Infrared Focal Plane Arrays Performance Achievements and Future Trends

Dragana Perić, *Member, IEEE*, Branko Livada

***Abstract*—This paper gives a review of current infrared focal plane arrays from the point of view of the practical application capabilities in the long range surveillance systems. We have tried to point out the vital components of the IR detector and gave the current trend of development that will be useful for a system architect whose task is to select components from the most competitive technologies available on the market now and to have in mind what is expected to be available in the near future.**

***Index Terms*—Infrared technology, infrared detectors, Infrared focal plane array, System architecture, Long range surveillance.**

I. Introduction

Infrared Focal Plane Array (IR FPA) is a sensing device, consisting of an array of light-sensing pixels at the focal plane of a lens that is sensitive to infrared radiation. The device operates by converting infrared photons to an electrical signal, and using it to construct an image of the sample. Strictly speaking detector array should be placed in the image plane that is close to focal plane but not exactly the same.

Five decades ago, a new semiconductor concept introduced Charge Coupled Devices (CCD) which paved the way to solid state imaging systems [1-2]. Successes from implementation of silicon CCDs in visible spectrum were followed by employing similar techniques to obtain IR FPAs that were realized in integrated two-dimensional arrays of detectors on the focal plane with multiplexed readouts [3].

Nevertheless, physical differences between visible CCD and IR FPA required additional procedures to be undertaken. Most obvious difference is resulting from the material used for detector and multiplexer readouts. While visible CCDs have both realized in silicon, IR FPAs have to cope with different type of materials (narrow bandgap semiconductor photon detectors, silicon multiplexers) and technology challenge of their interconnection. Also, narrow bandgap materials used in IR FPAs imposed the necessity of cryogenic cooling in order to decrease electronic noise to approach the photon noise limit. For this reason such IR FPAs are constructed in integrated dewars that complicate the detector design and impose strict requirements for electrical and mechanical interfaces [4].

IR technology was military used and controlled technology and its extraordinary advances in capabilities within a short time period during the last century were boosted by Cold War arms race [5]. These advances reflect in researches considering photon IR detection technology semiconductor material science and sophisticated manufacturing technologies.

IR FPA manufacturing technology is expensive on the one hand but should be high volume production on the other hand. Since IR FPA found their place also in civilian applications, even in our homes and mobile phones, the quantity of IR FPA is increasing and high volume production is becoming reality.

As commercial application need less expensive detectors, also uncooled IR FPA are being developed, offering good performances while less complicated IR FPA manufacturing, operating at room temperature therefore not needing cryogenic cooler. In some medium range surveillance application this type of detectors is also interesting. Such detectors are used in Shortwave Infrared (SWIR) and Longwave Infrared (LWIR) spectral range.

In the literature there are a lot of various reviews of the IR detector technology examples mainly from scientific development results. These reviews are good for judging scientific advancement, strategic technology development planning, manufacturing facility development and deployment. Goal of this paper is to give some guidelines to a systems architect of a long range surveillance system for selecting the proper IR FPA in order to achieve desired performances. We will point out some parameters that are important and specific for IR FPA and discuss the current trends of IR FPA development.

II. Trends in Infrared Focal Plane Arrays

Historically, IR FPAs are appearing in the second generation (staring systems–electronically scanned). On the detector roadmap, third generation is considered staring systems with large number of pixels and two-color functionality, and fourth generation (staring systems with very large number of pixels, multi-colour functionality and other on-chip performance improvement functionalities [5].

The historical time line of the IR detector road map is illustrated in Fig. 1. It took more than half of century to pass the way from single detector to high density FPA. The spectral sensitivity of the various detector types is illustrated in Fig.2, The lot of different narrow band semiconductor

Dragana Perić is with the Vlatacom Institute of High Technologies, 5 Milutina Milankovica, 11070 Belgrade, Serbia (e-mail: dragana.peric@ vlatacom.com).

Branko Livada is with the Vlatacom Institute of High Technologies, 5 Milutina Milankovica, 11070 Belgrade, Serbia (e-mail: branko.livada@ vlatacom.com).

materials were considered as good candidates, but only sone of them survived the race.

