Eye-safe laser radar 3-D imaging

Roger Stettner and Howard Bailey
Advanced Scientific Concepts, Inc. Santa Barbara, CA 93103

Richard Richmond
Air Force Research Laboratory, WPAFB

Abstract

This paper reviews the progress of Advanced Scientific Concepts, Inc (ASC). flash ladar 3-D imaging systems and presents their newest single-pulse 128 x 128 flash ladar 3-D images. The heart of the system, a multifunction ROIC based upon both analog and digital processing, is described. Of particular interest is the obscuration penetration function, which is illustrated with a series of images. An image tube-based low-laser-signal 3-D FPA is also presented. A small-size handheld version of the 3-D camera is illustrated which uses an InGaAs lensed PIN detector array indium bump bonded to the ROIC.

Keywords: Flash Ladar, 3-D Imaging, 3-D Focal Plane Array

1. Introduction

Although 2-D and 2-D range gated images are potentially very useful for locating and identifying objects, the information that can be extracted from a silhouette image is limited. Adding an additional dimension, range, is desirable as a method of improving our ability to extract objects from background interference and to provide additional feature information that improves that capability of automatic target recognition algorithms. An ideal 3-D imaging system would be one that could capture all of the scene information at a single shot or laser flash. This 3-D flash ladar image approach would freeze each pixel in relation to the others reducing the need for preprocessing of the image to correct pixel registration. Pointing speed, accuracy and agility requirements would be reduced to what would be needed in order to track the target. Because the entire scene would be illuminated, the per pulse energy requirements would be similar to those for a range gated approach. But, because only one pulse would be needed for each frame, the average laser power required would be less, comparable with that needed for a single pixel scanned ladar approach. Furthermore a 3-D flash ladar approach has the potential of generating time resolved 3-D movies for increased target information.

This paper is organized as follows: First the components of a 3-D imaging flash ladar system are described. The most critical component, the 3-D FPA is then discussed. Functionality of the 3-D FPA is determined by the Readout Integrated Circuit (ROIC) and the ASC-designed, AVDAR ROIC is discussed in Section 3 along with images captured with a 128 x 128 AVDAR ROIC. Detectors incorporating gain are important for compact systems and ASC's Image Tube approach is described in Section 4.

The ASC hand held 3-D imaging flash ladar system is depicted in Figure 1. It is representative of a flash ladar system. The system consists of a laser transmitter which together with the transmit optics directs a laser pulse at a target. The receive optics collects the target-reflected light and focuses the laser light on the 3-D FPA. Drive electronics provide the clocks and biases that operate the sensor and the output electronics conditions and digitizes the data output from the sensor, and then transfers the data to the processing computer for further 3-D processing and display. In Figure 1 the drive and output electronics circuit boards are inside the camera housing. The laser transmitter is also inside the camera housing.

