Low-Cost, Large Format, Radiation Resilient, Mid and Long Wave Infra-Red Focal Plane Arrays

Gregory Gosian **Mark Dapore**
L3Harris Technologies - Space & Sensors Division
7500 Innovation Way
Mason, OH 45152
UNITED STATES

gregory.gosian@l3harris.com

THIS DOCUMENT DOES NOT CONTAIN TECHNICAL DATA AS DEFINED BY THE ITAR 22CFR§120.33 OR THE EAR 15CFR§772

ABSTRACT

Proliferated Satellite Constellations offer an attractive solution for missile launch detection, low signal-to-noise (SNR) infrared search & track (IRST), as well as for Space Domain Awareness. Delta-V to Low-Earth Orbit/Medium Earth Orbit (LEO/MEO) is lower, ground and atmosphere resolutions and SNRs achievable are higher, and technology refresh can be accomplished more readily when compared to placing assets in Geostationary Earth Orbit (GEO). Additionally, disaggregated constellations are better able to absorb loss of individual assets without suffering a corresponding loss of system capability, especially when employing platform networking and redundancy. A major consideration of deploying constellations of up to several hundred satellites is that their implementation has to be accomplished without a major cost increase when compared to the few GEO assets they are to supplant. Additionally the deployment must take place over a short period of time (not decades) in order to achieve operational effectiveness, so the ability to achieve high manufacturing rates is vital. Finally, while the price tag of satellite busses, communication systems and processing has decreased, the same has not been true of traditionally utilized infrared sensors.

L3Harris has developed a radiation resilient Strained Layer Superlattice (SLS) detector material that supports high manufacturing yield and delivery cadence in large formats, while maintaining sensitivity for five- to seven-year LEO missions. The detector material is suitable for staring, TDI or hyperspectral configurations. Additionally, the L3Harris IR focal plane assemblies (FPAs) provide an intrinsic laser-resilience due to structure and material stack-up. When hybridized to radiation hardened Digital Read Out Integrated Circuits (DROICs), processing can be accomplished on the FPA such as random directional Time Delay Integration (TDI), motion compensation and SNR enhancement, prior to reading the data. The detector material can benefit from further development to intrinsically reduce the dark current for Space Situational Awareness and similar missions, but is presently suitable for shot-noise limited applications as well as other missions with due considerations applied.

1.0 L3HARRIS – EO/IR FOCAL PLANE ASSEMBLIES FOR SPACE

L3Harris has over thirty years of experience producing Infrared (IR) Focal Plane Arrays (FPAs) and Integrated Dewar, Electronics, and Cooler Assemblies (IDECAs) for commercial and government applications. The Space & Sensors Division in Mason, OH (Figure 1-1), is the site of our IR FPA foundry.

Figure 1-1: L3Harris Space & Sensors

The 245,000 square foot facility employs over 750 employees producing:

- Detector dies of various sizes, wavebands and architectures, and pixel pitches
- Read Out Integrated Circuit (ROIC) processing and hybridization
- Final IDECA assembly
- Testing – Quantum Efficiency x Fill Factor (QExFF), spectral response, dark current, detector Modulation Transfer Function (MTF), pixel cross-talk (for sun staring), black-body testing (temperature sweep vs integration times), Focal Plane Assembly (FPA), Noise Equivalent Delta Temperature (NEDT), Noise Equivalent Irradiance (NEI), standard pixel characteristics (operability, defects, shorts opens, gain/offset/noise anomalies)

L3Harris specializes in staring arrays, as opposed to scanning arrays. This focus enables a number of missions executed by proliferated low earth orbit constellations (satellites, sensors and processors) that would be almost impossible to achieve with any other configuration of platform, orbit, target radiometry, and sensor.

