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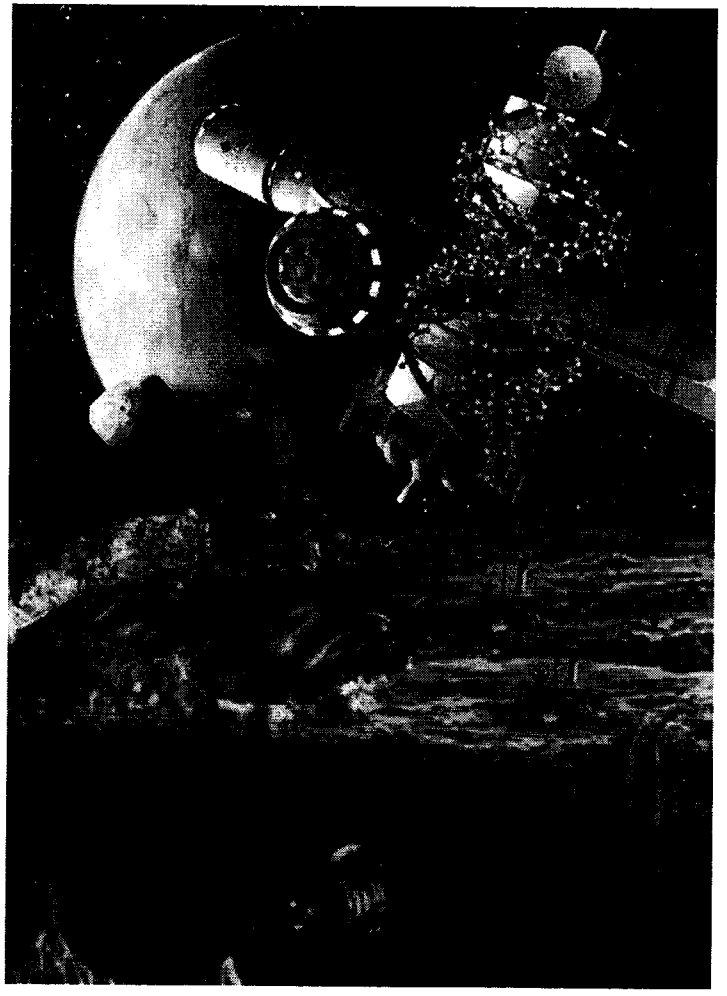

Advanced Sensor Development at JPL

Dr. Timothy Krabach

Program Manager
Life Detection Science & Technology

Jet Propulsion Laboratory

Breakthrough Sensors

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- **Scope of activities**
  - **Detectors and Focal Planes with quantum – limited sensitivity for all regions of the electromagnetic spectrum**
    - **Some areas of the EM spectrum (submillimeter, UV, Xray) are a unique NASA concern**
    - **Sensitivities required by NASA missions in all cases exceed those in the commercial and military sectors**
  - **Advanced components for active sensing instruments**
    - **Radar, lidar, metrology systems are core NASA capabilities**
    - **Key areas are laser development, photonic circuits, optics and antenna development**

Breakthrough Sensors

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- **Scope of activities (continued)**
  - **In situ sensors probing the physical, chemical, and biological properties**
    - **Missions landing on, boring under, and flying about other bodies in the solar system demand a suite of in situ sensors**
    - **Long term human exploration missions will need numbers of sensors to enable robust, low cost environmental control and medical care**
  - **Advanced Sensor Electronics**
    - **Need Mixed Signal, micropower, and communication capability capable of operating in severe environments**

Challenges in Detection of Extant or Extinct Life on Other Bodies

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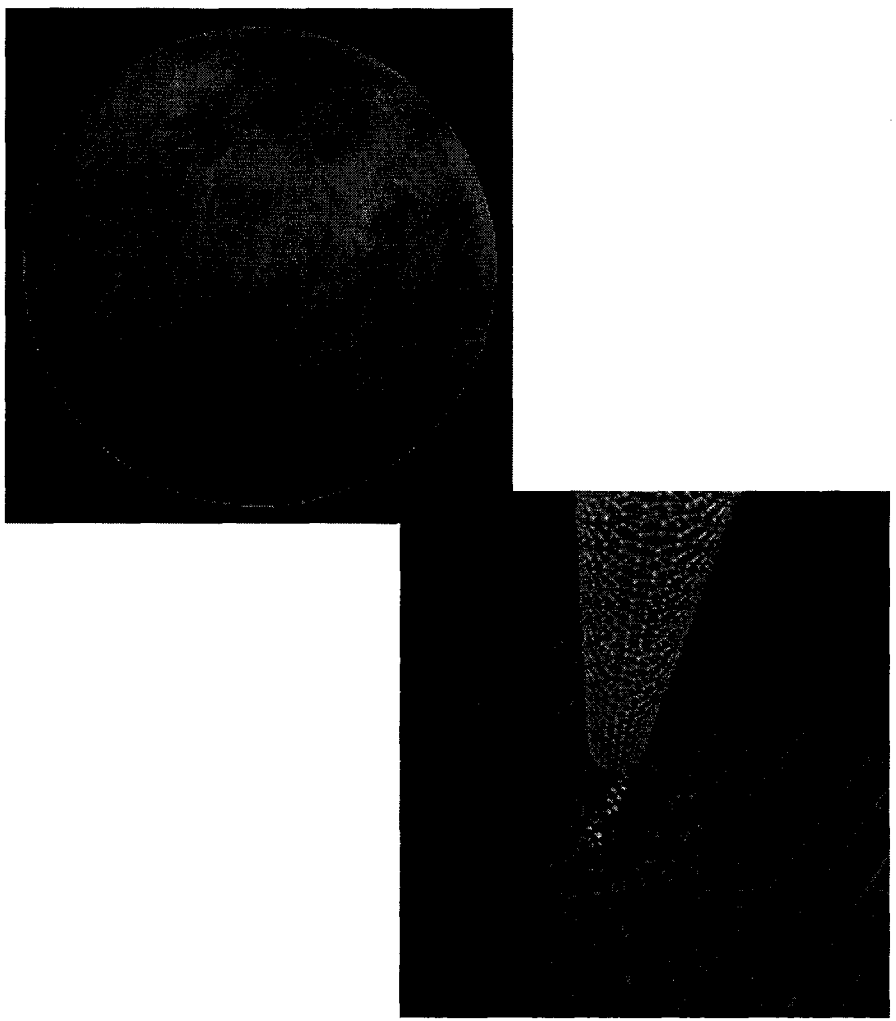

- **Uncertainties in definitive signatures**
  - Unlikely there will be a single silver bullet
- **Need for Investigation across a wide spatial range**
  - Likely require global to nano scale data collection
- **Coordinating Multiple, Mixed Measurements and Instruments**

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Mission Constraints

- Need large reductions in total mass, power, volume over similar instruments on Earth
- Need large reductions in user-operator interactions for deployed systems
- Need tightly integrated systems approach for suites of sensors, platforms, and vehicles

- How does one guarantee calibrated operation after months (years) of storage during flight?

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Advanced Sensor Deployment and Mobility Systems

Robotic Exploration

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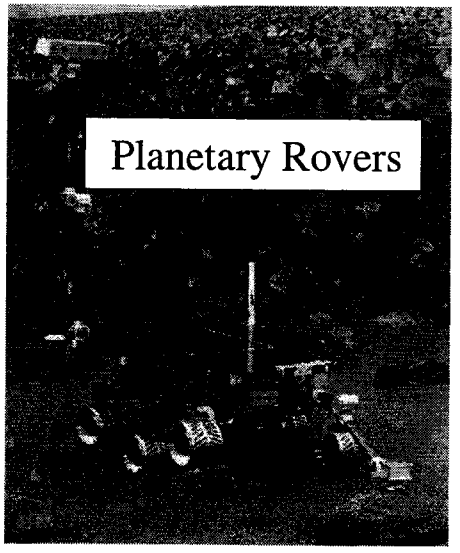

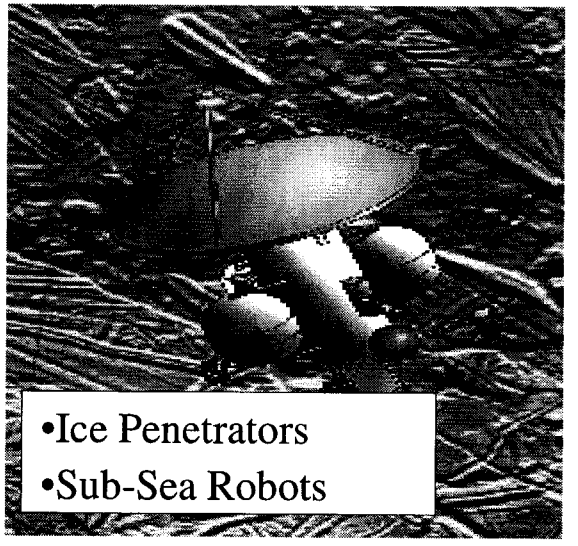

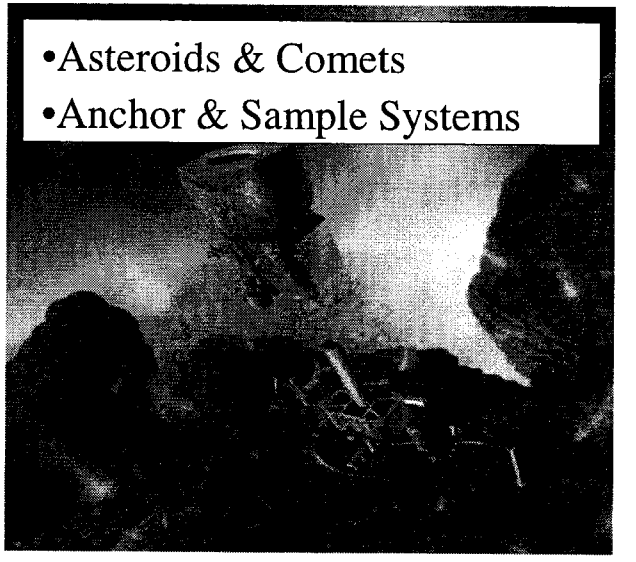

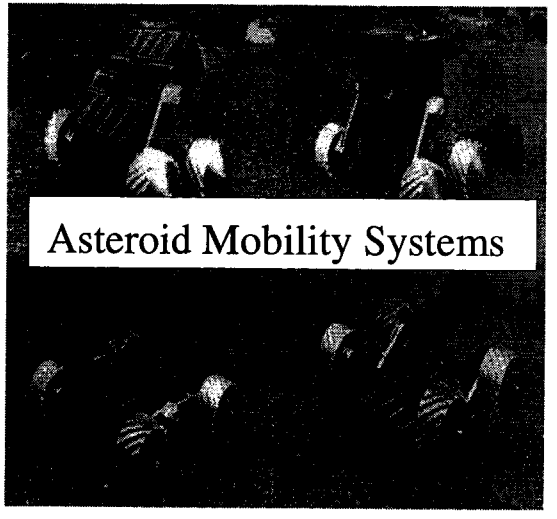

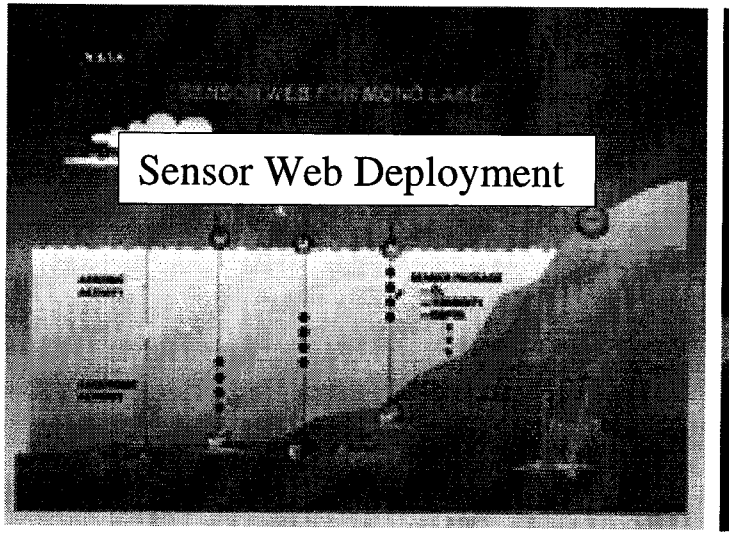

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Micropower

Micropower technology will enable:

- Wide range of spacecraft architectures (distributed architecture, smart power, robust and fault tolerant systems etc.)
- Highly miniaturized power sources for use in small, compact vehicles for exploring a great variety of environments
  - Cold, hot, high g, high radiation, sun-obscured...
  - Long life survivability in extreme environments
- Integrated lightweight power storage.
- Integrated microsystems will have to rely on efficient and adaptive on-chip power management and distribution
  - Active components
  - Passive components
- Use energy and power in a smart way

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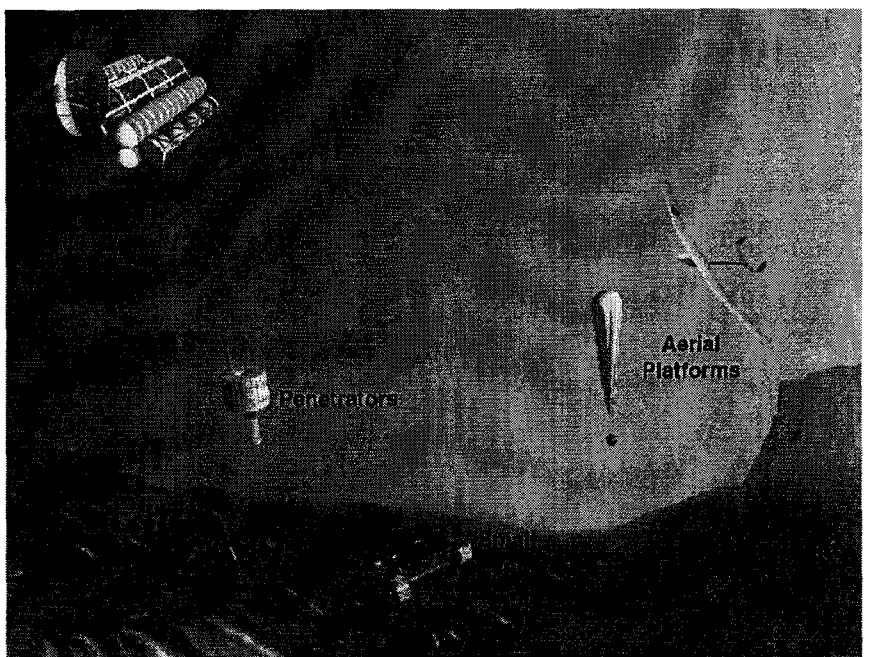
Miniaturized Power Sources

- **Need for highly miniaturized power sources**
  - **NASA missions call for use of a number of small, compact vehicles for exploring a great variety of environments**
    - **Cold, hot, high g, high radiation, sun-obscured...**
    - **Long life characteristics highly desirable (includes shelf life)**
- **Ultimate goal is to have power integrated within SOAC-type chip architecture**
  - **Enabling technology for a variety of sensors, distributed microsystems, and other electronic, optoelectronic components**
  - **Do better than primary electrochemical batteries!**
- **Technology Insertion Opportunities**
  - **NASA Enterprises: Outer Planet Exploration Program, Mars Exploration Program, HEDS, Interstellar probes**
  - **Terrestrial applications**



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Sensor and Instrument Technologies for In situ Exploration

Imaging Sensors

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- **Focal Plane Sensors**
  - **Are at the heart of all remote sensing and many in situ instruments**
  - **Are critical for many navigation sensors in space and ground platforms**
  - **Improvements in focal planes (sensitivity, size, etc.) offer an extremely high science payoff, and offer both performance and miniaturization benefits for mobile platforms**

- **NASA R&D on focal plane technology spans the electromagnetic spectrum**

Common Characteristics of NASA Image Sensor R&D

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- **Emphasis on high performance within a sensors range of application**
  - **Demand from needs of science instruments for NASA missions**
- **Solutions providing high stability, low drift, low noise**
  - **Driven by requirements for excellent calibration, and stand alone operation (few tweaks)**
- **Focal Plane technologies that simplify overall sensor and instrument implementation**

Detectors and Focal Planes

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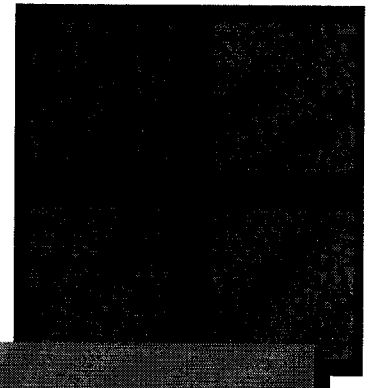
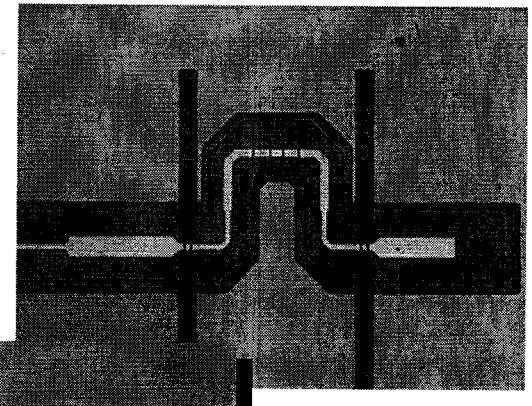
MW/LW Infrared
Low-noise InSb FPAs
Quantum Well focal planes

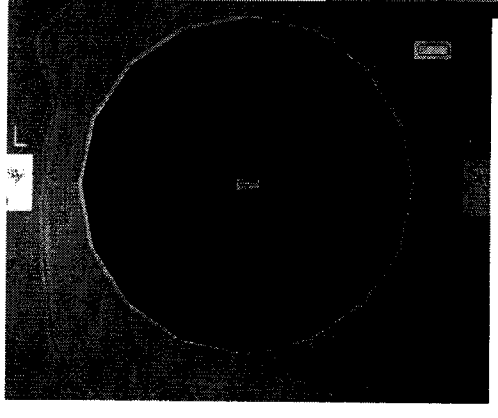


QWIP pixels

Twin slot SIS mixer

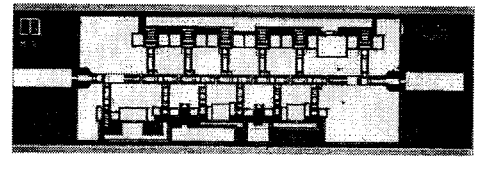


Far Infrared
Si:As BIB arrays
Micromesh Bolometer Arrays



Micromesh bolometer

Submillimeter
Superconducting SIS mixers
THz sources / amplifiers



InP HEMT
200 GHz amp

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QWIP Technology

Motivation

Develop Narrow-band, Broad-band, and Multi-band large format, uniform, stable, and high sensitivity long-wavelength infrared (LWIR) focal plane arrays (FPAs).

