Development of a High-Definition IR LED Scene Projector

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ABSTRACT

Next-generation Infrared Focal Plane Arrays (IRFPAs) are demonstrating ever increasing frame rates, dynamic range, and format size, while moving to smaller pitch arrays.[1] These improvements in IRFPA performance and array format have challenged the IRFPA test community to accurately and reliably test them in a Hardware-In-the-Loop environment utilizing Infrared Scene Projector (IRSP) systems. The rapidly-evolving IR seeker and sensor technology has, in some cases, surpassed the capabilities of existing IRSP technology.

To meet the demands of future IRFPA testing, Santa Barbara Infrared Inc. is developing an Infrared Light Emitting Diode IRSP system. Design goals of the system include a peak radiance >2.0W/cm^2/sr within the 3.0-5.0μm waveband, maximum frame rates >240Hz, and >4million pixels within a form factor supported by pixel pitches ≤32μm. This paper provides an overview of our current phase of development, system design considerations, and future development work.

Keywords: Infrared Scene Projection, IRSP, Hardware-In-the-Loop, Infrared Light Emitting Diode, ILED

1. INTRODUCTION

The proliferation of advanced IRFPA systems has challenged the IRFPA test community to develop systems that can fully exercise them. These advanced IRFPA systems boast large formats, small pixel pitches, high-dynamic ranges, and very-high frame rates. While a number of methods exist for testing such systems, the use of IRSP systems in a Hardware-In-The-Loop (HWIL) environment allows for high-fidelity, synthetic imagery to be projected to the IRFPA system. This imagery is intended to closely resemble that of real-world scenarios. With the ever-expanding capabilities of IRFPA systems, comes a corresponding expansion in real-world phenomena which may be detected. Testing IRFPA systems in a live environment is expensive, potentially dangerous, and often times unpredictable due to the many factors which affect such testing. Utilization of IRSP systems in a HWIL environment allows for cost-effective, safe, and highly-repeatable testing of IRFPA systems. However, next-generation IRFPA systems are emerging that will have test requirements which surpass the capabilities of many current IRSP systems.

Santa Barbara Infrared Inc. (SBIR) is an industry leader in the development and production of IRSP systems. For over 15 years, SBIR has responded to the varying needs of the IRFPA test community to bring them effective, reliable IRSP systems capable of fulfilling test requirements. These test requirements are often unique to specific applications, thus requiring unique capabilities of the IRSP system used to test them. In some areas, the requirements of next-generation IRFPA systems have moved beyond the capabilities of our current MIRAGE XL and OASIS IRSP systems. To meet the needs of advanced IRFPA detector system design, development, and testing, SBIR is pursuing the development of several advanced IRSP systems and components.[2,3,4] SBIR has teamed up with industry experts from Attollo Engineering, Power Photonic, and Oleson Convergent Solutions to design and develop an IRSP system with an Infrared Light Emitting Diode (ILED) emitter core. In this paper, we outline the initial progress in the ILED IRSP system development.

Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XXVII,
edited by Gerald C. Holst, Keith A. Krapels, Proc. of SPIE Vol. 9820, 98200X
2016 SPIE · CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2225852

2. BACKGROUND AND SYSTEM DEVELOPMENT GOALS

The inherent properties of ILEDs make them an attractive option for meeting a number of the future requirements of IRSP systems. ILEDs rely on the transition of electrons and holes to generate photons. This process is very fast, allowing for rise and fall times of ≤10μs to be realized. The ability to tune the emission wavelength, as well as the relatively narrow full-width-half-maximum spectral output of an ILED, allows for very high in-band radiance efficiencies. The Current-Voltage (I-V) characteristics of an ILED emitter array can be tuned to match the requirements of a Read-In-Integrated-Circuit (RIIC) used to drive it. The materials growth, device fabrication, and packaging of ILEDs closely resemble that of IRFPAs, allowing for ILED emitter array formats to be well-matched to next-generation IRFPAs. For these reasons, multiple efforts have been pursued to develop ILED emitter arrays for the use in IRSP systems.[5,6,7,8] To date, these efforts have been primarily focused on the development of the ILED emitter arrays and the supporting RIIC technology, with little work towards bringing a fully-integrated IRSP system based on ILED technology to fruition. SBIR's ILED-based IRSP system development efforts represent a key stepping-stone to such an integrated system.

