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Infrared Sensors, Devices, and Applications IV

**Paul D. LeVan
Ashok K. Sood
Priyalal Wijewarnasuriya
Arvind I. D'Souza**
Editors

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Paul D. LeVan, Air Force Research Laboratory (United States)
Arvind I. D'Souza, DRS Sensors & Targeting Systems, Inc.
(United States)

Summary:

Infrared Sensors, Devices, and Applications IV

Conference Chairs

Paul D. LeVan, Air Force Research Laboratory (United States)

Ashok K. Sood, Magnolia Optical Technologies, Inc. (United States)

Priyalal Wijewarnasuriya, U.S. Army Research Laboratory (United States)

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

SESSION 1: Advanced Detector Material and FPA Component Studies

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

Interface and facet control during Czochralski growth of (111) InSb crystals for cost reduction and yield improvement of IR focal plane array substrates [9220-2]

N. W. Gray, V. Perez-Rubio, J. G. Bolke, W. B. Alexander, 5N-Plus Semiconductors (United States)

The author described seeing in melt, for steps including growth, wafer dicing, lapping, and polishing of 5" diameter wafers. The challenges are anisotropic segregation and dislocation formation. The author provided a very detailed explanation of on- and off-axis growth and convex and concave surfaces from isotherms in melt (these can be controlled). Tellurium is a contaminant, and the allowable range is tight and can only be met by employing new approaches. Dislocation control is possible by allowing a tapered (as opposed to a large area) surface to be removed slowly from the melt, resulting in less thermal shock. A repeatable process has been found. Although the 111 orientation has always been specified by customers, it was unclear to experts in the audience why the easier 100 orientation could not be employed to make equally superb InSb photodiodes.

Fabrication of resonator-quantum well infrared photodetector test devices and focal plane arrays [9220-3]

J. Sun, K. K. Choi, M. D. Jhabvala, C. A. Jhabvala, A. Waczynski, K. Olver, U.S. Army Research Laboratory (United States) and NASA Goddard Space Flight Ctr. (United States)

The "Resonator QWIP" approach promises higher responsivity with an array (e.g., 4x4 per pixel) of diffractive elements on the underside of QWIP detector array. The author first described the significant advantages and disadvantages of QWIP sensor arrays, including the availability of large substrates, low 1/f noise, and "self-passivation". Thinned, QWIP pixel designs incorporating varying configurations of resonators were fabricated, with quantum efficiency as high as 70% measured in one case. In a separate study, varying the number of quantum wells between six

and 21 was described. Questions included one on misalignment sensitivity of the resonant structures and misalignment impact on efficiency.

Embedded plasmonic-enhanced quantum well infrared photodetector [9220-4]

R. L. Brown, A. Bonakdar, S. J. Jang, Northwestern University (United States); O. G. Memis, Intel Corporation (United States); H. Mohseni, Northwestern University (United States)

In describing the reduced volume QWIP, the author began by first citing work by Wie Wu in the area of plasmonic enhancement of QWIP performance (winner of the 2010 SPIE best student paper) and wishing to extend the earlier results from the single pixel to the 2-D sensor array configuration. The approach to embed the plasmonics below the surface layer allows for the placement of indium bump contacts. Other areas of emphasis include a spin-on dielectric application to keep a specialized photoresist away from the detector surface, thus avoiding the SiO₂ absorption feature near 8 microns using a flip chip bonding approach with cold welding via gold. A question on whether surface leakage currents were more appreciable for the smaller pixel structures was addressed, with the answer that these currents are small and have not yet been measured.

Design and development of SiGe based near-infrared photodetectors [9220-44]

J. W. Zeller, Magnolia Optical Technologies, Inc. (United States) and State University of New York College of Nanoscale Science and Engineering (United States); Y. R. Puri, A. K. Sood, Magnolia Optical Technologies, Inc. (United States); S. McMahon, H. Efsthadiatis, P. Haldar, State University of New York College of Nanoscale Science and Engineering (United States); N. K. Dhar, DARPA/MTO (United States)