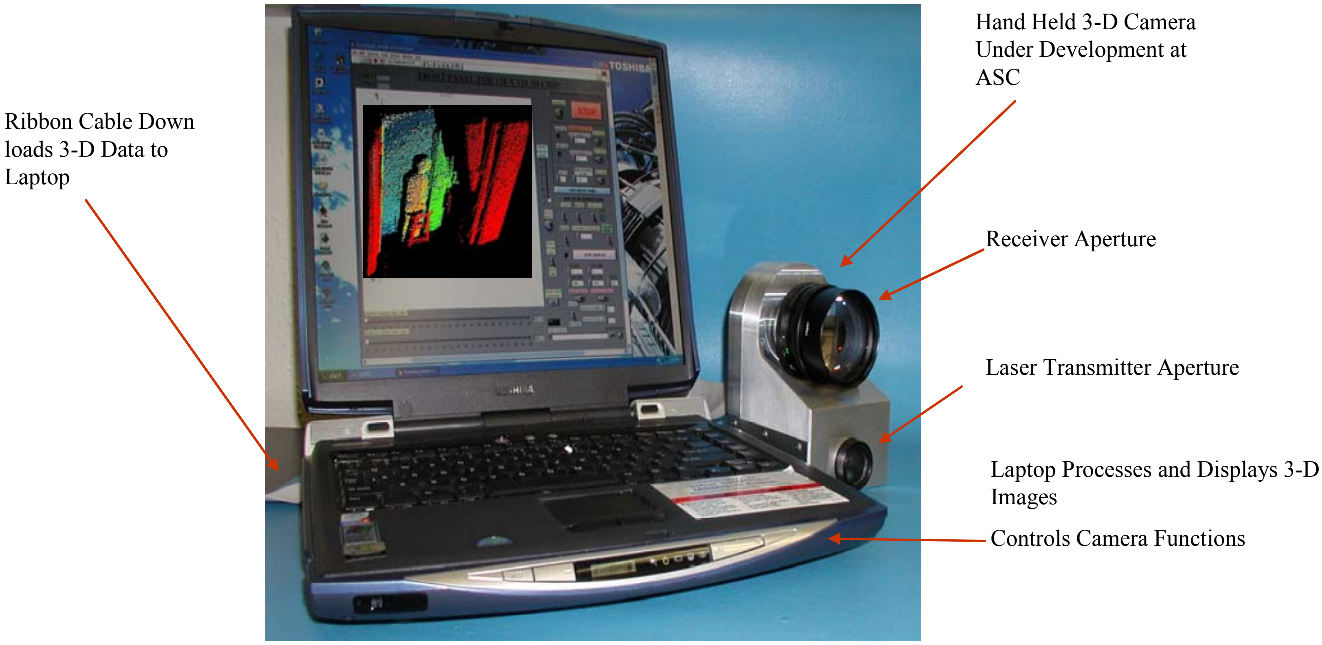

Figure 1. Representative 3-D Flash Ladar Imaging System

2. The Hybrid 3-D FPA

Typically the 3-D FPA is a Readout Integrated Circuit (ROIC) bump bonded to a solid state detector array to form a hybrid. Each unit cell, operated independently of the other unit cells in the array, is bump bonded to an independent detector in the detector array. The general hybrid design is depicted in Figure 2.