SBIR has set goals to design, develop, and build an IRSP system which incorporates an ILED emitter array with the following characteristics: 1) exhibits a peak radiance >2.0 W/cm^2/sr within the 3.0-5.0μm (MWIR) waveband, 2) operates at maximum frame rates >240 Hz, 3) supports a 2048x2048 array format, and 4) features a pixel pitch of ≤32μm. Each of these requirements represents an approximate 2x improvement over that of existing, commercially available, state-of-the-art IRSP systems. Leveraging SBIR's IRSP system expertise, a careful trade study was carried out to define target ILED array and system parameters. SBIR is approaching the development of the ILED IRSP system as an iterative process, similar to that of previously developed IRSP systems. The following sections give a brief overview of SBIR's current state of development of the ILED system, as well as planned future efforts.

3. INFRARED LED DEVELOPMENT AND TESTING

SBIR is currently researching and developing an ILED array that will maximize radiance output with minimized power input levels. We have currently produced a small format test array of ILEDs that incorporates a 15-stage, Interband Cascade Light Emitting Diode (ICLED) active region device structure, and is designed for a peak emission of 3.4μm at 77K operation. Similar device structures have been designed to exhibit high power outputs for room temperature operation.[9] The 77K electroluminescent spectrum of the ICLED device is shown in Figure 1. The Full-Width at Half-Maximum (FWHM) of the spectral emission is approximately 550nm. Note that nearly 91% of the emission spectrum falls within the MWIR waveband.

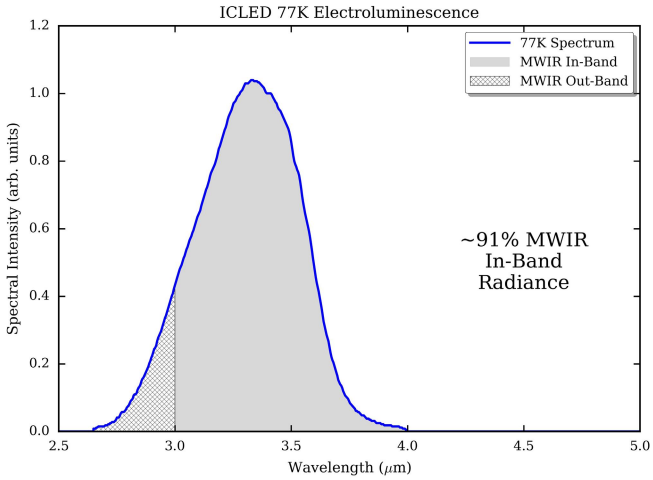

Figure 1. The 77K electroluminescence spectrum of a 15-stage ICLED. The solid shaded region depicts the amount of the spectrum that falls within the MWIR band, while the hatched region indicates that portion of the spectrum which falls outside of the MWIR band. Approximately 91% of the spectral intensity falls within the MWIR band.

The test arrays feature individual ICLED devices with pitches varying from 24-32µm. This allows for assessment of performance as a function of pitch size. The array architecture exhibits a high fill-factor of ~70% for all pitch sizes, which is noteworthy, as the output radiance of an emitter array scales linearly with fill-factor. A fully-processed test array featuring 32µm pitch devices is shown in Figure 2.

