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Infrared Sensors, Devices, and Applications V

Paul D. LeVan
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Infrared Sensors, Devices, and Applications V

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Arvind I. D'Souza, DRS Sensors & Targeting Systems, Inc. (United States)

Session 1: Novel Detectors and Materials

Session Chairs: Paul D. LeVan, Air Force Research Lab. (United States); Arvind I. D'Souza, DRS Sensors & Targeting Systems, Inc. (United States)

Advanced EO/IR technologies at DARPA/MTO (Invited Paper) [9609-32]

J. S. Lewis, Defense Advanced Research Projects Agency (United States); N. K. Dhar, U.S. Army Night Vision & Electronic Sensors Directorate (United States); L. A. Elizondo, R. Dat, Booz Allen Hamilton Inc. (United States)

Dr. Lewis began by describing the program structure in MTO, the Micro-Systems Technology Office, with the mission to "create or prevent strategic surprise". The technologies span the electro-magnetic spectrum, and focus areas include EM spectrum, tactical information extraction, and exploiting globalization through the use of its emerging products.

Details were provided on the AWARE program for Advanced Wide (100° x 60°) field of view Architecture for image Reconstruction & Exploitation. The program leveraged commercial off-the-shelf cameras (382 total) to make a 2 GPixel camera, with a pixel size of 1.4 micron. This program has had many successes, including demonstration imagery at sporting events, for which the entire stadium is captured in a single image, and where magnification of individual regions of interest show detail at the level of shoelaces. A commercial spin off of this technology (from Duke Univ.) is the Acuity Corp., with recent its success mentioned.

The contractor team for PIXNET, for fused reflected and thermal imaging, includes Raytheon Visions Systems, UTAS (InGaAs), and DRS (the only LWIR approach, with an uncooled micro-bolometer). These are clearly divergent approaches involving different wavebands, suggesting a high level of complementariness.

Finally, interesting developments in the area of micro-coolers (small size, weight, and power for the soldier) were presented. Continuous Joule-Thompson capability exploiting MEMS technologies obviates the need for large compressors. Technical challenges include replacing compressors working at near 100 to 1 pressure reduction, with MEMS much lower at 4 to 1. These MEMS compressors have piezo-electrically driven actuators, and the overall cooling cycle is isenthalpic. Can Sterling performance be met or exceeded for the current goal of 70 °K? Yes, in theory, by adding stages. However, the near-term goal of 150 °K would meet the needs of a variety of higher-operating temperature MWIR (and SWIR?) focal plane arrays. When cascaded, each stage has a refrigerant optimized for its operating temperature.

Semi-insulating GaAs and Au Schottky barrier photodetectors for near-infrared detection (1280 nm) [9609-1]

A. I. Nusir, Y. F. Makableh, O. Manasreh, Univ. of Arkansas (United States)

This technology exploits the Schottky barrier formed by locating GaAs against gold contacts. The author showed how the metallic work function energy combines with the electron affinity of GaAs to produce band gaps in the range of 1 eV, which is sensitive to infrared radiation in the range of 1.3 microns. In fact, spectral responsivity of this approach results in a peak at shorter wavelengths corresponding to the GaAs and a longer wavelength peak (near 1.3 microns) corresponding to the Schottky barrier. Applications include telecom at 1.3 micron and 1.55 micron wavelengths. Switching speeds are related to the carrier mobility in GaAs. Average turn-on time is ~0.6 sec. Very high ratios (~10^4) have been found for photocurrent to dark current, at a five volt operating bias.

