Space Astrophysics Detectors and Detector Technologies

Contributed Talks

(close to final)

Gas Proportional Pixel Detectors for X and Gamma-ray Imaging

P. Deines-Jones[1], K. Black[1], S.D. Hunter[1], J.R. Huang[2], T. N. Jackson[2], K. Jahoda[1], H. Klauk[2], and W. Qian[2]

[1]NASA/Goddard Space Flight Center, Greenbelt, MD 20771

[2]Center for Thin Film Devices, 121 Electrical Engineering East, Pennsylvania State University, University Park, PA 16802

Well detectors are pixelized gas proportional counters that are true two-dimensional imagers. Well detectors are attractive not only for their imaging capabilities (currently less than 300 mm FWHM resolution), but they are also economical to produce and simple to operate even in very large areas. These detectors are mechanically robust, highly stable even at large gas gains and operate at room temperature. We are developing well detectors for large-area (~400 cm^2) X-ray imagers, as well as for very large-area (>10 m^2) electron trackers for gamma-ray imaging.

We describe the fabrication and performance of our 5 x 5 cm^2 prototypes and discuss our development plans for both X-ray imagers and electron trackers. This includes demonstrating the technology for focal plane detectors for LOBSTER-ISS, a capillary-optic soft X-ray monitor proposed for the International Space Station in 2006.

Characterization of a multianode photomultiplier tube for use with scintillating fibers to detect gamma rays

Keith Rielage, McDonnell Space Sciences Center & Dept. of Physics, Washington University, St. Louis, MO 63130

The performance of a multianode photomultiplier tube (MAPMT) with 64 anodes coupled to scintillating fibers has been examined. Such a detector system can be used in a pair- production gamma-ray telescope as well as in other applications. The characteristics of these tubes (Hamamatsu R5900-00-M64) will be presented including single photoelectron sensitivity, electrical and optical cross-talk, and dark count. Environmental test results of these devices will also be presented.

Detector systems for the X-ray evolving universe spectroscopy mission (XEUS)

M. Bavdaz, A. Peacock, A. Parmar, M. Beijersbergen, J. Schiemann+

Space Science Department of ESA, ESTEC, 2200AG Noordwijk, Netherlands

Tel.: 00 31 71 565 4933, Fax: 00 31 71 565 4690

[+]Directorate Of Manned Spaceflight and Microgravity ESA, ESTEC, 2200AG Noordwijk, Netherlands

Abstract The study of the origin and early evolution of our universe will become more accessible within the coming decade. With improved telescopes we will be reaching towards larger distances and thus looking further back in time. Very large apertures and highly sensitive detectors are needed to observe these highly red-shifted and very weak sources. In order to be able to perform X-ray diagnostics on the first black holes at redshifts of more than 4 and study their evolution, XEUS needs to have a sensitivity of 10^{-18} erg/cm^2/s and an angular resolution of below 5 arcseconds. A wide energy bandpass and high spectral resolution complement the demanding requirements. A telescope mirror diameter of 10m with a focal length of 50m is needed to achieve such performance. An innovative mission scenario had to be developed for XEUS, utilizing the extensive infrastructure available with the International Space Station (ISS).

The strawman payload of XEUS consists of a semiconductor based wide-field imaging spectrometer and two high resolution cryogenic spectrometers with imaging capability. The proper thermal environment for the detectors will be provided by closed cycle coolers and passive radiators. The detector instruments will form the basis of the Xeus Detector Spacecraft, and will be protected from straylight by appropriate baffles and filters. The requirements for the detector instruments on XEUS will be described, together with the current status of the ongoing study activities and possible detector system implementations.

mbavdaz@estec.esa.nl

Hard X-ray Telescope for Space Flight Use

Upendra Desai, Larry Orwig, Code 682 GSFC/NASA

Lawrence Mertz, Digiphase Technology, Palo Alto, CA.

Carl Gaither, CNA Corporation, Washington, DC

Walter Gibson, Center for X-ray Optics University at Albany, N.Y.

As a proof of concept, we have designed, fabricated, and tested a novel hard x-ray telescope. The concept uses two coarse fresnel zone plates (FZP) as a bi-plane coder. This two-plane coder produces Fourier transformation of the source distribution on the image plane. The major constraints to achieve high angular resolution in single plane coded aperture imaging are (1) the limitations of how fine a feature one can make in thick high "z" materials used as the coder and (2) the limitation of spatial resolution to resolve such features in the image plane detector. In the bi-plane coder using FZPs one does not have to resolve the fine features of the coder. The Moire fringes generated by the bi-plane coder can be easily resolved by a detector with coarse spatial resolution and can provide high angular resolution. We have used zone plates made from 1-mm-thick tungsten with 144 zones and a narrowest zone of forty-one (41) microns. The total thickness of 2 mm of both the plates enables casting of shadows up to 250 KeV. We present some results of the exposure of such a telescope to the X-ray beam facility at M.S.F.C. at Huntsville.