Space Science Enterprise	**- Planetary remote sensing, astronomy**
Earth Science Enterprise	**- Earth remote sensing**
HEDS Enterprise	**- Cabin & crew safety**
Aerospace technology	**- Advance air transportation technology**

Challenges

Design & develop new device concepts, Improve light coupling techniques, develop new device fabrication processes, develop new materials growth processes.

Benchmark

Competitive technologies: HgCdTe, InSb, Silicon BIBs, Thermal detectors

QWIP-Competitive technologies

HgCdTe:

No large format arrays in LWIR

No 2-D arrays beyond 12 μm

High 1/f noise knee

Low operability & uniformity

InSb:

No Multi-band FPAs

Silcon BIBs:

No large format arrays

Operates at very low temperature

Thermal detectors:

Low sensitivity

Slow speed

BROADBAND QWIP FPA

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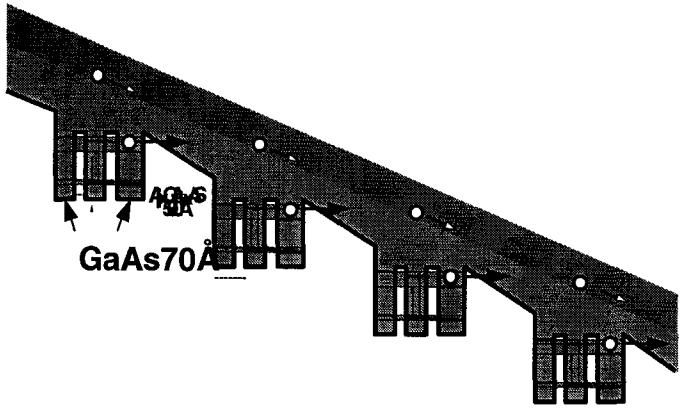


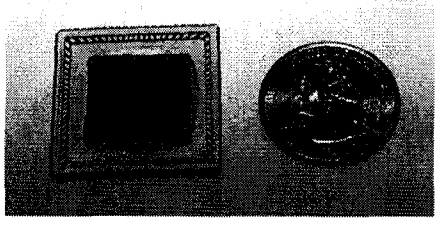
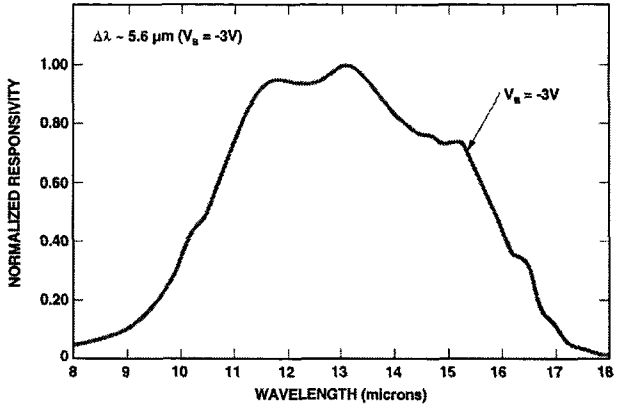
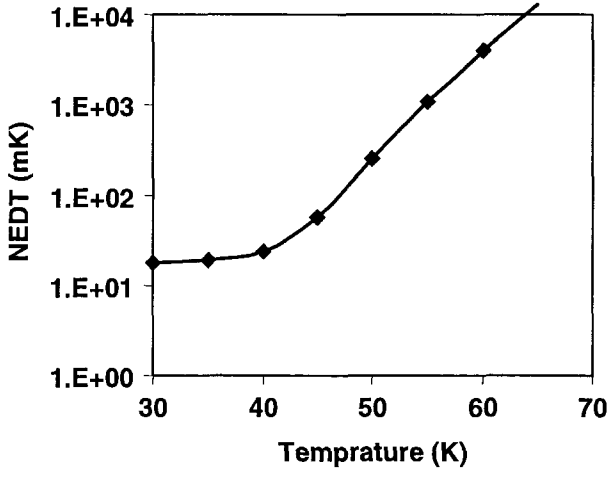


Image on left shows the first 640x512 broadband focal plane array having 15.4 micron cut off wavelength. Current industry state of the art at this wavelength is 1x128. Image on left is taken with this focal plane array. Array NEDT-24 mK at 40K, Uniformity 0.05%, Operability 99.99%, Number of pixels - 327,680





TWO 640X512 ARRAYS DELIVERED TO SOLID STATE IMAGING INTERFEROMETER PROJECT

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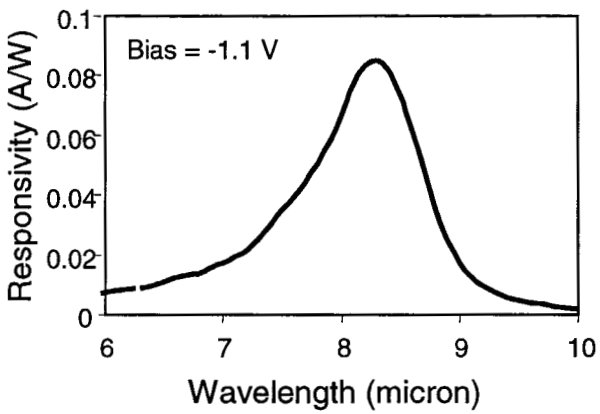
LARGE FORMAT LWIR QWIP FPA

RESPONSIVITY



NETD

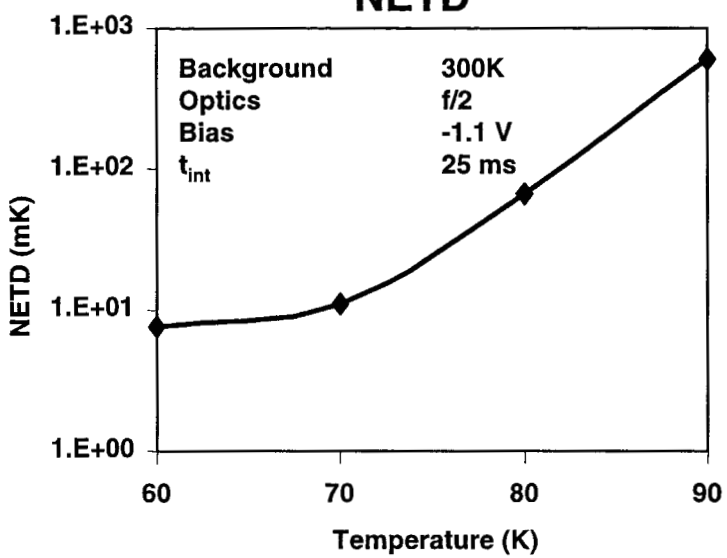


Image taken with 640x512 pixel LWIR QWIP focal plane array. Array NEDT-26 mK at 40K, Uniformity 0.1%, Operability 99.92%, Number of pixels - 327,680

640X512 PIXEL PORTABLE LWIR CAMERA

JPL

QWIP

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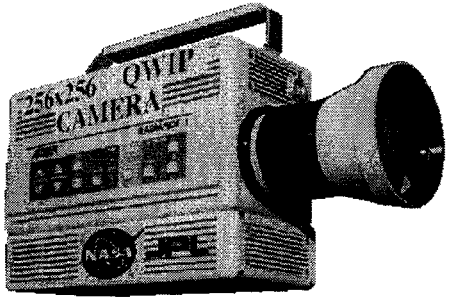
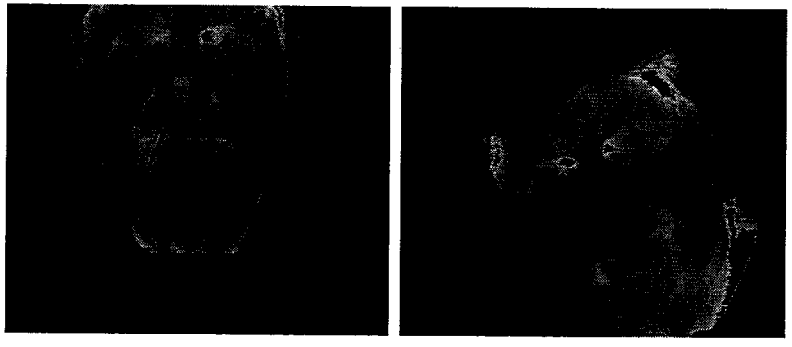
Jet Propulsion Laboratory
California Institute of Technology

Shedding New Light on Cancer Detection

NASA/JPL QWIP Camera



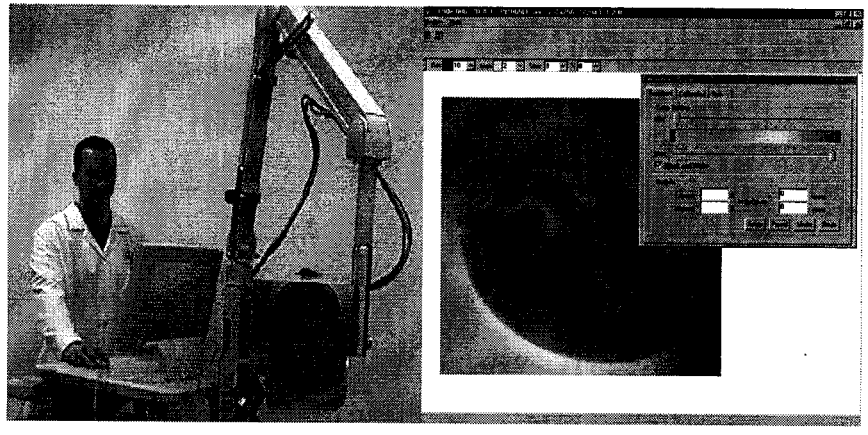
Skin Cancer



Patient 30285 - Carcinoma, skin

JPL

Breast Cancer



Omnicorder Technology's BioScan System based on NASA/JPL developed QWIP technology.

Brain Tumor

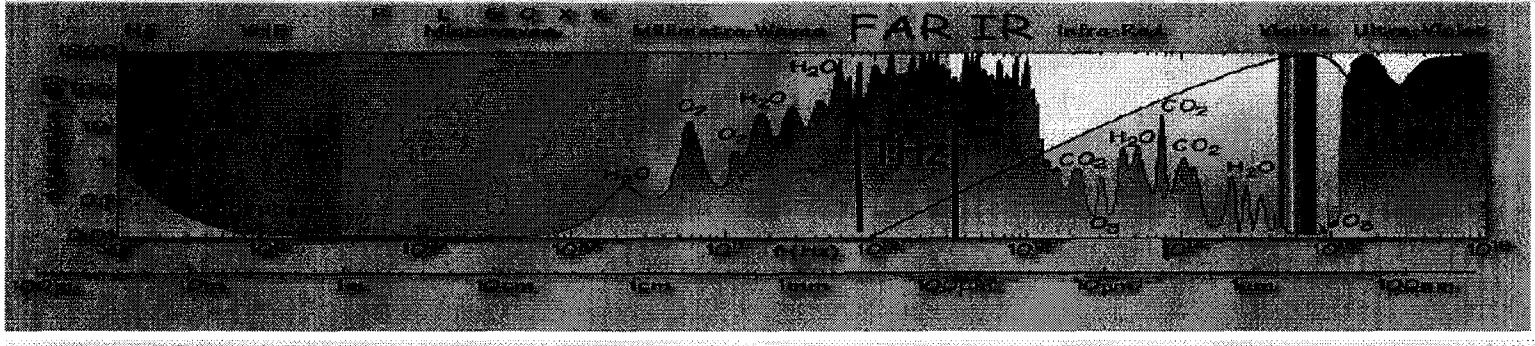
Dr. Michael Levy, USC/Children Hospital.

- **QWIP technology won FDA approval for use in breast cancer detection.**
- **Dana-Farber Cancer Institute uses QWIPs to monitoring effectiveness of cancer treatment in patients.**

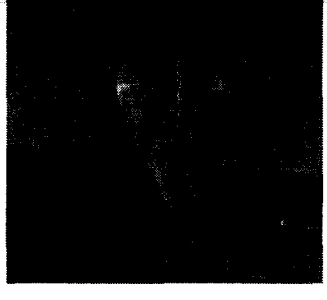
Submillimeter Wave Technology Overview

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Motivation: Due to high atmospheric absorption, low energy levels, and its occurrence at a cross-over region between wave and classic electronic behavior, the THz frequency range remains one of the least tapped, but information rich, bands of the electromagnetic spectrum. Although there is little commercial interest, for NASA, it is a region with extremely high signal (science) content due to an abundance of astronomical, planetary and atmospheric sources.

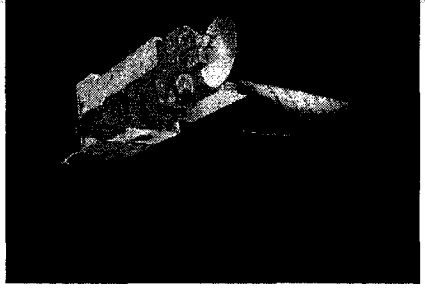


State-of-the-Art: THz components and instrumentation are *non-existent* in the commercial sector. NASA in general, and JPL in particular, are major sponsors of THz technology development and, as a result of the Code R programs, we have built up enormous capability in the area of THz sensors. There are still significant hurdles to overcome, especially in the areas of THz sources and THz instrumentation.



High Altitude Balloon

Airborne Platform (DC8/SOFIA)



Earth Orbiter/Sounder

Planetary Sounder

RF / THz Heterodyne Receivers

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Jet Propulsion Laboratory
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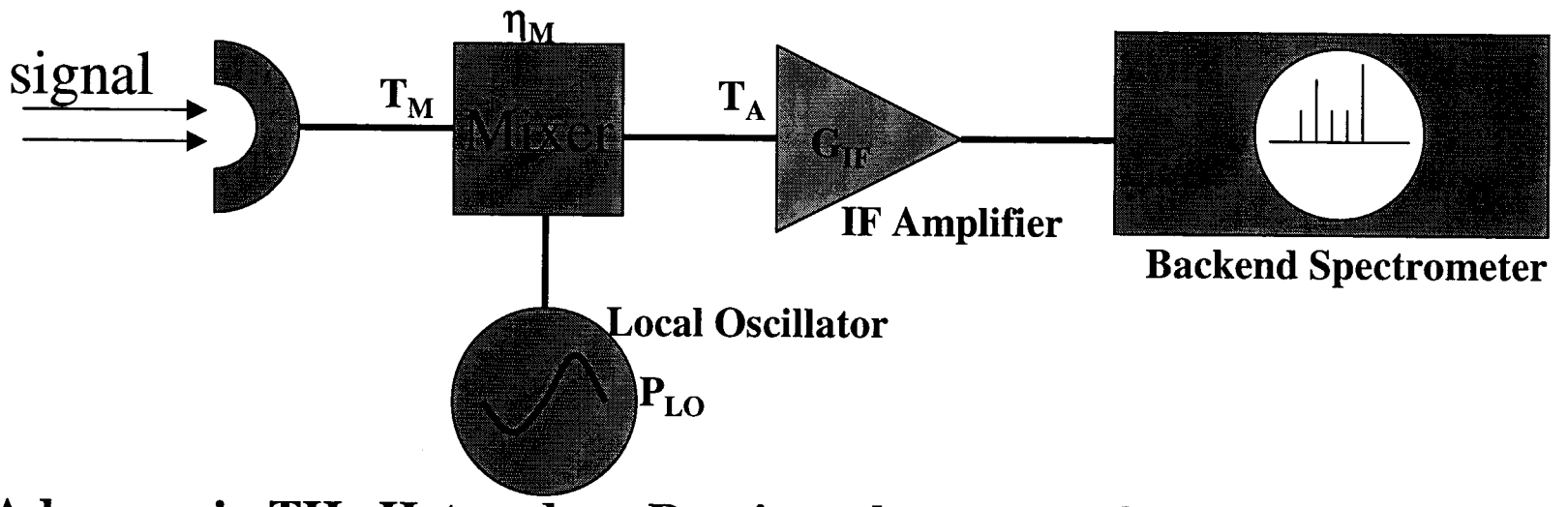


Advances in THz Heterodyne Receivers have come from combining developments in:

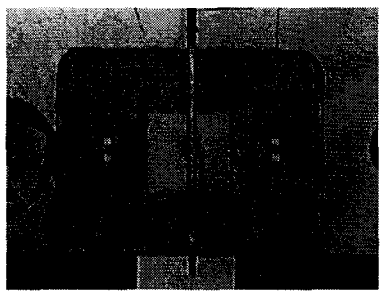
- Mixer technology: Superconducting SIS, Hot Electron Bolometers, Planar Schottky
- Local Oscillators: Monolithic Multipliers, Photomixers, Electron devices
- Low Noise Amplifiers: InP and GaAs MMICs

Next Challenge: Heterodyne Imagers for Astrophysics and Biological sensing

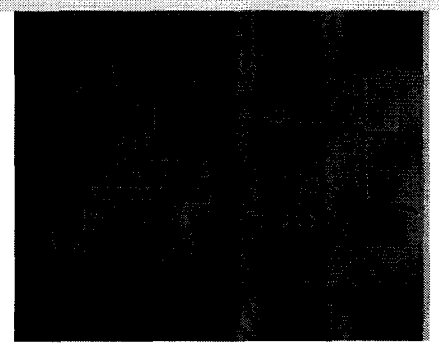
Submillimeter Wave Technology- Semiconductor Sensors

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

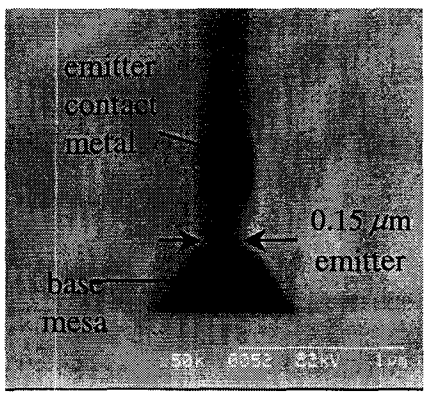
Although superconducting sensors have the highest sensitivity and are generally required for astrophysical sources, many planetary and Earth applications have sufficiently strong spectral signatures that sensors based on room temperature Schottky diode technology or low-noise front end amplifiers can meet the science requirements.

