New detection modules for free space optics

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Abstract—The paper presents the construction and test results of new detection modules for Free Space Optical Data Link operated in the 8-12μm wavelength range.

In these modules Polish detectors manufactured at the Polish VIGO System Ltd. company were applied. High sensitivity of the detection modules was achieved using photodiodes with immersion lens. Detector noise was reduced as a result of photodiode cooling by means of a four-stage thermoelectric cooler and reverse biasing.

The developed detection modules will be used in a next-generation optical link capable of operating in more difficult weather conditions as compared to the links currently offered.

Two detection modules were tested. The first of them consists of a photodiode without biasing, and the second one of a photodiode with reverse biasing

For several years intensive work has been carried out on the development of broadband optical communications in open space, at the wavelength range of 10μm [1-2]. Quantum Cascade Lasers (QCLs) and infrared (IR) photodiodes are very suitable for such applications [3-5]. The QCL emission wavelength can be chosen in the so-called atmospheric window region, i.e. around 8-14μm. The most promising is to use IR photodiodes with thermoelectric coolers and control systems. Control systems should ensure constant temperature of the photodiode working in a wide range of ambient temperatures.

Photodiodes are based on complex HgCdTe heterostructures grown on GaAs substrates with a metal-organic chemical vapor deposition technique with immersion lens formed by micromachining in GaAs substrates [7-10, 14]. Transmission rates of photodiodes with nanosecond time constants and preamplifier bandwidths of more than 100MHz were obtained [13]. The noise level and the available preamplifier bandwidth depend mainly on the capacity of a photodiode [11, 12]. The photodiode capacitance should be less than 5pF. The capacity can be achieved by using an immersion lens and devices with reverse biasing.

In the paper we present the main test results of two new detection modules. The first of them consists of an unbiased photodiode (detection module 1), and the second one - a biased photodiode (detection module 2).

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In detection module 1, the HgCdTe photodiode with an immersion lens, cooled by a four-stage thermoelectric cooler (4TE) to about 200K, was used (Fig.1a). To obtain high sensitivity of these modules low noise preamplifiers were used.

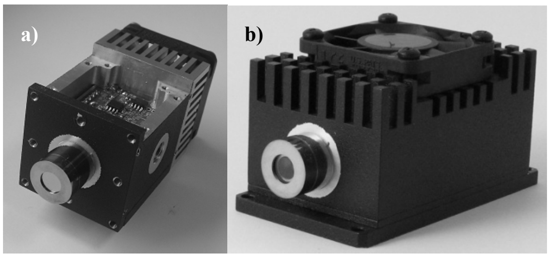

Fig. 1. Detection modules with an unbiased (a) and biased (b) photodiode.

The preamplifier is based on OPA 847 circuits characterized by low input noise voltage ($0.85nV/Hz^{1/2}$) and a moderate value of the input noise current ($2.5pA/Hz^{1/2}$). The low noise voltage of the preamplifier can be minimized when a low impedance photodiode is used. This problem is particularly important at high frequencies when the circuit input impedance is determined by the capacity of the photodiode, as shown in equation below [6]:

$$I^2_{ntotal} = \left[I^2_{nph} + I^2_{nd} + I^2_{nb} + I^2_n + \frac{4kT\Delta f}{R_L} \right] + \omega^2 \left[V^2_{nd} C^2_d + V^2_n \left(C_d + C_i \right)^2 \right] \qquad (1)$$

where I_{ntotal} is the noise equivalent signal current, I_{nph} is the shot noise generated by photo-current, I_{nd} is the shot noise of dark current, I_{nb} is the shot noise from background current, I_n is the current noise, R_L is the load resistance, V_{nd} is the voltage noise of the serial resistance, V_n is the preamplifier noise voltage, C_i is the input capacitance of the preamplifier, and the C_d is the input capacitance of the detector.

There are two terms in equation (1) - a white noise term in the first set of square brackets and another one - which result in noise current increasing in proportion to frequency. Although the capacitor does not add noise, the detector noise voltage (V_{nd}), and preamplifier noise voltage (V_n) are increased by the C_d and the $C_d + C_i$, respectively, as evident from the coefficient of that term in equation 1. Analyses of this equation have shown that in matching the preamplifier to the detector, it is important to minimize the sum of: $I_n + V_n^2 \omega^2 (C_d + C_i)^2$.

Figure 2 shows the block diagram of the detection modules.

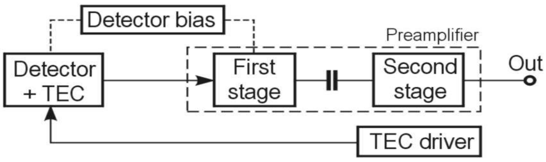

Fig. 2. The block diagram of the detection module

The main part of the module is the HgCdTe photodiode cooled by a four-stage thermoelectric cooler (4TE). The first detection module consists of a detector + TEC, two-stage preamplifier and a TEC driver. The second one includes the same elements plus a detector bias circuit.

The current signal from a photodiode is read by the broadband (approximately 1 GHz) transimpedance preamplifier. This preamplifier provides also the biasing of the detector with a DC reverse voltage of about 200mV. In this way, the conditions for a maximum signal-to-noise ratio in a wide waveband are created. However, low-frequency noises are caused by bias voltage. The noise level is not so high as compared to the 1/f noise bandwidth with a detector module.