Advanced X-ray CCD Detectors for the Constellation-X and MAXIM Missions

George R. Ricker, MIT

Modeling of CdZnTe Strip X-ray Detectors

Emrah Kalemci, Center for Astrophysics and Space Sciences, University of California at San Diego

We developed a computer simulation of a CZT detector that predicts induced charge as a function of time on each electrode for various electrode configurations and various interaction positions. We tested the model results and experimental data agreed well with the expectations. It helped us to understand the basic properties of these detectors such as hole trapping, small pixel effect, diffusion and charge splitting among anodes.

Position-Sensitive CZT Detectors for X-Ray and Gamma-Ray Astronomy

J. Matteson, W. Heindl, E. Kalemci, M. Pelling, R. Rothschild, T. Skelton, UCSD, P. Hink, K. Slavis, WUSTL

Our collaboration of researchers from UCSD and WUSTL has been developing position- sensitive CZT detectors for X-ray and gamma-ray astronomy for several years. We present a summary of important results. Crossed-strip readout techniques have been developed to give 500 micron resolution in 2 mm thick detectors, which have good efficiency up to ~200 keV. Advanced electrode techniques eliminate the deleterious effects of hole-trapping on energy resolution, i.e., tailing in the spectrum peaks. Essentially Gaussian line profiles are observed at all energies, and the energy resolution at 122 keV is 2.8%. Detectors have been fabricated up to 32 mm x 32 mm size. A "ruggedized module" with 4 such detectors in under development to prove the techniques are ready for use in large area arrays in space-borne instruments, e.g., thousands of cm2, which would be used with coded masks for all-sky surveys. ASIC and conventional discrete readout electronics have been used. Laboratory tests have demonstrated very high strip-to-strip selectivity, and have proven the ability of our techniques to achieve high quality coded mask imaging. Balloon flight tests have demonstrated low background in both actively and passively shielded configurations. Radiation damage tests with 200 MeV protons at a particle accelerator resulted in peak shifts of only ~10% for a fluence equivalent to ~10 years in space.

Magnetic Calorimeters for X-Ray and Gamma-Ray Detection

George Seidel, Brown University

Cryogenic magnetic calorimeters, based on the measurement of the magnetization of a dilute concentration of paramagnetic ions (Er) in a metallic host (Au), have the potential to be excellent photon detectors for many applications. Their features include high sensitivity, fast response, ability to work with large heat capacities, and ease of fabrication in large arrays. To date we have obtained an energy resolution of 13 eV at 6 keV in a detector essentially 100% efficient at 10 keV and a resolution of 120 eV in a calorimeter more than 80% efficient at 140 keV. A magnetic calorimeter is a well-defined thermodynamic system whose response to an energy deposition can be calculated accurately. Consequently, we predict being able to improve on the current performance by an order of magnitude.

NTD Germanium-Based Microcalorimeters for X-Ray and Gamma-Ray Astronomy

Eric Silver [a], Simon Bandler [a], Herbert Schnopper [a], Stephen Murray [a], Marco Barbera [c], Norm Madden [b], Don Landis [b], Jeff Beeman [b], Eugene Haller [b], Greg Tucker [d]

[a] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

[b] Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720

[c] Osservatorio Astronomico di Palermo, Palermo, Italy

[d] Brown University, Providence, RI 02912

We discuss advances in understanding NTD germanium-basedmicrocalorimeters and review their performance at x-ray and gamma ray energies. The technology for constructing large field-of-view detector arrays with NTD

thermistors that are applicable for explorer-class missions as well as Constellation-X will also be discussed.

Superconducting Transition-Edge Sensor X-Ray Microcalorimeters

John M. Martinis, N. Bergren, S. Deiker, G. C. Hilton, K. D. Irwin, S. W. Nam, D. A. Rudman and D. A. Wollman

Recent advances in superconducting transition-edge sensor (TES) x-ray microcalorimeters have resulted in excellent energy resolution (2.0 eV at 1.5 keV and 4.5 eV at 5.9 keV) and have opened a path to the fabrication of arrays for x-ray astronomy. Next-generation x-ray missions such as Constellation-X will require very high performance spectroscopic and imaging x-ray detector arrays. TES microcalorimeters are likely to fulfill the detector requirements of such missions due to their excellent energy resolution, compatibility with multiplexed, ultra-low power superconducting readout, and lithographic fabrication processes.

Our recent results have been achieved with several different detector designs. We first present results achieved using an aluminum-silver bilayer fabricated with a shadowmask process on a silicon-nitride membrane. Using this device, we have demonstrated 2.0 +- 0.1 eV FWHM energy resolution for 1.5 keV Al K-alpha x-rays produced in a scanning-electron microscope. We further describe a microcalorimeter fabricating using a fully lithographic process. This detector consists of a molybdenum-copper bilayer on a silicon nitride membrane micromachined in a "fly swatter" pattern to control the thermal conductance. For this device, we have measured an energy resolution of 4.5 +- 0.1 eV FWHM for 5.9 keV x-rays from an Fe-55 source. Both of these energy resolutions are the highest that have been reported to date using non-dispersive soft x-ray detectors.