1.1 Space-based detection challenges

Heritage Intelligence/Surveillance/Reconnaissance missile detection satellites located in GEO look for bright missile plumes (high W/steradian signatures). The decreasing target signatures of advanced threat systems (such as hypersonic glide weapons) demand higher resolution sensors for robust detect-and-track solutions. This drives the need for sensors with smaller Instantaneous Field Of View (IFOV) that don’t sacrifice wide Field of View (FOV). As the Russia-Ukraine conflict has demonstrated, the initial deployment of hypersonic weapons systems is upon us, and so mid-course maneuvering is a deployed capability. Boost-phase state vectors are no longer adequate to predict adversary weapon flight paths. Non-ballistic maneuvering dictates that precise knowledge of target state at all times is required for effective intercept or countermeasure engagement.

2.0 NEAR-PEER SPACE DOMINANCE

Adversaries can utilize space launch and ground-based weapons to threaten NATO space-based assets in a variety of ways:

- Kinetic energy impact (direct, fragmentation)
- Disabling of sensitive electronics by high-power radio-frequency (RF)
- Disabling of sensors by high-power electromagnetic radiation (lasers)
- Disabling Critical Systems: Power Generation (solar panels), Communications, Thermal Management

There is the possibility of implementing defense systems, such as utilizing guard satellites that engage incoming threats to protect the ISR platform, or other similar self-defense systems on the ISR platform itself. However, preemptive engagement with other country's satellites risks escalation of hostility. Also, consider the “bar fight” analogy – the contest is typically fought and won or lost with the first punch. By the time NATO can react to a threat to an orbital asset, it likely is too late to implement mitigation

In 2019, General John Hyten, the Vice Chairman of the U.S. Joint Chiefs stated, “[Most military satellites were designed for a] benign environment, just like commercial satellites…I don’t want to buy any more fragile, un-defendable satellites.”

One solution to the undefendable ISR platform is to move from an architecture of a few high-cost assets in Geostationary Earth Orbit (GEO), to many low-cost in Low Earth Orbit/Medium Earth Orbit (LEO/MEO). Disaggregating assets provides ability to absorb loss of a significant number of assets, without a corresponding loss of capability. The constellations can be rapidly reconstituted from covert in-orbit spares or through operationally responsive launch. Lower costs also allow for rapid technology insertion and upgrades. Additionally, placing assets in LEO orbits cost less than placing them in higher, more energy demanding altitudes. Missile launch detection capability is maintained but surveillance from LEO allows for detection and tracking of advanced hypersonic threats, because the ranges between the detector and target have been closed by approximately a factor of 30x.

To achieve the goals of advanced detect and track of low thermal signature targets, the sensor requirement is for smaller IFOV for increased spatial and temporal resolution, as well as to maintain suitable signal-to-noise ratio. But FOV cannot be sacrificed because that leads to large regions of interest not under continuous surveillance.

2.1 A Gedanken Experiment

Consider that a constellation of ISR platforms is desired with the following characteristics:

- Constellation of 200 satellites w/ target cost <€2B (not including initial engineering)
    - €10M per satellite, including launch costs
    - €75M per launch vehicle; 20 satellites per launch = €3.75M per satellite launch costs

Therefore, the satellites must be low SWaP (space, weight & power) and <€6.25M / unit, and that figure includes:

- Processor
- Communications (RF and optical)

- Power generation and management
- Thermal control
- Assembly, Integration & Test
- End-of-life / deorbit
- Sensor

This implies that an ultra-large format IR sensor can have a cost comprising approximately 10% of the overall payload cost. This will be difficult to achieve with traditional IR sensor technologies, but Strained layer Superlattice sensors could very easily be the technical solution for ultra-large format (2K x 2K and larger), running at higher operating temperatures compared to traditional sensors (to impose a lower burden on power generation and heat dissipation systems).