Heterojunction depth in P+-on-n eSWIR HgCdTe infrared detectors: generation-recombination suppression [9609-2]

J. Schuster, U.S. Army Research Lab. (United States) and Boston Univ. (United States); R. E. DeWames, Fulcrum CO. (United States); E. A. DeCuir Jr., U.S. Army Research Lab. (United States); E. Bellotti, Boston Univ. (United States); N. Dhar, U.S. Night Vision Electronic Sensing Directorate (United States); P. S. Wijewarnasuriya, U.S. Army Research Lab. (United States)

Highly detailed, three-dimensional models were shown to provide a theoretical understanding of extended SWIR (>1.7 microns with a 3 micron goal). The proposed use of heterojunction as a means to reduce generation-recombination current targets operations in the 150 °K temperature regime. (This approach makes sense; only a narrow band gap is needed in the absorber region, whereas a wide band gap can be employed on the non-absorber side of the pn junction.) In addition, graded Cd composition was investigated to reduce the voltage dependence of QE, and this graded Cd composition also increases the range of p-type depth that yields performance, easing device fabrication tolerances. In response to a question from the audience, it was pointed out that fabrication challenges can be addressed by relaxing the few tenths of micron tolerance on the composition and doping profile overlaps; this is possible with the new designs. Although an example was provided for planar architecture, a similar theoretical approach is possible for mesa architectures.

Compositional control of the mixed anion alloys in gallium-free InAs/InAsSb superlattice materials for infrared sensing [9609-3]
H. J. Haugan, F. Szmulowicz, K. Mahalingam, G. J. Brown, S. L. Bowers, J. A. Peoples, Air Force Research Lab. (United States)

In this presentation, the author described the issue relating to Antimony separation from intended locations in superlattice structures of InAs/InGaSb, and motivated the concept of "frustration" in terms of failures of the material to achieve layer sharpness. The analysis tools, used for evaluating the grown material, include x-ray energy dispersion and x-ray rocking curves. These analyses have pointed to the need for alternative growth methodologies, with the possibility of higher growth temperatures to keep Sb in place. Good x-ray rocking curve results have been obtained in this case. One sample in particular was noted as significant, having 5% Sb in InAs. These efforts are important as the Schottky-Read-Hall lifetimes are short for this material, and the "gallium-free" version, although having longer lifetimes as reported in the literature, still suffers from Sb separation and degraded performance. Notably, D* in Ga-free detectors was found lower than in superlattices with Ga.

Enhancement of electron-injection detector performance by their unique three-dimensional geometry [9609-6]
V. Fathipour, H. Mohseni, Northwestern Univ. (United States)

A unique three-dimensional detector geometry was described; it involves a high sensitivity electron injection capability. A very elegant movie illustrated the operational mechanism of the electron injection process, showing the buildup of photocarriers at a barrier, and the resulting flow of these carriers upon subsequent photon absorption. Two variations in geometry involving the injector area were perfected and evaluated. The smaller injector was found to have a factor of 10 less dark current. Optical gain is also a significant figure of merit; gain was found to improve by substantial amounts with the smaller injector. A model has been subsequently developed that predicts these figures of merit on the basis of the injector size. Note was also made of the fact that the InP employed is a mature and low-cost material.

A new detector for high-speed swept source optical coherence tomography [9609-7]
V. Fathipour, H. Mohseni, Northwestern Univ. (United States)

Following the thorough description of the electron-injection detector in the previous presentation, an application of the device for Optical Coherence Tomography (OCT) was described. The medical applications include the areas of ophthalmology, cardiovascular health, and other fields. An analogy was made with ultrasound interferometry, for which indirect detection provides useful diagnostics. The issue with the current technology is size; increased portability would be of real benefit for the new emphasis on point-of-care testing and diagnoses. Source infrastructure can be dramatically reduced if the unity gains of the currently used PIN detectors would be replaced with a Gain 50 version of the electron-injection detector. A balanced detection technique was described that results in additional significant sensitivity increases. Important figures of merit for this application include remarkable noise levels and very short response times.

Characterization on Geiger-mode operation of deep diffused silicon APDs [9609-9]
E. B. Johnson, X. J. Chen, M. McClish, R. Farrell, K. Vanderpuye, J. Christian, Radiation Monitoring Devices, Inc. (United States)

This paper, presented by Xiao Chen, described a solid state replacement technology for photomultiplier tubes (PMT). Low-light-level applications are many, including scintillation detection. The very fast (< 10 nanosec) response time, and relatively low dark count rate (for an operating temperature of -50 °C) were described. The "after pulse" properties have also been characterized. In response to an audience question, the spectral response of these Geiger-APDs was noted to be much broader than that of photomultiplier tubes (e.g., the Multi-alkali, Na-K-Sb-Cs, S20). Possibilities now include an SSPM (solid state photomultiplier) sensitive to individual photons.