In order to achieve the highest performance with these low-impedance detectors, it is necessary to optimize the Superconducting Quantum Interference Device (SQUID) readout for a particular detector, and to place the SQUID in close proximity to the TES. We will discuss the instrumentation of our detectors using two-stage SQUID amplifiers fabricated at NIST. Finally, we will discuss plans for the fabrication of large format arrays of these devices, in which we will integrate micromachined structures, TES microcalorimeters, and multiplexed SQUID amplifiers into focal plane instruments for sounding rocket flights, Constellation-X, and other x-ray astronomy applications.

UV Digital Cameras Based on 32x32 and 128x128 Arrays of AlGaN p-i-n Photodiodes

J.D. Brown, J. Matthews, J. Boney, P. Srinivasan, J.F. Schetzina,

North Carolina State University, Department of Physics - Box 8202, Raleigh NC 27695-8202, USA. e-mail: jan_schetzina@ncsu.edu

Visible-blind UV digital cameras based on 32x32 and 128x128 arrays of AlGaN p-i-n photodiodes have been successfully developed. The nitride photodiode structures were synthesized on 2-inch diameter sapphire substrates polished on both sides in a low-pressure MOVPE system that employs vertical gas flows and fast substrate rotation. Two types of diode structures were prepared. The first type consists of a 1.5 mm thick n-type layer of $Al_{0.2}Ga_{0.8}N$:Si grown by MOVPE onto a low temperature AlN buffer layer on sapphire. On top of this layer is a 0.2 mm undoped GaN active layer followed by a 0.5 mm p-type GaN:Mg layer. This structure produces devices that respond to UV radiation in the 320-365 nm wavelength region when illuminated through-the-substrate. Selected test diodes displayed 300K peak responsivities as large as R = 0.21 A/W at 360 nm, corresponding to an internal quantum efficiency of 82%. Detectivities as large as D* = 6.1 x 10^{13} cm $Hz^{1/2}$ W^{-1} were measured at 360 nm. This is one of the largest D* values ever obtained for any semiconductor photodetector at any wavelength and temperature, and is within a factor of six of D* values for UV-enhanced photomultiplier tubes. The second type of diode structure studied employs a base n-type layer of $Al_{0.35}Ga_{0.65}N$:Si onto which undoped and p-type layers of $Al_{0.2}Ga_{0.8}N$ are deposited sequentially by MOVPE. These devices respond to UV radiation in the 280-320 nm wavelength region. Selected test diodes of this type exhibit peak responsivities R = 0.14 A/W at 300 nm, corresponding to internal quantum efficiencies of 66%, and detectivities as large as D* = 1.2 x 10^{13} cm $Hz^{1/2}$ W^{-1}

32x32 and 128x128 diode arrays were hybridized to Si readout integrated circuits (ROICs) using flip-chip bonding techniques in which In bump bonds were employed. The hybridized focal plane arrays (FPAs) were then wire-bonded to leadless chip carriers (LCCs) and inserted into the UV camera for testing. The UV digital camera employs an adjustable fused quartz lens for focusing the desired UV scene onto the AlGaN FPA, together with readout and testing electronics controlled by computer. The nitride FPA image can be read out from the Si ROIC and displayed real-time at frame rates ranging from 15-240 frames per second, or a sequence of images can be stored by computer as a digital image data set from which a selected frame or sequence of frames can be used to generate digital UV images or movies. A variety of UV imagery in the 280-365 nm region has been obtained using the nitride UV camera. Single-frame visible-blind UV images of alpha-numeric scenes and geometric objects, along with digital UV movies of pulsed xenon lamps, UV welding, and flame imagery will be presented.

Within the next 12 to 24 months at NCSU, we expect to develop large-format (1024x1024) UV focal plane arrays hybridized to low noise silicon ROICs that are suitable for astronomical imaging applications. These imagers will be visible-blind, and will respond to UV wavelengths from 250-365 nm, or any selected wavelength band within this UV spectral region.

This work is being supported by DARPA and ARO.

Development of GaN-based films for use in UV sensitive but visible blind detectors

Mel Ulmer (presenter), Manijeh Razeghi and Bruce Wessels,

Northwestern University

We have been developing p-type material specially for use in photo-cathodes, and Hamamatsu has converted one of these films into a photo-cathode that they put in a photo-tube. The tube had good response characteristics. Also at Northwestern University GaN based films have been fabricated into p-i-n junctions and we will present results of work done in this area as well. We will also discuss future prospects for both photo-cathode based device and p-i-n based devices.

Novel MgZnO UV detectors

R. D. Vispute, W. Yang, S. Choopun, R. P. Sharma, and T Venkatesan

CSR, Department of Physics, University of Maryland, College Park, MD.

