the photocathode so that it does not obstruct the optical image, a system for focusing the electron beam onto the receiving surface of the target electrode, said system including: means for providing a constant, homogeneous d.c. electric field throughout a region between said surfaces of the photocathode and electrode, and means for providing a constant, homogeneous d.c. magnetic field throughout said region, said fields having longitudinal vectors canted relative to each other so that the magnetic field longitudinal vector extends along an axis between said surfaces.

2. The device of claim **1** wherein both said surfaces are planar and parallel to each other.

3. The device of claim **2** wherein said photocathode is opaque.

4. The device of claim **2** wherein said photocathode is semi-transparent.

5. The device of claim **2** wherein said photocathode is semi-transparent, and including means for directing a first optical image directly on said planar surface of said photocathode, and means for directing a second optical image on said planar surface of said photocathode via transmission through the photocathode.

6. A device for converting an optical image into an electron image comprising a photocathode having a planar surface responsive to the optical image for deriving an electron beam in response to the image impinging thereon, a target electrode having a planar surface for receiving the electron beam, said target electrode being displaced relative to the photocathode so that it does not obstruct the optical image, said planar surfaces being parallel to each other, whereby a region exists between said planar surfaces that includes a longitudinal axis at right angles to said planar surfaces and a further axis that extends between said planar surfaces and is canted relative to the longitudinal axis, and electron lens means for providing for electrons of said beam throughout said region: (a) constant acceleration along and parallel to the further axis, (b) cyclotron motion about the further axis, and (c) constant radial velocity in planes perpendicular to the plane containing both said axes and parallel to the planar surfaces.

7. The device of claim **6** wherein said electron lens includes: means for providing a constant and homogeneous d.c. electric field throughout said region along the longitudinal axis, and means for providing a constant and homogeneous d.c. magnetic field throughout said region along the further axis.

* * * * *