FLIP CHIPPED INGAAS PHOTODIODE ARRAYS FOR GATED IMAGING WITH EYE-SAFE LASERS

J. Bentell[1], P. Nies[1], J. Cloots[1], J. Vermeiren[1], B. Grietens[1] , O. David[2] , A. Shurkun[2] and R. Schneider[2]
[1]XenICs N.V., Leuven, BELGIUM
(Tel : +32 16 38 99 00; E-mail: jvn@xenics.com)
[2]Airborne & Helmet Systems, Elbit Systems, Haifa, ISRAEL
(Tel : +972-4-831 53 61; E-mail: info@elbit.co.il)

Abstract: An InGaAs photodiode based short wave infrared camera with an actively Q-switched Er:glass laser was used for gated imaging of objects at approximately 500m at night.

Keywords: Gated imaging, pulsed lasers, near-infrared, SWIR, range gating.

1. INTRODUCTION

1.1 Gated imaging

Gated imaging is a class of the Time-Of-Flight imaging technologies where a camera with tightly controlled opening and closing times of the shutter is used in conjunction with a high power pulsed light source. Image contrast is enhanced by gated imaging by limiting the exposure time of the camera to the return time of an emitted light pulse from an object at a defined distance d. If the light source and camera are collocated, the exposure time should occur at a time after light pulse emission given by

$$\Delta t = 2d/c \, , \qquad (1)$$

where c is the speed of light.

The principle of gated imaging is outlined in Figure 1 and can be used to enhance image contrast in scenes where the object of interest is obscured by clutter or strong light sources that are blurring or saturating the imager. The camera shutter may be electrooptical, e.g. a Pockel’s cell [1] or electrically controlled by CMOS switches in the imaging electronics [2].

The gated imaging technologies may be divided into two distinct classes: *Single-shot* and *Multi-shot*. Single shot imagers capture the returned light from one single light pulse and forms and image, while multi-shot imagers integrate the light from several returned light pulses in each image frame [3].

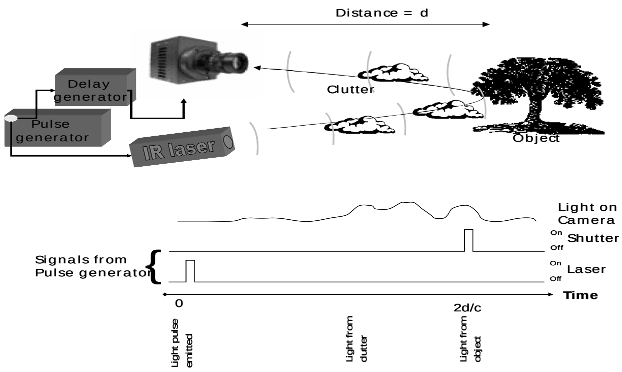

Figure 1. Example of gated imaging with pulsed laser: A tree is partially obscured by mist or other clutter that reflects light and reduces the contrast in the image of the tree. The electronic shutter of the camera is kept closed (i.e. the camera is not integrating light) during the time that the light from the clutter is incident. The shutter is opened only at the time of incidence of the light from the tree.

Whether single or multi shot technology should be used is a complex issue with several input parameters, such as required image depth resolution, distance, and scene dynamics. The main reason for the complexity is that the available pulsed laser light sources are very limited in power, repetition rate and pulse width.

1.2 Eye-safety and the SWIR band

The light sources suitable for pulse emission are lasers. Thus, eye-safety is a concern and a main limiter for the implementation of gated imaging in many applications. The solution to this issue is to avoid using the visible wavelength band, despite the availability of mature imaging technology in this range.

On the other hand, the middle range of the Short-Wave Infra-Red (SWIR) band (0.9 μm – 2.5 μm) is particularly well suited for all imaging applications based on active and modulated illumination due to a few interesting properties of this wavelength range:

- Eye-safety of laser light is ensured by the strong absorption by the water content of tissue.
- Glass optics may be used, enabling large apertures operating a long distances.
- The high speed properties of InGaAs photodiodes may be utilized for signal detection and demodulation.
- A wide selection of high power laser types is available.
- Objects tend to be more recognizable for humans when imaged with SWIR cameras than with infrared imagers for longer wavelengths.

