Performance Analysis of Short-Wavelength Infrared Optical Sensors

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***Abstract*-We report in this paper our latest results on fabrication and testing of optical sensor for imaging in short-wavelength infrared regime. We are comparing the performance of our imaging sensor in two permitted regimes by the readout integrated circuit used.**

I. Introduction

There is an increasing demand to add non-visible band imaging methods to the traditional machine vision operation in order to improve or find new applications. A spectral domain of interest is the Short Wavelength InfraRed (SWIR) region/band situated between 0.9 µm and 2.5 µm. There are few high impact imaging applications such as seeing through fog and haze or low level night illumination, in addition to separating plastics and food sorting applications. The new developments are important because of room temperature operating devices with dark current close to silicon based imaging devices. The state of the art is based on producing a photodetector array using InP/GaAs technology bonded to a silicon CMOS readout integrated circuit (ROIC). The bonding is mostly done using Indium bumps. In this paper we use the optical sensor or focal plane array (FPA) interchangeably.

II. Fabrication of Photodetector Arrays (PDA)

The epitaxial layer is grown on InP wafer by metal-organic chemical vapour deposition (MOCVD) system on a highly doped n^+ InP substrate. The first layer grown is a 1 µm thick, undoped n-InP buffer, which is followed by about two micrometers of InGaAs absorbing layer, lattice matched to InP, and a 1 µm thick Si-doped cap layer. A photodiode the p+ - n junction is formed in the InGaAs layer by diffusing Zn through the InP cap layer. Areas of Zn diffusion are defined by a SiNx diffusion mask. The depth of the p-n junction depends on the absorbing layer thickness. This positioning of the junction ensures that the depletion layer and the built-in electric field associated with it are located within the InGaAs absorption layer. MOCVD growth of InP and InGaAs was performed in a Thomas Swan showerhead reactor.

Zn diffusion was performed in the MOCVD reactor using dimethylzinc as the Zn source. The fabrication process is conventional with several lithographic steps for pixels definition and contacts implementation. We fabricated 512 x 640 pixels photodetector arrays with 25 µm and 15 µm pitch. A second lithographic process is used to define the size of the Indium bumps. The thickness of Indium was determined by the PDA pitch. After dicing of both PDA and ROIC wafers the two chips were bonded following a flip-chip technique. The resulted chip is a hybrid FPA (or an imaging optical sensor).

The ROIC provides the proper bias on the each detector (pixel) and executes the reading [1]. The current approach for pixel reading is mediated by few circuit setting: capacitance transimpedance amplifier (CTIA), direct injection (DI), and the source follower per detector (SFD).

The new ROIC design proposed by New Imaging Technology (France) allows the photodiode "reading" in two mode [2]: a "solar cell" (SC) mode where the photodiode is left unbiased and the conventional approach where the photodiode (PD) is under negative bias and the charge is collected by a capacitor. This new SC mode operates with the photodiode in an open circuit; the integration of all charges is carried out using the diode capacitance which afterward it is read out after the selected exposure time. The conventional PD mode uses a negative bias (-0.1V to -0.5V); a ROIC capacitor is used to collected all photo-carriers. It was demonstrated that the SC mode approach allows for a wide dynamic range and an ultralow fixed pattern noise [2].

III. Testing of Focal Plane Arrays

Several measurements are carried out at the wafers level, such as dark current measurements and they will not be discussed here. This paper is mostly focused on hybrid FPA testing. There are many spectral, performance and noise features of interest: responsivity, spectral response, noise, the number of dead and hot pixels, the shape of pixels histogram, the uniformity response within array, response linearity and others. Due to limited space in this report we are going to focus on the noise (root-mean-square RMS) measurements and the charge collection for the two ROIC operation modes. This paper is focused on testing 512 x 640 pixels array with 15 µm pitch bonded with NSC1101-V2 ROIC (New Imaging Technology, France). Our electrical testing setup is built around Pulse Instruments System 7700 (Pulse Instruments, USA), which includes several programmable integrated equipment for maximum low noise performance. The setup provides up to eight channels for biases and up to eight channels for time diagram implementation and control. The setup allows the design and implementation of different time diagram which allows us to test several ROIC configurations. The FPA is tested using the ROIC in two different mode:

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"solar cell" and conventional photodiode mode. There are three voltages relevant to the photodiode operation: Vdetcom, Vrstref and Voffset. Vdetcom is connected to the common substrate (common to all pixels) and Vrstref controls the other contact of the photodiode (pixel). In our experimental setting the reading window of the pixel voltage must be situated between -2V and 2V. This is achieved by modifying accordingly the Voffset. In case of SC mode the Vdetcom and Vrstref are equal (set to 0.8V), while in the conventional negative bias of the photodiode we set for Vdetcom and Vrstref to 1.1V and 0.8V respectively.