3.0 STRAINED LAYER SUPERLATTICE

In the past, conventional target detect and track requirements were fulfilled by exquisite and more expensive large format sensors on Geostationary Earth Orbit (GEO) platforms. Because some FPA technologies' manufacturing yields are comparatively low (poor operability, excessive non-uniformity, low stability), many attempts are required to obtain a usable large format FPA, leading to long lead times and high costs per FPA. Additionally, characteristics that have made traditional technologies advantageous, such as low dark current/low dark noise, are less relevant for background limited infrared photograph (BLIP) applications, such as "look-down/earth background" sensing. SLS IR detector material can be fabricated for mid-wave, long-wave, or dual-band IR sensors.

In addition to meeting the subsystem technical figures of merit to achieve mission objectives, the Defense Community is tasked with insuring that the delivery cadence of relevant technologies can meet the formation and re-constitution schedule requirements of proliferated Low Earth Orbit (pLEO) constellations. As SLS is fabricated by commercial foundries, the manufacturing base is itself disaggregated and the production can be distributed over multiple suppliers, insuring that the production rate of raw SLS material remains constant and high.

3.1 SLS for Proliferated LEO Surveillance Constellations

Staring array technology meets mission concepts of operation (CONOPs) by enabling:

- 100% custody of non-ballistic targets, when compared to scanning systems
- Assured handoff of target tracks to other assets when target leaves on platform FOV and enters another
- Large format IR sensors utilize lower GSDs to minimize background irradiance and maximize SNR.

For example, the L3Harris 4K x 4K IR FPA (3-1) is usable for a variety of pLEO missions. It is a single chip (not abutted), and more than 100 can be manufactured per year in support of a rapid pLEO deployment. This sensor is not an "in-development" effort; it has been deployed on a number of airborne Intelligence, Surveillance and Reconnaissance (ISR) platforms over the last two decades.

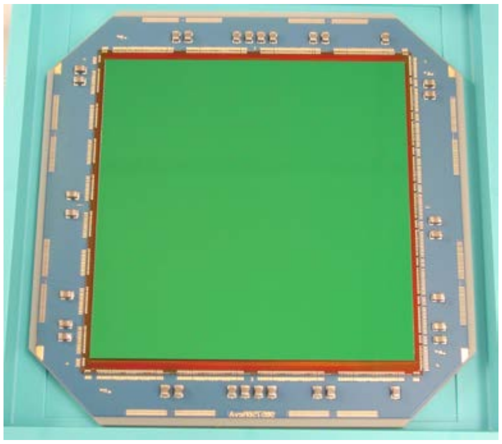

Figure 3-1: 4K x 4K FPA

3.2 L3Harris Focal Plane Technology

All IR FPAs are constructed of several layers of thermally mismatched materials, bonded together at room temperature. A top layer optical silicon, and a similar thickness of silicon ROIC underneath, are separated by an extremely thin layer (typically two orders of magnitude thinner than the Optical Si and ROIC) of detector material with a differing coefficient of thermal expansion (CTE). After cooling down to operating temperature, the detector layer's different CTEs generate stresses and displacements that lead to performance degradation, loss of pixels, and in extreme cases can cause FPA breakage.

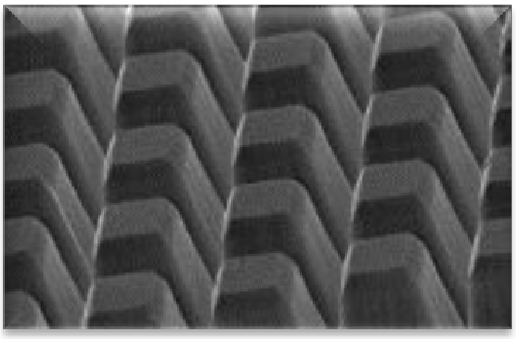

Figure 3-2: Reticulated Pixels

L3Harris FPAs use a fully-reticulated pixel geometry; each pixel is physically separated from its adjacent neighbors Figure 3-2). As a result our FPA's detector layer is structurally decoupled from the optical silicon layer above and ROIC silicon layer below. Thermally induced stresses are mitigated; warping and displacement of the FPA surface is minimized.