1.3 Infrared imaging technologies

Today, image sensors based for all major transmission bands of the atmosphere are available based on materials and technologies indicated in Figure 2. This work regards infrared imagers based Indium Gallium Arsenide (InGaAs) photodiode arrays (PDAs), which is the best material for the SWIR band. In fact, all photodetectors used in long haul telecom systems are based on InGaAs.

InGaAs imagers are manufactured by flip chipping a PDA to a Read-Out Integrated Circuit (ROIC) chip with Indium bump bond connections between each photodiode and a multiplexed array of current sensing circuits on the ROIC, as illustrated by Figure 3. The flip chip assembly comprises a focal plane array (FPA) image sensor and is mounted in a camera with lens optics and electronics for transfer of image data from the FPA to a computer.

2. EXPERIMENT

2.1 Materials

In this work, the capabilities of a XenICs InGaAs PDA-based SWIR camera adapted for high speed electronic shutter control and laser synchronization was investigated, first in a lab environment then in the field. The camera has 320 x 256 pixels resolution on a pitch of 30 μm.

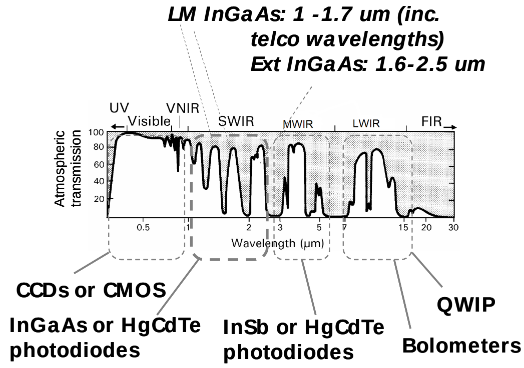

Figure 2. Atmospheric transmission band and related materials and technologies for imaging.

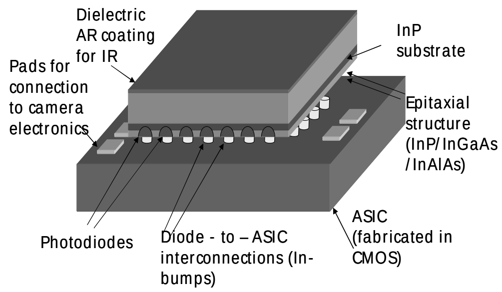

Figure 3. Outline of Infrared Image Sensor based on InGaAs photodiodes.

The ROIC of this camera utilizes a Capacitive Transimpedance Amplifier (CTIA) circuit design as photocurrent sensor. The CTIA circuit may operate as a single shot gated imager, provided that the amplifiers and switches are fast enough. As illustrated in Figure 4, this CTIA configuration may switch between two gain modes by selecting the total integration capacitance of the CTIA circuit; either high gain mode with C1 = 10fF or low gain mode with C1+C2=200 fF, meaning that the response to the same light level is ~20 times higher in the high gain mode with an associated noise increase. The CTIA output is connected to a Sample-and-Hold (S/H) stage before the read-out multiplexer that buffers the signal and enables the ROIC to operate all pixels simultaneously. The exposure time is started by the opening of the CTIA feedback switch and stopped by the opening of the S/H switch.

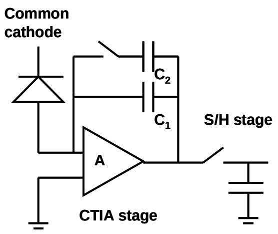

Figure 4. CTIA Current integrator cell with photodiode anode connected to the input terminal. All photodiodes in the array share a common cathode.

2.2 Laboratory investigation

The speed of the imager was analyzed with a fiber optic lab setup prior to the field tests. The lab setup consisted of a fiber coupled semiconductor laser connected to a Lithium Niobate Modulator (LNM) which was controlled by a tunable delay generator connected to the internal trigger of the camera. The output of the LMN was exposed on the PDA through a cleaved fiber end.