Development of large area nanostructured antireflection coatings for EO/IR sensor applications [9609-38]
A. K. Sood, G. Pethuraja, R. E. Welser, Y. R. Puri, Magnolia Optical Technologies, Inc. (United States); N. K. Dhar, U.S. Army Night Vision & Electronic Sensors Directorate (United States); P. S. Wijewarnasuriya, U.S. Army Research Lab. (United States); J. Lewis, Defense Advanced Research Projects Agency (United States); H. Efstathiadis, P. Haldar, SUNY Polytechnic Institute (United States); E. F. Schubert, Rensselaer Polytechnic Institute (United States)

The author described highly efficient, nanowire-based anti-reflection coatings operating even at large angles for use in the UV, Vis, and NIR that have been demonstrated with prospects for extension into the MWIR and LWIR. Refractive index values are small and correspond to high levels of absorption. The technology achieves its capability with variable-angle growth. The metrology for measurements down to 0.1% reflection values was described. Deposition has been demonstrated on both sides of a glass substrate, on areas as large as six inches in diameter. Questions relating to the effects of contamination and porosity changes were asked; nothing has been observed along these lines according to the presenter. Also, high run-to-run reproducibility has been demonstrated.

Session 2: Models, Simulations, Theory

Session Chairs: Priyalal S. Wijewarnasuriya, U.S. Army Research Lab. (United States); Ashok K. Sood, Magnolia Optical Technologies, Inc. (United States)

Determining the electrical mechanism of the surface resistivity property of doped polyvinyl alcohol (PVA) and the pyroelectric property of polyvinylidene difluoride (PVDF) thin films [9609-10]

M. Edwards Sr., Alabama A&M Univ. (United States) and Institute of Higher Science Education Advancements and Research (United States); A. Janen, P. Guggilla, J. Polius, J. Douglas, M. Curley, Alabama A&M Univ. (United States)

This presentation described interesting materials, including multi-wall carbon nano-tubes, fabricated in the university laboratory, and films that exhibited pyroelectric and resistivity-based sensitivities to infrared light. This author described the preparation and characterization of films employing multi-wall carbon nano-tubes, for which surface conductivity following Ohm's Law was noted. In response to the question as to the nature of the surface current mechanism, the author reviewed possible electrode-limited conduction behaviors: Schottky, Fowler-Nordheim, tunneling and thermionic. Comparisons with tri-glycine sulphide were described. The demonstration of methyl alcohol sensitivity for one of the film types inspires similar sensitivity investigations for the case of ethyl alcohol.

Series-coupled fiber double-ring in Mach–Zehnder interferometer for temperature sensing [9609-20]

Y. Zhang, Y. Wu, X. Zhang, H. Li, P. Yuan, Harbin Institute of Technology (China)

A theoretical investigation was described for optical filters and shows narrow (~0.5 nm) dips in transmission, with the sharpest asymmetric line shapes found near the resonance wavelength; these observations motivate the use of this Mach–Zehnder interferometer as a highly sensitive temperature sensor. The approximate wavelengths for the attenuation feature are in the 1.3 micron region, and various amounts of "wavelength de-tuning" provide variation on the spectral shape and structure. The approach thus appears suitable for highly sensitive, compact and stable temperature sensing.

Session 3: Focal Plane Arrays and Electro-Optical Components

Session Chairs: Priyalal S. Wijewarnasuriya, U.S. Army Research Lab. (United States); Arvind I. D'Souza, DRS Sensors & Targeting Systems, Inc. (United States)

Fabrication of Resonator-Quantum Well Infrared Photodetector (RQWIP) with 10.2 µm cutoff [9609-14]

J. Sun, K. K. Choi, K. Olver, R. X. Fu, U.S. Army Research Lab. (United States)

In this presentation, a QWIP architecture was described in which there is a pairing of the wells, with two closely spaced wells separated from other pairs by a relatively larger distance. Diffractive elements are the basis of the light coupling structure, which serves to convert normally incident radiation into a propagation direction along the layers of QW, which can be detected. Structures were grown with three scale factors for evaluation, and differences were noted in terms of responsivity. These test devices combine relatively high quantum efficiencies (~40%) with modest photoconductive gains (~0.2 at 0.7 volt bias) to achieve respectable levels of responsivity. The outcome of the investigations led to the fabrication of a megapixel focal plane array, with the detector material thinned following the approach reported in the literature by the author and his coworkers. The NEDT figures of merit were found to approach 10 milli-Kelvin at the lower operating temperatures. Deviations between the theoretical levels of response profile broadness and those observed might be explained in terms of dopant migration.