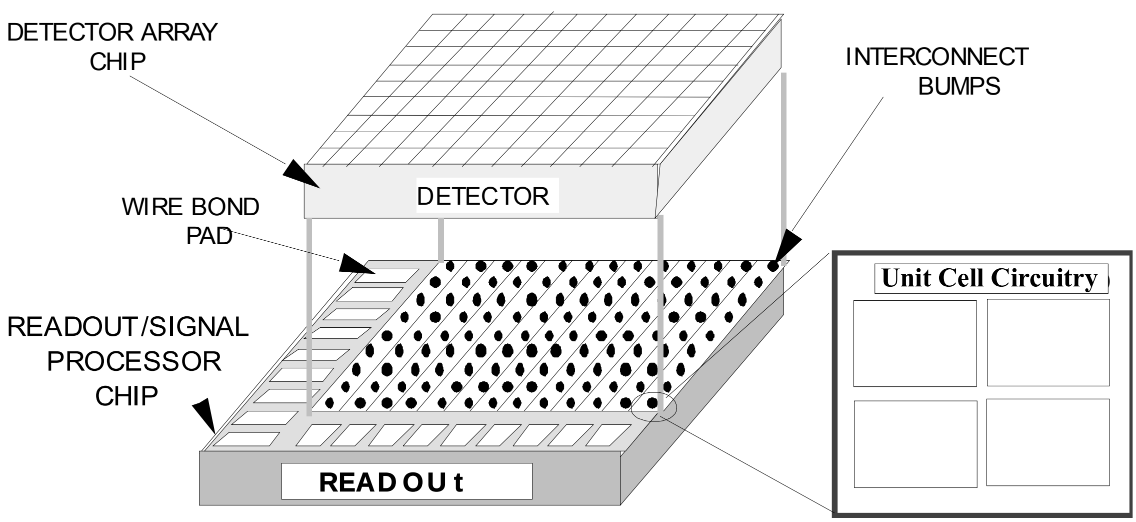

Figure 2. 3-D FPA Hybrid Design. ROIC bump bonded to detector array chip

The Figure 2 hybrid 3-D FPA design is a very general configuration and can be used with a variety of detectors. For example silicon InGaAs or HgCdTe PIN or APD arrays. 3-D FPA gain is important for reducing laser power and developing compact systems. InGaAs or HgCdTe arrays allow for eye safe operation. For all the images discussed in the next section the eye safe laser wavelength was 1.54 um and the detector array was InGaAs. An alternate image tube, high-gain, 3-D FPA design is described in Section 4.

The Readout or ROIC in Figure 2 is the critical component in the hybrid. Fundamentally each pixel contains circuitry, which independently counts time from the emission of a laser pulse, from the camera, to the capture of the reflected pulse in a pixel.

In addition pixel circuitry captures temporal information about the returned pulse. Pixel and ROIC circuitry support additional functions. For the ASC-designed AVDAR ROIC all functions are described in the next section.

3. The Multi-Function 128 x 128 AVDAR 3-D ROIC and Single Laser Pulse (Flash) 3-D Images

The 128 x 128 AVDAR ROIC performs its functions by a unique combination of both analog and digital circuitry. Figure 4 illustrates these functions.