Besides being structurally decoupled from the other materials used in the focal plane, the reticulated pixels on the detector layer are also completely isolated from each other. Photon and electrical crosstalk are eliminated and detector modulation transfer function (MTF) approaches theoretical maximum (Figure 3-3). Maximizing MTF is essential to achieve the high energy on detector (EOD) required for low SNR target detect and track, because while background levels are identical in both reticulated and non-reticulated pixels, reticulation insures that the target signal isn't shared with adjacent detector elements so higher target SNR can be obtained.

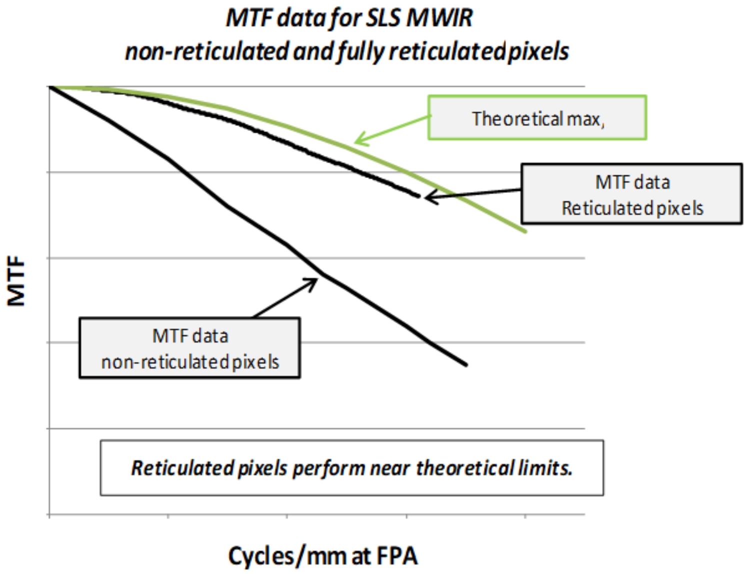

Figure 3-3: Reticulated vs. Non-reticulated MTF4K x 4K FPA

3.3 Laser Resilience

As LEO sensors can be subjected to ground-based directed energy countermeasures, laser resilience is a consideration for LEO optical sensors. The optical silicon in L3Harris FPAs behaves as a fuse. Laser fluences high enough to cause damage deposit energy in this layer and deform it. The incoming beam is scattered, reducing the areal energy density in the subsequent detector and ROIC layers (Figure 3-4).

Since 2000, laser tests conducted on InSb FPAs with the same structure, have not been able to disable an L3Harris focal plane completely; only small regions, rows or columns have been rendered inoperative

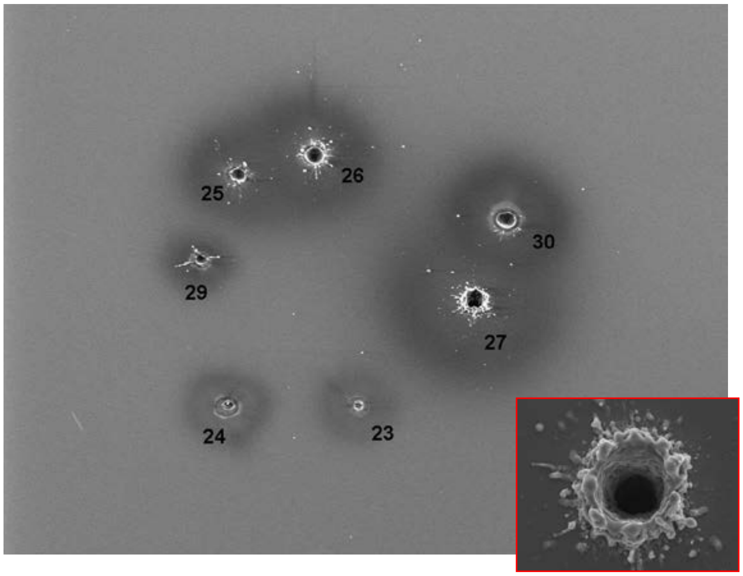

Figure 3-4: Reticulated vs. Non-reticulated MTF4K x 4K FPA

3.4 L3Harris FPA Performance

Intrinsic shielding provided by a Dewar can assure excellent performance over a 5 to 7 year mission lifetime by limiting total ionizing does to less than 2 krad. A Quantum Efficiency x Fill Factor of >75% at end-of-life can easily be obtained (Figure 3-5).