The first requirement of the testing setup is to achieve a uniform illumination of the device under test (DUT). Two approaches were reported: using an integrated sphere or the DUT is situated at a long enough distance such that the illumination is uniform across the tested FPA. We implemented both approaches and used an InGaAs photodiode with NIST traceable calibration (Thorlabs, USA) to verify the uniformity across the tested FPA to be within 3%.

A set of 50 frames were recorded. This set of frames were processed to calculate an average frame and a standard deviation frame. In these frames each pixel is replaced with the voltage average and the voltage standard deviation across the 50 frames. The average frame is used to calculate the spatial uniformity and while the standard deviation frame allows temporal noise calculation. The total noise is calculated using

$$\sigma_{total} = \sqrt{\sigma_{temp}^{2} + \sigma_{spat}^{2}} \qquad (1)$$

In fig. 1 is total noise measurements for the two ROIC operation modes. As can be seen the total noise is significantly larger for the case of conventional negative bias photodiode setting. On the horizontal axis of fig. 1 is the total optical power measured with an integrating sphere/detector system (Thorlabs, USA). The light source was a LED operated at 1450 nm (Thorlabs, USA).

Fig. 2 and Fig. 3 show the pixel voltage dependence with integration/ exposure time. In the first case as expected the conventional negative bias photodetector shows a linear dependence with the integration time. R-squared indicated a very good fit with a linear model. In case of SC mode the diode capacitance is used to collect and store the photo generated carriers. It is obvious the model is non-linear in this case. This information is relevant in cases were the operation speed requirements impose limitation in the imaging time.

IV. Conclusions

We are reporting in this paper the fabrication and characterization of SWIR FPA with the resolution of 512 x 640 pixels with 15 µm pitch. We have outlined two set of measurements: RMS noise and the charge collection in two ROIC operation modes.

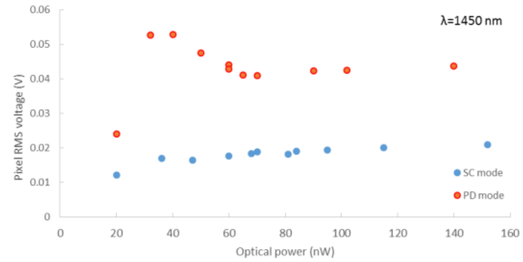

Fig.1 Total noise measurements includes all sources of noise form PDA and ROIC

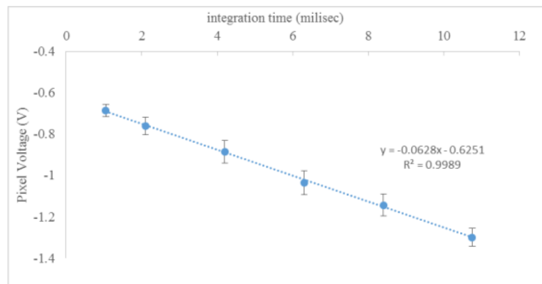

Fig.2. Pixel voltage dependence with integration time for the conventional negative bias (-0.3V) photodetector mode.

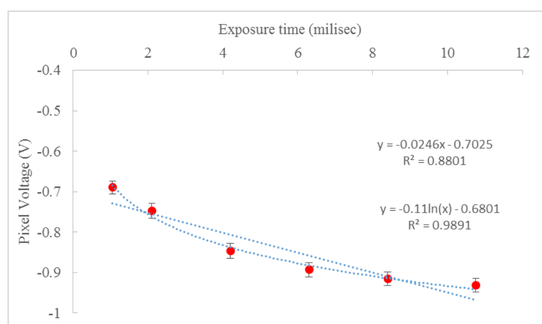

Fig. 3. Pixel voltage dependence with exposure time for SC mode. The inset shows the best fit for a linear and non-linear dependence.

References

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