Low Noise Readout using Active Reset for CMOS APS

Boyd Fowler, Michael Godfrey, Janusz Balicki, and John Canfield

Pixel Devices International, Sunnyvale, CA, USA, 94086

Temporal noise in CMOS active pixel sensors (APS) is typically larger than in CCDs. CMOS APS will not displace CCDs in many markets until this fundamental problem is overcome. Pixel reset noise is the largest temporal noise component in photodiode APS and is on the order of kT/C. Pain and Tian independently describe techniques to reduce reset noise to kT/2C without adding lag, but further reduction is still necessary to compete with CCDs. In this paper we introduce a new technique for resetting photodiode pixels, called active reset, that reduces reset noise without adding lag. Active reset can be directly applied to standard photodiode APS. Active reset uses bandlimiting and capacitive feedback to reduce reset noise. We discuss the operation of an active reset pixel, and present an analysis of lag and noise. We do not analyze the effect of 1/f noise, since it is typically much smaller than thermal and shot noise. Measured results from a 6 transistor per pixel 0.35um CMOS implementation are presented. These results show that reset noise can be reduced to less than kT/25C using active reset. We find that theory, Monte Carlo simulation and measured results all match closely.

Development of a Hybrid CMOS Visible Focal Plane Array for Space Based Applications

Y. Bai, J. T. Montroy, J. D. Blackwell, M. Farris, L. J. Kozlowski, K. Vural, J. D. Garnett, Rockwell Science Center, 1049 Camino Dos Rios, Thousand Oaks, CA 91360

Rockwell Science Center is developing a hybrid CMOS visible focal plane array (FPA) technology for high-end scientific applications that require a broad band spectral response, high quantum efficiency, high speed, low noise, highly-integrated functionality and radiation hardness. As a high performance alternative to advanced monolithic detector arrays, such as CCD and APS, the hybrid design enables independent optimizations of the detector array and readout electronics. It also offers an attractive readout commonality with the instrument’s IR channels for integrators of sensor suites such as for hyperspectral spectrometers. In this presentation, the development of Rockwell’s CMOS-based hybrid visible FPAs are described, including key detector performance aspects, interface electronics requirements, radiation hardness and concomitant implications for space applications. We will present the latest results of large format hybrid focal plane arrays with ~100% optical fill factor, high broadband QE spanning ultraviolet (UV) through near infrared (NIR), wide dynamic range, and high pixel operability. Specifically, dark current of ~0.01e-/sec and read noise ~6e- have been measured on a 1024x1024 FPA that uses Hawaii readout integrated circuit. Initial radiation data indicate a total ionization dose (TID) tolerance greater than 35Krad for our standard CMOS process.

Fully depleted, 300 micron thick CCD image sensors with applications in the x-ray, UV, visible and near-IR regions

S.E. Holland, D.E. Groom, M.E. Levi, S. Perlmutter, Lawrence Berkeley National Laboratory University of California, Berkeley, CA 94720

R.J. Stover, M. Wei, University of California Observatories/Lick Observatory University of California, Santa Cruz, CA 95064

We are developing large-format, high-quantum-efficiency charge coupled devices (CCD's) for astronomy and astrophysics applications. The CCDs have high quantum efficiency at red and near-infrared wavelengths due to an active thickness of 300 micron, which also results in good efficiency for low-energy x rays. The CCDs are operated back illuminated with good blue response, and the self-supporting 300 micron-thick substrate eliminates the high costs associated with the thinning process required for conventional back-illuminated CCDs. Point spread and modulation transfer function are determined by diffusion of carriers in an electric field and are well understood and characterized. The p-channel CCDs are fabricated on high-resistivity substrates and are expected to have improved radiation resistance to charged particles due to the near elimination of phosphorus in the CCD channel region. The relatively large thickness results in increased sensitivity to cosmic ray and background radiation, and these effects are under investigation.

Large-area, photon-counting, mega-pixel arrays in UV/Optical

Prof. Katsushi Arisaka

UCLA, Department of Physics and Astronomy

PO Box 951547

Los Angeles, CA 90095-1547

Phone: (310)825-4925, Fax: (310)267-2483

Detection of Ultra High-Energy cosmic rays and neutrinos is of fundamental importance to unveil the highest energy Universe. Space based experiments such as OWL and EUSO have recently been proposed as the next generation experiments in this field. These experiments require large area (~10m^2), single-photon-counting, mega-pixel arrays sensitive in UV/Optical range. This paper reviews the current status of candidate devices as well as future prospects.