This presentation explored SiGe PIN as an alternative to InGaAs, exploiting 12" diameter silicon wafers. Very high frequency response (approaching 50 GHz) and current density comparisons with InGaAs were described. Reported dark current density values were greater than four orders of magnitude higher than InGaAs. Compressive strain on Ge with respect to silicon reverses over the range of room and growth temperatures (a one two-step high and low temperature growth process for reduction of threading dislocations). Details on band structure with and without tensile strain motivated the decrease in energy bandgap and increased in cut-off wavelength, for better coverage of the telecom waveband. Test structures of 20, 50 and 200 micron diameters were fabricated, I-V curves were measured, and responsivity was evaluated. Both Auger and SIM diagnostics were employed; evidence of tensile strain was found. Audience questions touched on the use of Ge rather than Si substrates (yes, but it is cost issue), whether point defects for low-temperature seed growth were seen, and if vastly lower dark current levels in InGaAs were seen (yes, but telecom application is digital and dark current levels are compatible with this).

SESSION 2: Performance Modeling and Simulation; Noise

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

Study of real-time image denoising and hole-filling for micro-cantilever IR FPA imaging system [9220-5]

Y. Feng, Y. Zhao, L. Dong, M. Liu, X. Liu, X. Li, Z. Zhao, Beijing Institute of Technology (China); X. Yu, Peking University (China); M. Hui, H. Wu, Beijing Institute of Technology (China)

This presentation was by Ph.D. student Mr. Guo (a substitute speaker for the original presenter). He described the advantages of uncooled infrared sensors, including their low cost. This innovative cantilever approach shines LED light onto an array of bolometric microlevers, which deflect according to the amount of absorbed IR and direct the LED light onto a CCD array, with differences on the CCD array corresponding to pixel signals. Procedures for replacing bad pixels ("de-noising") were described. Corrected imagery of hand, face, and soldering iron radiation was shown. (The bad pixels, either noisy or in the form of outages, may result from vibration, instability of illuminating light, manufacturing defects, or optical aberrations). The details of the bad pixel compensation technique were described in mathematical form.

Hyperspectral modeling of an infrared focal plane array [9220-6]

S. Mouzali, S. Lefebvre, S. Rommeluère, Y. Ferrec, J. Primot, ONERA (France)

This paper concerns an innovative substrate for HgCdTe that incorporates a wedge angle, with the goal of forming a static, in-place, Fourier Transform Spectrometer capability within the FPA itself ("Microspoc"). The current design operates at wavelengths between 1.5 and 5 microns, with a resolution in wavenumbers of $\sim 20\text{cm}^{-1}$. Careful measurements of spectral response were made with a laboratory monochromator, and corrections were determined to obtain uniformity of the cut-off wavelength along the spatial direction of the FPA. The spectrum is recovered not with a Fourier Transform, but rather using one of the innovative algorithms that the author described. Results with a "3 wave model" were discussed; this compensates for multiple paths between the three interfaces (substrate face, substrate-detector array interface, and detector array backside).

Surface resistivity temperature dependence measures of commercial, multiwall carbon nanotubes (MWCNT), or silver nano-particle doped polyvinylidene difluoride (PVDF) and polyvinyl alcohol (PVA) films [9220-7]

M. Edwards, S. Egarievwe, T. Kukhtareva, J. Polius, A. Janen, J. Corda, Alabama A&M University (United States)

Prof. Edwards first reviewed PVDF for pyro-electricity and PVA with Ag nanoparticle doping to enhance absorption as a basis for thermal sensing. Surface resistivities

were measured as a function of temperature, and these measurements were calibrated with commercial films. Obtaining stress-free PVDF still presents a challenge. The incorporation of Ag nanoparticles leads to resistivity that is found to increase over the temperature range from 22°C to 40°C. During the question-and-answer period, the importance of determining a predicted coefficient of performance for thermal sensing was mentioned; this is one of the author's planned areas of investigation.

SESSION 3: Detector and FPA Characterization

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

The influence of sunlight irradiation on the characteristics of InGaAs detectors [9220-8]

X. Shao, Y. Zhu, X. Li, H. Tang, T. Li, H. Gong, Shanghai Institute of Technical Physics (China)

The author described applications of sensing technology for meteorological satellites in geosynchronous orbits. A degradation in the operability of a European Space Agency satellite detector was noted. For these studies, spectral responsivity was found to be unchanged by solar radiation. However, an increase in the lattice constant is suggested by the measured changes in the Bragg reflection angles; it was noted that this matches the InP lattice constant for x values near 0.53, $\text{In}_{1-x}\text{Ga}_x\text{As}$. It is postulated that by inducing a population of thermal electrons, excessive amounts of solar radiation lead to a form of "thermal stress degradation". In response to an audience question, smaller changes would be expected for smaller pixels of FPAs, compared with larger test structure dimensions.