All optical modulator based on silicon resonator [9609-16]
H. Pinhas, L. Bidani, O. Baharav, M. Sinvani, M. Danino, Z. Zalevsky, Bar-Ilan Univ. (Israel)

The presentation, by Hadar Pinhas, described an exploitation of the "plasma dispersion effect" for the realization of an optical modulator working in the 1.55 micron region. This works via the Plasma Dispersion Effect, in which the refractive index changes with free carrier concentration. In addition, the absorption coefficient increases the free carrier concentration. Wavelength scanning, with wavelength steps in the amounts of 0.01 nm, was possible with the experimental setup.

The first trials found only a 3dB drop in transmission, but this was achieved with a respectable time constant—sub-100 nanosec. Anti-reflection coating applied to the silicon resonator increases transmission efficiency close to 98%, making for a 12dB change, which is adequate for the intended application. A "thermo-optical effect" was noted, with separate temporal regimes for this effect (having a longer time constant) and the plasma dispersion effect that is sought (and exhibiting a shorter time constant); the authors have emphasized the need to address this issue further.

Design of ultra-thin metallic grating based circular polarizer in the near infrared [9609-17]
D. Hu, P. Wang, P. Lin, F. Gao, J. Du, Sichuan Univ. (China)

The presentation began with a description of the conventional approach for generating circularly polarized light, using a linear polarizer and quarter wave plate. Double gratings were combined to form circular polarizers. In one alternative approach that also uses a quarter wave plate, the transverse magnetic (TM) wave interacts with a gold grating, with the angle of the vector relative to the grating direction tunable to allow for the generation of left- and right-hand circular polarization. The polarized transverse electric (TE) wave, located in the direction of grating metals, also forms part of the analysis.

Session 4: Innovative EO Fiber Applications

Session Chairs: Ashok K. Sood, Magnolia Optical Technologies, Inc. (United States); Paul D. LeVan, Air Force Research Lab. (United States)

Design and development of wafer-level near-infrared micro-camera [9609-33]

J. W. Zeller, Magnolia Optical Technologies, Inc. (United States); C. Rouse, H. Efsthadiatis, P. Haldar, State Univ. of New York Polytechnic Institute (United States); N. K. Dhar, U.S. Army Night Vision & Electronic Sensors Directorate (United States); J. S. Lewis, Defense Advanced Research Projects Agency (United States); P. Wijewarnasuriya, U.S. Army Research Lab. (United States); Y. R. Puri, A. K. Sood, Magnolia Optical Technologies, Inc. (United States)

The capabilities at the Albany NanoTech (SUNY College of Nanoscale Science & Engineering) fab employed for the growth of SiGe on 12" (300 mm) wafers are impressive and exploited in this effort. Test structures were grown, characterized, and found to have approximate microAmp per square centimeter current densities at room temperature. With the goal of achieving wavelength response beyond 1.55 μm, the tensile strain imposed by the silicon substrate is exploited to increase the wavelength cut-off. For this to become practical, dislocations at the substrate growth interface must be controlled; these have been seen and are currently part of a reduction effort. SIMS characterization in particular on the grown films shows promising results but also identified some minor adjustments to the doping that are necessary. Current-voltage and photocurrent characterizations emphasized the reverse bias properties, and time response measurements with a chopped radiation source were accomplished. Measured spectral response extends out to 1.6 microns. In response to a question, the authors noted that ROIC hybridization is deferred until improved material performance is achieved.