Delta-doped imagers for UV and EUV applications

S. Nikzad, T.J. Jones, T.J. Cunningham, P.W. Deelman, and S.T. Elliott

Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

The large imaging format, high sensitivity, compact size, and ease of operation of silicon-based sensors have led instrument designers to choose them for most visible-light imagers and spectrometers for space-based applications, and this will probably remain the case in the near future. In fact, technologies presently under development will tend to strengthen the position of silicon-based sensors. CCD-CMOS hybrids currently being developed may combine the advantages of both imagers and new high-gain amplifiers and could permit photon-counting sensitivity even in large-format imagers. Back-illumination potentially enables silicon detectors to be used for photometry and imaging applications for which front-illuminated devices are poorly suited. Generally, back illumination requires treatment of the back surface such as delta doping.

Delta-doped CCDs were developed at the Microdevices Laboratory at the Jet Propulsion Laboratory in 1992. Using molecular beam epitaxy, fully-processed thinned CCDs are modified for UV enhancement by growing 2.5 nm of Boron-doped silicon on the back surface. Named delta-doped CCDs because of the sharply-spiked dopant profile in the thin epitaxial layer, these devices exhibit stable and uniform 100% internal quantum efficiency without hysteresis in the visible and ultraviolet regions of the spectrum. In this paper we will discuss, performance of delta-doped CCDs in UV and EUV, our in-house thinning capability, bonding approaches for producing flat focal plane arrays, and in-house capabilities of directly applied antireflection coatings. Recent activities on the extension of delta doping technology to other imaging technologies will also be presented.

The work presented in this paper was performed by the Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology, and was jointly sponsored by the National Aeronautics and Space Administration, Office of Space Science and the JPL's Director Research and Development Fund.

Camera-on-a-Chip technology for astronomical sensors

Don Hall, Institute for Astronomy, Hawaii

NGST Detectors: What We Need

Knox Long (STScI), Matthew Greenhouse (NASA/GSFC), Craig McCreight(NASA/Ames) & Bernard Rauscher (STScI).

HgCdTe Arrays for the Far-Infrared

A.L. Betz, R.T. Boreiko, Center for Astrophysics & Space Astronomy, University of Colorado, CB 593, Boulder, CO 80309

S. Sivananthan and R. Ashokan, Microphysics Laboratory, University of Illinois, Chicago, IL 60607

The versatility of HgCdTe as a photodetector material is well recognized between the near-IR and LWIR bands (1 mm < l < 20 mm). What appears not so recognized, however, is that there is no long wavelength cutoff for appropriately composed HgCdTe. Theoretically, HgCdTe photodetectors are possible for wavelengths at least as long as 200 mm. However, as the bandgap is reduced by increasing the HgTe fraction, the accuracy of the alloy composition becomes more critical. Nevertheless, the required accuracy can be met by precise molecular-beam-epitaxy (MBE) techniques, which have been refined for HgCdTe in the last few years. It is now realistic to consider HgCdTe devices for FIR wavelengths. As an intrinsic semiconductor, HgCdTe has a big advantage over extrinsic materials such as Ga:Ge. The 100 cm^{-1} absorption coefficient of HgCdTe is 100 times higher than that typical of low-doped Ga:Ge. Consequently, HgCdTe films can be as thin as 5 mm and still yield high quantum efficiencies. The same planar technology applied to near-IR HgCdTe arrays can be applied to FIR devices, and FIR arrays as large as 256x256 are realistic with available technology. We will discuss alloy versus superlattice device structures, cooling requirements, optical coupling, sensitivities, and limitations of the technology, and plans for demonstration arrays of 32x32 multiplexed elements optimized for the 50 mm and 100 mm bands.

betz@casa.colorado.edu

Initial Performance Results of the 2048x2048 2.5um HgCdTe Focal Plane Array

C. A. Cabelli, D. E. Cooper, J. T. Montroy, J. D. Blackwell, G. L. Bostrup, L.J. Kozlowski, K. Vural, C. Y. Chen, A. K. Haas, Y. Bai, J. D. Garnett, Rockwell Science Center, 1049 Camino Dos Rios, Thousand Oaks, CA 91360

Rockwell Science Center has recently produced the world's first 2048 x 2048 infrared focal plane array (FPA) for infrared astronomy. The 2048x2048, 18um pixel pitch “HAWAII-2”readout integrated circuit (ROIC) is designed for low background, low noise applications. We will report on the performance of the first FPAs consisting of the HAWAII-2 ROIC hybridized to 2.5um HgCdTe SWIR detector arrays. Performance will include quantum efficiency, uniformity, dark current, read noise and operability. Future directions for the HAWAII-2 ROIC will also be presented.

Quantum Well Infrared Photodetectors for Astronomy

Michael Ressler, James Bock, Sumith Bandara, Sarath Gunapala, Michael Werner

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109

Quantum Well Infrared Photodetectors (QWIPs) are realizations of the classic quantum mechanical well. In their simplest form, they make good narrow bandwidth (dl/l = 10%) infrared detectors with many desirable properties such as tunable bandpasses, high temperature operation, and ultralow 1/f noise. They are easily manufactured as arrays of detectors, with formats of 640x480 already in existence, and recent developments have yielded 50% bandpass devices as well as dual color devices. We discuss the basic construction of QWIPs, their prospects for use in space astrophysics missions, and their measured performance at the prime focus of the Palomar 5-m telescope.