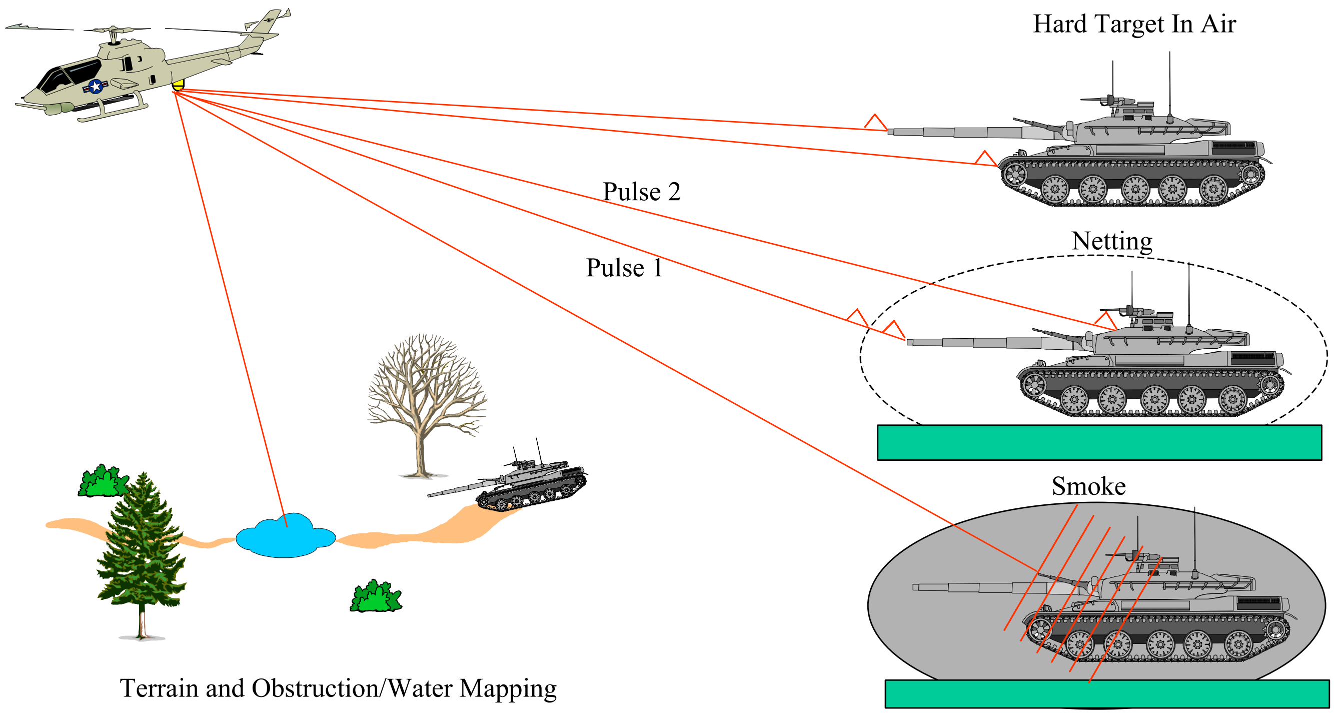

Figure 4. Function of AVDAR ROIC: hard target 3-D imaging, 3-D imaging through camouflage, 3-D imaging through smoke and 3-D imaging though water.

A short laser pulse is emitted from the laser transmitter on the helicopter in Figure 4. The transmitter optics spreads the beam out over the field-of-view of the receiver, which covers the entire target object. In the top diagram of Figure 4, Hard Target in Air, those points on the target, which are closest to the receiver/transmitter, such as the tank cannon, reflect light back first. As the laser pulse propagates across the target, laser light is progressively reflected back to the receiver from all points of the target facing the receiver. Each pixel at the 3-D FPA, see Figure 2 for example, is able to capture the individual round trip time to the target and in addition other circuitry captures the returning pulse shape. This additional information is used to increase the range precision, increase the range resolution, detect multiple targets in a single pixel and provide still further information about the target. By capturing the range to the target for each pixel in the two dimensional focal plane, the third dimension is produced. By use of proper algorithms, and both the analog and digital data, sub-inch range precision can be achieved for relatively modest signal-to-noise ratios (typically on the order of 10 - 20) with reasonably long pulse lengths (typically a full width half maximum equal to 5 ns). Minimal analog-data processing, can be used for standard 3-D images, with range precisions of about 6 inches. Figure 5 illustrates a hard target image.

In the second diagram from the top in Figure 4, Hard Target Response Thorough Camouflage Netting, the first return for most of the pixels is the netting. Assuming some net transparency, the pulse capture circuitry allows a second return to be distinguished if the target is beyond the net. For objects deeper than 20 feet, the receiver can be programmed, for the second laser pulse, to ignore the net return and react only to targets beyond the net or to targets beyond a programmed range.

In the third diagram from the top in Figure 5, Penetration Thorough Smoke, the hard target first return circuitry is suppressed and pulse capture circuitry is turned on after a specific range. Reflection from a hard target in the smoke will

