Development of a 3-Color InGaAs FPA Demonstration System

Jun Li, Takayoshi Fukaya and Walter F. Kosonocky
New Jersey Institute of Technology, Electronic Imaging Center
University Heights, Newark, New Jersey
Gregory H. Olsen, Marshall J. Cohen and Michael J. Lange
Sensors Unlimited, Inc., Princeton, New Jersey

Abstract

This paper presents the development of a 3-color InGaAs FPA demonstration system which can image three distinct spectral bands. The system consists of a prototype camera, a programmable frame grabber, and a host PC for image processing and data analysis. Preliminary experimental results, including measurement of the spectral response and testing of the integration time control, have been carried out.

Imager Description

In recent years, the demand for near infrared (NIR) detectors is growing rapidly. More and more applications require NIR detectors with high sensitivity and fast response. A system for the demonstration of a novel three wavelength InGaAs focal plane array (FPA) with detection wavelength range of 0.9 to 2.5 µm is presented in this paper. The system can be used in many applications, such as temperature measurement, gas spectroscopy, and blood-flow inspection.

The 3-color FPA consists of three interleaved 32×32 InGaAs diode arrays[1]. Each of them is sensitive to a certain region of the NIR spectrum. In this paper, the detectors responding to wavelength ranging from 0.9 to 1.7 µm are referred as "blue" (B), 1.2 to 2.1 µm as "green" (G), and 1.6 to 2.5 µm as "red" (R), respectively. Figure 1 shows a schematic structure of a 3-color pixel element. Detectors for each color reside at a different level with blue being at the bottom and red on the top. In the back illumination mode with light incident upon the substrate side, the epitaxial layer stack's filtering effect provides excellent optical isolation between each color.

The three sets of detectors make up an 96×96 array and the array is indium-bumped to a switched FET 128×128 CMOS readout multiplexer[2]. Figure 2 illustrates two different types of pixel readout arrangement of the 3-color FPA. In the case of column mode, the 32 BGR detector triplets correspond to 32 active FPA columns and each of them is followed by two blank columns. In the case of row mode, there are 96 active rows in the form of 32 active triplets and each row corresponds to 32 single-color detectors that are separated by two blank pixels.
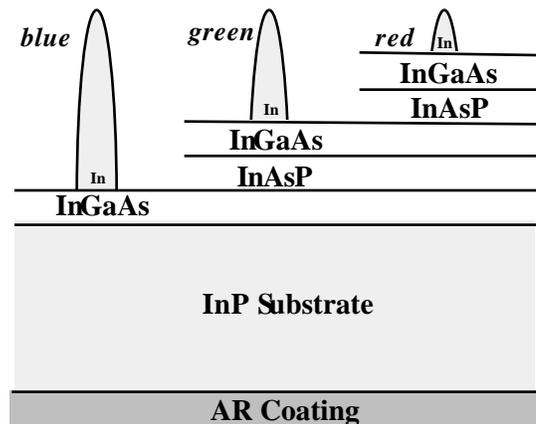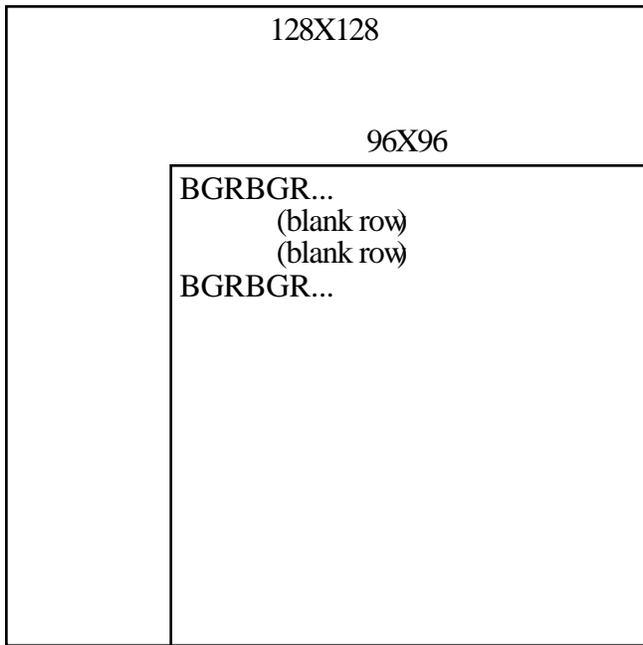