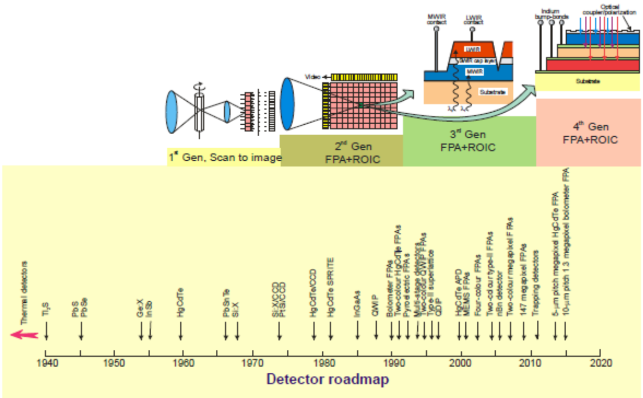

Fig. 1. History of the development of infrared detectors and systems. [5]

Different detector materials

Among materials used in third and fourth generation IR detectors which are selected due to their advantages [6-9] are:

- HgCdTe detectors are used to image rapidly moving objects for the very short integration time.
- QWIP devices had excellent homogeneity and better Noise Equivalent Temperature Distance (NETD), but their integration time had to be much longer.
- Sb-based III–V material systems offered mechanical robustness and have quantitatively weak dependence of band gap on composition,
- Type II InAs/GaInSb superlattices offer the capacity to tune the cutoff wavelength between 3 and 30 µm by varying the individual layer thickness [9]. Detectors have very uniform image (lower NEDT) and lower unit cost.

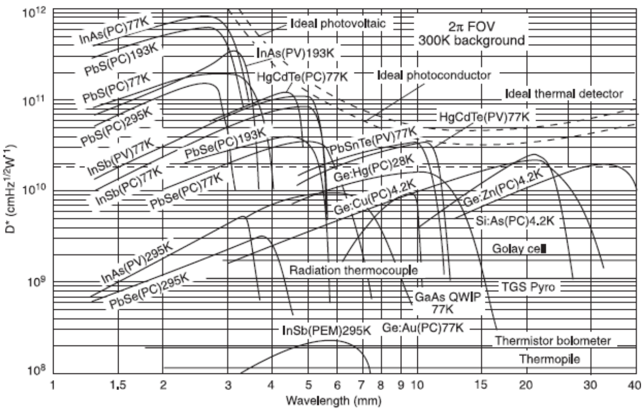

Fig. 2. Comparison of detectivity D^* of various available detectors when operated at the indicated temperature. [6]

As we see, most of the IR detector materials, in order to provide good detectivity (sensitivity to IR radiation), operate at cryogenic temperatures and require cooling.

Uncooled IR detectors materials

Uncooled IR FPA technology failed to attract much attention in the beginning, but around 1992 with promising results in LWIR detection, they became popular [10, 11]. Materials used for uncooled microbolometers are principally:

- Vanadium oxide – VOx - high performance demonstrated with this technology, lower NETD.
- Amorphous silicon – α-Si - technology much more oriented on low price commercial applications.

Another spectral region, Shortwave infrared (SWIR), also offers uncooled IR detection and has recently gaining a lot of application both in commercial apart from its use in military. Material that have the predominant use is InGaAs, which can be used with Termo Electrical (TE) cooling in order to minimize noise effects and obtain high performance.

Therefore, selection of the technology which is best to use is driven by the specific requirements of the system and the project application.

A. Trends in detector materials development

Actual strategies of leading institutions for planning IR detector development, that are driving the progress in this field, are in setting up an alternative business model for production in which there is a tendency to expand cooperation from dedicated military to commercial foundries in order to reduce production and maintenance costs [12]. For the last 50 years, HgCdTe was the most used material for IR FPA used in military. Since it is costly, low yield, difficult to process and not used for commercial products, strategy is turning to other materials from III-V based structures, that can offer affordable production, high yield, high performances even on higher operating temperature, which can be manufactured using commercial foundries. Superlattice structures based on antimonide, offer similar features as HgCdTe because their spectral response can be tuned to cover from SWIR region to Very Longwave Infrared (VLWIR) and their quantum efficiency is high. Their advantage over older technology is in being more robust and flexible for design.

