Long–range night vision camera based on SWIR photocathode

K J Smirnov¹, V V Davydov²,³, A P Glinushkin³
¹Bonch-Bruevich Saint Petersburg State University of Telecommunications, Saint Petersburg 193232, Russia
²Peter the Great Saint Petersburg Polytechnic University, Saint Petersburg 195251, Russia
³All-Russian Research Institute of Phytopathology, Moscow Region 143050, Russia

Abstract. Technological aspects of manufacturing SWIR sensitive detector on the basis of InP/InGaAs/InP photocathode and electron-bombarded CCD are given. Scheme of the digital camera for long distance detection is represented. SWIR camera operating mode and properties in case of implementation of impulse laser source are discussed.

1. Introduction
There has been a growing interest in development of imaging systems for determining the position of various objects [1-6]. A special place among them is occupied by optical systems for determination of object position using different methods of information processing [7-14]. Most of these systems work in conditions of good visibility and favorable weather. The situation changes significantly if it is necessary to observe and locate an object in poor or zero visibility conditions. The problem of creation observing and location systems which operate in this environments is extremely relevant for military surveillance and civilian tasks. Requirements for maximum detection range, as well as the possibility to easy interpret an object could not be achieved by common night vision devices, such as thermal detectors based on microbolometers as well as photon detectors based on electron-optical converters with GaAs photocathode [15-20]. At present time the most perspective way to realize night vision system it is creation of photodetector which is sensitive in eye-safe short-wave infrared spectral range (SWIR).

The readout and conversion scheme of such devices are similar to visible and near-infrared devices. However, application of SWIR allows to achieve significantly better parameters of detection characteristics due to decrease of the Rayleigh scattering, presence of atmospheric window and the peak of night lighting. The additional improvement of detection characteristics could be achieved by realizing of complex active night vision scheme, which is shown in figure 1.

It consists impulse-mode laser source (1.54 μm. Nd:YAG shifted laser) and synchronized gated-mode SWIR camera. In addition to high performance of range and resolution, the protection against light interference is achieved due to their suppression in the number of times equal to pulse duration of the camera gate (10⁴-10⁵ times). And also due to spectral selection of the object of observation when using in the receiving part of the gated night-vision system narrowband filter with a bandwidth corresponding to the working area of the laser source spectrum. Pulse-mode scheme provides accurate measurement of the distance to the object of observation by the delay value. Accuracy of measurement is several meters. False range measurement is excluded, as all objects that can cause a false signal (branches of trees, bushes, etc.) are cut off by the delay.
To achieve the pulse duration below 100 ns the main part of gated camera – photosensitive sensor should include SWIR-photocathode [21]. The purposes of the work were to develop SWIR-sensitive photodetector based on photocathode and to implement it in gated night-vision camera.

2. SWIR gated camera

Requirement of implementation photocathode technology and spectral range of photosensitive device could be fulfilled by implementation of InP/InGaAs/InP heterostructure activated with Cs and O₂. It based on the principle of inter–valley electron transfer (transfer electron photocathodes – TEP) and sensitive in 0.9–1.7 μm spectral range [22, 23]. The device design is shown in figure 2. In vacuum photoelectronic device the electron-bombarded charge-coupled device (EBCCD) should be used as the photoelectron converter [24]. Applying of high voltage between photocathode structure and EBCCD allows to accelerate existing photoelectrons and to achieve the electron-bombarded gain (EBS) process in the structure of CCD. The principal scheme of camera with InP/InGaAs/InP based photodetector is shown in figure 3.

Figure 1. Scheme of gated night-vision system.

Figure 2. Device design: 1 – input window, 2 – InP/InGaAs/InP photocathode structure, 3 – device body, 4 – photoelectron converter holder board, 5 – EBCCD, 6 – inputs and outputs.

Figure 3. Functional scheme of SWIR gated camera: 1 – photosensitive detector with TEP and EBCCD, 2 – amplifier, 3 – filter, 4 – analog-digital converter, 5 – synchrogenerator, 6 – level converters, 7 – voltage driver, 8 – high-voltage power supply 9 – USB interface, 10 – focusing lens, 11 – synchronizing to laser supply, 12 – 27 V. camera power supply, 13 – video out.
3. Photocathode
As a result of previous works the quantum efficiency of InP/InGaAs/InP heterostructure in optimal operating mode at static radiation at the level of 5% was achieved [25]. The additional quantum efficiency could be achieved by applying additional supply voltage on T₁ bias electrode. But in case of this the dark current rate increases exponentially [26]. The dependencies of the effective photo emission current and the dark current by the voltage Uₛ on the bias electrode are shown in figure 4.