Figure 1: Pixel Structure of the 3-Color FPA

To operate the FPA, three timing pulses are required to produce the video output: PCLK (pixel clock), LSYNC (line synchronization), and FSYNC (frame synchronization). Pixels are clocked at both the rising and falling edges of the PCLK. LSYNC starts at the raising edge of PCLK and has a duration of one PCLK period. Exposure is initiated by the rising edge of the FSYNC signal, and the length of FSYNC determines the optical integration time in integer line-times. After the falling edge of FSYNC and a delay of 2 line-times, the first video line is clocked out from the FPA. Figure 3 sketches the waveform for the operation of the readout multiplexer.
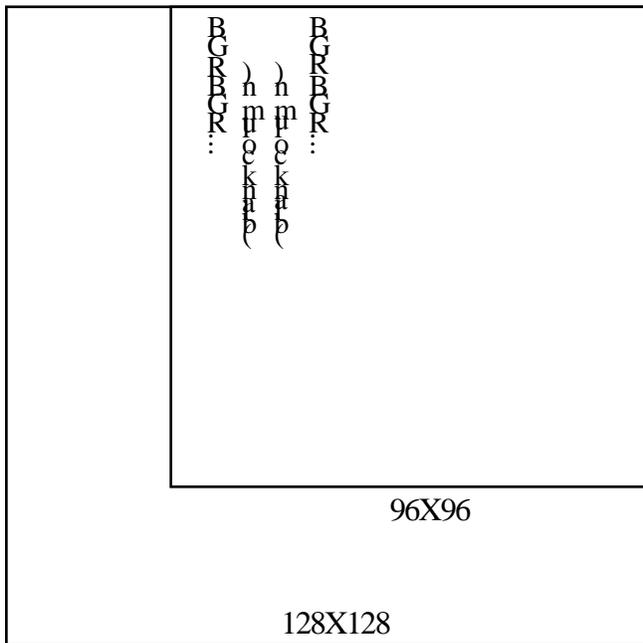
System Configuration

The system was developed for the demonstration and evaluation of the 3-color InGaAs FPAs. The major components of the system are a host PC, a prototype camera, and a frame grabber. The block diagram of the system is shown in Figure 4.

- The host computer is a Pentium PC with 100 MHz CPU and Intel chipset for compatibility with the frame grabber. Microsoft's Visual Basic is employed for programming.

128X128

96X96

BGRBGR...
(blank row)
(blank row)
BGRBGR...

(a) Row Mode Arrangement

B   B
G   G
R   R
B)h   )h B
G |n |n G
R |t |t R
: |e |e :
|g |g
|r |r
|a |a
|t |t
|i |i
|o |o
|n |n
| |
|c |c
|k |k
|n |n
|a |a
|t |t
)p   )p

96X96

128X128

(b) Column Mode Arrangement
Figure 2: 3-Color FPA Pixel Arrangement

Figure 3: Waveform for Operating the 3-Color FPA

Figure 4: 3-Color System Configuration

- The camera supplies power, bias and all the necessary timing pulses to run the FPA which is cooled in a test Dewar. It also provides analog video and synchronization signals to the frame grabber for digitization.

The optical integration time can be set manually to 8 different values between 1 and 256 line-times which correspond to 244 μsec through 62.5 msec. Manual gain and offset adjustments are also available.
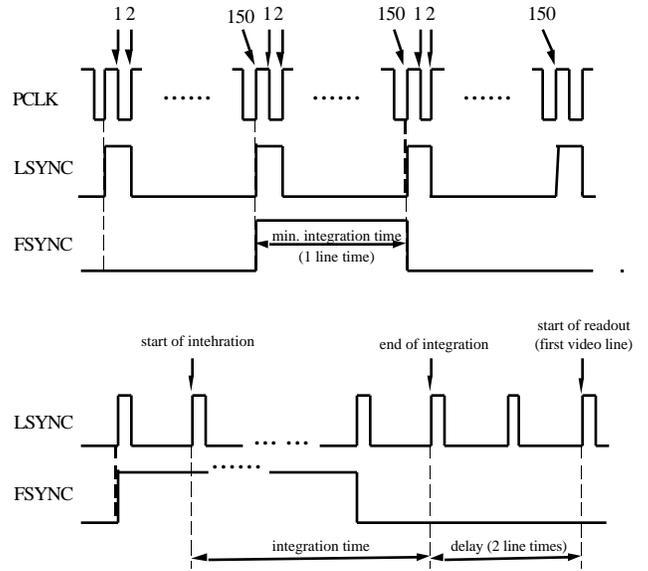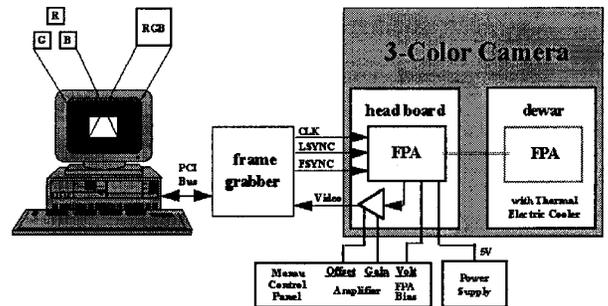
The frame grabber is comprised of an Image Capture PCI board (IC-PCI) together with a Variable Scan Acquisition Module (AM-VS), both obtained from Imaging Technology, Inc. The IC-PCI has a memory system running at 120 MB/sec. It can act as a PCI bus master, and its special circuitry automatically de-interlaces the image on-the-fly. The AM-VS supports standard and non-standard analog video input.