Major goals in front of the new III-V based design and production are:

- Provide alternative to HgCdTe for LWIR spectral range detection and dual band detectors.
- Provide alternative to cryogenically cooled InSb detectors in Midwave Infrared (MWIR) spectral detection by Type II Strained Layer Superlattice (SLS) and High-operating Temperature (HOT) technology. This could increase overall system Mean Time Between Failure (MTBF) because cooler lifetime is increased.
- Large format FPA high yield production using high

diameter (up to 8”) substrate material, that is compatible with well developed Silicon Very Large Scale Integration (VLSI) technology.

- Decrease cost of the detector.

B. Detector cooling

Cooled IR FPAs need special type of architecture that is called Integrated Dewar Detector Cooler electronics Assembly (IDDCA) in order to provide optimal working environment to the IR FPA and to deliver digital data to user system. In Fig.3. block scheme with main components of the cooled IR FPA detector architecture is presented.

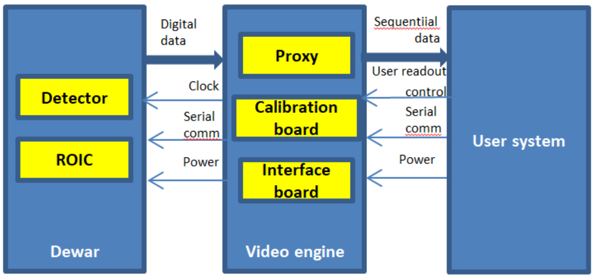

Fig. 3. Block scheme of the cooled IR FPA detector architecture

Detector is set in cooled environment and in order to eliminate stray light internal cold shield is provided that matches required optics F number. Feedthrough unit with adequate number of pins is used for connection of FPA with electronics of read out circuitry. Dewar is integrated with Stirling type cooler of required power.

As a new trend in cooled IR development brings HOT detectors with higher operating temperature 150K, required power of the Stirling cooler is decreased and that results in increase in lifetime of the cooler which is often critical component for MTBF of a cooled electro optical system. An increase in the FPA temperature up to 150K and above improves cooler thermodynamic efficiency reduces the detector assembly thermal losses. These are potential benefits allowing a cryocooler's size, weight and power consumption reduction and also improved performance and low price [13]. From the point of view of systems architect it is important to be aware of all advantages and drawbacks of a cooled system, that although offers the highest optical performance, need to be dimensioned well for overall cost of maintenance and in this evaluation cryogenic cooler plays an important role.

C. Read Out Circuitry ROIC

Read Out Circuty (ROIC) is responsible for transfering data from IR FPA to the user systems. IR FPA sensors pixel size is impacted by the challenges associated with hybridization of the detectors material to the silicon ROIC’s (bonding of indium bumps), but efforts that have been recently made and technology advancements made possible realization of smaller pixel IR FPAs. For alignment optimization, coefficient of thermal expansion between the materials of the ROIC substrate, detector epi layers, detector substrate etc., have to be taken into account and compensated using compensatory materials in order to minimize thermal-induced deflection.

Small pixel performance in IR systems requires the optimum trade balance between the optics design, the spectral bands, integration time and the applied signal processing techniques [14-18]. In new trend of IR detector developments pixel is smaller while FPA dimension is increased with more pixel elements.

ROIC can comprise more advanced image processing functionalities as shown in Fig.4, or they can be implemented in further processing chain, so called video engine or video core unit.

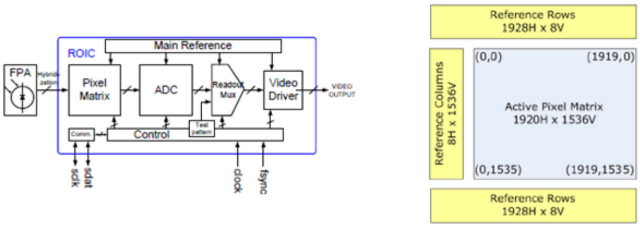

Fig 4 . High definition ROIC structure [19]