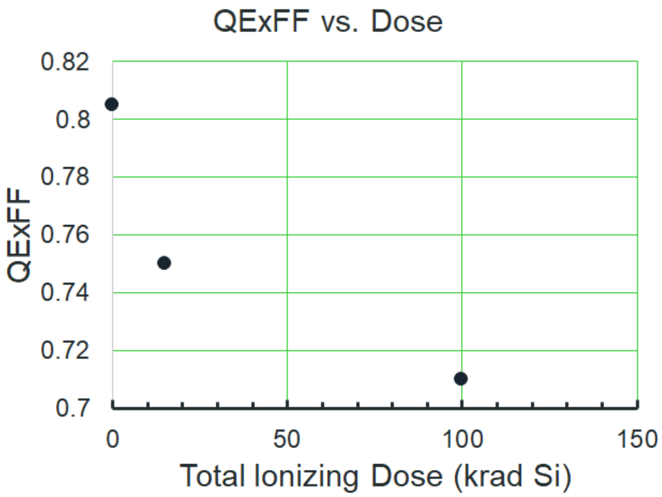

Figure 3-5: Quantum Efficiency x Fill Factor

Similarly, dark current can be kept below 2 uA/cm^2(Figure 3-6).

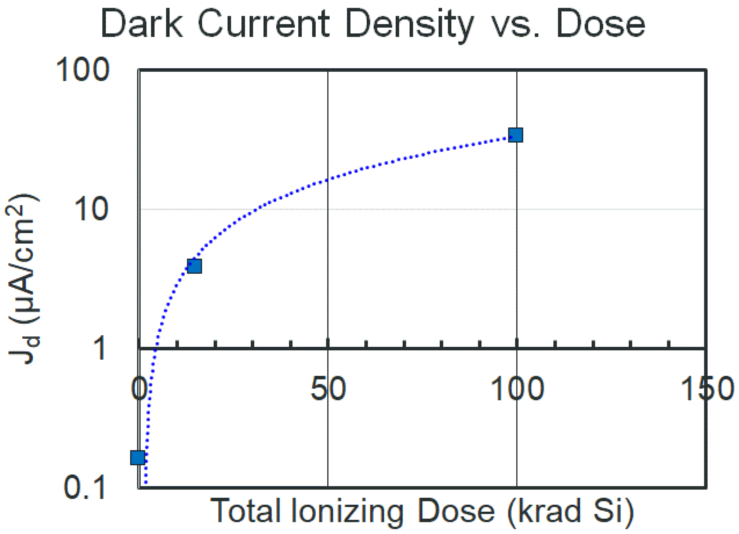

Figure 3-6: Dark Current

4.0 SUMMARY

Familiarity with and emotional attachment to older technologies may be an impediment to changing paradigms. Performance metrics not usually considered need to be prioritized, and herein is where SLS presents advantages not normally prioritized:

- Operability (>99.8% working pixels)
- Uniformity (every pixel, nearly equal response)
- Stability (as low as one recalibration/day)
- Near-theoretical maximum Detector Modulation Transfer Function
- Cost
- Manufacturability and manufacturing cadence – how many can be obtained per year

While a number of legacy IR detector technologies may provide some improved performance on a per-pixel basis, the mission requirements (including cost and delivery schedule) must dictate the appropriate technical solution. Emotional attachment to legacy technologies could prevent the entertainment of newer technologies that can achieve the mission objectives. The Systems Engineering Approach must be taken: “Design is based on requirements. There's no justification for designing something one bit "better" than the requirements dictate.”