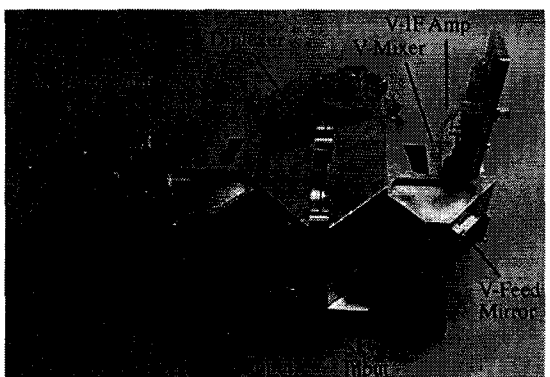


Custom fabricated JPL 2.5 THz mixer chip in a waveguide mount.

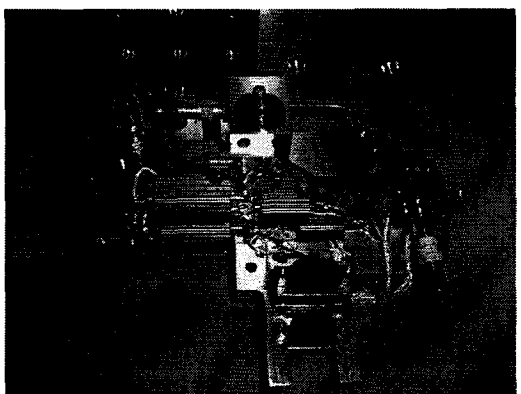


Antiparallel-pair JPL planar Schottky diodes





Two channel receiver for 2.5 THz flight application to measure stratospheric OH



JPL 640 GHz Protoflight Receiver for the measurement of HCl and ClO.

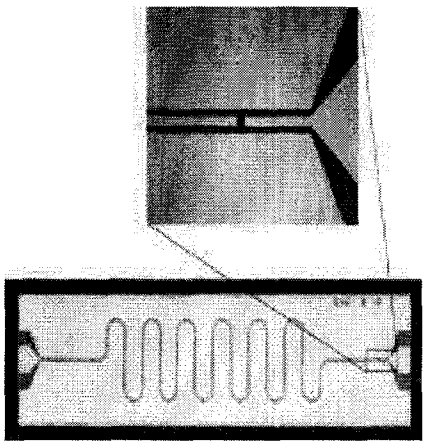
HBT Transistor Scaling:

By depositing a submicron collector from the *back* of the device, we can continue scaling features on the *front* of the device for even greater gain and speed. Above is a 0.15 μm emitter defined by e-beam lithography at JPL.

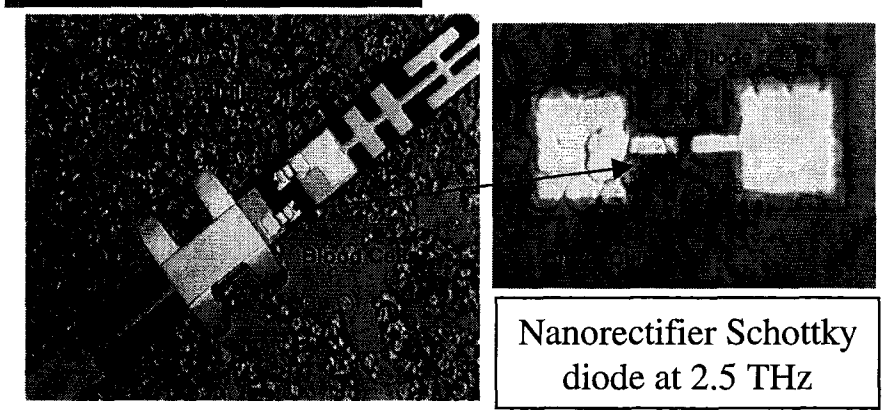
Submillimeter Wave Technology
Future Trends

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

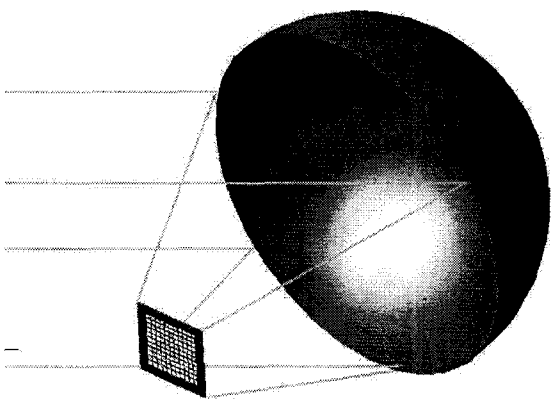
Novel Applications for THz Technology: New applications for THz technology are beginning to emerge as components are developed. Examples include THz wireless power transmission, imaging application, superconducting ultra-sensitive detectors, bio-instrumentation, and in-situ instruments etc .



Advanced superconducting detector devices. Above is a prototype resonator which is the heart of the Kinetic Inductance detector. Another exciting device is the Hot Electron Direct Detector (HEDD).



Nanorectifier Schottky diode at 2.5 THz



Concept: THz camera front-end used together with an off-axis parabola for beam focusing/shaping.

Wideband High Frequency Amplifier Technologies

Motivation Provide microwave and millimeter wave integrated circuits (MMIC's) needed for future NASA missions but not commercially available because of frequency range, bandwidth, power consumption, or space qualification. The benefits are enabling missions requiring arrays of sensors which would not be affordable or would not have the required performance without MMIC technology.

Challenges The challenges are higher frequencies (> 100 GHz), greater bandwidth (> 40 GHz), lower noise at cryogenic temperatures, and lower power consumption (<< 100 mW) than available MMIC's.

Benchmark Demonstrate MMIC performance and identify sources for foundry fabrication and module assembly and testing needed for NASA missions requiring engineering models within the next five years.

W-Band LNA

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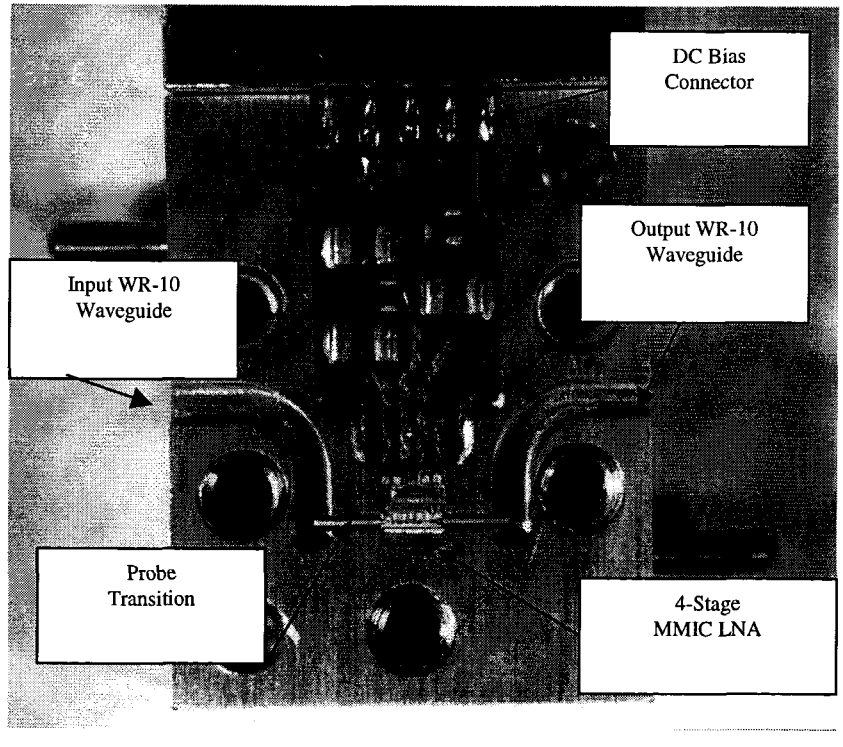
Jet Propulsion Laboratory
California Institute of Technology

W-Band Cryogenic MMMIC LNA for Planck Cosmic Background Measurement

World Record LNA Noise Temperature - 29K at 90 GHz



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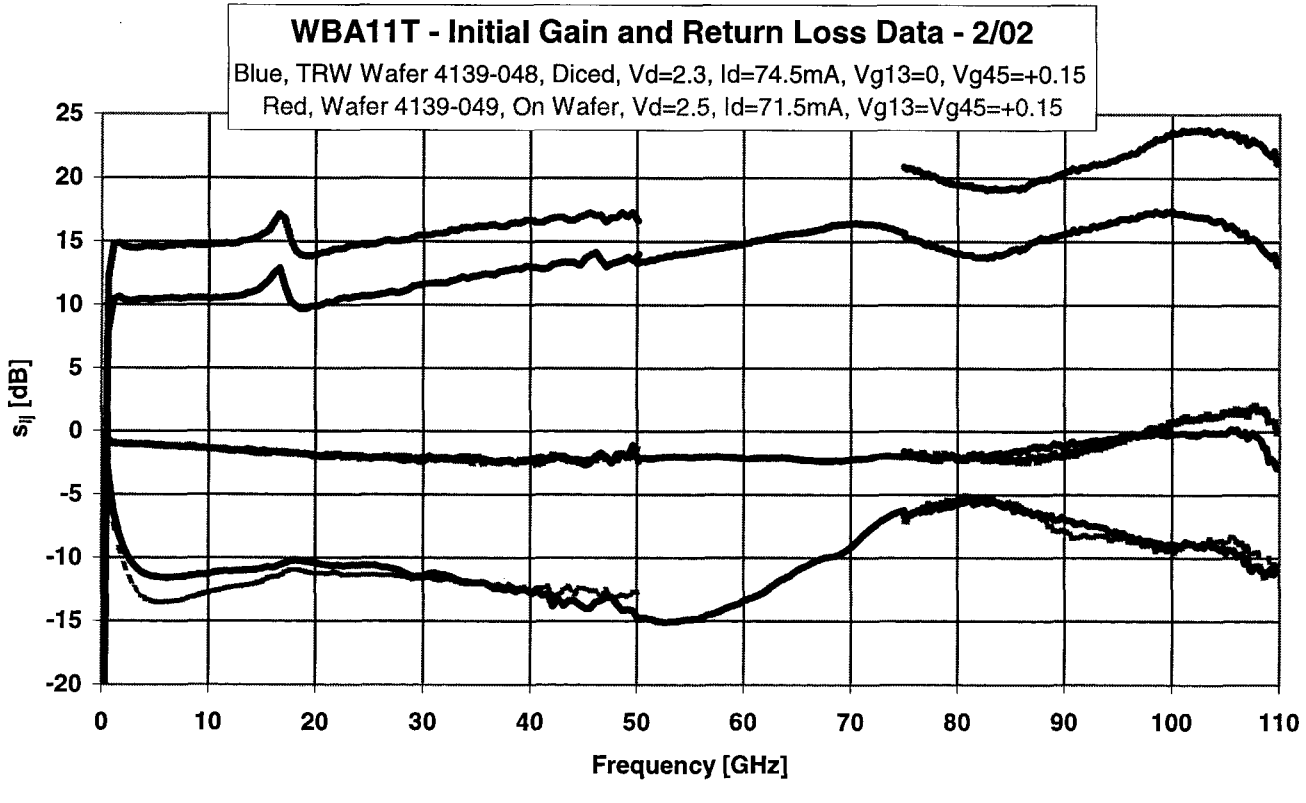
1 to 110 GHz Very Wideband Low Power MMIC Amplifier – Initial Results

S. Weinreb and M. Morgan

- Record gain-bandwidth, 15 to 24 dB over the entire microwave frequency range
- Size 2 x 0.73 x .075 mm. Power consumption 180mW. Single supply bias
- Expected NF of 5dB. P1dB 0dBm, and Psat +6dBm
- With a matching pad at input forms an active isolator with > 50 dB isolation.
- Glitch at 16 GHz and low-frequency slope will be corrected on next iteration



Direct Detectors and Focal Planes

National Aeronautics and Space Administration
Jet Propulsion Laboratory
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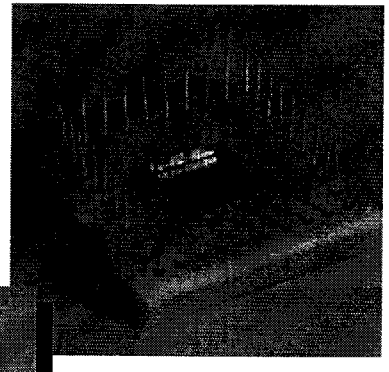
NASA missions probe the entire electromagnetic spectrum in studying the earth, the planets, and the universe

Visible
Science Grade CCDs
CMOS Active Pixel Sensors

Delta-doped UVCCD

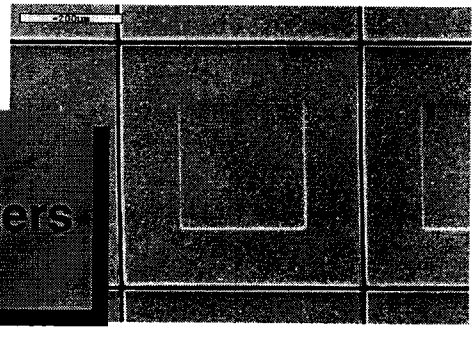


CZT X-ray focal plane

Ultraviolet
GaN Staring Hybrid FPAs
Delta-doped SiCCDs

CMOS APS "camera on a chip"

X-ray
Transition Edge Calorimeters
CZT Staring Hybrid FPAs



TES pixels

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APS Technology

NEEDS

Space-Science:
- Large format visible/UV detectors
- HST follow-on, SNAP, SUVO, TPF:
- OWL: energetic cosmic rays
- Solar coronagraph, solar doppler magnetograph

Planetary exploration:
- Mars Smart lander, Sample return, Scouts
- Landers, rovers, descent imaging, survey, in-situ sensing, miniature raman, autonomy
- Sun-sensors
- Outer Planets: fly-bys (Saturn, Titan, Europa)

Star-trackers: miniature, Gyro-less trackers

Optical Communication:

Space Station:
- Autonomous docking
- Wireless camera

Astrobiology:
- Integrated life detection systems: sensor fusion
- Small angle scattering spectroscopy
- Micro-fluidic bio-sensors

Earth-Science:
- Coastal imager – oceanographic applications
- High resolution spectroscopy
- AIR-MISR

CMOS Imaging CAPABILITIES

- *Ultra-low power (~10 mW):* 200x reduction
- *Great miniaturization:* 10-100x reduction
- *Random Access capability*
- *Ease of operation and integration*
  - Single-chip imager: "camera-on-a-chip"
  - Standard single power supply
- *More radiation tolerant:* > 10 Mrad. Imager
- *Best-suited for ultra-large format imaging*
  - High speed and low-noise
  - Dead-zone free "mosaicing"
  - Noise does not increase with data rate
- *Versatile, multi-functional smart imager*
  - On-chip processing
  - Real-time embedded tracking, object-ID
  - SNR optimization

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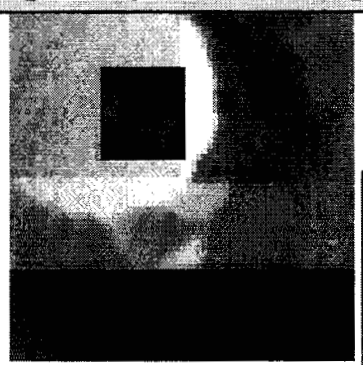
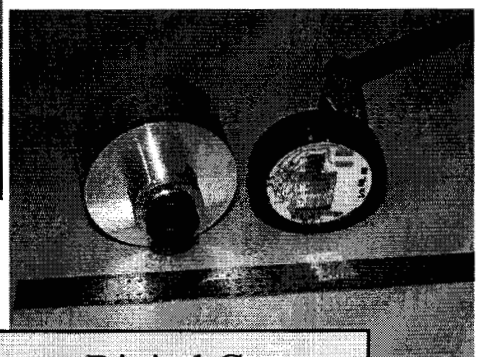
Capabilities