Mid-infrared GeTe4 waveguides on silicon with a ZnSe isolation layer [9609-36]

V. Mittal, C. Craig, N. P. Sessions, D. W. Hewak, J. S. Wilkinson, G. S. Murugan, Univ. of Southampton (United Kingdom)

As part of a project to detect biological molecules on the surface of tiny waveguide structures, the author began with nice animations of the vibrational modes of the water vapor molecule, which motivates the presence of absorption features in the infrared region. Sputtering deposition of layers of $GeTe_4$ on ZnSe, with an underlying substrate of silicon allows the $GeTe_4$ material to define the waveguide channel. The experimental setup consists of a quantum-cascade laser with wavelengths from 2.5 microns to 14 microns, the waveguide, and the detector. Using a FLIR camera, the infrared radiation near the 6.8 micron wavelength was seen emerging from various channels of the fabricated waveguide. Wavelengths in the multichannel waveguide extend from 3.7 micron to 9 micron wavelengths. A new source for improved ZnSe for use on the silicon was noted as needed and is being pursued.

Integrated multi-color illumination source for lab-on-a-chip fluorescence analysis [9609-21]

A. J. Zakariya, Ministry of Interior (Kuwait); E. Mulla, Ministry of Electricity and Water (Kuwait)

This lab-on-a-chip fluorescence analysis approach conceives of LEDs operating at three separate wavelengths, as a result of varying the amounts of quantum well mixing. The fluid under test (in this case, blood plasma) flows through micro-fluidic channels for illumination by a three-color LED system. Tuning of the LEDs, GaAs/AlGaAs, as part of an impurity-free vacancy interdiffusion (IFVD) approach, arises as part of the fabrication's thermal process. Fabrication of test structures involved selective lithography of SiO_2, with height the varying parameter. Prototype testing was accomplished, with emitted wavelength selectivity demonstrated and measured in the 775 nm to 805 nm wavelength region. Ultimately, the near-infrared emission from these LEDs would be extended over the full range of UV to IR, to permit the broadest range of applicability. The resulting medical applications have both diagnostic and treatment potential.

Mechanically induced long period fiber gratings on single mode tapered optical fiber for structure sensing applications [9609-22]

M. G. Pulido-Navarro, S. Marrujo-García, J. A. Álvarez-Chávez, J. S. Velázquez-González, F. Martínez-Piñón, Ctr. de Investigación e Innovación Tecnológica (Mexico); P. J. Escamilla-Ambrosio, Ctr. de Investigación en Computación (Mexico)

A tapering of optical fibers can be achieved at elevated temperatures and with tensile stress, and this taper can be exploited with a variable index of refraction in the fiber core that results from a phase change at temperatures above 600 °C. The resulting fiber transmission properties are then related to the stress in the fiber, with shifts in the attenuation features of up to 20 nm measured at wavelengths near 1.57 microns, making the approach sensitive to impending failure of structural elements in which the fiber is buried. The author described this and other applications of the technology.

PET and PVC separation system based on optical sensors [9609-23]

G. G. Pérez-Sánchez, Univ. Autónoma Metropolitana (Mexico); J. A. Álvarez Chávez, Ctr. de Investigación e Innovación Tecnológica (Mexico); J. R. Pérez-Torres, Tecnológico de Estudios Superiores de Coacalco (Mexico); A. Gómez-Vieyra, Univ. Autónoma Metropolitana (Mexico)

After noting the severe ecological impacts of waste plastics, the presenter presented a system for separating minor contamination levels of PVC from a PET waste flow, so that the latter may be economically recycled. In this method, wavelengths are transmitted through "flakes" of the materials. The near-infrared transmission spectra of the two materials were shown, and these differences are exploited in transmission to enable discrimination. An audience member suggested, due to the variable thicknesses of the material flakes, a ratio method employing two wavelengths located on and off a spectral feature that may provide a more robust discrimination capability.