Video and synchronization signals fed into the frame grabber from the camera can be either single-ended or differential. To interface the frame grabber with the camera, the acquisition module is programmed to receive external timing. The voltage range of the video signal before ADC should be between 0.8 and 1.5 V. Since the voltage range of the video signal from the camera is 2.0V, the programmable prescale factor is set to 1, and the positive reference and the negative reference are adjusted to 1.2V and 0.0V, respectively

A video line is in the form of 128 active pixels and 22 blank pixels. Horizontal offset and horizontal active are set

corresponding to these numbers. A video frame is in the form of 128 active lines and a certain number of blank lines.

The number of blank lines depends on the integration time setting of the camera and can be calculated as current integration line-time plus 10. Vertical offset and vertical active are set according to these numbers.

Software Development

The 3-color FPA demonstration system was programmed using Visual Basic (VB) Pro 3.0. Visual Basic is recognized as one of the best highly accessible and productive software programming environments that can be employed in rapid application development. Its fundamental philosophy of pre-built functionality, program reusability, and powerful debugging tools dramatically reduces the time to create and modify custom applications compared to programming in C/C++. This makes VB a powerful tool for prototype system software development which features constantly changing requirements. However, the advantage of using VB comes at the expenses of speed and size.

The graphical user interface for the 3-color system is designed as a virtual-instrument which uses PC's bit-mapped screen to simulate a physical instrument so that the display of the PC looks like the front panel of a traditional instrument with buttons, dials, etc.

The frame captured by the frame grabber is kept in IC-PCI's 4 MB memory. There are two different ways to transfer data from the on-board memory to the host memory: In bus master operation, the IC-PCI is granted control of the PCI bus and becomes the source of both addresses and data to some other target location within the system. Live video display works in this fastest data transfer mode. In bus slave operation, the host processor does all the work involved in accessing the frame area on the IC-PCI board. Obviously, this pass-through mode is slow.

ITEX-IC, the development supporting software for the frame grabber, provides function calls icp_read_area() and icp_write_area() for the host access to the data in a certain frame area, and icp_rpix() and icp_wpix() for the host access to the data of a single pixel. icp_read_area() and icp_write_area() perform bus master transfer when it is enabled, and icp_rpix() and icp_wpix() perform bus slave transfer. Obviously, accessing an area using pixel by pixel bus slave transfer is much slower than area transfer in bus master mode.

The access to the on-board frame memory is always on DWORD (32 bit unsigned double-word) boundaries, and each DWORD packs four pixels. The pixel packing scheme must be figured out in order to read a frame into host memory for further processing. To find out the frame data arrangement, both area and pixel access functions were called to read in the same frame and compare the data for each pixel, and the guessing scheme was changed until the results match. Figure 5 shows the pixel packing scheme in a frame.
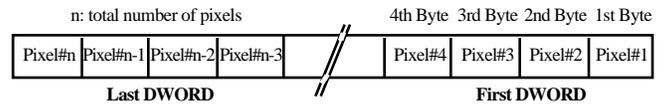

Figure 5. Pixel Packing Scheme

The functions of the 3-color system are listed below. In the descriptions, "current image" indicates the current image on display. it can be an image captured by Snap or Grab, or a resultant image of Average, Correction, or Database/Load, whichever is the latest.