In Table 1 the basic parameters of the HgCdTe unbiased (1) and biased (2) photodiode optimized for the wavelength range of 10μm are listed.

Table 1. The basic parameters of the unbiased (1) and biased (2) HgCdTe photodiode optimized for the wavelength range of 10 μm with 4TE.

Parameter	Unit	Photodiode 1	Photodiode 2
Bias voltage	V	0	0.2
Current responsivity @ 10μm	A/W	4.1	15.4
Active area	mm^2	0.3×0.3	0.3×0.3
Detectivity @ 10μm	$cmHz^{1/2}/W$	1.25×10^{10}	3.8×10^{10}

Table 2 presents the basic parameters of the detection modules. For the first module the measured time constant is about 4ns, and for the second one - about 260ps. The measurements were made using 20ps laser pulses with a wavelength of 10 μm and an oscilloscope with an 8GHz band.

Table 2. The basic parameters of the detection modules optimized for a wavelength range of 10μm.

Parameter	Unit	Detection module 1	Detection module 2
Transimpedance @ R_{LOAD}=50Ω	V/A	27×10^3	13.5×10^3
Output resistance	Ω	1000	50
Gain bandwidth	MHz	0.001÷150	0.001÷1000
Noise voltage	$nV/Hz^{1/2}$	430	210
Voltage sensitivity @ 10μm	V/W	130000	210000
Detectivity @ 10μm	$cmHz^{1/2}/W$	9×10^9	3×10^{10}

An example of current-voltage characteristic for these photodiodes is presented in Fig. 3. The curve is characterized by a specific shape.

The current-voltage plot of the photodiode measured at 200K shows three different areas. In the first one, the reverse voltage increases with current and reaches the value of -60mV. In the second one, between -60mV to -100mV, the current was saturated. For larger values of reverse bias, in the third area, a tunneling effect was observed.

The analysis of the curve in Fig. 3 shows that the reverse bias dark current at 200K is proportional to the device area indicating an insignificant role of the surface. This is true both for the saturation and the tunnel-like dark current range. Precise examination of dark current dependences indicates that the linear range at low voltages is due to series resistance while the dark current in the saturation range is the diffusion dark current generated in an absorber by the Auger or Shockley-Read-Hall mechanism.

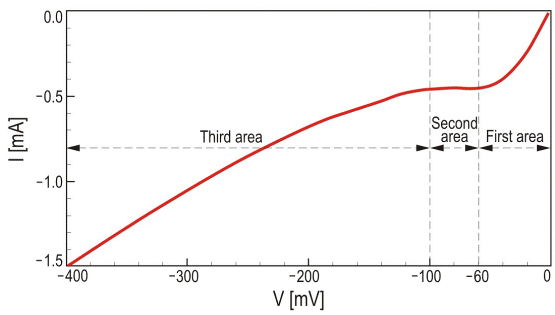

Fig. 3. Measured current-voltage plots at 200K (physical area equal 0.03x0.03mm^2).

The spectral characteristics of detectivity for the detection modules and the HgCdTe photodiodes are presented in Fig. 4. A standard method for measurement of the detectivity was used [15].

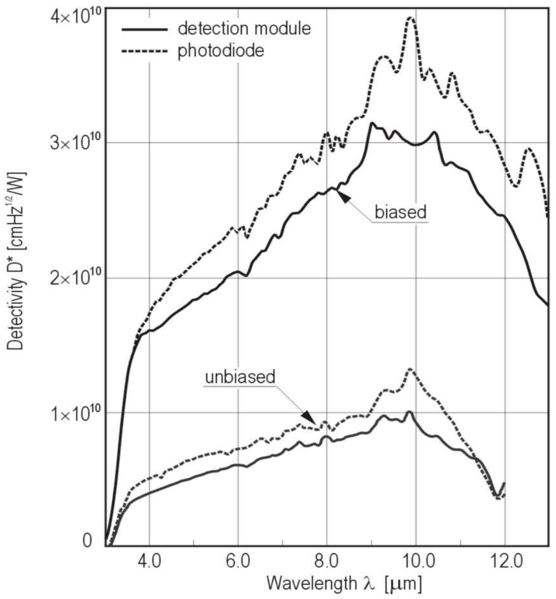

Fig. 4. The spectral characteristics (detectivity vs. wavelength) of the detection modules and the spectral characteristics of the HgCdTe photodiodes.

The detectivity of a detection module in both cases is only a bit less than that of the photodiode thanks to the minimization noises of a preamplifier.

The detectivity value of a biased detection module is more or less three times greater than detectivity values of an unbiased detection module.

In conclusions, the analysis was aimed at photodiodes in the wavelength of 10μm. The photodiodes have been manufactured by the Vigo System Company.

High sensitivity was obtained by combining a multi-layer $Hg_{1-x}Cd_xTe$ heterostructure with an immersion lens. To decrease the noise level the photodiode was equipped with a four-stage thermoelectric cooler and reverse bias.

The constructors believe that the high-sensitive photodiode that has been optimized for the wavelength of 10μm will allow for the creation of a second generation optoelectronic link. The link ensures a better range in adverse weather conditions as compared to currently available options.

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