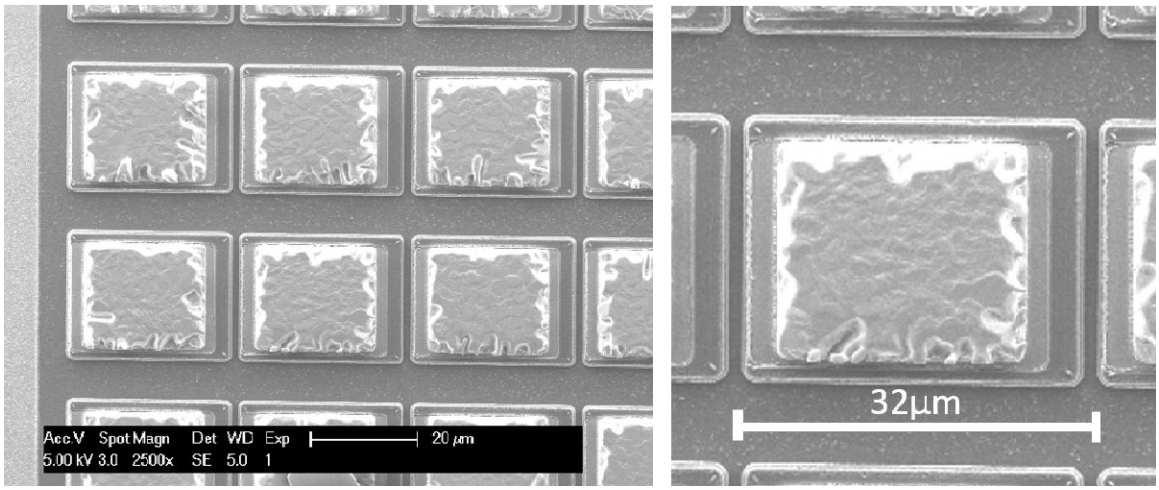

Figure 2. SEM micrograph of a fully-processed, 32µm pitch test array (left) and zoomed-in portion of the array (right). Horizontal and vertical spacing between adjacent pixels is 2µm and 8µm, respectively.

Devices were fabricated and then flip-chip-bonded to a Silicon (Si) fanout header. The hybridized structure was then packaged and wirebonded to a Leadless Ceramic Chip (LCC) carrier. This test configuration allows for assessing the device's performance in a manner which closely resembles that of a fully hybridized ILED-RIIC array. The LCC is mounted in a pour-filled, liquid nitrogen (LN_2) test Dewar with electrical feed-throughs. Testing and characterization utilized the SBIR Calibration and Radiometry System (CRS). The CRS features an IRCameras IRC800 MWIR camera, motion stages, and blackbody calibration sources. The ILED devices were driven with a D.C. current supplied by a Keithley Source-Measure Unit.

The Light-Current-Voltage (LIV) characteristics of one of the ILED test dies is shown in Figures 3a) and b), and the resultant 3.0-5.0µm waveband apparent temperature is shown in Figure 3c). The data collected feeds into system level requirements including RIIC design and thermal dissipation management. All devices exhibit peak radiance levels with equivalent MWIR apparent temperatures which exceed that of current, state-of-the-art IRSP systems. However, these radiance values are still a factor of 2.3-3.0 less than is necessary to achieve an in-band radiance >2.0 W/cm^2/sr. To increase the radiant output and achieve the goal of >2.0 W/cm^2/sr within the MWIR waveband, future efforts will focus on optimization of device active regions and processing techniques.

