TECHNICAL PHYSICS LETTERS VOLUME 25, NUMBER 1 JANUARY 1999

Use of porous dielectric films for electron-optical image conversion

Kh. N. Vezirov

Institute of Photoelectronics, Academy of Sciences of Azerbaijan, Baku

(Submitted May 21, 1998)
Pis'ma Zh. Tekh. Fiz. **25**, 83–87 (January 26, 1999)

It was established experimentally that, unlike the photoelectronic principle, the image conversion principle developed here can convert an image in a broader spectral range with a suitable choice of semiconductor material. For example, a device was fabricated with a sensitivity of 5 and 2 mA/W at the 2 and 2.5 μm wavelength, respectively. © *1999 American Institute of Physics.* [S1063-7850(99)03101-8]

It is known that electron-optical image converters operate on the principle of photoelectronic emission, i.e., emission of electrons by a photocathode under the action of incident radiation.[1] The long-wavelength photoelectronic emission threshold, which determines the spectral sensitivity of the image converter, depends mainly on the work function of the photocathode. Since a silver–oxygen–cesium photocathode has the lowest work function of all known films, approximately 0.5–0.8 eV (Ref. 2), image converters with this photocathode exhibit at least some sensitivity to the 1.5 μm wavelength range. However, no images converters capable of operating beyond 1.8 μm are available, which is a major disadvantage. Thus, extending the spectral sensitivity range of image converters into the middle infrared is a very relevant scientific and technical problem.

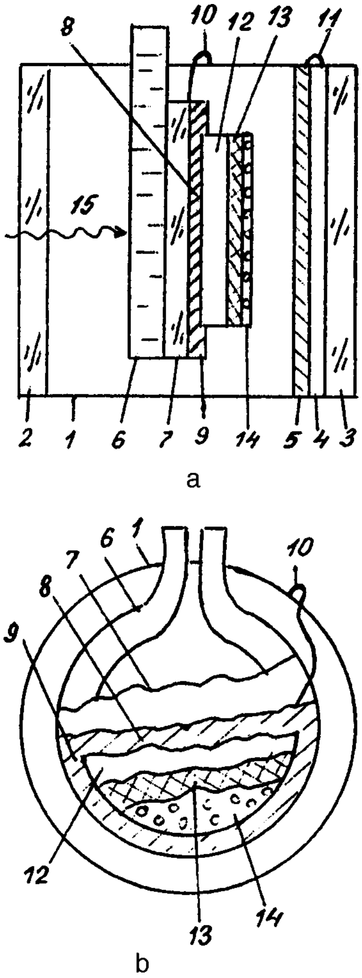
The present author succeeded in extending the sensitivity range of the image converter by using a different operating principle. Figure 1a shows the operating principle of this type of image converter. The molybdenum glass image converter consists of a casing *1*, 9 cm in diameter and 10 cm long, with entrance and exit windows *2* and *3*. A luminescence screen comprising a layer of phosphor *4* and a layer of aluminum *5* was fabricated at the exit mirror using conventional technology for image converter production. Unlike conventional image converters, this device also contains a cooling system *6* shown separately in cross section in Fig. 1b. The cooling system consists of a curved glass tube *6* filled with a coolant (such as dry ice) as required during operation of the image converter. The surface of a transparent plate *7* affixed to the tube *6* was coated with a semitransparent molybdenum film *8* around 10 nm thick by thermal deposition in vacuum. The edges of this film *8* were made thicker in the form of a ring *9* (this ring *9* is the baffle of a normal image converter[1–3]). In practice, the ring *9* and the film *8* are a single entity, since the film *8* was fabricated first and then the ring *9* was added. The baffle *9* and the luminescence screen have contact outputs *10* and *11* (0.2–0.3 mm diameter molybdenum wire) vacuum-tight welded into the glass. After suitable heat treatment (outgassing at 300–450°C under vacuum), a semiconducting film *12* was grown onto the film *8*, for example, polycrystalline lead sulfide 2.5 cm in diameter and 200–500 nm thick.

After the film *12* was sensitized, a friable (very porous) dielectric film *13* of aluminum oxide around 150–250 nm thick was deposited on its surface. The dielectric film was produced by thermal deposition of aluminum in air at a pressure of 0.4–0.6 Torr. After the dielectric film had been outgassed in vacuum at 120–180°C, a silver–oxygen–cesium photocathode *14* only around 10 nm thick was fabricated on its surface using a special technology. This photocathode had an island-like structure and functioned as a film with a minimal work function. The photocathode *14* was fabricated by heating an oxidized layer of silver in cesium vapor. The cesium atoms also penetrate into the pores of the dielectric film *13* and reach the surface of the semiconducting film *12*. This can lead to the formation of donor surface states at the surface of the semiconducting film and matching of the Fermi level in the bulk of the semiconductor to the top of the valence band. In this case, the photoemission threshold or the photoelectronic work function corresponds to the work function determined by thermionic emission.