Study on 512×128 Pixels InGaAs near infrared focal plane arrays [9220-9]

X. Li, H. Tang, S. Huang, X. Shao, T. Li, Z. Huang, H. Gong, Shanghai Institute of Technical Physics (China)

This paper described 512x128 InGaAs FPAs that employ a CTIA (capacitive trans-impedance amplifier) to maintain a proper operating point for the pixel biases over a broad range in photocurrent. Square InGaAs test structures with sizes of 100 μm , 200 μm , and 300 μm on a side were used to determine the diffusion current's limited operation, with current densities in the range of 35 nA/cm². A surface passivation approach was mentioned. For the 30 micron pixels in the 512x128 FPA, some G-R current contribution is believed possible. A linear response with increasing integration time was noted.

Resonant scanning mechanism [9220-10]

J. Wallace, M. Newman, H. Gutierrez, C. Hoffman, T. Quakenbush, D. Waldeck, C. Leone, M. Ostaszewski, Ball Aerospace & Technologies Corporation (United States)

John Wallace described a resonant scanning mechanism for applications that include airborne beam steering. This approach provides uniformity and a "high density" of transmitted light. The fast elevation axis includes the resonant springs, and the slower, larger swing, outer axis, which both have position feedback. It was the calibration that posed a special challenge in characterizing the mechanism over its range of beam steering angles; the rms level of absolute pointing accuracy was reported and is impressive. During question-and-answer period, the "adaptive control" approach was mentioned as a means to keep power dissipation low, and the lifetime of the cabling that spans the gimbals is projected as 10 years or longer.

MWIR InAsSb FPA data and analysis [9220-11]

E. Robinson, A. I. D'Souza, A. C. Ionescu, D. Okerlund, DRS Sensors & Targeting Systems, Inc. (United States); T. J. De Lyon, R. D. Rajavel, H. Sharifi, HRL Labs., LLC (United States); N. K. Dhar, DARPA (United States); P. S. Wijewarnasuriya, U.S. Army Research Laboratory (United States); C. Grein, University of Illinois at Chicago (United States)

An nBn structure fabricated on GaAs substrate results in G-R dark current suppression when operating at temperatures near 150 Kelvin. A ROIC employing subframe averaging (switched capacitor) realizes effective well capacities of 13 million and 24 million electrons, depending on the mode. Two versions of the device were measured; reported levels of pixel operability (in terms of noise-equivalent temperature) were outstanding at 99.66%. In response to the audience question-and-answer session, a short wavelength (~0.5 micron) response is possible if substrate removal techniques are employed. Also, the observed corner delamination of the hybridization is to be expected for not having employed epoxy on these test FPAs. Finally, a comparison of dark current densities to HgCdTe was mentioned as challenging.

SESSION 4: Applications of EO Sensing Technology

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

Human suspicious activity recognition in thermal infrared video [9220-12]

J. Hossen, E. Jacobs, F. Chowdhury, The University of Memphis (United States)

The author discussed various algorithms for the detection of "suspicious activity" in video data streams. Algorithmic acronyms included GMM, GEI, PCA, MDA, LARK, and PLSA, with most cross-referenced to publications on the briefing slides. In response to audience questions, segmenting and feature extractions (relating to recorded activities) are conducted in that order.

Analysis of total oil and fatty acids composition by near infrared reflectance spectroscopy in edible nuts [9220-13]

C. V. Kandala, J. Sundaram, Agricultural Research Service (United States) and The University of Georgia (United States)

This presenter described a variety of IR spectral techniques to evaluate the characteristics of nuts (including peanuts and pecans) and seeds (including corn, mustard, and soy). Total oil content, for example, differentiates edible peanuts from those processed for oils. By employing a FOSS IR reflectance spectrometer operating over the wavelengths from 700 nm to 2300 nm, the strengths of absorption bands of OH, CH, and NH can be quantified and are diagnostic of these characteristics. New algorithms for training and validation of the analysis techniques, relying on a "calibration group" of two important peanut types, were mentioned. A thorough discussion of the RPD statistic motivated discussions on diagnostics with and without shell removal for the two peanut types.