NTD Germanium: Current Successes and Future Directions

E.E. Haller and J.W. Beeman

University of California, Berkeley and Lawrence Berkeley National Laboratory

Neutron Transmutation Doped (NTD) Germanium thermistors are currently used in many highly productive large-format bolometer arrays including SCUBA, BOOMERANG, and BOLOCAM, and have been selected for use in the SPIRE and Planck HFI instruments. The continued preference of these thermistors over competing technologies stems from several unique characteristics that are associated with NTD Germanium. These include: 1) precise and uniform doping that is inherent in the NTD process, 2) materials can be produced for optimized (impedance matched) thermistors operating at essentially any temperature between 4K and a few milliKelvin, 3) the R vs T dependence is theoretically well understood, 4) high sensitivity over a wide dynamic range, decreasing the need for ultra-stable bath temperatures, 5) new low volume device configurations (flat pack geometry) result in very low heat capacity, and 6) the transducer engineering is well understood and developed. This list leaves few unknowns, allowing optimized focal plane designs.

While these characteristics have lead to widespread use of NTD Ge, the need for significantly larger arrays places new demands on NTD Germanium thermistor engineering. In response we are now pursuing research on novel NTD chip geometries. One approach uses thin, free-standing metal strips, or "flying leads" that are produced as an integral part of the chip. This will allow the user to simply bond the free end of the leads to a fan out, obtaining the thermal link and electrical connections in one simple step. We are also developing an integrated approach with thin film NTD germanium deposited directly onto a Silicon Nitride film coated Silicon wafer. This will, for the first time, allow fully lithographed NTD Ge/SiN-based arrays that could be produced without any hand wiring steps. Arrays of 1000 thermistors and larger will become feasible by this approach

SQUID Mulitplexers for Large Transition Edge Sensor (TES) Detector Arrays

S. Nam, J. Chervenak, E. Grossman, K. Irwin, J. Martinis, National Institute of Standards and Technology, H. Moseley, R. Shafer, Goddard Space Flight Center

As any multi-channel detetor technology matures, the desire for progressively larger formats requires the development of a multiplexed read out. We have developed a SQUID multiplexer which has been used to read out a small array of IR-submillimeter Transition Edge Sensor (TES) bolometers. With careful optimization, an array of microcalorimeters (e.g. X-ray, optical) can also be multiplexed. The basic elements of the SQUID multiplexer will be reviewed. We will also present results from a multiplexed IR bolometer array and describe progress on the development of a SQUID multiplexer system for TES microcalorimeters.

Single-Photon Energy Resolving Detectors based on thermoelectric Sensors and Digital Superconducting Readout for hyperspectral imaging.

Armen Gulian, NRL

We are developing the QVD detector, a hyperspectral replacement for CCDs, which could represent a revolutionary increase in capability for future NASA missions. The QVD detector is an array of photon counting pixels, each of which converts the energy of an incoming photon to heat (Q), thermoelectrically converts the heat to a voltage (V), and processes the voltage pulse into a digital (D) signal. The absorbed energy is quickly thermalized and homogenizes within the absorber to create a predictable electronic temperature gradient across a thin film thermoelectric sensor.The QVD sensors have a wide dynamic range in energy (0.1-30 keV), counting rates up to 1 MHz per pixel, quantum and focal plane efficiencies in excess of 90%, and potential resolving powers ~10,000 at 10 keV. The QVD design lends itself naturally to large megapixel arrays because of the simplicity of its biasing and readout. The sensor requires no external voltage or current bias, has one lead per pixel, and allows the electronics to be positioned in close vicinity to the sensor, which make fabrication easier, and avoids some of the complexities of other microbolometer concepts. The recent progress in developing and testing a single-unit prototype device and critical elements of the superconducting read-out circuit, the basic building elements of the large format array, is reported.

Voltage-biased Superconducting Bolometers for the far-Infrared to millimeter wavelength range.

Adrian T. Lee, Jan M. Gildemeister, Mike Myers, Paul L. Richards, Jesse Skidmore, and Jongsoo Yoon

http://bolo.berkeley.edu/bolometers/publications.html

We are developing bolometers, which use a voltage-biased superconducting transition-edge sensor to produce a null detector with strong electrothermal feedback. We refer to such a device as a Voltage-biased Superconducting Bolometer (VSB). The negative feedback isolates the bolometer responsivity from fluctuations in refrigerator temperature and changes in the infrared background power. It also increases the bolometer linearity, dynamic range, and speed. The SQUID readouts operate at low temperatures, dissipate very little power, and have large noise margin.

We are currently developing a planar-antenna coupled VSB. The devices will utilize frequency multiplexers so that a single focal plane pixel can simultaneously measure multiple bands. These frequency multiplexers will be built from superconducting microstrip transmission lines and therefore will have fairly low loss. A wide range of bandwidths is possible with this technology with resolving powers of several to 100 or more.