In order to increase the emission of photoelectrons transferred to the semiconductor conduction band, the electron affinity energy of the material must obviously be reduced, which is equivalent to reducing the thermionic work function. This reduction in the thermionic work function is automatically achieved by cesium atoms reaching the surface of the semiconductor. The cesium atoms form a dipole layer on the vacuum-facing semiconductor surface, with the positive pole directed toward the vacuum. The electric field concentrated inside this layer facilitates the emission of electrons from the semiconductor into vacuum (into the pores of the dielectric). The reduction in the work function is proportional to the surface density of adsorbed cesium atoms and their dipole moment.

A very important factor for understanding the mechanism responsible for these processes is that the real value of the electron affinity does not depend on the bulk semiconductor doping and is determined by the material and state of its surface. In addition to cesium atoms the surface of the semiconductor may also have cesium oxide molecules, which have a higher dipole moment than cesium, so it is quite likely that states close to negative or zero electron affinity will form on the surface of the semiconductor.

When a working voltage (2–15 kV) is applied between the outputs *10* and *11*, thermal electrons which are always



a

b

FIG. 1. Schematic of image converter (a) and cooling system (b).

present at room temperature as an electron cloud above the photocathode *14* are drawn off to the luminescence screen and as a result, the surface of the dielectric film *13* becomes positively charged and an electric field is created in the bulk. When the radiation being converted *15* enters the semiconducting film *12*, electrons form in its conduction band. Half of these drift toward the vacuum-facing surface and are emitted into the pores of the dielectric film *13* because of the extremely low work function (electron affinity). On entering the dielectric film *13*, the electrons emitted by the semiconducting film are accelerated and undergo avalanche multiplication in the pores as a result of secondary electron emission. This causes an even greater increase in the charge of the dielectric film, lowers the electron affinity, and results in the establishment of self-sustaining electron emission.[4] As they pass through the film *13*, the electrons enter the vacuum where they are accelerated by the anode voltage, bombard the screen, and cause it to luminesce.

Infrared radiation *15* from an object passes through the window *2* and the plate *7* and creates a specific irradiance distribution on the surface of the film *12*. This leads to an increase in the bulk concentration of free carriers, where the spatial distribution of the free electron concentration corresponds to the spatial distribution of the irradiance on the surface of the film *12* and thus corresponds to the spatial distribution of the brightness on the surface of the screen.

A change in the illuminance (irradiance) of sections of the film *12* changes the free electron concentration in these sections and alters the self-sustaining emission current from these sections, which produces a change in the brightness of the corresponding sections of the luminescence screen.

Electrons leaving points in the film *12* as a result of the radiation *15* are replenished mainly from the film *8*.

The sensitivity of this image converter at 1.06, 2.0, and 2.5 μm was 4.0, 5.0, and 2.0 mA/W, respectively, the spectral sensitivity characteristic was practically the same as that of zinc sulfide, and the spatial resolution was ∼12 r lm/mm.

To sum up, it has been established experimentally that unlike the photoelectronic principle, the proposed self-sustaining emission principle for image conversion can convert an image in a broader spectral range with a suitable choice of semiconductor material, which substantially extends the range of application of the image converter.

[1] M. M. Butslov, B. M. Stepanov, and S. D. Fanchenko, *Image Converters and Their Application in Scientific Research* [in Russian], Nauka, Moscow (1978),432 pp.

[2] V. S. Fomenko, *Handbook of Emission Properties of Materials* [in Russian], Naukova Dumka, Kiev (1981), 340 pp. [previous edition published as *Handbook of Thermionic Properties, Electronic Work Functions, and Richardson Constants of Elements and Compounds* Consultants Bureau, New York (1966)].

[3] V. Gartman and F. Berngard, *Photomultipliers* [in Russian], Gosénergoizdat, Moscow (1961), 208 pp.

[4] N. A. Soboleva and A. E. Melamid, *Photoelectronic Devices* [in Russian], Vysshaya Shkola, Moscow (1974), 327 pp.

Translated by R. M. Durham