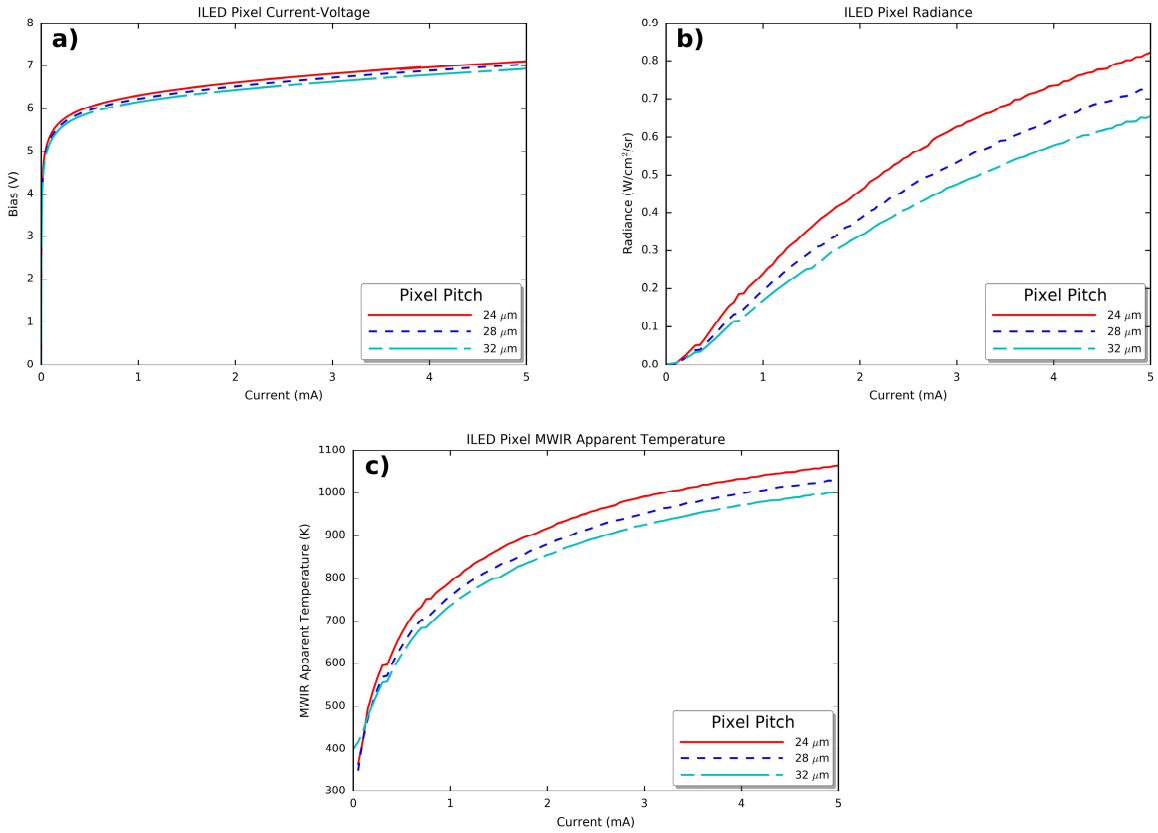

Figure 3. Measured a) Current-Voltage, b) Current-Radiance and c) Current-MWIR-Apparent-Temperature response of a 15-stage Interband Cascade Light-Emitting Diode (ICLED) with three different device pitches (24µm, 28µm and 32µm).

4. RIIC DEVELOPMENT AND MODELED SYSTEM PERFORMANCE

Leveraging our experience with previous IRSP development efforts, as well as concurrent RIIC development efforts under the Ultra High Temperature (UHT) program, SBIR has completed initial RIIC driver cell development for the ILED IRSP system. A careful trade study was performed which took into account: the emitter format and pitch, the I-V characteristics of the ILEDs, the projected RIIC yield, thermal step size for projection of near ambient imagery, and the desired frame rate. For this reason, the ILED RIIC has been designed to support both "tiled" and fully-monolithic array formats. Scalable array architectures have been studied extensively by SBIR, and offer an attractive method for achieving a cost-effective operational solution for building-up large-format emitter arrays from smaller, higher-yielding RIIC sub-array "tiles".[4] This is achieved joining the RIIC tiles via Quilt Packaging nodules, as shown in Figure 4a). These nodules have been successfully demonstrated with gaps ≤5µm. The current ILED RIIC design has wirebonds along only one edge, enabling 3-sided quilting, however the chip layout was designed for future support of full 4-sided quilting as well. Through-Silicon-Vias (TSVs) have been incorporated to support power routing of the high currents needed to drive ILED pixels with minimal voltage drops. In addition to power routing, TSVs also support other signal Input-Output in 4-sided quilted configurations. TSVs have been demonstrated on a 6" wafer with a 100% yield. Figure 4b) shows a Scanning Electron Microscopy (SEM) image of a zoomed in portion of the 6" wafer, in which 90µm diameter TSVs were demonstrated.