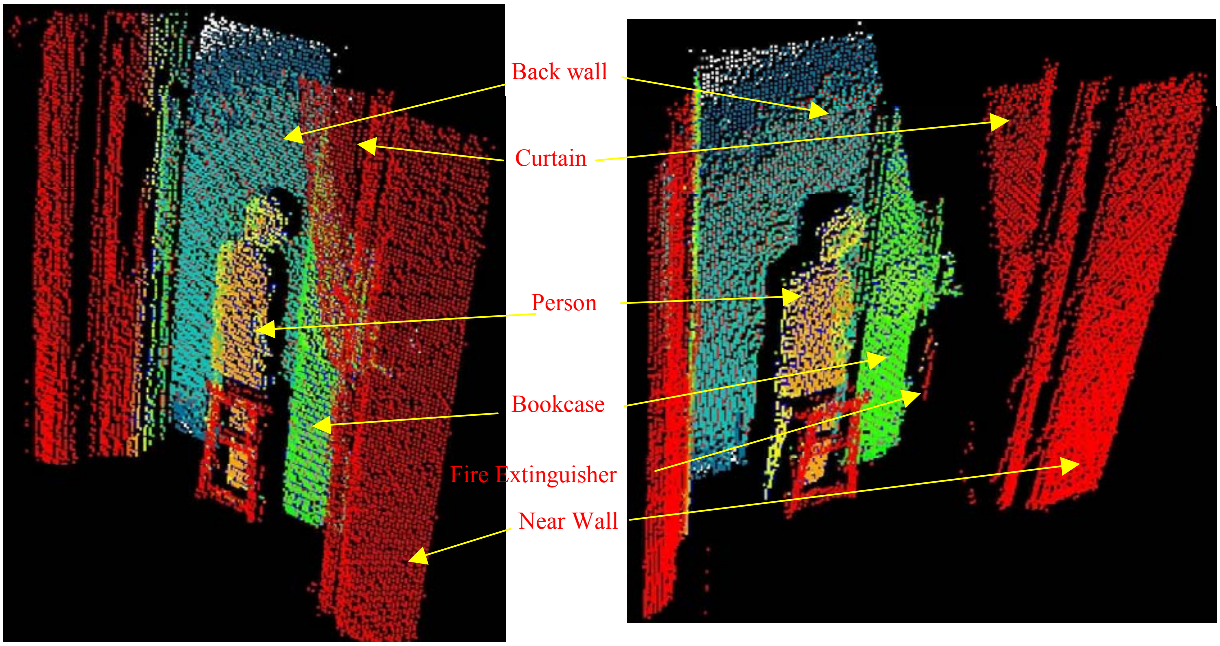

Figure 5 a and b. Two different angles of the same hard target 3-D 128 x 128 single-pulse flash ladar image; raw unprocessed and uncompensated data with the simplest range algorithm. Color-coded range.

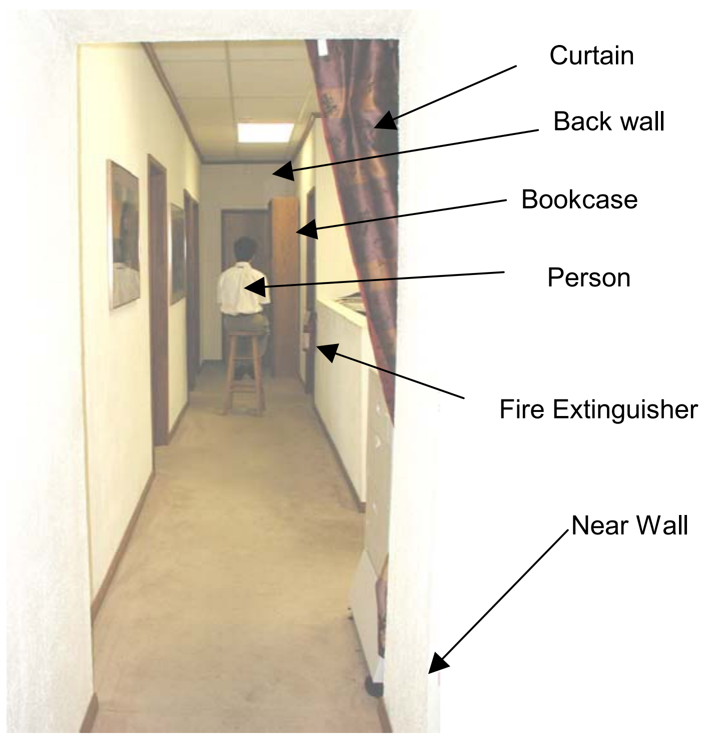

Figure 6. 2-D Image associated with Figure 5.

dominate the reflection from the smoke in the sample. Just as for hard targets in the atmosphere, parts of the target which are deeper in the smoke will show up on later samples in the two dimensional focal plane, giving the third dimension. The twenty samples available in the AVDAR design can be made to scan through the smoke with progressive laser pulses and processing algorithms can produce a 3-D image of the target in the smoke.

Figure 8 illustrates the raw data from obscuration penetration without the smoke. This is similar to the penetration through netting with the targets located far from the netting.

In the fourth diagram from the top in Figure 6, Penetration Thorough Water Obstructions, the hard target response threshold circuitry is also suppressed and the pulse capture circuitry finds the bottom much like a target is found in smoke. The difference is that a different laser should be used. Usually longer laser wavelengths penetrate smoke best while the best water penetration is with .53 um.