**CMOS APS can be miniature, rugged, and low-power:
WILL IT HAVE SCIENCE GRADE PERFORMANCE**

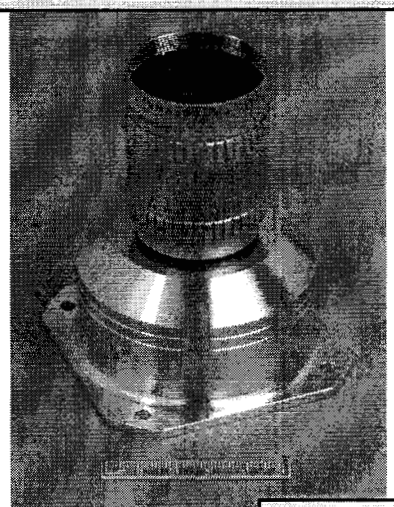
Spatially variable exposure





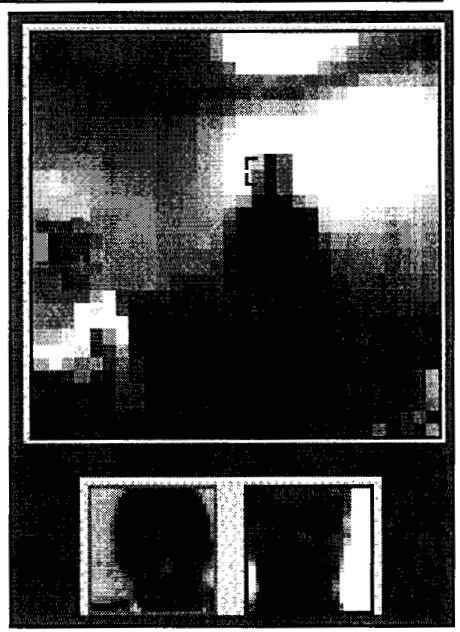
Miniature Digital Camera

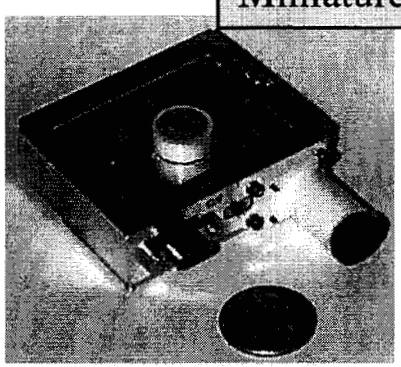
Miniature Gyroless-star-tracker



C. Liebe et al.

Reconfigurable Vision Camera





Wireless APS camera

Sun Sensor

S. Mobassar et al.

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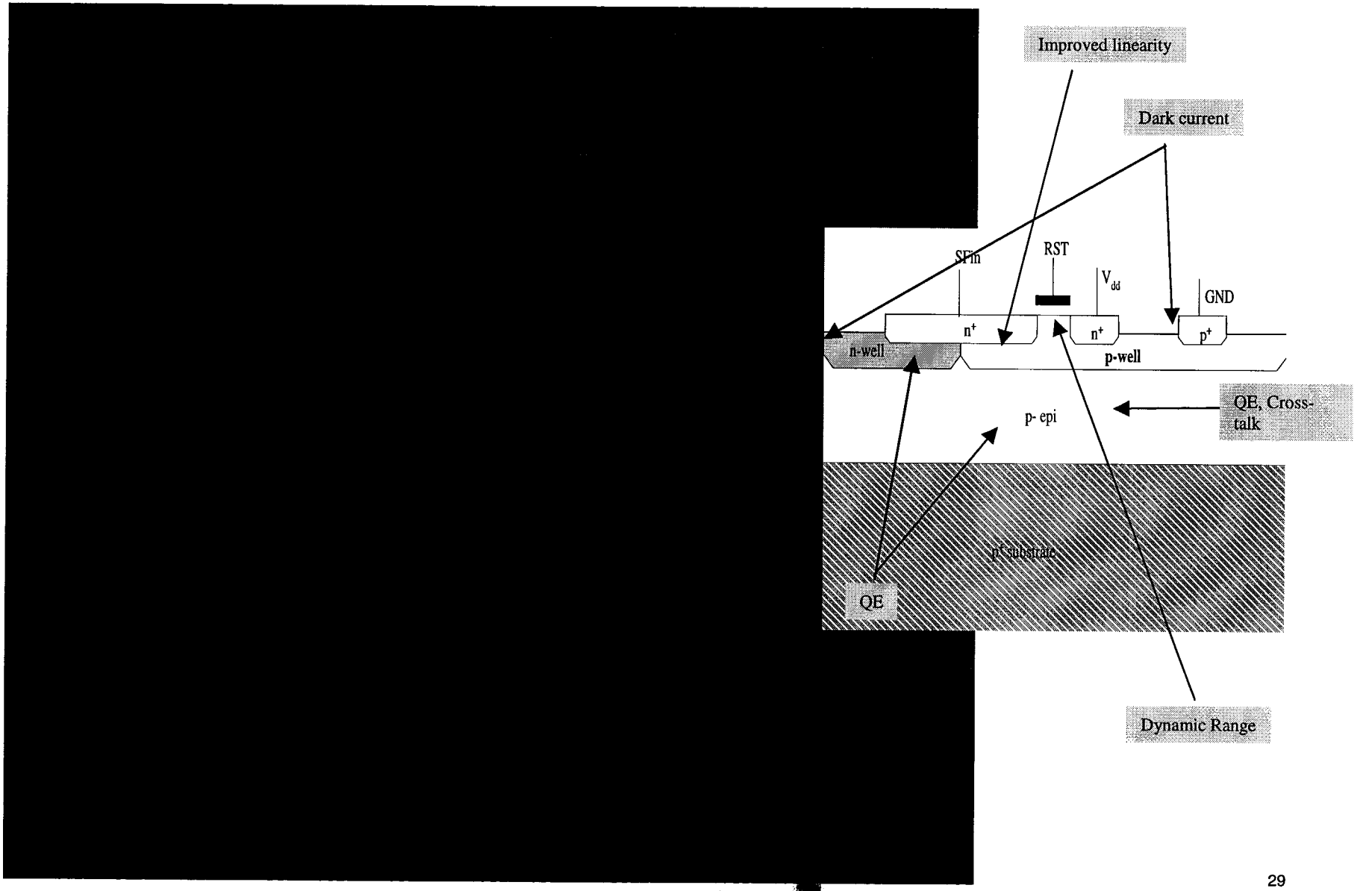
APS Challenges



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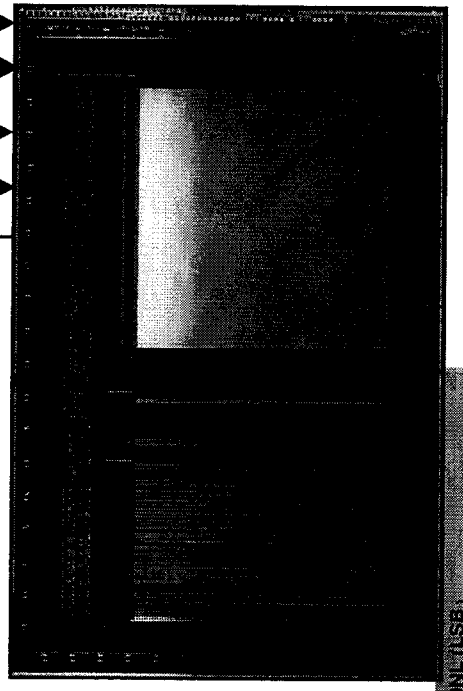
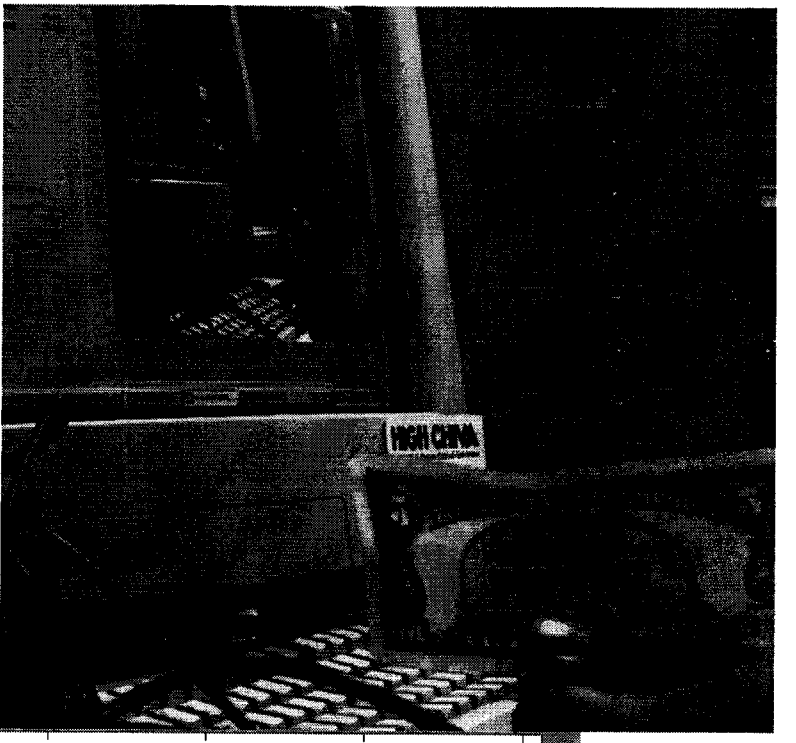
One-chip Digital Imager

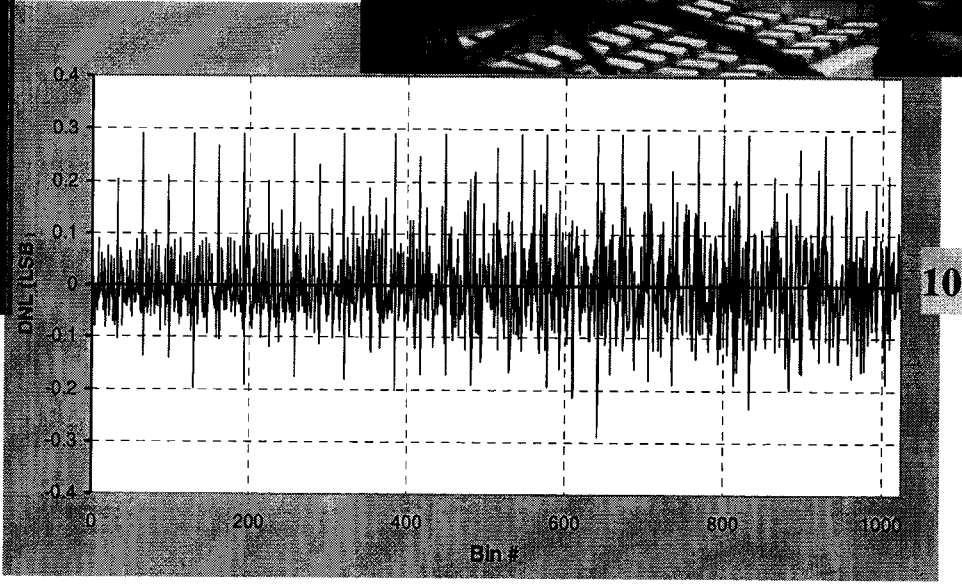
- 512x512 imager w/ integrated timing & control & column-parallel ADC
- Ultra low power: < 15 mW
- 5 wire interface

Vdd
Gnd
Clk
Din
Dout



Digital Image at video-rate





10 bit ADC

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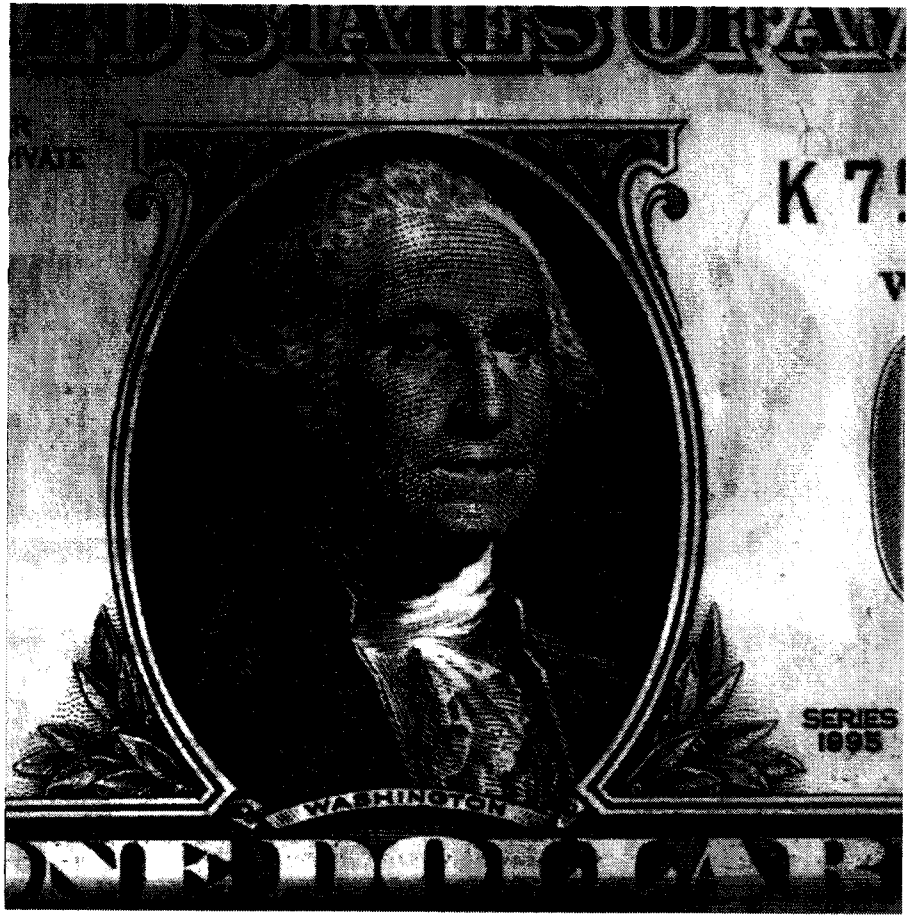
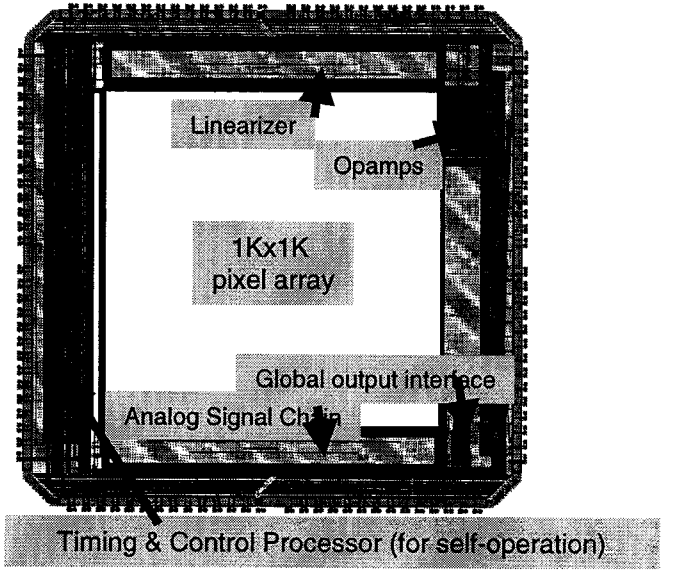
Megapixel Imager - Results





Format: 1024x1024
Pixel size: 9 µm
Full well: 175Ke
Response: 15µV/Ph
QE: 42%
Spectral band: 400-1000 nm
Noise: 30 e/5e w/CDS
Response uniformity: 0.8% r.m.s.
Linearity: < 1% INL