- Snap—This function captures one-shot image and displays the still image on the screen.
- Grab—This function grabs images in real-time and displays the live video on the screen. Data is transferred out of the IC-PCI over the PCI bus to the memory on the display card and display is done completely by the host display processor.
- Average—This function averages 16 consecutive frames to reduce temporal noise and displays the resultant image on the screen.
- Reformat—The camera treats the imager as a pure 128×128 FPA without extracting the 3 color information. This Reformat function rearranges the current image into three 32×32 images corresponding to each wavelength and displays them along with a fourth image, which is the composite image of the three. The image corresponding to the detectors of 1.7 μm cutoff wavelength are displayed in blue (B), 2.1 μm in green (G), and 2.5 μm in red (R). The composite image is displayed in RGB false color with the three images of R, G, B being primary components.
- Zoom—This function allows the user to zoom the current image. A dialog window pops up to prompt users for input of the zoom percentage. When the cursor is on the zoomed image and the left button on the mouse is pressed down, a small window pops up and shows the position of the pixel pointed by the cursor.
- Background—This function reads in the current image and keeps it as the offset image for one-point nonuniformity correction.
- Nonuniformity—This function calculates and displays the histogram of pixel value distribution over the current image.
- Correction—This function performs one-point non-uniformity correction. It subtracts the offset image from the current image and displays the resultant image on the screen (see Background also).
- Integration Time—This function allows the user to set integration time by changing vertical offset

according to the change of integration time setting on the front panel of the camera. Integration time can be selected from a pop-up dialog window.

- Defect—This function displays the current image in a way that red represents white or hot pixels, and blue represents black or cold pixels. Two threshold values are used in the determination of bad pixels, and a pop-up dialog window allows user to enter the values.
- Database—This function allows the user to save the current image into a disk file, or retrieve a disk file and displays it on the screen. A pop-up screen lets the user change current drive, directory interactively, and shows a file list of certain user-determined type.
- Test—This function shows the average pixel values for pre-selected R, G, B pixels respectively in a pop-up window.

It is currently used in some special pixel-based testings, such as spectral response measurement and integration time control testing. A file is overwritten or created when the operation is performed. It stores the date, time, and all samples of R, G, B values in order. When the function is executed, a display window pops up and shows the averaged R, G, B values for the pre-selected pixels and the default sampling rate is set to one minute. Each time when a new sample is displayed, the bell will ring once. The sampling time interval can be changed. Clicking on the display window, a dialog window will show up to prompt input for sampling time interval and duration. Clicking on the dialog window, the display window will show up again and the testing starts again from the beginning.

- Exit—Quit the program.

Testing and Evaluation

During system integration and software development, a single color 128×128 InGaAs FPA with cutoff wavelength at 1.7 μm was tested at room temperature.

Two 3-color InGaAs FPAs were tested at 77 K in a Dewar cooled with liquid nitrogen. To have the FPA work properly, FPA bias voltage, offset voltage, and gain voltage were adjusted to the appropriate levels, and the position of the A/D converter sampling pulse was tuned for the align-ment of the FPA operation and the frame grabber operation. Figure 6 contains images taken by the camera system with the 3-color InGaAs imagers indium-bumped for operation in the row mode and the column mode, respectively.
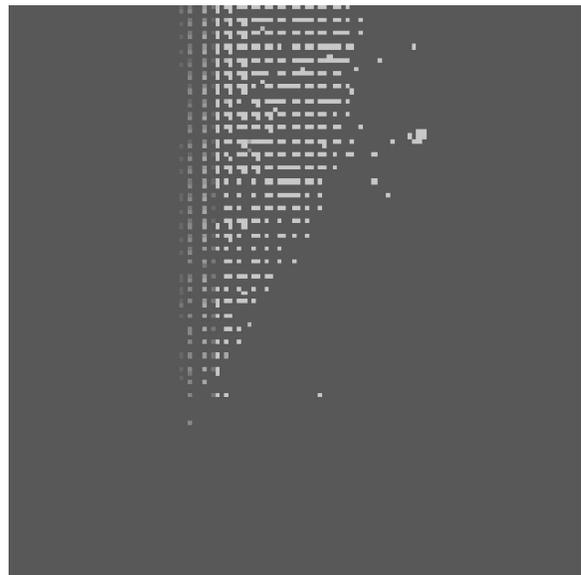
Preliminary experiments have been performed for measuring the spectral response of the FPAs. The optical integration time control was also tested.

Acknowledgment

(a) Row Mode Image

(b) Column Mode Image
Figure 6. Images from 3-Color InGaAs Imagers

References

1. D.-S. Kim, S. R. Forrest, M. J. Lange, G. H. Olsen, and M. J. Cohen, "A Three Wavelength Infrared Focal Plane Array Detector Element*," IEEE International Photonics Technology Letters*, Vol. **6**, No. 2, 1994.
2. D.-S. Kim, S. R. Forrest, M. J. Lange, G. H. Olsen, and W. F. Kosonocky, "A Monolithically Integrated InGaAs-InP p-i-n/JFET Focal Plane Array," *IEEE International Photonics Technology Letters*, Vol. **8**, No. 4, 1996.