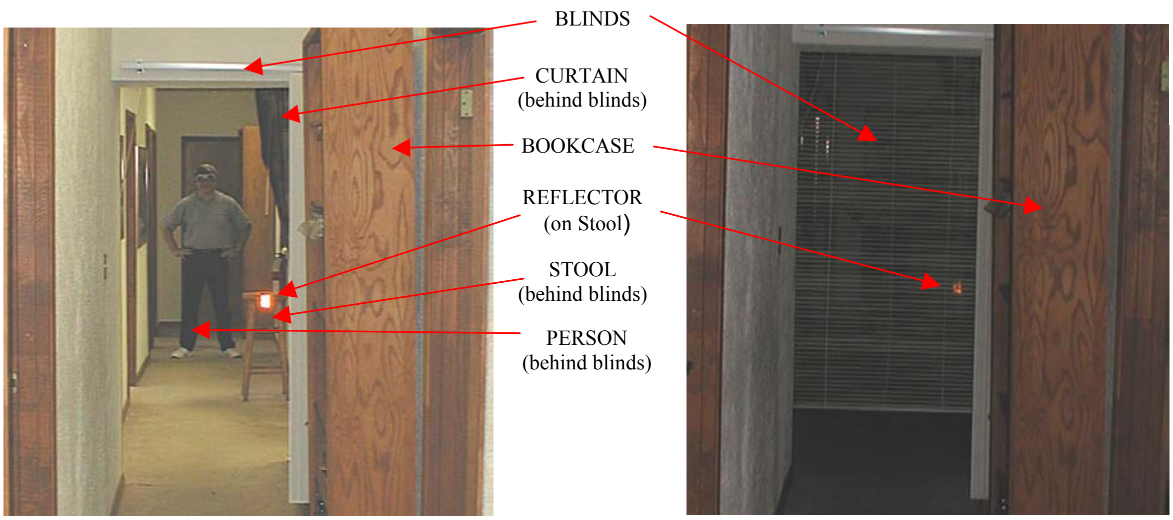

Figure 7. 2-D Pictures of Camouflage Penetration Experiment. (LHS) Blinds pulled up to show person and stool behind blinds. (RHS) Blinds down and closed 50%. Stool and person are totally obscured in the 2-D image. Some light from the reflector on the stool appears in the 2-D image.