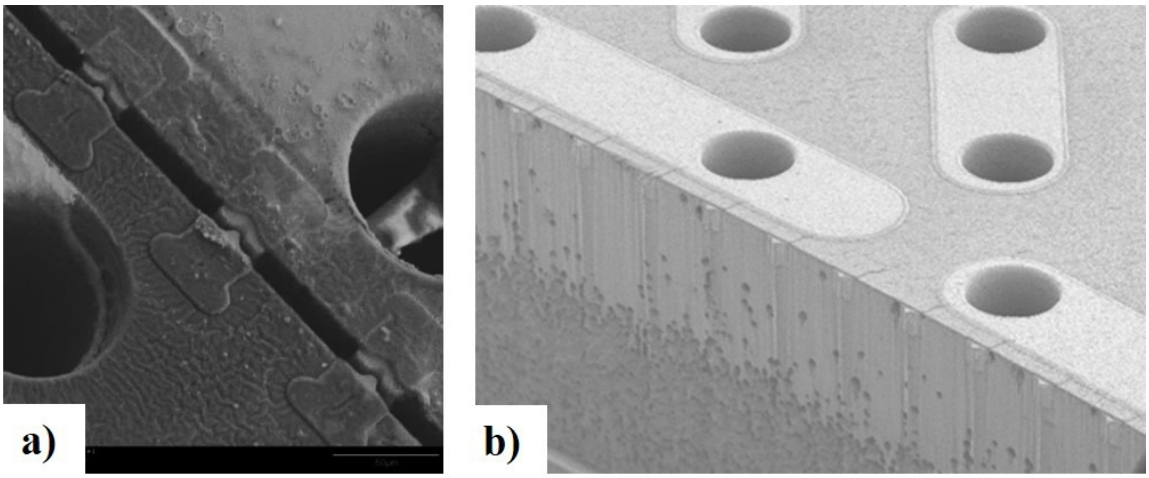

Figure 4 SEM images of a) two die connected with Quilt Packaging and b) a TSV contact chain test structure that achieved a 100% yield across a 6" wafer.

The forward voltage characteristics of ILEDs are strongly dictated by the energy bandgap of the ILED, as well as the number of cascaded active regions incorporated into the design. For this reason, the ILED RIIC has been designed to support multiple ILED technologies, and features an appreciable compliance voltage and maximum current supply.

Critical to the design and performance of IRSP systems is the minimum thermal step size which may be projected, specifically for near ambient (~300K) scenes.[10] An inherent property of ILEDs is their highly non-linear change in radiance with change in current input. As shown in Figure 5a), the radiance resolution of an ILED has a very steep increase for low drive currents. This poses a challenge for ILED-based-IRSP systems to project a thermal step size that is small enough to sufficiently exercise some modern and future IRFPA systems. The minimum projected thermal step size is a product of the Digital-to-Analog-Converter (DAC) bit-resolution, the minimum step size achievable by the RIIC (ideally noise-limited), the output characteristics of the emitter as a function of input, and the full output dynamic range. ILED device modeling based on the collected data shown above supports that the RIIC design can both handle the output characteristics of ILEDs and minimize the projected thermal step size, all while maintaining a maximum output sufficient to achieve the goal of >2.0 W/cm^2/sr within the MWIR.

Using both the simulated RIIC drive characteristics and the collected ILED data, a model of the ILED to RIIC drive response was created (see predicted results in Figure 5b). In generating the model, a 14-bit resolution DAC was assumed. The model indicates that the baseline RIIC design could support driving the current ILED pixels to a MWIR radiance level equivalent to an apparent temperature >900K, surpassing legacy systems. However, the model also reveals that the minimum thermal step size achieved for a 300K apparent temperature output is 262mK. For near ambient apparent temperatures, this would be unsatisfactory for testing some of the existing and future IRFPA systems. Future RIIC development efforts will be aimed at iterating the RIIC design to increase the maximum current drive, reduce the pixel pitch (with a goal of 24μm), and improve the radiance resolution when projecting typical terrestrial temperatures.

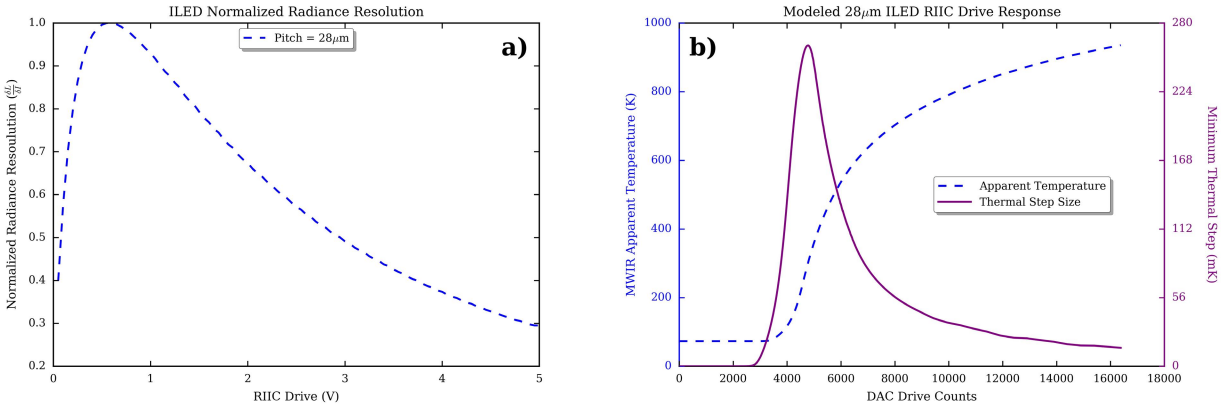

Figure 5. The modeled results in a) show the normalized radiance resolution of a 28µm ILED. Note the very steep increase in radiance as a function of current for low current drive input. The modeled results in b) show the 28µm-pitch ILED array apparent temperature and thermal resolution (minimum step size) as a function of RIIC drive input. The model was built using both RIIC performance simulations and collected ILED data, and assumes a 14-bit DAC.