Session 5: Components and Applications of EO/IR Technology

Session Chairs: Arvind I. D'Souza, DRS Sensors & Targeting Systems, Inc. (United States); Paul D. LeVan, Air Force Research Lab. (United States)

LWIR pupil imaging and prospects for background compensation [9609-24]

P. LeVan, Air Force Research Lab. (United States); Ü. Sakoglu, Texas A&M Univ. (United States); M. Stegall, G. Pierce, SE-IR, Inc. (United States)

The author described the results of employing a sensitive, low-flux focal plane array (FPA) for moderate flux operations in a system that images the optical pupil onto the FPA. A detailed characterization was provided of the system employing this FPA, over a broad range of pixel fluxes. The goal of the characterization was to address the question of non-uniformity correction (NUC) over the entire flux range, using a standard NUC approach. At the end of characterization discussions, mention was also made of using commercial tracking platforms for infrared background subtraction. A capability based on this approach was shown to have a broad range of applications. These applications include generating scene motion in the laboratory for quantifying performance of "real-time, scene-based non-uniformity correction" approaches. Another application is to effectuate subtraction of backgrounds that are bright relative to the source, by alternating the viewing aspect between the source and adjacent, source-free backgrounds.

High-performance near-infrared spectrally encoded microscopy by using a balanced detector [9609-25]

J. Liao, W. Gao, Nanjing Univ. of Science and Technology (China)

This approach for spectrally encoded microscopy begins with a swept source that is transmitted to a "circulator" for distribution to a grating and sensor and, in parallel, to balanced detectors. Higher resolution is found when the balanced detection scheme is employed. The resolution of the fabricated device was showcased with images of a coin displayed for "direct detection" and then with balanced detection.

Development of high gain avalanche photodiodes for UV imaging applications [9609-34]

A. K. Sood, J. W. Zeller, R. E. Welser, Y. R. Puri, Magnolia Optical Technologies, Inc. (United States); R. D. Dupuis, M. Ji, J. Kim, T. Detchprohm, Georgia Institute of Technology (United States); N. K. Dhar, U.S. Army Night Vision & Electronic Sensors Directorate (United States); J. S. Lewis, DARPA/MTO (United States); R. L. Peters, U.S. Dept. of the Interior (United States)

This paper, on the development of high gain avalanche photodiodes for UV imaging applications, was presented by Dr. Sood and described the results of years of experience with this technology. First, several target and background phenomenology issues were described for the UV. In addition to smaller pixel format FPAs, larger pixel pitch structures are of interest for UV APD arrays. Growth of the GaN/AlN APDs was by metal organic, chemical vapor deposition, and performed at Georgia Tech. This material was processed into sensor array test structures based on a PIN architecture, and gains as high as 10^5 have been measured.

Large format MBE HgCdTe on silicon detector development for astronomy [9609-35]

B. J. Hanold, D. F. Figer, J. Lee, K. Kolb, I. Marcuson, Rochester Institute of Technology (United States); E. Corrales, J. Getty, L. Mears, Raytheon Vision Systems (United States)

This MBE HgCdTe on silicon detector development for astronomy emphasizes very low dark currents (fractional electrons per sec at a 40 °K operating temperature) with SWIR cut-off wavelengths (and with wavelength cut-ons as short as 0.4 micron), and the goal of extending performance to MWIR once the less challenging issues in SWIR are addressed. The current ROICs used for evaluation are a 2K x 2K, 20 micron pitch with read-out noise levels in the range of five electrons. The ultimate goal is an 8K x 8K, 15-micron pitch FPA. Ten 2K x 2K FPAs have been tested to date. Test structures for this developmental effort explore variations in mesa widths and their impacts on both dark current and responsivity. A nice data acquisition system with cooling based on a closed cycle Helium system was described; it includes automation capabilities, enabling longer data collecting without operator presence. Other characterization methods were mentioned: Proton dosing achieved at the proton therapy facility of Massachusetts General Hospital, complimented with serendipitous cosmic ray "hits" for the measurement of adjacent pixel crosstalk. Thinning of the fabricated FPAs is key to achieving shorter infrared and visible wavelength responses. Most notable in the recent characterization is the measured tail in the upper end of the dark current distribution. Defect-revealing cross sectional analysis points to the existence of substrate lattice matching shortfalls, and the potential need for thicker buffer layers. Performance predictions with and without thinning illustrated increased shorter wavelength response as a result of the thinning.