Temperature-tuned erbium-doped fiber ring laser with Mach-Zehnder interferometer based on two quasi-abrupt tapered fiber sections [9220-14]

R. Selvas-Aguilar, Universidad Autónoma de Nuevo León (Mexico); A. Martinez-Rios, Ctr. de Investigaciones en Óptica, A.C. (Mexico); G. Anzueto-Sanchez, Universidad Autónoma del Estado de Morelos (Mexico); A. Castillo-Guzmán, M. Hernández-Luna, R. Robledo-Fava, Universidad Autónoma de Nuevo León (Mexico)

The laser wavelength in this case can be controlled by a variety of techniques, including bending, stress, and temperature of the fiber through which it passes. The current approach achieves up to 12 nm of wavelength variation, when temperature is varied from 20°C to 110°C. In the present approach, an Erbium-doped fiber is immersed in a bath of glycerol, for which the index of refraction is temperature dependent. Interesting behavior occurs at the temperature for which the refractive indices are identical for the glycerol and fiber, which is a temperature near 75°C. A quasi-linear shift in wavelength was found over the range from 80°C to 110°C. The author identified some of the simple improvements that are possible with this system. In response to an audience member's question, the index of refraction of glycerol was noted to decrease as temperature increased.

Development of blood vessel searching system using near-infrared light stereo method for clinical blood sampling [9220-15]

K. Cheng, Y. Morita, E. Nakamachi, Doshisha University (Japan); N. Honda, K. Awazu, Osaka University (Japan)

An innovative approach was described for finding and guiding a blood extraction needle to deep-tissue blood vessels which are difficult for manual medical personnel to perform. The stereo method explored wavelengths at 660 nm, 870 nm,

and 940 nm, correcting for the refractive effects at the air and skin interface. A prototype was evaluated by constructing a representative blood vessel in material having similar structure and optical properties of tissue. Location accuracies were quantified and are in the range of 0.05 mm to 0.15 mm, relative to an assumed 2 mm diameter blood vessel. Additional work in automated needle insertion is planned.

High reflected cubic cavity as long path absorption cell for infrared gas sensing [9220-32]

J. Yu, Q. Gao, Z. Zhang, Harbin Institute of Technology (China)

Increasing the path length of gas for long-path absorption improved the detection of gases. This spectroscopic approach exploits molecular absorption features (e.g., O₂ near 760 nm). The configuration of a "tandem cubic cavity" was described, and the related equivalent optical path length (EOPL) was quantified with validated equations. The empirical approach speaks to aperture diameter variations that allow optimization of "tunable diode laser absorption spectroscopy".

SESSION 5: Novel Sensing Concepts

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

Approaching high temperature photon counting with electron-injection detectors [9220-16]

V. Fathipour, S. J. Jang, I. Hassaninia, H. Mohseni, Northwestern University (United States)

This paper covered the linear mode electron injection detector for wavelengths in the range of 1.5 microns to 2.5 microns, operating at temperatures above 150 Kelvin. The relative advantages and disadvantages of a transition edge superconductor operating at sub-Kelvin temperatures, and HgCdTe avalanche photodetectors, were first outlined. This approach involves an InGaAs absorber, and the predicted excess noise factor is favorably close to unity. Rise times as short as 5 nanoseconds were reported; recovery times as short as 100 nanoseconds were reported in response to audience questioning. This reversed-biased architecture employs a barrier in the energy levels at which an avalanche of electrons resides. Efforts were put forth to eliminate a surface leakage problem in earlier versions of the architecture. Predicted dark count rates, for pixel sizes to be used with a ROIC, are in the 1 Hz regime at 210 Kelvin, much better than the current SOA.

Dual behavior of optical antenna integrated with sub-wavelength photodetector to achieve ultra-high specific detectivity [9220-17]

A. Bonakdar, R. L. Brown, H. Mohseni, Northwestern University (United States)

Use of an antenna structure to reduce detector volume and thereby dark current was reported by this presenter, for wavelengths from 3 microns to 8 microns. First,

impacts by the antenna on increased recombination rates were considered. A comparison of implementation issues were outlined for HgCdTe (interband) versus AlGaAs (intersubband). Based on a LDOS (local density of states) argument, relative radiative and non-radiative rates contribute to noise in differing amounts in these two material systems, and the resulting enhancements with the antenna structures are found to differ. Predictions suggest a favorable outcome in the case of AlGaAs, with prospects for surpassing BLIP of a traditional QWIP. More investigations are required to fully quantify a fabrication approach. A question relating to metal losses affecting EM waves was addressed.

