Section
Remote Sensing System and Spacecraft Technologies

A NOVEL PHOTODIODE IN ON-BOARD MICRO RECEIVER IN 400-800 NM RANGE

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Abstract: On-board electromagnetic radiation sensors require more effective photodetectors. Here, we analyze novel dynamic operation hybrid Gate-PIN photodetector, embedded in an on-board 400-800 nm range microelectronics receiver. Both theoretical and experimental characteristics revealed for that photodetector have allowed designing dynamic scenarios of its operation in optical band, as well as possible applications inside on-board systems. We mention clear temperature dependence, low supply voltage, microscale dimensions, signal integration feature, and other characteristics of the micro receiver with such detector.

Keywords: PIN photodiode, spacecraft, remote sensing.

Introduction

Electromagnetic signals detection, including remote sensing, is one of the most important ways of obtaining information on a spacecraft board. The received signals lying in different ranges of the wide frequency band have a one-dimensional structure or create a two-dimensional image. For instance, in the “Ikonos-2” satellite [1, 2] the optical node includes CCD elements (12 μm x 12 μm) based on Si for panchromatic scanning and Si photodiodes (48 μm x 48 μm) for multispectral scanning. In the “WorldView-2” satellite [3, 4], the optical node includes a CCD elements (8 μm pixel size) based on Si for panchromatic scanning and CCD elements (32 μm pixel size) for multispectral scanning. Optical visible range and infrared sensors detect the solar radiation reflected or scattered from the Earth and the reflected laser radiation. The detecting occurs in a single spectral channel (IKONOS PAN, SPOT HRV-PAN) or in multi-channel systems (LANDSAT MSS, LANDSAT, SPOT HRV-XS, IKONOS MS, MODIS, MERIS). The hyperspectral "Hyperion" system obtains the images using one hundred or more adjacent spectral bands. This system has potential applications in such fields as coastal area management (for instance, phytoplankton, pollution, changes in bathymetry monitoring) and agriculture (for instance, the monitoring of the health status, moisture and maturity of the crop).

High requirements for the spectral sensitivity, stability, noise level, dimensions and other characteristics are imposed on the space borne radiation detectors, which requires their further improvement. The vacuum photoelectric multipliers possess the highest sensitivity, but they are presented by macro-technological tools only. The photomultipliers do not provide the capability of a parallel two-dimensional image, do not possess mall dark currents and low noise level. They are characterized by insufficient vibration resistance, require high-voltage power sources, and their photocathodes are subjected to degradation. Photoelectron multipliers based on microchannel plates are characterized by unstable operation under ionizing radiation. The conventional semiconductor photodetectors and CCD arrays require high-sensitivity broadband amplifiers and signal integrators, such circuits possess a high noise level. Microelectronics semiconductor photodetectors with a broadband preamplifiers could make losses of low amplitude peaks, increase of electronic noise, appearance of interference, and artifacts. The drawbacks of existing photon detecting devices applied on spacecraft board can be continued.

Materials and Methods

Recently, novel hybrid PIN diode with an embedded gate appeared [5]. That device operates in a dynamic regime with the space charge storage and further neutralization, and possesses a high quantum efficiency in visible light range. Presumably, that device has good prospects for use in the weak signals detection in the visible range, however it has never been evaluated from the point of view of its applying on board a spacecraft. In this paper, the prospects assessment of use an on-board visible range photodetector based on such a hybrid PIN photodiode, operating in a dynamic regime, in the remote sensing systems is provided. The analysis includes the experimental determination of the device characteristics, as well as a theoretical study of the basic physical phenomena providing these characteristics.

The DPD contains two heavily doped p-Si and n-Si regions separated by a slightly doped (or undoped) region, and an embedded metal oxide semiconductor (CMOS) gate located around the p region. A pulsed forward voltage when switching the DPD from the reverse bias causes a large forward current after a significant time delay T_{trig} in the microsecond-millisecond range. The forward current magnitude is controlled only by the value of applied forward voltage, and is independent of the incident light intensity. For instance, the output current of the DPD is 0.8 mA, which is more than four orders greater than the photocurrent magnitude, which is equal to 18 nA in the static regime [5]. In contrast, the time delay T_{trig} is a function of the absorbed light power.

According to the proposed model, the direct current is switched on when a certain amount of electrons N_{crit} is accumulated under the gate in the barrier area [5]. The time delay is defined as follows [5]:

$$T_{trig} = N_{crit}/(G + G_{dark}), \qquad (1)$$

G is a coefficient proportional to the absorbed light power at a fixed wavelength, G_{dark} is the self-generation or dark current coefficient. According to this estimation, the dependence of the inverse triggering time $1/T_{trig}$ on the incident light power is linear function. The critical parameter, being of fundamental importance, is the self-triggering temperature dependence caused by the dark current only, in the absence of light. The dark current is formed by the thermal generation of electron-hole pairs in the substrate ($I_{thermal}$) and by the cathode to anode leakage.

The measurement of the photocurrent delay time, instead of its magnitude, provides a new efficient method of light detecting.

In our research, we study novel photodiode temperature dependences and operation processing experimentally and by means of a computer modeling in COMSOL.

Results

A physical model of the over space charge barrier current has been developed, which is confirmed by computer simulation. The time delay for the photocurrent switching during the action of the forward voltage is due to the neutralization of the accumulated space charge.

Main characteristics of the device have been obtained, possessing the elimination of a broadband high-sensitivity preamplifier, integrator, and analog-to-digital converter:

- weak photon fluxes integration measurement,
- linear dynamic range of integration,
- certain well-controlled temperature characteristics,
- microscale dimensions,
- possibility of 2D/ 3D imaging,
- low supply voltage (1 volt approx.), and low power consumption,
- predictable reaction on humidity,
- high vibration and shock resistance.

Conclusions

The novel results obtained indicate significant opportunities for the new photodetector application in the on-board hardware of spacecraft, including remote sensing systems.

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RELATIVE ORBIT AND ATTITUDE COUPLED CONTROL BASED ON SLIDING-MODE VARIABLE STRUCTURE CONTROL

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Abstract: The problem of relative orbit and attitude coupled control of spacecraft formation flying is studied. In this paper, the coupled attitude and orbit nonlinear dynamic model of six degrees of freedom (6-DOF) is proposed. Considering a variety of space perturbations and model uncertainties, power reaching law sliding-mode variable structure control method is used to develop an orbit and attitude coupling cooperative controller, also the finite time convergence is performed using Lyapunov stability method. Numerical simulations are carried out to verify the validity of the proposed controller. The results show that this controller can achieve synchronization control of the relative orbit and attitude, and it provides good control accuracy and stability.

Keywords: Formation flying; orbit and attitude control; sliding mode variable structure control

Introduction

Recently, formation flying using micro satellites appeared to be a new and promising trend. In aerospace industry, this new technology makes way for new and better applications, such as navigation, remote sensing, electronic reconnaissance, stereo imaging, and etc.

Modeling and control for relative orbit and attitude maneuvers are critical technologies in most spacecraft formation flying missions,