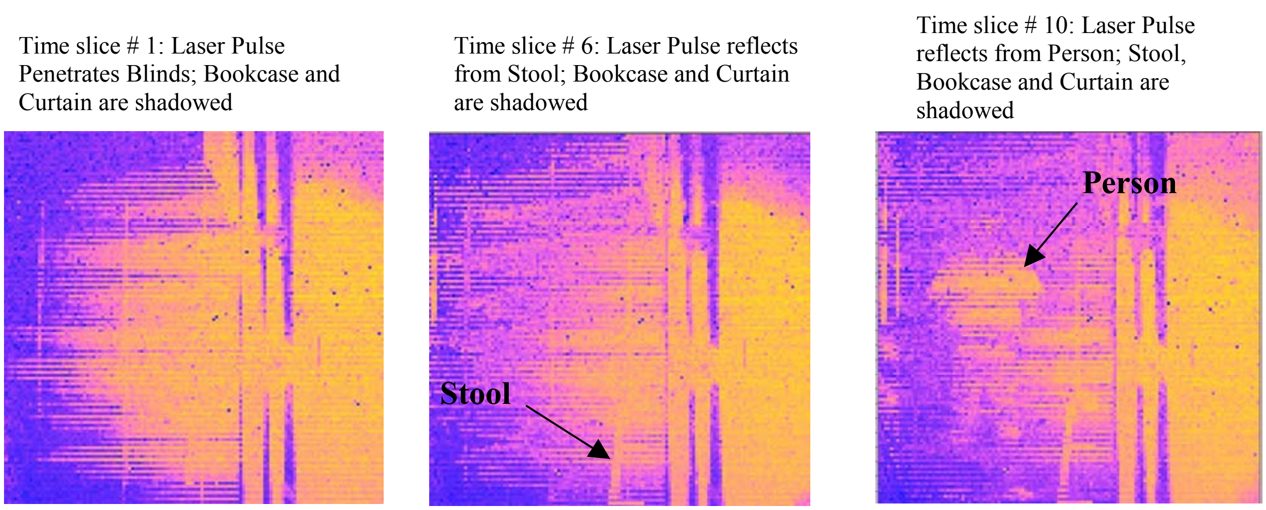

Figure 8. Obscuration Penetration with the Current 128 x 128 ASC ROIC: Single laser pulse, raw unprocessed and uncompensated data. Selected time slices from behind obscuration. Each pixel captures multiple consecutive time slices.

The 3-D FPA used in producing the Figure 5 and Figure 8 images was the Figure 2. hybrid where the detector array was InGaAs PIN diodes. In order to reduce capacitance the junction area was small and lenses etched into the substrate were used to increase the fill factor. Reference 1, a companion paper, discusses 3-D flash imaging with a lensed APD array using a

32 x 32 AVDAR ROIC. In the next Section we discuss progress in 3-D Image Tube FPAs, a very promising low noise, high gain technology.

4. Image Tube 3-D FPA Progress

Detector gain technology is important for reduction of laser power and the image tube 3-D FPA is important example of this technology. The image tube gain technology is made possible by the development of eye-safe photocathodes (References 2 and 3). Figure 3 illustrates an electron bombarded (EB) image tube 3-D FPA.

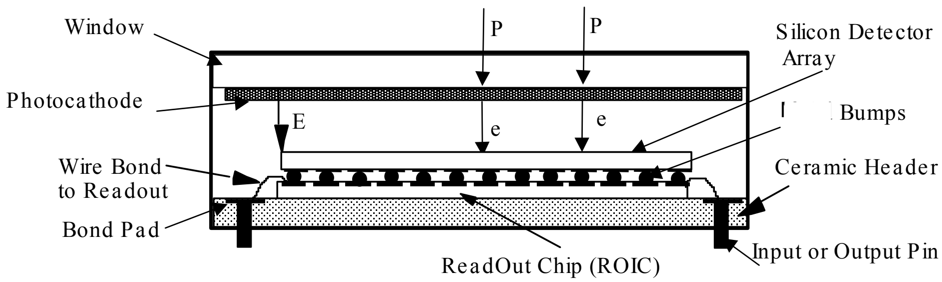

Figure 3. Electron Bombarded (EB) Image Tube 3-D FPA

The image tube 3-D FPA works as follows: photons pass through the window and interact with the photocathode producing a photoelectron. This electron is accelerated by the electric field E through a potential measured in kV and penetrates into the silicon of the hybrid causing gain by impact ionization. Approximately one electron-hole pair is produced for each 3.6 eV for those photoelectrons which penetrate into the active silicon region. The noise factor is less than 1.1.

If all the parameters of the imaging system were held constant, except for the detector array, it is anticipated that the image tube with current photocathode quantum efficiency would be effective at a range that was 3 times greater than a lensed InGaAs PIN array.

4. Conclusions

This paper presented 3-D Flash ladar imaging results from ASC's newest imaging system. These results illustrate the versatility, usefulness and promise of the AVDAR ROIC approach to 3-D ladar.

5. Acknowledgements

This work was supported by AFRL WPAFB under Contracts F33615-95-C-1656 and F33615-96-C-1852, and supported by DARPA under Contract F33615-00-C-1709.

6. References

1. J. Dries, B. Miles and R. Stettner, A 32 x 32 Pixel FLASH Laser Radar System Incorporating InGaAs PIN and APD Detectors, SPIE AeroSense, Defense and Security Symposium 4/04, session
2. Verle Aebi, et al., Near IR Photocathode Develop. 1IRIS Specialty Group on Active Systems, 3/97
3. Verle Aebi, et al,Gallium Arsenide Electron Bomb. CCD Technology, SPIE Conf. on Image Intensifiers and Appl., July 1998.