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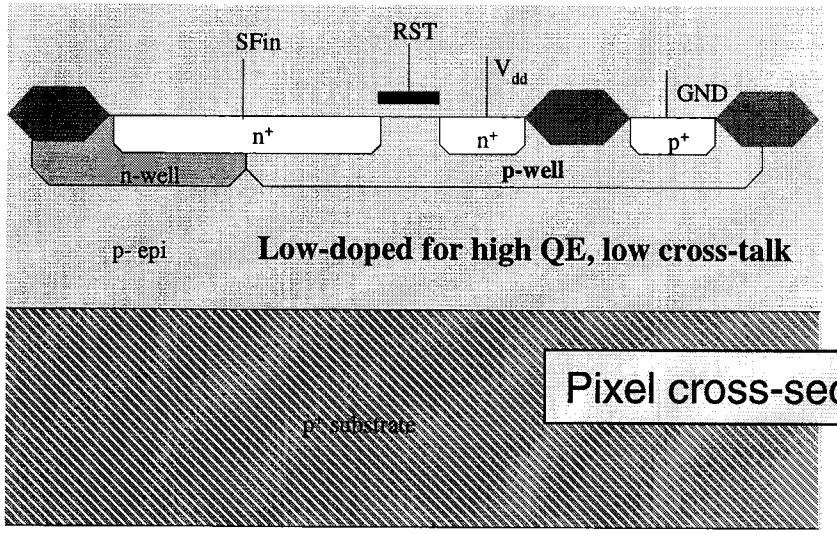
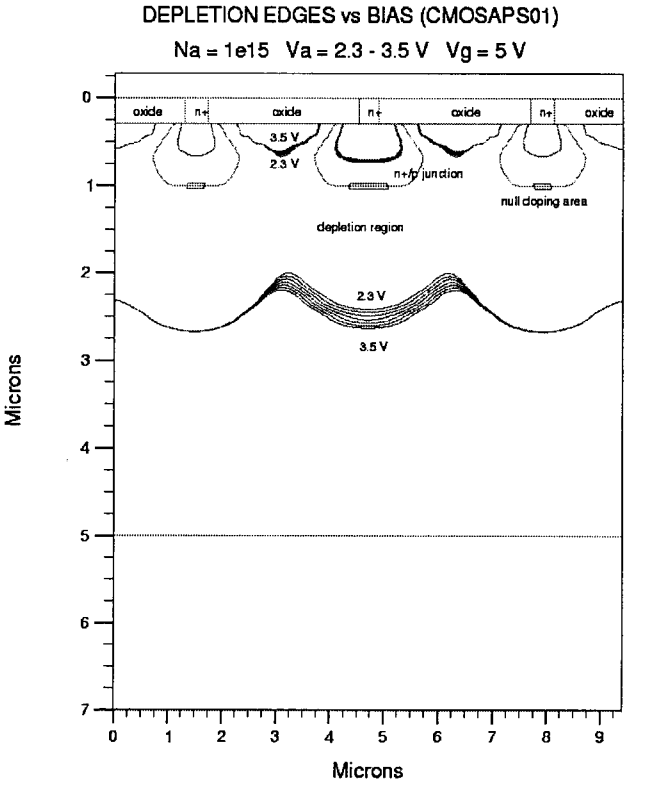
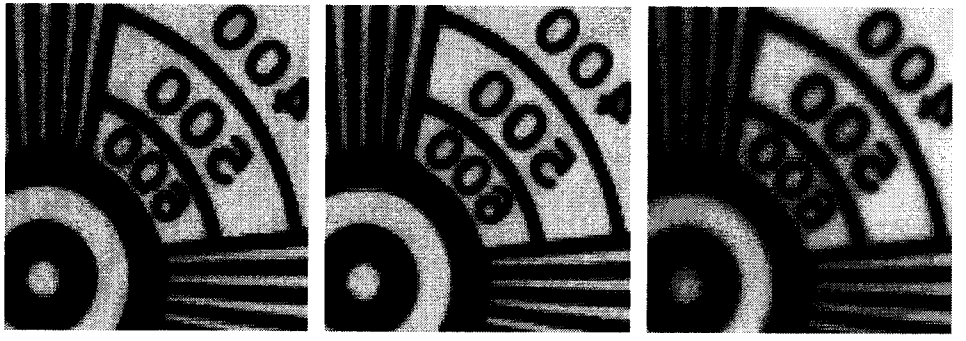
Megapixel Imager - Design



Pixel cross-section

Large Depletion ~ 3 µm
Can be increased further via back biasing
Can be accomplished through post-processing





500 nm 700 nm 900 nm

Lasers and Photonics

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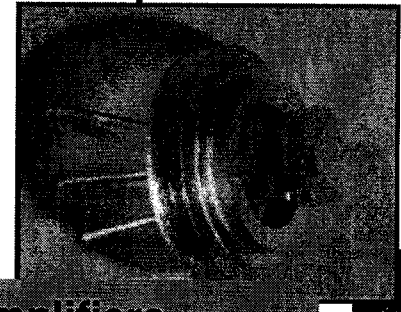
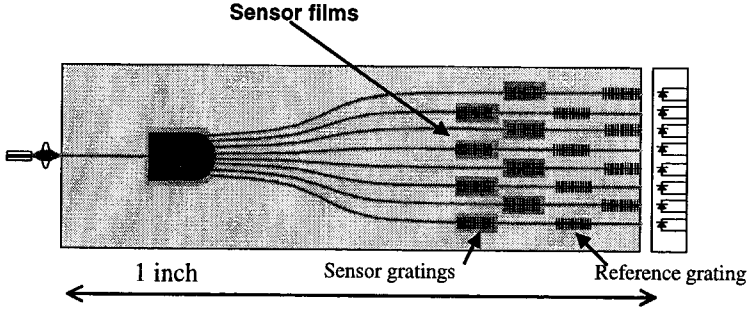
Tunable Diode Lasers
- 2.04 & 1.37 µm TDL for Mars
- LWIR quantum cascade lasers

2.04 µm TDL



Fiber Laser / Amplifiers
- 944 nm microlidar source
- 2 µm eye safe fiber laser lidar

0.5W Optical Amplifier



Photonic Waveguide Devices
- Ultrastable diode lasers (<100kHz)
- Waveguide biosensor arrays
- Widely tunable lasers for Raman

Tunable Diode Lasers

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Jet Propulsion Laboratory
California Institute of Technology

Objectives:

Design and fabricate novel high power and narrow linewidth semiconductor lasers in near-IR and mid-IR spectral regions to meet NASA Space Science and Earth Science requirements.

Applications:

Spectroscopy:

Space science

- •Chemical analysis on planetary surfaces
- •Structure and Evolution of Universe-Sensors
- •Laser based science instruments

Life sciences

- •Detecting hazardous trace contaminates to support human exploration of Space
- •Tunable diode laser-based autonomous sensors for life support
- •Instrument Network for atmospheric contaminant detection

Communications:

- •Inter-Spacecraft communication

Microinstruments:

- •μLIDAR

LIDAR, Metrology and Interferometry:

- •Space Interferometer Missions
- •Obtaining high resolution images and exterme-accuracy astrometry
- •Measurement of global atmospheric winds through the use of LIDAR
- •Measurements of atmospheric gases and aerosals through differential absorption LIDAR

Tunable Diode Lasers for Spectroscopy

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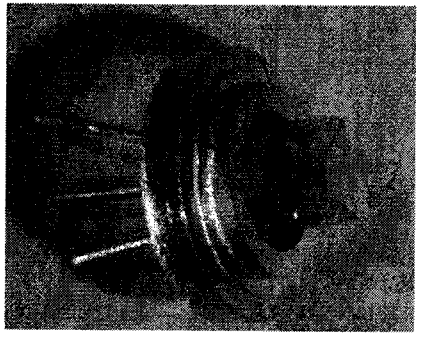
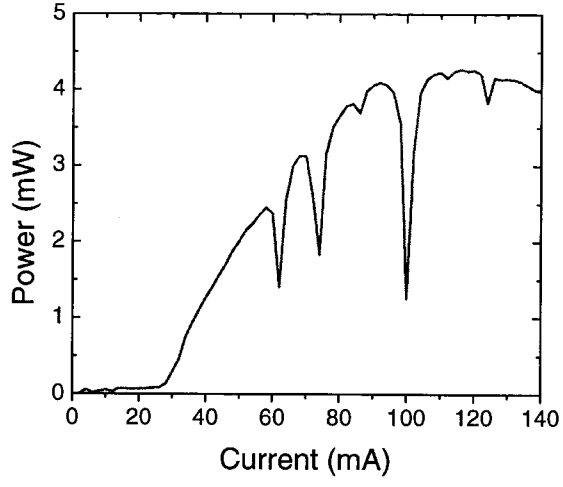
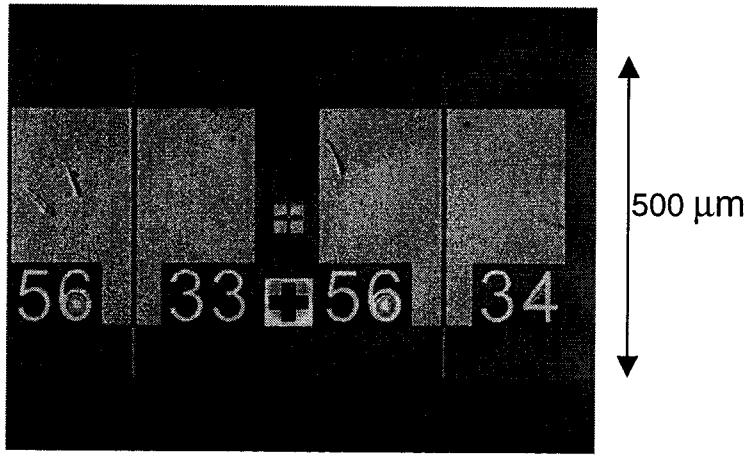




1.37 μm TDL

Wavelengths must be accurate to 1 part in 10^{-3}.
Requires uniform material growth and precise grating pitch control.



Recent TDL lasers :
(**InGaAsP / InP**)

1.37 μm	H_2O
1.43 μm	CO_2
1.26 μm	HF
1.52 μm	NH_3
1.65 μm	CH_4
1.74 μm	HCl
1.89 μm	H_2O
2.04 μm	CO_2 (isotope)

TDL: Relevance to Earth Science Enterprise Missions

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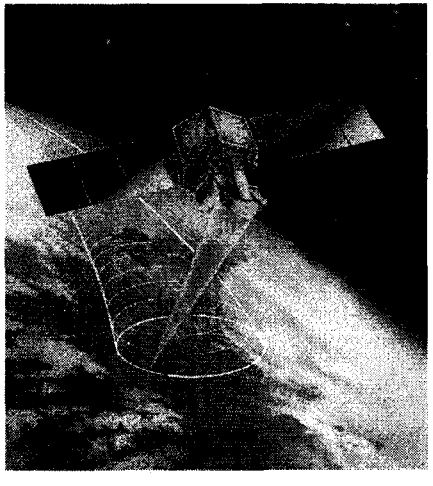
Space-Based Coherent Doppler Wind Lidar

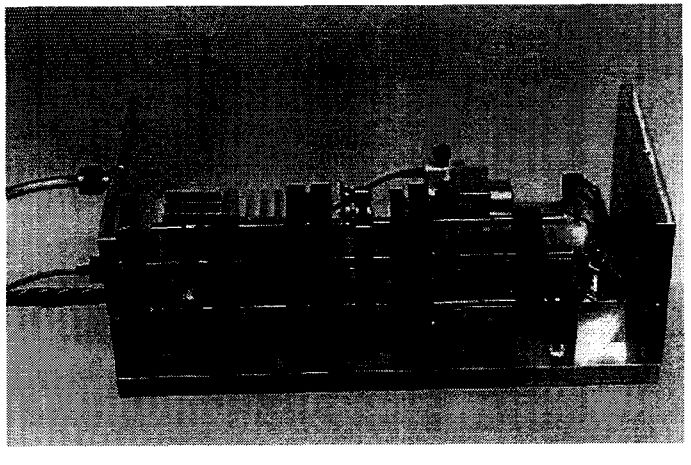


Coherent Doppler wind lidar candidate for ESE OP-2 mission is reliant on off-nadir beam scanning geometry for retrieval of vector winds by Doppler analysis of radiation backscattered by entrained aerosols and cloud particles.

Off-nadir scan pattern induces large platform-induced Doppler component which must be compensated by scan-synchronous tuning of a frequency-agile local oscillator (LO) laser. Frequency-agile LO technology development has thus far implicitly assumed same laser material as transmitter laser (Tm:YLF, Tm,Ho:YAG, etc.). *Target operating λ is c. 2.05 μm.*

Current diode-pumped crystal laser devices are mechanically complex and relatively cumbersome; tuning stability and reproducibility are critically dependent on maintenance of stringent alignment tolerances.

	Solid State Laser	**Diode Laser**
Mass	1kg	few grams
Power Consumption	10 W	fraction of a watt
Reliability	low	high
Power Output	100 mW	25-50 mW (JPL)
Linewidth	<2 kHz	<50 kHz



Lasers: Future Plans

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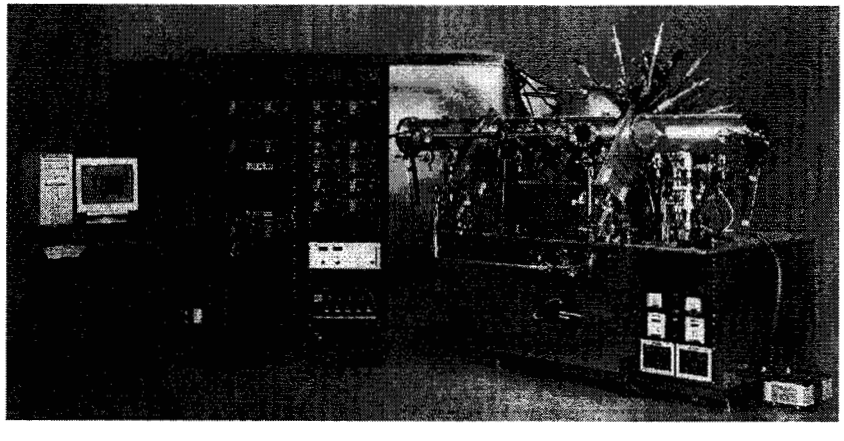
Sb-based lasers:

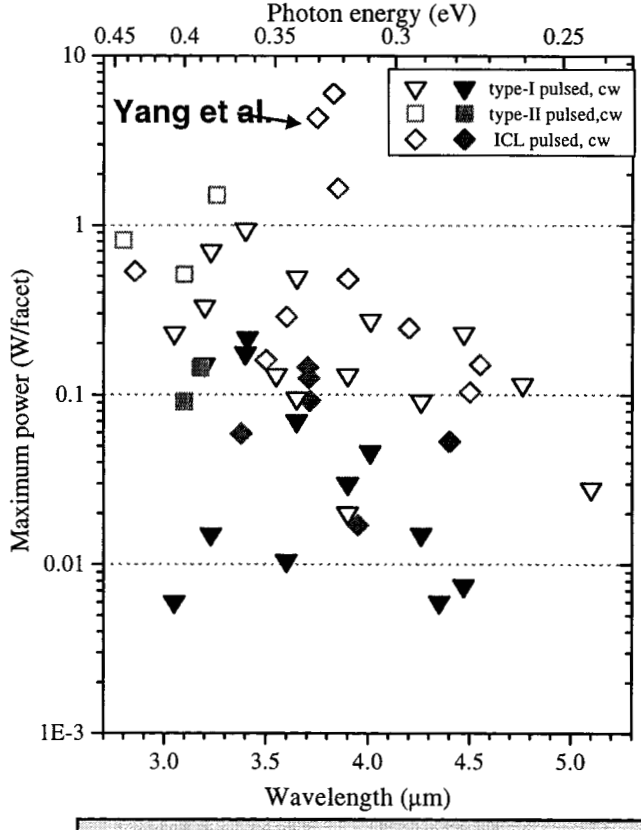
•Sb-based III-V material system produce 2-6 micron single mode high power lasers

• Sb- based material systems also basis for work in quantum dots for detectors and electronics



JPL's New Sb MBE System ($ 1200K)

Research Status of III-V Sb-based Interband Diode Lasers



Record-high peak power (~6W/facet) demonstrated by ICL

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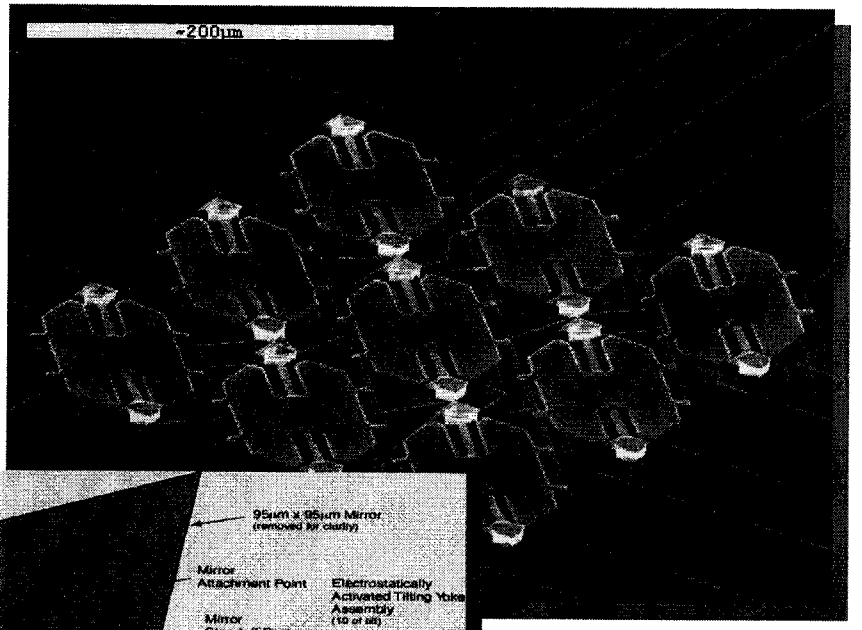
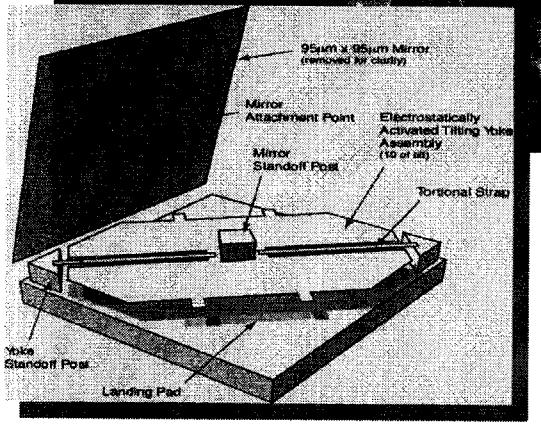
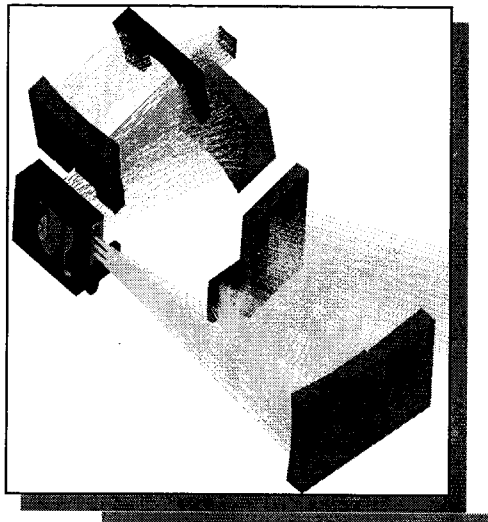
Novel Optical Elements