The system was configured so that the LNM emitted a 20ns long pulse at a given delay time from the start of the camera trigger. The delay was varied in order to acquire a response function of the system to light at a given incidence time in the cycle. In the high speed mode, the FPA operates with a fixed delay of 5 μs between the trigger and the closing of the shutter. The exposure time is varied by moving the opening time, as illustrated by the ideal response curves in Figure 5.

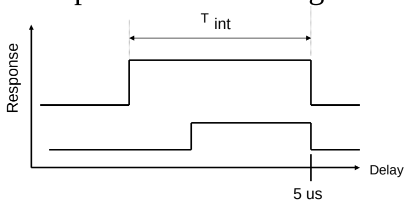

Figure 5 Ideal shape of the response function for two exposure times (Tint)

Figure 6 shows some of the results of this investigation. The important features are the edge of the response function, i.e. fast edges indicate rapid gating. Some observations were made:

- In both modes, the edge resolution is approximately 200 ns, which corresponds to a theoretical 30 m depth resolution
- Integration times lower than 1 μs are possible.
- It was found that the speed of the imager is limited by the finite current driving capabilities of the CTIA op amp. This effect is causing a high input impedance of the current integrating circuit and is the source of the low straight slope of the response function at long delay times, particularly visible in high gain mode. This slope sets an *upper* limit to the amount of light that can be detected.
- In high gain mode, the input resistance can be smaller than in low gain due to the smaller capacitances involved.

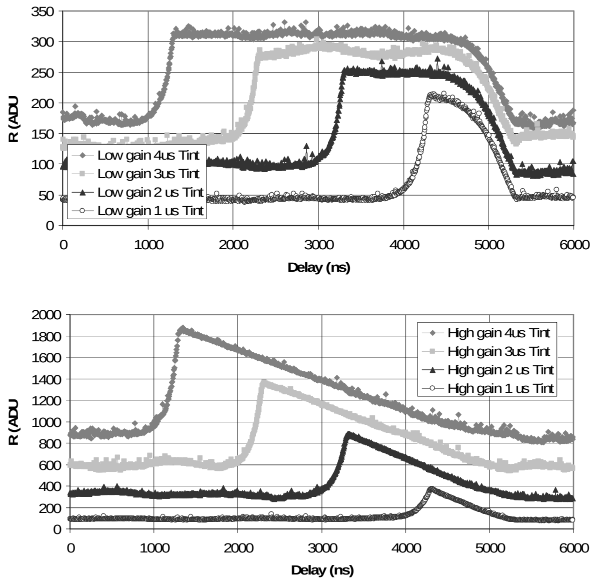

Figure 6. Photo response of pixel to a 20 ns long light pulse incident on imager at different delays with regard to the camera trigger pulse. A longer delay means a later light pulse. The curves are slightly offset with longer exposure times in higher positions.

2.3 Field test

An actively Q-switched Er:glass laser was used for the field tests. This laser is capable of emitting 50 mJ pulses of a few ns length. The camera and laser were rigged at a window in a tall building and a few different objects at a distance of approximately 500 m were selected for imaging. The objects were in darkness but close to a busy traffic intersection at night.

A few of the images collected are shown on the last page. The selected scene here contains a large lamp post approximately 75 m in front of the target (a small building). The scene was illuminated with the laser pulse, but with a varied delay between the light emission time and camera shutter opening. Note that the lamp post is not visible (only its shadow) when the delay is changed from 1130 ns to 1440 ns.

Figure 7. (6 IR-photographs) Images taken with different delays (520, 750, 1130 and 1440 ns) between emitted laser pulse and start of the camera cycle. Note the intensity of the illumination of the lamp post in front of the building. At 1130 ns delay, the post is clearly visible, but at 1440 ns delay only its shadow on the building is seen.

3. CONCLUSIONS

The gated imaging capabilities of a CTIA based SWIR camera have been investigated. It has been found that the speed of the CTIA is limited by the need for a fast op amp in each pixel, not the speed of switching. Different circuit architectures will be evaluated and presented by XenICs.

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4. REFERENCES

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