We have also developed some fabrication methods for building large arrays of absorber-coupled bolometers with high yield. The bolometers use Silicon-Nitride suspensions and micromesh absorbers. Arrays of 10^3 to 10^4 bolometers will be practical using these new methods. We will present results from prototype bolometers built with this fabrication process.

Ideal Integrating Bolometer

Al Kogut GSFC. Email - KOGUT@stars.gsfc.nasa.gov

We describe a new "ideal integrator" bolometer as a prototype for a new generation of sensitive, flexible far-IR detectors suitable for use in large arrays. The combination of a non-dissipative sensor coupled with a fast heat switch provides breakthrough capabilities in both sensitivity and operation. The bolometer temperature varies linearly with the integrated infrared power incident on the detector, and may be sampled intermittently without loss of information between samples. The sample speed and consequent dynamic range depend only on the heat switch reset cycle and can be selected in software. Between samples, the device acts as an ideal integrator with noise significantly lower than resistive bolometers. Since there is no loss of information between samples, the device is well-suited for large arrays. A single SQUID readout could process an entire column of detectors, greatly reducing the complexity, power requirements, and cost of readout electronics for large pixel arrays.

Characterization of Transition Edge Sensor Arrays for Detection of Submillimeter Radiation

J. A. Chervenak, K. D. Irwin, E. N. Grossman, and C. D. Reintsema

National Institute of Standards and Technology, Boulder

S. H. Moseley and C. A. Allen

Goddard Space Flight Center, Greenbelt, MD

We have fabricated linear arrays of transition edge sensor (TES) bolometers on 'Pop-Up' silicon membranes, a foldable micromachined structure which enables high filling factor 2D pixel arrays for submillimeter radiation. TES bolometers have low noise, high sensitivity bolometric performance and enable high pixel count, close packed arrays for new instruments capable of operation in the submillimeter region. We have tested several different designs for the superconducting element. Sources of excess noise which sometimes arise in the devices are identified. These include excess heat capacity on the membrane which is thermally decoupled from the superconducting element and electrical fluctuations depending on the boundary conditions of the sensor. Iterating on device designs which incorporate these constraints, a lithographically fabricated array has been fabricated which uses Mo/Cu bilayers as the superconducting element. The devices exhibit a *1/f* knee of about 100 mHz as well as near-phonon-noise-limited noise equivalent power (NEP). We have also conducted preliminary investigations of detector response to incident submillimeter radiation using a cryogenic blackbody emitter. Results of the polarization dependence of the measured signal are presented.

Superconducting Transition Edge Sensor Bolometer Arrays for Submillimeter Astronomy

Dominic Benford GSFC

Hot-electron direct detectors: feasibility of NEP H 10^{-20} W Hz at submillimeter waves

Boris S. Karasik, William R. McGrath, and Henry G. LeDuc

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

Michael E. Gershenson

Dept. of Physics and Astronomy, Rutgers University, Piscataway, NJ 08854

Andrew V. Sergeev

Dept. of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202

We present a concept for a hot-electron direct detector (HEDD) capable of counting single millimeter-wave photons. Such a detector will meet the needs of future space far-infrared missions (NEP £ 10^{-19} W/ÖHz) and can be used for background-limited detector arrays on SPIRIT, the 10-meter space telescope and SPECS. The detector is based on a microbridge (1-µm-size) transition edge sensor fabricated from an ultra-thin film of a superconductor with the critical temperature T_c = 0.1-0.3 K. A very strong temperature dependence of the electron-phonon coupling allows to adjust the electron-phonon scattering time, t_{e-ph}, to the desired time constant of the detector (t =10^{-4}-10^{-3} s) at T = 0.1 K; further adjustment of t_{e-ph} is possible due to the electron-mean-free-path dependence of t_{e-ph}. The microbridge contacts are made from a different superconductor with a higher critical temperature (Nb); these contacts will block the thermal diffusion of hot carriers into the contacts because of the Andreev reflection. The low electron-phonon heat conductance, high thermal resistance of the contacts, and small heat capacitance of electrons in a micron-size bridge determine the noise equivalent power of ~ 10^{20} – 10^{-21} W/ÖHz at T = 0.1 K, which is 10^2 to 10^3 times better than that of the state-of-the-art bolometers. By exploiting the negative electro-thermal feedback, the detector time constant can be made as short as 10^{-5}-10^{-4} s without sacrificing sensitivity.

Preliminary results on hafnium hot-electron bolometers will be reported. The measurements of the electron-phonon relaxation time have demonstrated that the bolometer response time of ~ 0.7 ms at T = 0.1 K is possible without using any high-thermal-resistance suspension of the detector (the Hf films were deposited directly on a bulk sapphire substrate). For a device with lateral dimensions 1´1 µm^2, this would result in a *NEP* H 10^{-20} W/Hz$^{1/2}$ due to the thermal fluctuations. Prototype antenna-coupled devices have been fabricated. These prototypes will be used for testing the spectral properties of the detector up to the THz frequencies. Possible ways of integration of these new devices in large arrays will be discussed.