![Figure 4. Photocurrent of the InP/InGaAs/InP heterostructure depending on the supply voltage Uₛ on the bias electrode: 1 – effective photo emission current; 2 – dark current.](image)

Figure 4. Photocurrent of the InP/InGaAs/InP heterostructure depending on the supply voltage Uₛ on the bias electrode: 1 – effective photo emission current; 2 – dark current.

One of the methods to increase the quantum efficiency of the photocathode is to implement pulse operation mode. Due to the short operating time, the number of charge carriers decreases and they do not form a barrier layer in the near-surface area of the metal-semiconductor contact, which is prevents the drift of photoelectrons into vacuum. It allows to apply a considerable values of bias voltage, which is contributes to increase the quantum efficiency. In consequence of using proximity-focusing technology the active surface of the photocathode structure should be 1.4x1.0 cm in case of 1.38x9.8 cm CCD size. Therefore, the uniformity of InP/InGaAs/InP structure is the most significant problem.

4. Electron-bombarded charge-coupled device
Purpose of registration of accelerated electrons with charge-coupled devices is a complicated issue. Application of front-side illuminated CCD’s in that case is not possible, because of degradation of Poly-Si electrodes by bombardment of them high-energy irradiation. Irradiation of the device from back-side also does not allow to achieve effective registration process of photoelectrons due to their absorption in the thick structure of the CCD substrate (250-500 µm).

Therefore, in order to obtain a more effective electronically sensitive structure, a number of technological operations on existing front-side CCD crystals should be performed. The first stage is thinning active region of CCD substrate from 350 µm to 15 µm with the help of selective chemical etching in the HNA system (HF:HNO₃:CH₃COOH:H₂O) [27]. The construction of thinned CCD is shown in figure 5. In order to create effective transport of photoelectrons to the CCD’s sub-gate areas (n-channel layer), in the zone thinned to 15 µm, the process of B⁺ ion implantation is carried out to form a p⁺ layer on the substrate surface. This lead to form a gradient of charge-carriers concentration in the substrate epi-layer, which is allow to achieve effective drift of photoelectrons to the CCD sub-gate area.
Optimal energy of ion doping beam was established as 13 keV. After B+ ion doping it is necessary to carry out low-temperature (673 K) annealing for restoring of damaged crystalline structure of CCD.

As a result of these operations, on the basis of the initial front-side CCD with frame transfer, sensitivity to photoelectrons was obtained. Therefore, the incident photoelectrons from photocathode could be collected and amplified due to internal electron-bombarded gain process in manufactured EBCCD. The signal from EBCCD could be processed by analog-to-digital conversion typical for standardized CCDs.

![Figure 5](image)

**Figure 5.** Scheme of back-side electron-bombarded CCD 1 - initial crystal substrate thickness $d_1$=525 µm, 2 – active thinned area $d_2$=15 µm, 3 - contact plates.

The suggest design of SWIR camera allows to use it in passive (detection of only natural radiation without additional laser source), active (camera detects reflected radiation from object illuminated by SWIR laser source) and active-impulse mode (in addition to common active mode the high voltage power supply connected to TEP synchronized to laser pulse duration). Active-impulse mode allows to collect only the radiation reflected from the target area of interest. In this way, only the objects in a volume defined by the area covered by the laser beam and a depth of field set by the gate time width are presented in the image [21].

5. Conclusion

Development of SWIR-sensitive gated photodetector systems allows to exceed characteristics of existing night vision cameras based on Gen 3 photocathodes and also uncooled InGaAs-FPA cameras. Sensitivity in 0.9–1.7 µm. spectral range is obtained with the help of InP/InGaAs/InP heterostructure. Photoelectron to electric signal conversation and internal amplifying are accomplished by EBCCD. Applying of laser-gated imaging technology allows to meet the challenges of tactical targeting and target identification (ID) in exceptionally long range (>20 km).

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