5. CONCLUSIONS AND FUTURE WORK

In an effort to fulfill the increasing needs of the IRFPA test community, SBIR has teamed up with industry experts Attollo Engineering, Power Photonic, and Oleson Convergent Solutions to develop an IRSP system featuring an ILED emitter array with a peak radiance output >2.0 W/cm^2/sr MWIR. This system is being designed to exhibit frame rates >240Hz, and to support a minimum of a 2048x2048, ≤32µm pitch architecture. The work carried out thus far demonstrated ILEDs with peak emission at 3.4µm and peak radiance outputs >0.68 W/cm^2/sr (>900K MWIR apparent temperature). A RIIC unit cell supporting both monolithic and tiled, 28µm pitch array architectures has been designed and simulated. The simulated RIIC characteristics and collected ILED data were used to model the ILED system apparent temperature and minimum temperature resolution that may be achieved. In continuation of the ILED IRSP system development, SBIR plans to investigate methods to improve the ILED peak radiance by means of active region design and processing techniques. In addition, the RIIC design will be iterated to increase the maximum current output, decrease the pixel pitch, and improve the radiance resolution.

REFERENCES

[1] Schultz, K. I., Kelly, M. W., Baker, J. J., Blackwell, M.H., M. G. Brown, Colonero C. B., David, C. L., Tyrrell, B. M., and Wey, J. R., "Digital-Pixel Focal Plane Array Technology", Lincoln Laboratory Journal, Vol. 20, Number 2, (2014).

[2] Franks, G., LaVeigne, J., McHugh, S., Lannon, J., Goodwin, S., "Development of an Ultra-High Temperature Infrared Scene Projector at Santa Barbara Infrared Inc.", Proc. SPIE 9452 (2015)

[3] Sparkman, K., LaVeigne, J., McHugh, S., Lannon, J., Goodwin, S., "Ultra High Temperature Emitter Pixel Development for Scene Projectors", Proc. SPIE 9071 (2014).

[4] Sparkman, K., LaVeigne, J., McHugh, S., Kulick, J., Lannon, J., Goodwin, S., "Scalable Emitter Array Development for Infrared Scene Projector Systems", Proc. SPIE 9071 (2014).

[5] Das, N. C., Shen, P., Simonis, G., Gomes, J., Olver, K., "Light Emitting Diode Arrays for HWIL sensor testing", Proc. SPIE 5785 (2005).

[6] Bradshaw, J. L., Bruno, J. D., Lascola, K. M., Meissner, G. P., Pham, J. T., Towner, F. J., "Interband cascade resonant cavity surface emitting LEDs for 2d-array scene projectors", Proc. SPIE 7663 (2010)

[7] Jung, S., Suchalkin, S., Westerfeld, D., Kipshidze, G., Golden, E., Snyder, D., Belenky, G., "High dimensional addressable LED arrays based on type I GaInAsSb quantum wells with quinternary AlGaInAsSb barriers", Semicond. Sci. Technol. 26 (2011)

[8] Norton, D.T., Olesberg, J. T., McGee, R. T., Waite, N. A., Dickason, J., Goossen, K.W., Lawler, J., Sullivan, G., Ikhlassi, A., Kiamilev, F., Koerperick, E. J., Murray, L. M., Prineas, J. P., Boggess, T. F., "512 x 512 Individually Addressable MWIR LED Arrays Based on Type-II InAs/GaSb Superlattices", IEEE JQE, Vol. 49, No. 9 (2013).
[9] Abell, J., Kim, C. S., Bewley, W. W., Merritt, C. D., Canedy, C. L., Vurgaftman, I., Meyer, J. R., and Kim, M., "Mid-infrared interband cascade light emitting devices with milliwatt output powers at room temperature", APL 104, 261103 (2014)
[10] LaVeigne, J., Franks, G., Danielson, T., "Thermal Resolution Specification in Infrared Scene Projectors", Proc. SPIE 9452, (2015).