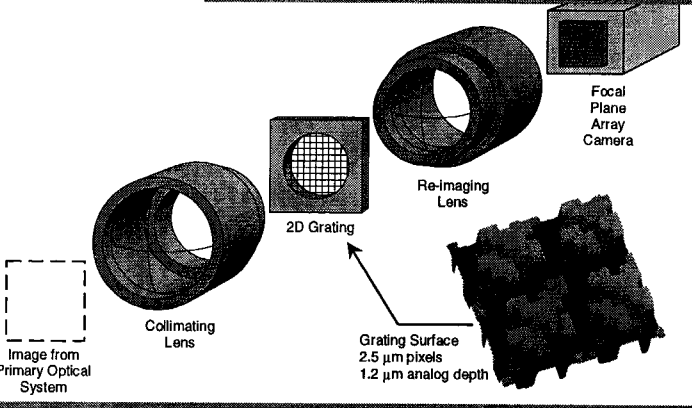




Individually Addressable Micro Mirror Arrays

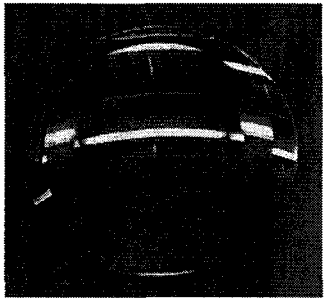


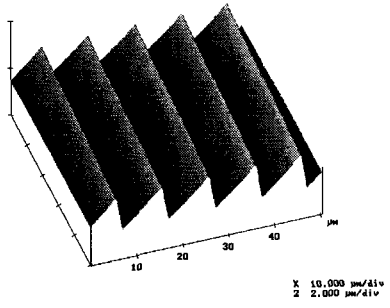
Miniature Infrared Hyperspectral Imaging



Computed-Tomography Imaging Spectrometer with Diffractive Gratings

Products





Left: convex blazed grating with room lights reflected (diffracted) from its surface, showing two different blaze areas. Right: Groove profile generated by atomic force microscope. Typical groove width 2-30 μm

Technical Objectives

- **Long term goal**: Development of grating and spectrometer forms spanning the complete range of potential NASA spectroscopy applications
- **Product at the end of FY 00**: For E-beam gratings, TRL 3 (-9); for X-ray gratings, TRL 1
- **Product at the end of 2-year period of CETDP funding**: For E-beam gratings, TRL 4 (-9); for X-ray gratings, TRL 4

(note: E-beam gratings have been flown, but improved forms have been under development)

Participants & Customers

- PI: P. Mouroulis, JPL
- Co-Is: F. Hartley, D. Wilson, P. Maker (JPL), M. Feldman, (LSU)
- Unique facilities: JPL E-beam lithography facility, LSU CAMD synchrotron
- Primary Enterprise Customer: Earth and Space Science equally.
- Examples: Delivering E-beam gratings to APL's MRO CRISM instrument

Accomplishments

- A new method for curved blazed grating fabrication has been demonstrated, using gray-scale X-ray lithography. The method has been shown to produce high-quality gratings over a greater curvature than any other method.
- A new E-beam machine has been shown to produce improved gratings in a shorter time than previously, enabling larger area and sag as well as finer pitch and reduced parasitic light.
- A new method for generating deep grooves for thermal IR applications has been demonstrated.
- Published/presented 6 papers

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Motivation: Concentric spectrometer designs incorporating curved gratings offer compactness, simplicity of construction, and higher performance than their conventional flat-grating counterparts for a large variety of applications. However, curved gratings with good blaze profile, sufficient curvature, and low parasitic light are difficult or impossible to make with conventional techniques.

Challenges: Specific challenges within this research were the installation, operation, and calibration of a new E-beam machine as well as setting up from zero a method for grating fabrication through X-ray lithography. In this latter part, the fabrication of the X-ray mask in conjunction with the choice of the resist are the key challenges.

Benchmark: Comparison of techniques for grating fabrication:

	Ruled	Holographic	E-beam	X-ray
Efficiency	High, but limited by variation of blaze angle over the extent of the grating.	Very difficult to achieve high efficiency over significantly curved surfaces.	Maximum efficiency can be achieved over specified wavelength band.	Maximum efficiency can be achieved over specified wavelength band.
Wavefront quality	Poor for non-flat substrates	High	High	High
Coherence (multipanel gratings)	Poor	Unknown	High. Phase can be adjusted between panels.	High in principle, phase adjustment should be possible.
Stray light (ghosts, satellites, "grass" or scatter)	Poor. Strong satellites can appear in significantly curved gratings. Grass is a known problem.	Best performance in principle, but practical implementation may not achieve theoretical limit.	Extremely low grass. Extremely weak satellites. Some ghost limitation, to be improved with new development.	Best performance in principle, possibility of very weak satellites introduced by periodic errors in stage motion (but not inherent).

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Summary : At the beginning of this project, E-beam gratings had already reached a level of maturity suitable for low resolution but high precision spectroscopy and were proven on NM-EO1 Hyperion. Gratings made by X-ray lithography were a mere idea.

We sought to expand the range of applications for E-beam gratings through finer pitch, greater groove depth, larger area/sag, and reduced parasitic light. We also sought to prove the potential of X-ray gratings for steeply curved or irregular substrates and minimum parasitic light, while retaining the high efficiency advantage of E-beam gratings.

Grating parameter	As of '00	As of '02	End of project
Minimum pitch (E-beam)	10 μm	1.7 μm	1.7 μm
Minimum pitch (X-ray)	--	6 μm	3 μm
Peak efficiency (E-beam)	91%	91%	91%
Peak efficiency (X-ray)	--	88%	88%
Maximum groove depth (E-beam)	2.5 μm	6 μm	6 μm
Maximum groove depth (X-ray)	--	1.5 μm	4-5 μm^
Maximum ghost/satellite (E-beam)	0.1%*	0.01%-0.1%**	0.01%-0.1%**
Maximum ghost/satellite (X-ray)	--	0.01%&	<0.01%&
Maximum sag (E-beam)	2 mm	3.8 mm	3.8 mm
Maximum sag (X-ray)	--	9 mm#	9 mm#
Maximum area (E-beam)@	5 cm diam.	10 cm diam.	10 cm diam.
Maximum area (X-ray)@	--	10cm x 5 cm	10 cm x 5 cm

*: subfield ghost
**: limiting factor is field ghost (satellite) revealed with more accurate measurements than previously. Spectral subfield ghosts for new E-beam gratings have been eliminated.
^: not yet demonstrated
&: Fixed ghost in spatial direction due to imperfect stage motion, not inherent to method, can be eliminated with better stage.
#: pitch-dependent
@: These are soft estimates, as a lot depends on pitch

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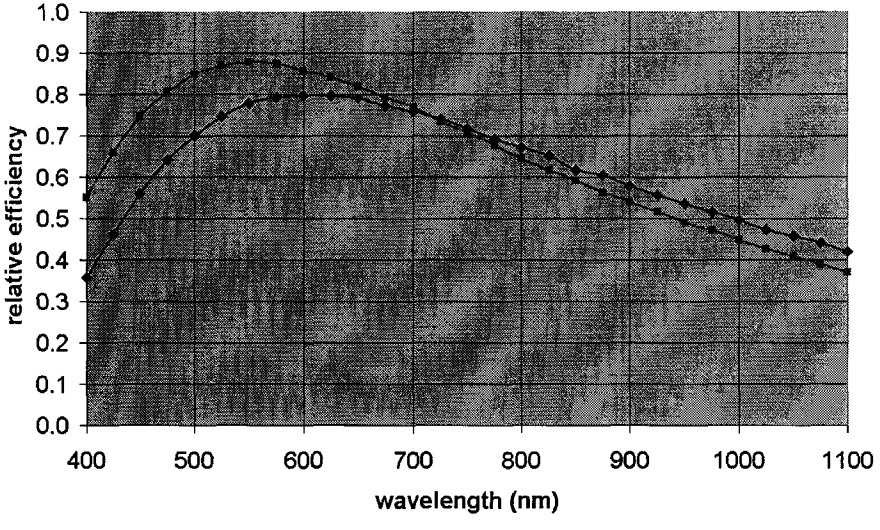
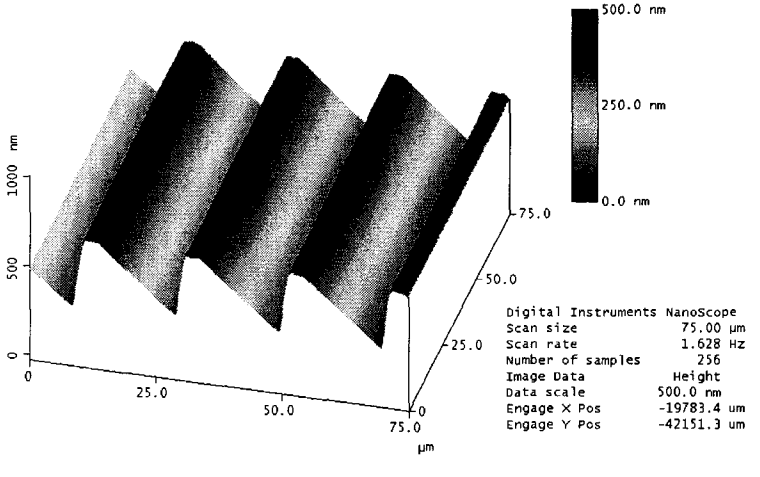
Gratings made by gray-scale X-ray lithography



Left: efficiency achieved to date. Lower (blue) curve shows efficiency obtained with first mask, higher curve shows efficiency obtained with improved mask.

Grating pitch 20 μm.

Right: Atomic force microscope scan showing the groove quality of the less efficient of the two gratings above.



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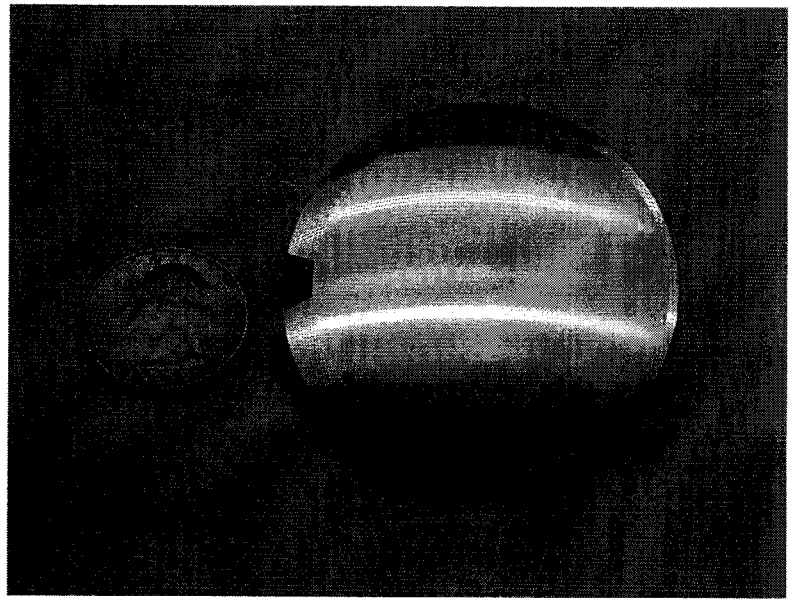
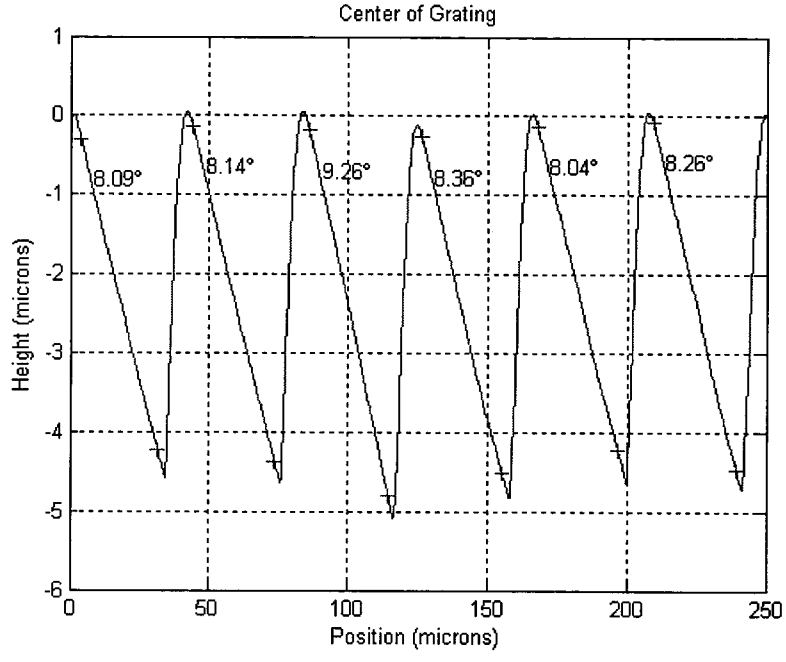
LWIR Convex Grating made by E-beam lithography





Specifications

- Period = 41 microns (24.393 lines/mm)
- Blaze angle = 8.326 deg (depth = 6.0 microns)
- Substrate radius of curvature 3.8643 inches (98.1532 mm)
- Grating diameter = 1.94 inches (49.2760 mm)
- Sag = 3.1426 mm

Average blaze angle = 8.36 deg

(deep grooves occur at field boundaries – every 8 grooves)

(Note: profilometer tip not sharp enough to resolve full depth.

Advanced Radar Technology

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Membrane T/R modules for lightweight membrane antennas

•The ultra-light, inflatable, membrane based ***passive phased array antenna*** has been already demonstrated for synthetic aperture radar (SAR) applications enabling dramatic reduction of weight and volume of space-based radars for planetary and Earth remote sensing.

Objectives:

•In order to increase performance of the membrane antenna while further reducing mass and volume, a membrane compatible transmit/receive (T/R) module is needed to demonstrate fully ***active phased array antenna*** with scanning capability.

•Key development areas include:

- •Defining the system architecture
- •Investigating different technologies such as MEMS, Optical MEMS and flexible Si for integration with the membrane antenna
- •Selecting the optimal power devices and heat removal technology.

Compact Conversionless Radar System

•Standard superheterodyne radar system, which uses multiple steps of frequency conversion, amplification, and filtering to process signals, is based upon the requirement that generation and detection of radar signals be performed at frequencies substantially lower than the radar operating frequencies. ***This architecture requires multiple and heavy electronic components.***

Objectives:

•In order to ***eliminate most of the components in the radar electronics***, microwave photonic components are being developed to enable generation and detection of signals directly at the radar operating frequency

•Key development areas include:

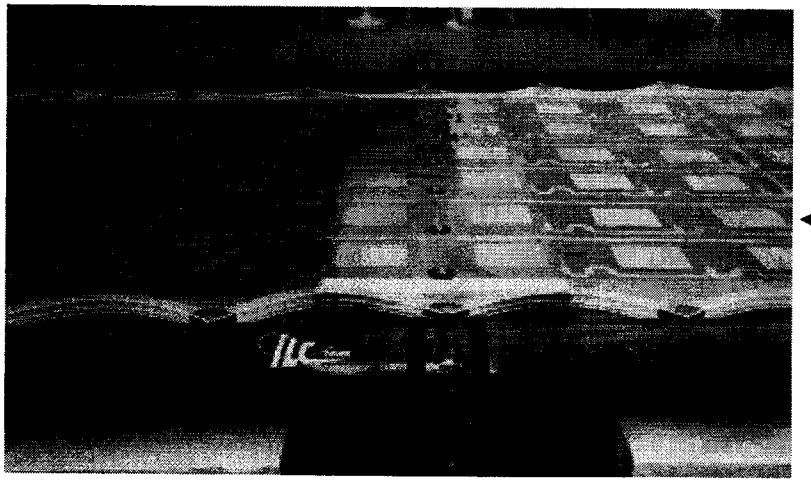
- •Innovative device for generating frequency modulated (chirped) waveforms at the radar operating frequency by modulation of optical signal
- •Novel technique for sampling these signals directly at the radar operating frequency using a low jitter optical clock.