Frequency tunable photo-impedance sensor [9220-20]

T. Saxena, S. Rumyantsev, P. Dutta, M. Shur, Rensselaer Polytechnic Institute (United States)

The author motivated a very innovative, frequency-driven structure that results in very high dynamic range for incident light, acting as a photoimpedance sensor. The functioning of the device is understood in terms of the illumination creating complex impedance, itself a function of the frequency of the external sinusoid. The complex impedance is understood in terms of carrier generation and recombination, impurity traps, etc. The frequency setting determines the illumination range for which responsivity is optimized. Simulation results showed an expected $\times 10^6$ dynamic range achieved over the range of driving frequencies. SOI material was identified for the desirable characteristics of deep depletion, acceptable capacitance, and favorable characteristic curves. Audience questions included one on the power dissipation for a high-frequency driving sinusoid; this is something the author wishes to pursue in detail.

SESSION 6: Applications of Detectors and FPAs

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

Er3+/Yb3+ co-doped all-fiber Mach-Zehnder interferometer for 1550 nm applications [9220-21]

G. Pérez-Sánchez, Tecnológico de Estudios Superiores de Coacalco (Mexico); E. F. Pinzón-Escobar, G. E. Sandoval-Romero, Universidad Nacional Autónoma de México (Mexico); J. A. Álvarez-Chávez, Ctr. de Investigación e Innovación Tecnológica (Mexico)

This presentation reported on an interferometer employing a long-period grating and operating at wavelengths near 1.55 micron. A "super luminescence" (or Amplified Spontaneous Emission) capability was described. Equations of spontaneous emission and details of a pressure-sensitive coupling constant were also discussed. Current progress includes sensing ammonia gas, with prospects for other gases with infrared active transitions. By employing a "weighted fiber", the Mach-Zehnder interferometer achieves a 1.45 micron to 1.65 micron wavelength

range. Future work will include an algorithmic quantification of the measured spectra for ease of interpretation.

Pupil imaging with a high sensitivity, LWIR focal plane array [9220-24]

P. D. LeVan, J. E. Hubbs, Q. T. Pratt, Air Force Research Laboratory (United States)

The presenter stressed that usefully long integration times could be achieved with a low-background and well capacity and LWIR FPA optimized for use with cooled optics in space through pupil imaging. The system controls extraneous background radiation with a small (150 μm) cooled pinhole that nevertheless transmits all the radiation of a point source collected by the fore-optic. Broad waveband response (3 μm to 12 μm) results from optimization of the fore-optic for both MW and LWIR. A field lens is used at the pinhole to reimage the entrance aperture and its surrounding cold stop. Integration times in excess of 10 milliseconds have been achieved for room temperature backgrounds with the Dewar cold stage operated at 50 Kelvin. The nature of a signal polarity reversal that was found for increasing levels of flux was described in detail.

An improved apparatus of infrared videopupillography for monitoring pupil size [9220-25]

T.-W. Huang, National Chiao Tung University (Taiwan); M.-L. Ko, National Chiao Tung University (Taiwan) and National Taiwan University Hospital, Hsin-Chu Branch (Taiwan); Y. Ouyang, Chang Gung University (Taiwan); Y.-Y. Chen, B.-S. Sone, M. Ou-Yang, J.-C. Chiou, National Chiao Tung University (Taiwan)

The author covered motivation, system description, the experiment and conclusions of the presentation. Diseases and eye dysfunctions (including diabetes, myopia, and glaucoma) were shown to cause different pupil reactions to light ("sympathetic response"). The measurement approach involves illumination of the pupil with a beamsplitter that also transmits an image of the eye's pupil to a CCD camera. Reimaged pupil diameters on a sensor array range from approximately 240 pixels to 305 pixels. Processes for removing light spots (possibly created by particulates in the eye) and other imaging defects were described. A test sample comprising 33 healthy, two myopic, and 10 diabetic samples was analyzed; at this time, the standard deviations are comparable to the difference in pupil measurements among the three test groups. A question from the audience probed the penetrating nature of 900 nm light; the author's work to date, however, seems to involve three shorter wavelength regions.

**Paul D. LeVan
Ashok K. Sood
Priyalal Wijewarnasuriya
Arvind I. D'Souza**