D. Video Engine Processing

Video engine is the electronics that performs image processing. It is usually provided by the camera manufacturer and offers several levels of integrations by modular design. Usually it is composed of several electronic boards, which split different functionalities for different level of image processing. Terminology used is most frequently referring to proxy board, calibration board and interface board of video engine. Typical functionalities of proxy board include low noise power distribution, cooler control, shutter control, Termo Electric Cooler (TEC) control and video analog to digital conversion. After this basic video signal acquisition it is necessary to do some corrections and calibrations like Non-Uniformity Correction (NUC), Bad Pixel Replacement (BPR), Dynamic Range Compression (DRC) and probably some more advanced processing, then to pass the video signal further to interface board that will put it in a delivery format (analog or digital like Camera Link, HD-SDI, Ethernet etc.).

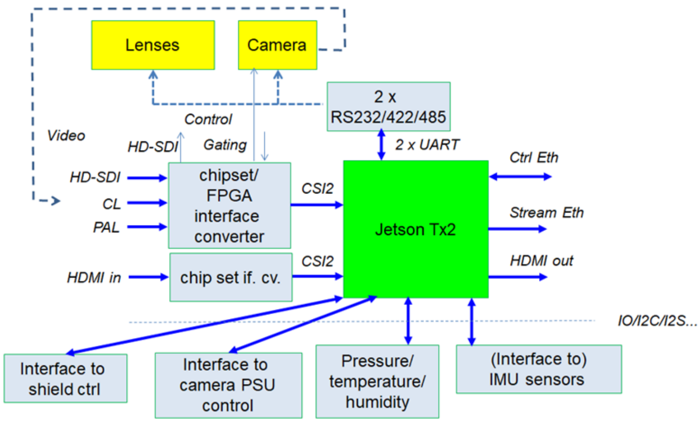

Fig.5. Block diagram of single vVSP channel processing unit

After this basic processing, system integrator can add more processing blocks in which other controls and algorithms are performed. In the Fig.5 block diagram of part of the Vlatacom

Institute video single vVSP channel processing unit is presented.

III. FPA APPLICATION CRITICAL PARAMETERS

When selecting IR detector for long range surveillance application, first decision have to be made about selecting the working spectral sensitivity band. Usually for coastal scenarios, MWIR spectral range (3-5 µm) is preferred, and for land application, medium distances LWIR (8-14 µm) uncooled detectors can answer the project need. As we discussed in the previous work, cooled IR FPA require use of cryogenic coolers that increase the overall system price and require costly system maintenance. However, current trends towards using HOT detectors are making possible the use of high performance IR detectors with lower prices and longer operational time with coolers' MTTF declared above 10.000 hours.

Technological improvements in manufacturing processes have enabled pixel minimization and also high diameter substrate material so it possible to manufacture IR FPA that have 1920 x 1024 pixels, or 1920 x 1536 with 10 – 15 micron pixel technology.

In order to optimize the overall dimensions and weight of the system it may be practical for a system integrator to implement its own electronics for video processing and, if possible, to use input signal as close as possible to the ROIC circuitry of the IR FPA. In that case, knowledge has to be acquired about manufacturing processes, and methodologies for compensation of detector non-uniformity and bad pixels. From the other side, this type of overall signal processing that is under control of the integration engineer offers more flexibility in customizing the solution for the specific project and implementing the most advanced algorithms for video processing like many types of video enhancement, video stabilisation using external Inertial Measurement Unit (IMU) sensors etc.

IV. CONCLUSION

IR FPA market is rapidly changing because of the increase of high volume production for non-military and commercial applications. The major trend in IR detectors design implies use of commercial foundries in order to decrease detector price and delivery time. Also reliability of the new products is designed to be higher because of the optimal use of coolers at higher operating temperatures. Large format small pixel IR FPA are becoming reality for use in surveillance projects such as border protection, coastal surveillance etc. Image fusion with other channels benefits from this development since IR FPA formats and resolutions are approaching those in visible spectrum range. For the multiple camera system integrators it becomes possible to approach close to detectors output and to control image processing pipeline in order to be able to optimize overall system performances.

System architects while selecting the proper equipment should be familiar with most critical steps of IR FPA manufacturing chain and strategical planning of future IR FPA generations development.

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