The ultimate goal is to combine these 2 technologies to create a lightweight, low volume and low cost Conversionless Flexible Active Membrane Phased-Array Antennas capable of 2-D scanning

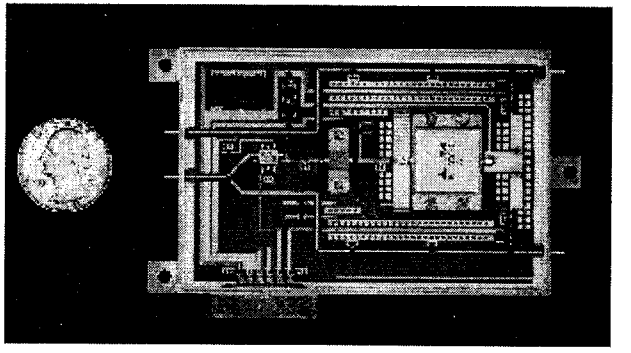
Advanced Radar Technology

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Motivation To develop the technologies required for membrane compatible T/R modules for active membrane SAR antennas. Applications of these spaceborne SARs are mapping, surface monitoring and change detection of Earth and other planets (Codes Y and S)



Inflatable membrane antenna



T/R module

Advanced Radar Technology

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

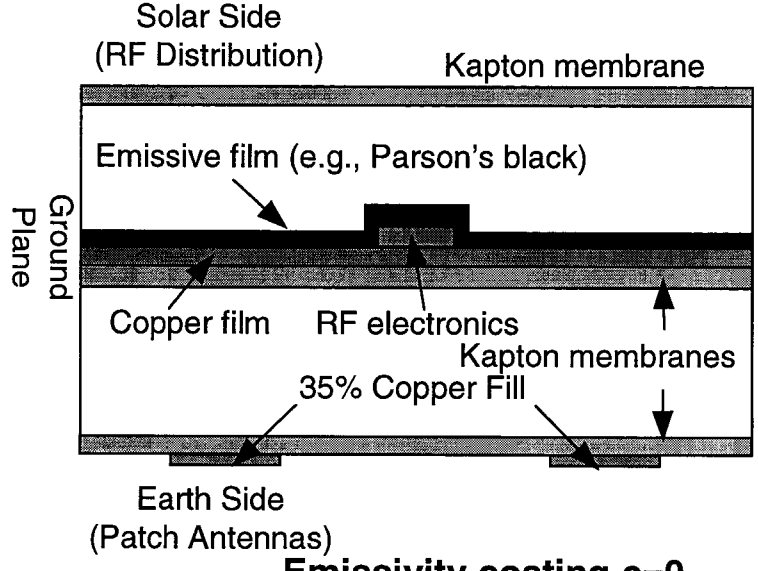
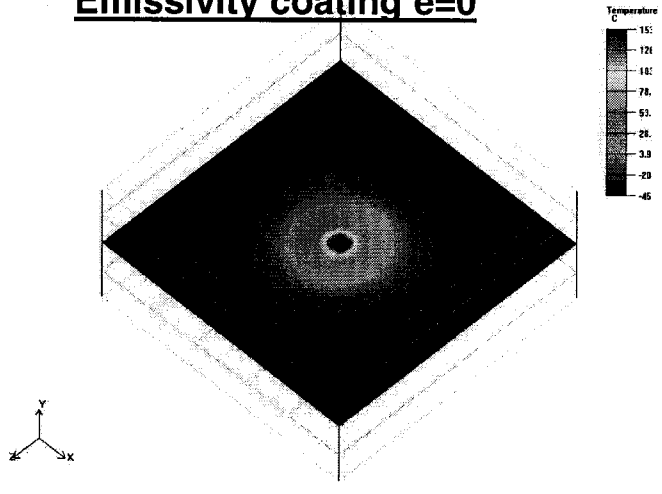


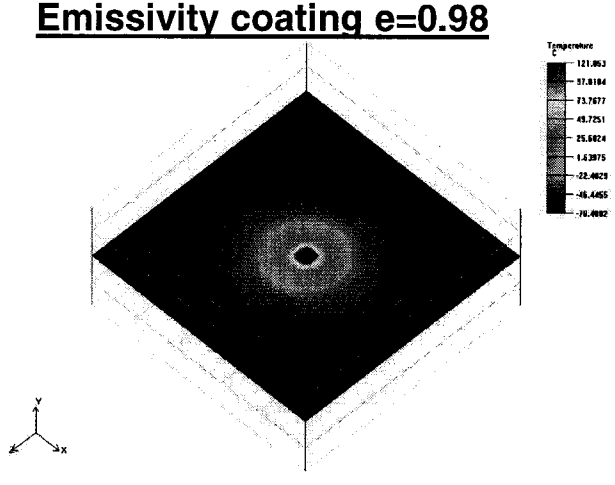
Table 1. Temperature Characteristics of Copper Ground Layer

Case 1: Emissive layer ε = 0.98			
Simulation Element	**Minimum**	**Maximum**	**Average**
Silicon Chip	103.4	121.9	120.2
Copper Film	-70.5	121.9	-24.4
Kapton Film	-70.5	121.9	-24.5
Case 2: Emissive layer ε = 0.0			
Simulation Element	**Minimum**	**Maximum**	**Average**
Silicon Chip	140.7	159.2	157.5
Copper Film	-45.0	159.2	6.3
Kapton Film	-45.0	159.2	6.1

Emissivity coating e=0



Emissivity coating e=0.98



M. Celis, K.T. Lien, E. R. Brown, J. Huang, and W. Edelstein, "Local Thermal Management for Space-Borne Inflatable RF Antennas," to be presented at the ITherm 2002 Conference, San Diego, CA. [46]

In situ Sensors

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Miniaturized Sensors Probing the Physical, Chemical, and Biological Properties of Samples

MEMS – based NMR spectrometer

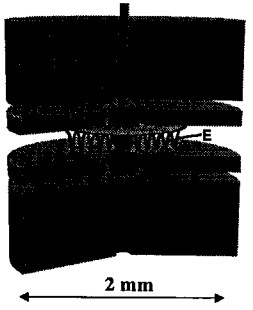
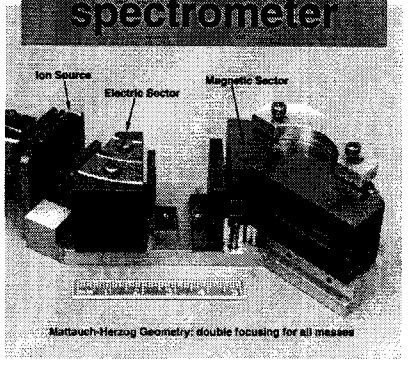
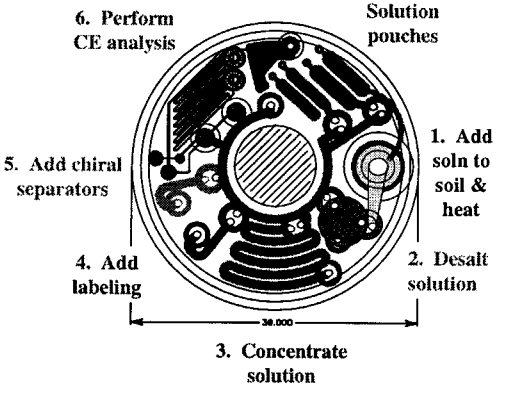


Figure 1: Schematic diagram of the microfabricated, force-detected nuclear magnetic resonance spectrometer. The key component is a mechanical oscillator made up of the sensor magnet C mounted on a silicon "diving board" or membrane D. The sample F sits in the cavity of an RF micro-coil E.

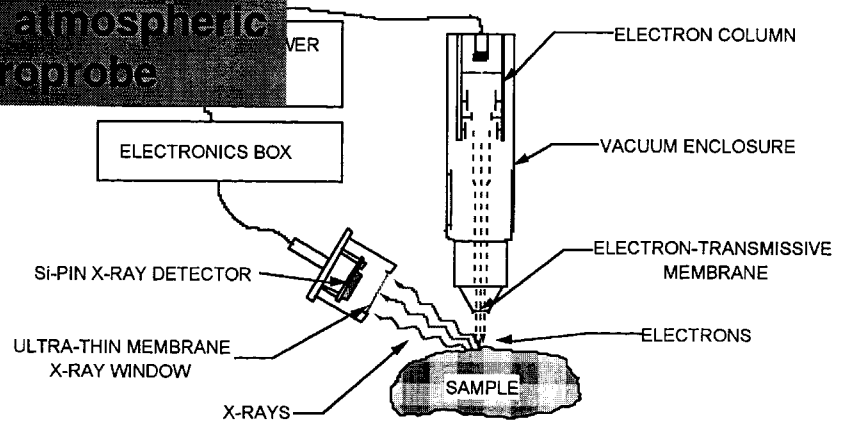
Miniature mass spectrometer



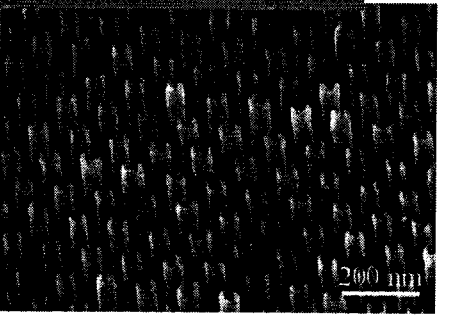
Microfluidic Sample Preparation



Miniaturized, atmospheric Electron microprobe



C nanotube arrays

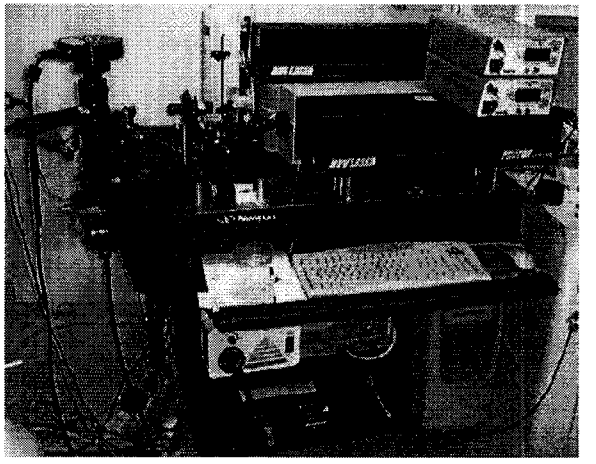


Portable DUV Fluorescent Imaging / Raman Spectroscopy System

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

- Leverages work for Astrobiology and Planetary Protection
- Can be used both for bacterial detection and sterilization
- Applicable to water quality and surface sterilization

Old Specifications:



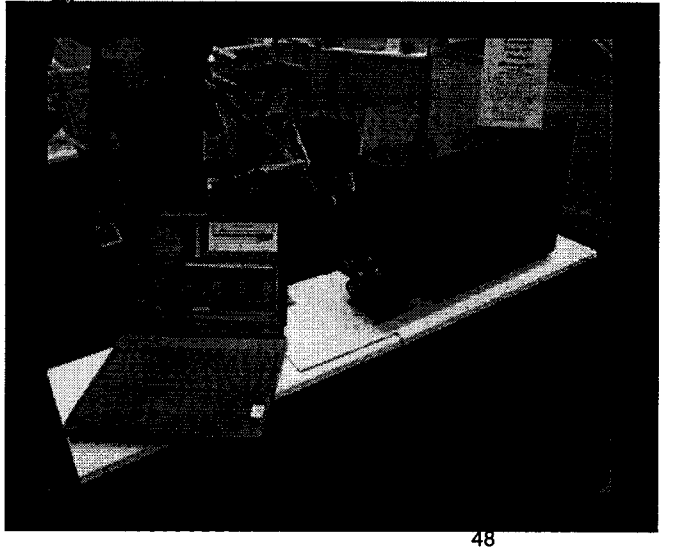
New Specifications:

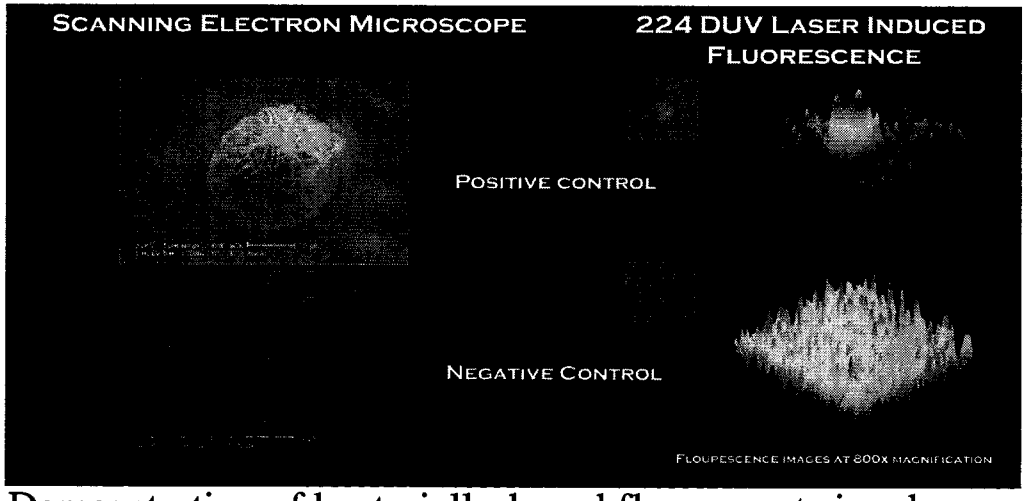
Size - 20cm x 25cm x 50.8cm

Weight - 10kg

Wavelengths - 1-3

Power Req. - <100W





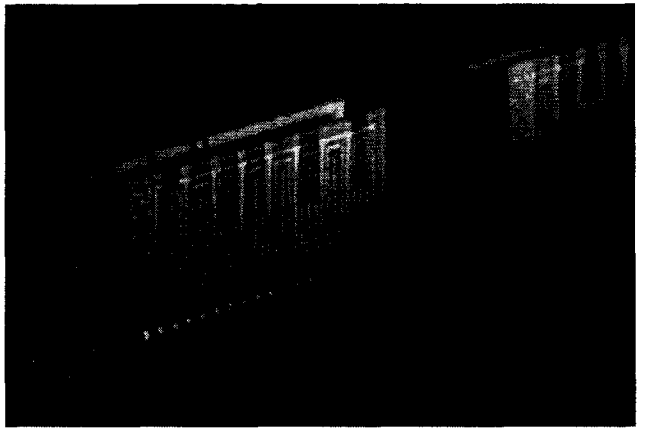
Demonstration of bacterially-based fluorescent signal

Electronic Nose

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Technology

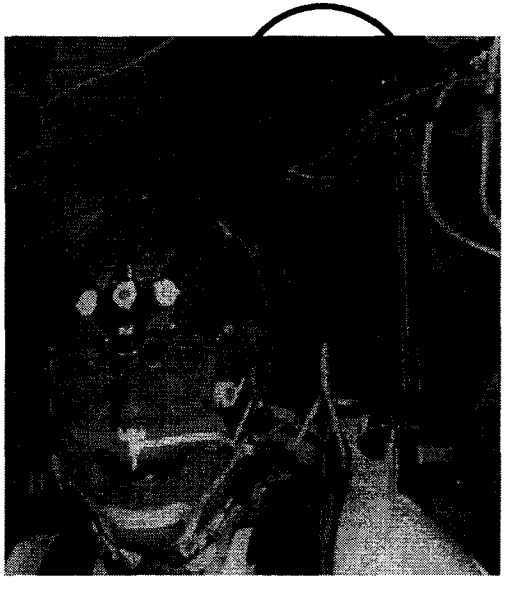
- Based on arrays of conducting polymers whose conductivity changes with exposure to different gases
- Chemicals identified by pattern of response across the array, in analogy to biological nose
- Flight experiment on STS 95 (1998) was the first ever continuous monitoring of any occupied spacecraft.



Performance

- High sensitivity & large dynamic range: 10 ppb - 10000 ppm
- Low power, mass, volume: < 2 W, 1.4 kg, 1700 cm^3 for complete system
- Real time event monitor: analysis in minutes
- Rapid response and recovery of sensors: seconds
- Can detect the presence of unanticipated chemicals
- Trainable to identify new chemicals

E-nose on board STS 95

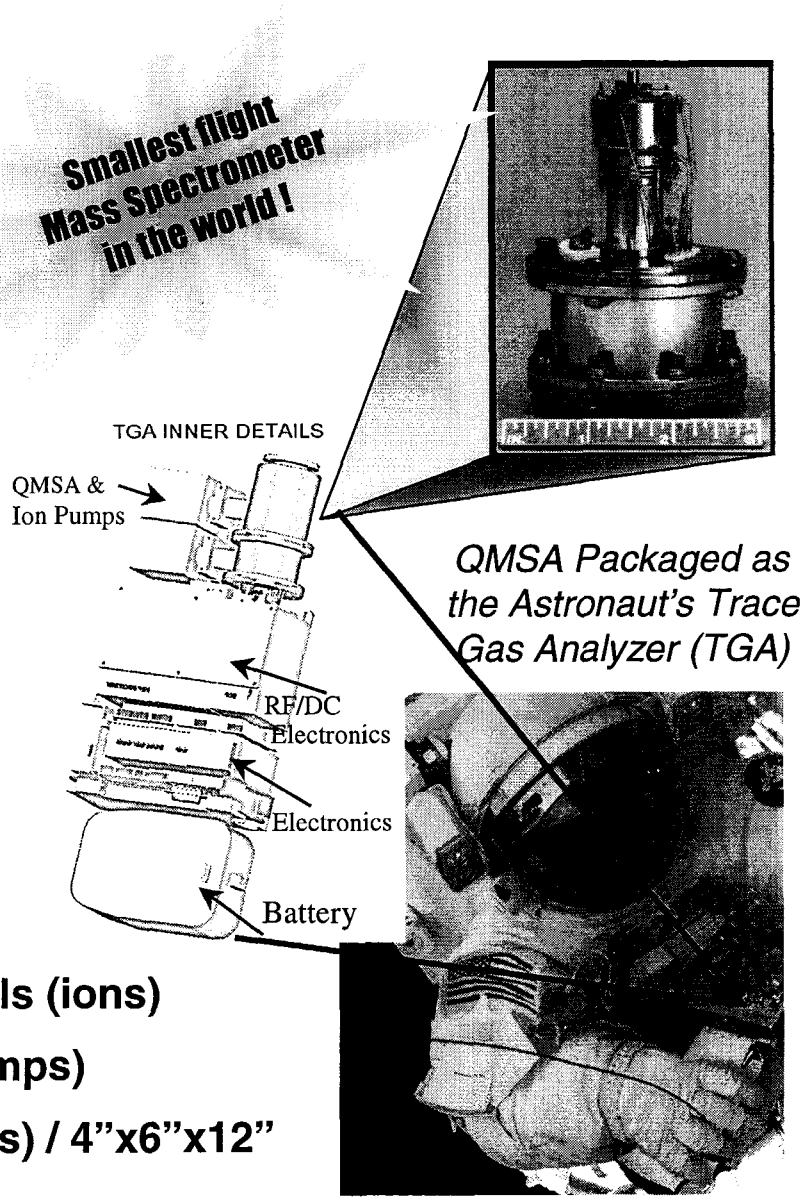


Miniature Mass Spectrometer

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Technology

- Miniaturized quadruple mass spectrometer maintains the mass range, resolution, precision & stability comparable to larger units with a sensitivity corresponding to ~ 500 ppb
- Improved ionizer development expected to yield explosives detector with 100x sensitivity of existing technologies
- Currently on board ISS to detect coolant leaks (ammonia), and propellant condensation (hydrazine)