Dr. Boris S. Karasik, Jet Propulsion Laboratory, California Institute of Technology, M/S 168-314 4800 Oak Grove Drive, Pasadena, CA 91109, tel. (818) 393-4438 office, (818) 354-8062 lab, fax: (818) 393-4683, email: Boris.S.Karasik@jpl.nasa.gov, URL: http://techinfo.jpl.nasa.gov/ssg

Wideband Lag Correlators for Heterodyne Spectroscopy

Andrew Harris, Universitry of Maryland

Tunable antenna-coupled intersubband terahertz (TACIT) mixers: the quantum limit without the quantum liquid.

M. S. Sherwin,[1] C. Cates,[1] K. Maranowski,[2] A. C. Gossard[2] and W. R. McGrath[3]

[1]Physics Department and Center for Terahertz Science and Technology, UCSB, Santa Barbara, CA 93106

[2]Materials Department, UCSB, Santa Barbara, CA 93106

[3]Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

At present, nearly quantum-limited heterodyne receivers for Terahertz (THz) frequencies require cooling to temperatures below 4K. The only way to reliably achieve such low temperatures is to use liquid Helium. For example, the FIRST satellite will fly a cryostat containing 2.6 m^3 of liquid He to cool hot-electron bolometer mixers and other detectors. The cryostat comprises a large part of the complexity and expense of the mission, and the duration of the mission is limited by the lifetime of the liquid Helium.

We propose a semiconductor-based "Tunable antenna-coupled intersubband terahertz" (TACIT) 1-3 heterodyne mixer for 1.5-5 THz, and predict it will have the following characteristics:

Operating temperature: 20K

Noise temperature: ~quantum limited

IF bandwidth: >10 GHz

LO power: <100 nW

A 20K operating temperature can be achieved with existing compact, reliable, closed-cycle mechanical coolers, and 100 nW THz LO power levels can be supplied by compact solid-state sources. Thus, successful development of TACIT mixers would enable, for the first time, relatively small and inexpensive, long-duration space-science missions which incorporate nearly quantum-limited heterodyne receivers for THz frequencies.

This talk will discuss the underlying physics of and a model for the TACIT mixer, including quantum efficiency, responsivity, noise, IF and RF bandwidths, parasitics, and RF design considerations. The talk will also show preliminary results on fabrication of a direct detector based on the TACIT concept.

1. Cates, C. L. *et al.* A concept for a tunable antenna-coupled intersubband terahertz (TACIT) detector. *Physica E* **2**, 463 (1998).

2. Cates, C. L. *et al.* in *9th International Symposium on Space THz Technology* (ed. McGrath, R. W.) 597 (Pasadena, 1998).

3. Cates, C., Williams, J. B., Sherwin, M. S., Maranowski, K. D. & Gossard, A. C. in *Terahertz Spectroscopy and Applications* (ed. Sherwin, M. S.) 58-66 (SPIE--The International Society for Optical Engineering, Bellingham, Washington, 1999).

Email: Sherwin@physics.ucsb.edu; Tel: (805)893-3774

Laser Micromachining of THz Waveguide, and Quasi-Optical Components

C. Walker, C. Drouet d'Aubigny, B. Jones, C., Groppi Steward Observatory, Univ. of Arizona

J. Papapolymerou, Dept. of Electrical and Computer Engineering, Univ. of Arizona

Laser micromachining techniques can be used to fabricate high-quality waveguide and quasi-optical components to micrometer accuracies. Successful GHz waveguide designs can be directly scaled to THz frequencies. We expect this promising technology to allow the construction of the first fully-integrated THz heterodyne imaging arrays. At the University of Arizona, construction of the first laser micromachining system designed for THz waveguide components fabrication has been completed. Once we have tested and characterized our system we will use it to construct prototype THz 1x4 focal plane mixer arrays, AR coated silicon lenses, THz LO sources, phase gratings and more. The system can micromachine structures down to a few microns accuracy and up to 6 inches across. In our talk we will discuss the design and performance of our laser micromachining system, compare it to other micromachining technologies, and illustrate the type and range of components this exciting new technology will make accessible to the THz community.

A novel approach for a tunable sub-millimeter detector

Faiz Rahman, Caltech

Recent experiments have shown that quantized energy levels can be formed in a semiconductor sandwiched between two superconductors. Such levels, called Andreev Bound States represent a system where interlevel transitions can be induced by Tera hertz radiation, resulting in changes in the conductivity of the super-semi-super sandwich. A simple antenna or feed horn coupling can then be used to realize a tunable sub-millimeter radiation detector for both photometric and spectroscopic observations.