QMSA Packaged as the Astronaut's Trace Gas Analyzer (TGA)

Performance

- Mass range / resolution - 1- 600 amu / 0.5 amu
- Dynamic range / crosstalk - 10^7 / 1 part in 10^4
- Sensitivity - $2x10^{12}$ (10^{14}) counts/torr-sec neutrals (ions)
- Power - 15 W at 150 amu (incl. electronics & pumps)
- Weight / size - 1400 g (incl. Electronics & pumps) / 4"x6"x12"

Micro Seismometer

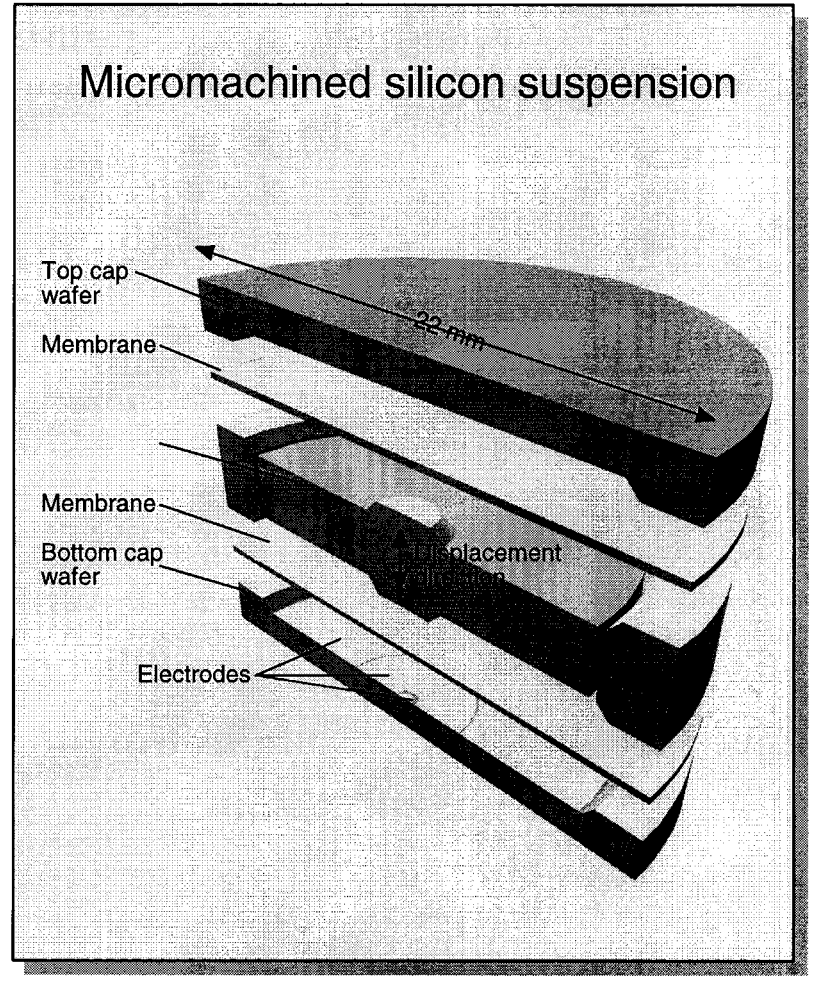
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Performance Goals:

- Mass: < 50 g (transducer)
- Volume: cylinder Ø 30 mm x 20 mm
- Operating Power: < 20 mW
- Sensitivity:
  - better than 10^{-8} m/sec^2/√Hz over entire band
  - 5 X 10^{-9} m/sec^2/√Hz at 10 Hz
- Bandwidth: 0.05-100 Hz
- Shock: 1000g, 100 ms half-sine
- Operating temperature: -80°C - +40 °C

Areas of Development:

- Suspensions - production of compact, robust, structures.
- Transducers - ultrasensitive, low-power position sensors.
- Control - electronically self centering, flat response, low noise

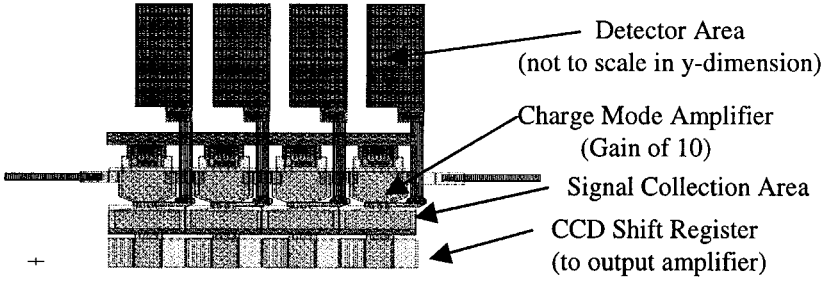


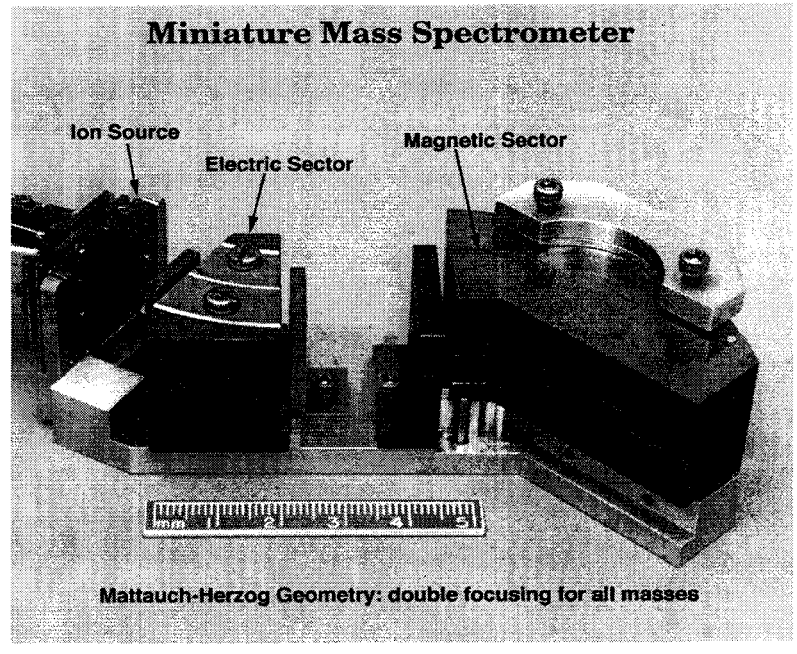
Miniature Mass Spectrometer (MMS)

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Objective:
Development of a unique, high performance miniature mass spectrometer. The detector is a key component of the MMS.

Array detector for a Miniature Focal Plane Mass Spectrometer based on **Direct Detection of Ions by Metal-Oxide-Semiconductor (MOS) Circuitry was developed under Code R funding**





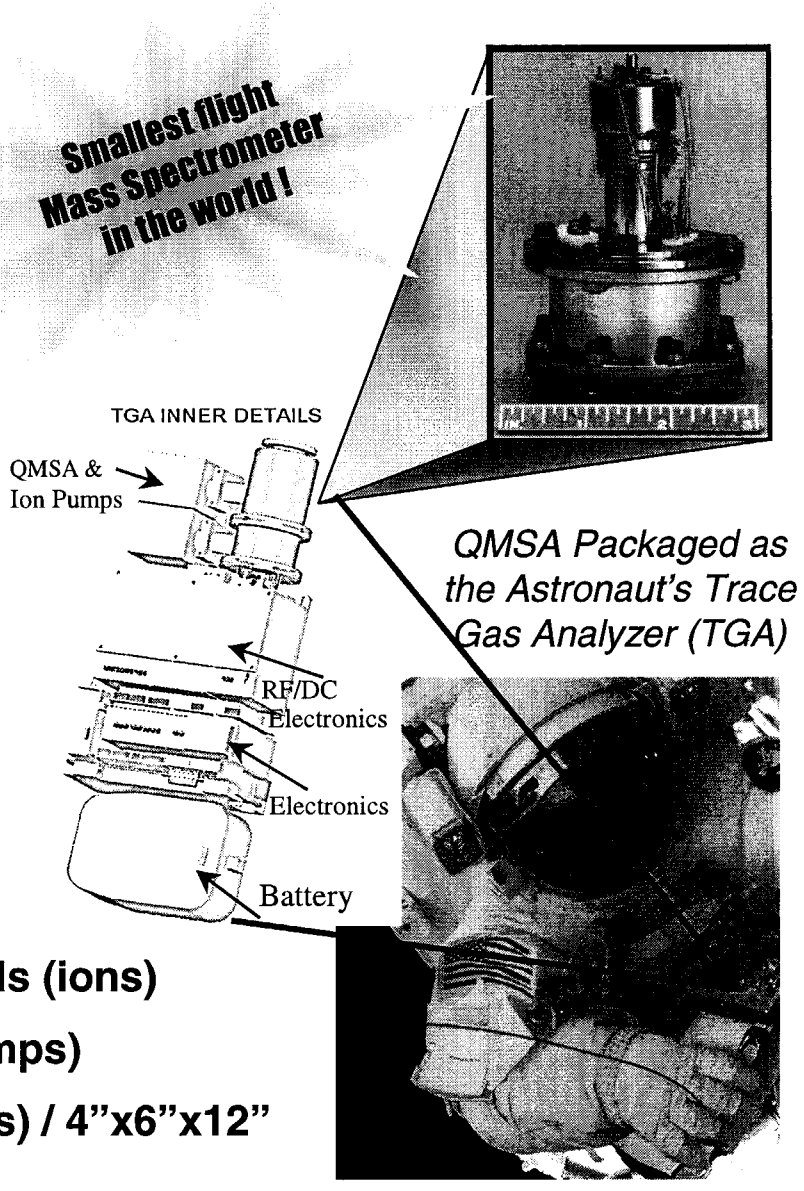
- *Michrochannel plate is replaced by array detector enabling operation at higher pressure*
- ***Rugged, Compact, and Simple to Implement***
- ***Improved Spatial Resolution and Sensitivity***

Miniature Quadrupole Mass Spectrometer

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Technology

- Miniaturized quadruple mass spectrometer maintains the mass range, resolution, precision & stability comparable to larger units with a sensitivity corresponding to ~ 500 ppb
- Improved ionizer development expected to yield explosives detector with 100x sensitivity of existing technologies
- Currently on board ISS to detect coolant leaks (ammonia), and propellant condensation (hydrazine)



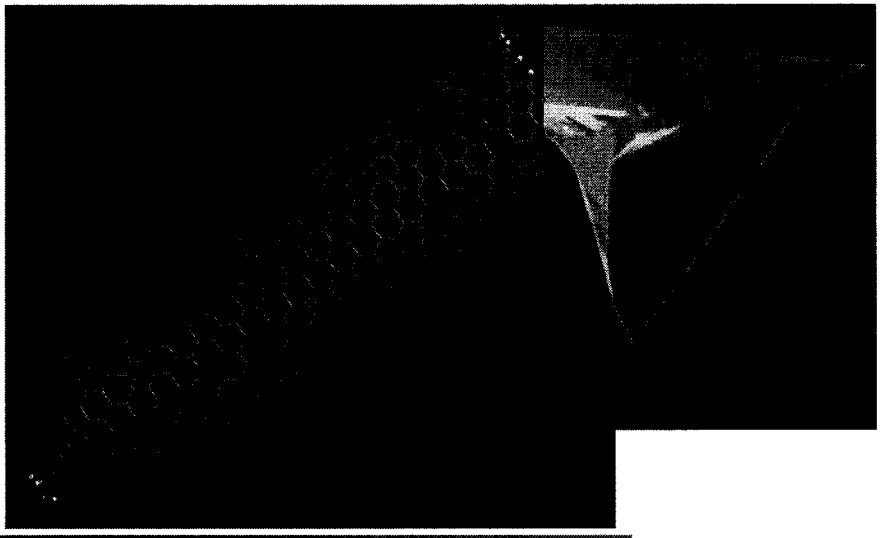
QMSA Packaged as the Astronaut's Trace Gas Analyzer (TGA)

Performance

- Mass range / resolution - 1- 600 amu / 0.5 amu
- Dynamic range / crosstalk - 10^7 / 1 part in 10^4
- Sensitivity - $2x10^{12}$ (10^{14}) counts/torr-sec neutrals (ions)
- Power - 15 W at 150 amu (incl. electronics & pumps)
- Weight / size - 1400 g (incl. Electronics & pumps) / 4"x6"x12"

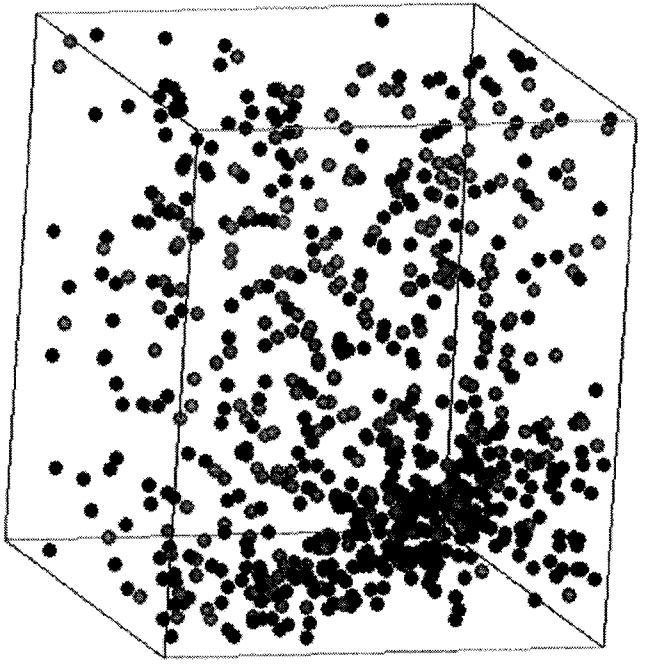
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Nano and Quantum – based Technologies

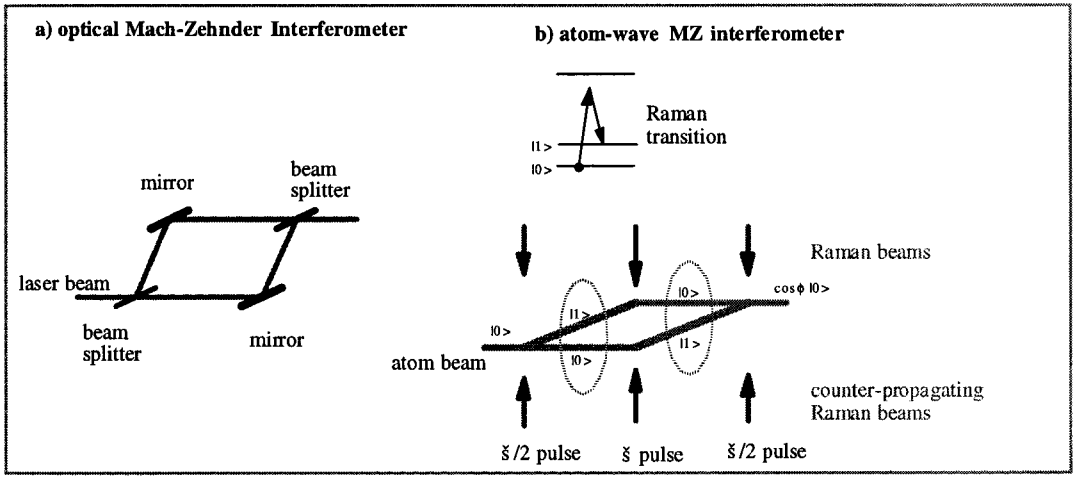


Carbon Nanotube Scanning Tunneling Microscope

3 dimensional atomic resolution image - Local Electrode Atomic Probe (LEAP)



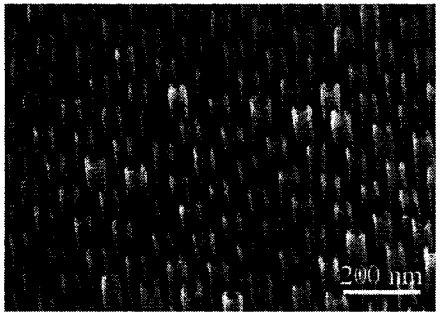
Coherent Atom Interferometry



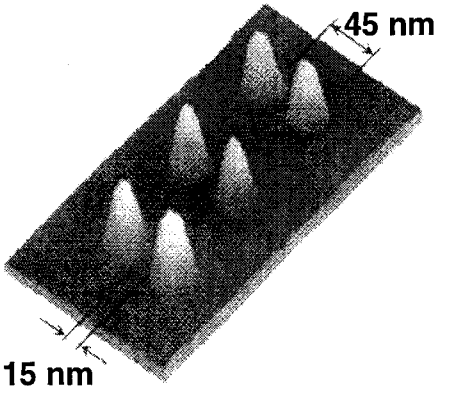
Nano Sensors

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Carbon Nanotube – based Sensors



- Electrophoresis sieve for molecular separations
- Cold Cathodes for THz nano vacuum tubes
- Nano Mechanical Resonators for RF filters

Quantum Dot – based Sensors

- High Temperature Infrared Sensors
- Tunable Diode Lasers (IR thru UV)
- Biochemical Sensor Arrays
- QD Computing on Wire
- Radiation Hard Nonvolatile Memory