SENSORS RESEARCH AND TECHNOLOGY

James A. Cutts

TECHNOLOGY FOR FUTURE NASA MISSIONS

AN AIAA/OAST CONFERENCE ON CSTI AND PATHFINDER

12 - 13 SEPTEMBER, 1988

WASHINGTON D.C.
SENSING TECHNIQUES FOR SPACE SCIENCE

PASSIVE REMOTE SENSING

ACTIVE REMOTE SENSING

IN-SITU SENSING
SENSOR RESEARCH AND TECHNOLOGY
GOALS AND APPROACH

• DEVELOP ENABLING AND ENHANCING SENSOR TECHNOLOGY
  FOR NASA SPACE SCIENCE MISSIONS

• EMPHASIZE DEVICE AND COMPONENT TECHNOLOGIES
  WITH MEDIUM-TERM AND LONG RANGE IMPACT

• PROGRAM ELEMENTS ARE
  • PASSIVE REMOTE SENSING TECHNOLOGY
    ☞ COHERENT (HETERODYNE) SENSING
    ☞ NON-COHERENT (DIRECT) SENSING
  • ACTIVE SENSING
  • SPACE COOLER TECHNOLOGY
PASSIVE REMOTE SENSING: TECHNIQUES AND APPLICATIONS

PASSIVE REMOTE SENSING

EM RADIATION

PHOTONS

ELECTRICAL SIGNAL

NON-COHERENT (DIRECT) SENSING

NATURAL RADIATION

LOCAL OSCILLATOR

RADIATION COLLECTOR AND MIXER

INTERMEDIATE FREQUENCY

COHERENT (HETERODYNE) SENSING

COHERENT (HETERODYNE) SENSING

NASA SPACE SCIENCE APPLICATIONS
ASTROPHYSICAL SOLAR SYSTEM EXPLORATION
EARTH SCIENCE APPLICATIONS

SPECTRAL RESOLUTION

NON-COHERENT

COHERENT

GAMMA X-RAY UV VIS IR FIR SUBMM MM
NASASA SUBMILLIMETER COHERENT SENSING

APPLICATIONS

- Measure trace species in atmospheres of Earth and planets and astrophysical gases and plasmas
- Map distributions of temperatures and velocities
COHERENT SENSOR RESEARCH
SUBMILLIMETER MIXERS

REQUIREMENTS

• QUANTUM EFFICIENCY
  > 10%, 300 - 3000 GHz

• RUGGED PLANAR
  TECHNOLOGY SUITED
  TO ARRAYS

• LOW LOCAL OSCILLATOR
  POWER

APPROACH

• DEVELOP THREE
  TECHNOLOGIES TO
  COVER SUBMILLIMETER
  SPECTRAL RANGE AND
  SUITABLE FOR DIFFERENT
  OPERATING TEMPERATURES

SIS TUNNEL JUNCTION

BASE ELECTRODE
CONTACT

20 Å MgO (INSULATOR)

BASE ELECTRODE
CONTACT

NON
COUNTER
ELECTRODE

SCHOTTKY BARRIER DIODE
IN Ga As

ANODE
CONTACT

METAL SEMICONDUCTOR
JUNCTION

INTERDIGITATED ELECTRODE
PHOTOCONDUCTIVE MIXER

INTERDIGITATED
ELECTRODE (GOLD)

MERCURY
CADMIUM
TELLURIDE
PHOTOCONDUCTOR

INSULATING SUBSTRATE
COHERENT SENSOR RESEARCH
SUBMILLIMETER LOCAL OSCILLATOR SOURCES

REQUIREMENTS
- LOW POWER AND MASS
- COMPACT AND RUGGED
- TUNEABLE 300-3000 GHz
- SPECTRALLY PURE WITH 1µW - 1mW OUTPUT

APPROACH
- DEVELOP THREE TECHNOLOGIES TO PROOF-OF-CONCEPT
- SELECT TECHNOLOGY FOR SPACE QUALIFIABLE PROTOTYPE IN 1988
COHERENT SENSOR RESEARCH
ACCOMPLISHMENTS

MIXERS

• SIS TUNNEL JUNCTIONS
  • HIGHEST FREQUENCY EVER REPORTED IN LEAD JUNCTIONS (600 GHz) - FY 86
  • FIRST DEMONSTRATION OF NbN MIXER - FY 88

• IDEPC/MCT DEVICES
  • ACHIEVED 2% QE AT 10 Thz - FY 87
  • DESIGNED AND FABRICATED DEVICE FOR 3 THz OPERATION - FY 88

LOCAL OSCILLATORS

• ALL SOLID STATE OSCILLATORS
  • DEMONSTRATED HIGHEST FREQUENCY FUNDAMENTAL SOLID STATE OSCILLATOR (6 µW @ 420 GHz)
  • DEMONSTRATED HIGH HARMONIC MULTIPLICATION

• BACKWARD WAVE OSCILLATOR
  • FIRST DEMONSTRATION OF OSCILLATION AT 200 GHz
NON-COHERENT SENSORS
INFRARED TO MILLIMETER WAVE TECHNOLOGY

REQUIREMENTS

• DIVERGENT REQUIREMENTS DEPENDING ON
  ▶ SPECTRAL REGION
  ▶ SPECTRAL APPLICATION

APPROACH

• ADAPT MATURING DoD-SPONSORED EXTRINSIC-SILICON TECHNOLOGY TO MEET NASA NEEDS FOR FAR IR

• DEVELOP NEW GERMANIUM-BASED TECHNOLOGY FOR SUBMILLIMETER

• DEVELOP ENABLING MATERIALS AND DEVICE TECHNOLOGIES TO MEET LONG RANGE NEEDS FOR LARGE ARRAYS AND HIGHER TEMPERATURE OPERATION

32 x 32 DETECTOR AND MULTIPLEXER

ULTRA HIGH MAGNIFICATION VIEW OF CROSS SECTION OF SILICON-COBALT SILICIDE DETECTOR MATERIAL
NON-COHERENT SENSORS
GAMMA RAY/X-RAY/ULTRAVIOLET

REQUIREMENTS

• HIGH SENSITIVITY
• SPECTRAL RESOLUTION
• MINIMAL COOLING
• DETECTOR ARRAYS WHERE PRACTICAL FROM 10 TO 10^6 ELEMENTS

APPROACH

• TRANSITION CCD TECHNOLOGY TO SPACE SCIENCE APPLICATIONS
• DEVELOP MERCURY IODIDE TO MEET NEEDS WHERE SENSOR COOLING IS IMPRACTICAL

CCD IMAGE OF BETA PICTORIS

MERCURIC IODIDE CRYSTAL FOR GAMMA RAY DETECTION
NASA

NON-COHERENT SENSORS
ACCOMPLISHMENTS

GAMMA RAY TO ULTRAVIOLET

CCD TECHNOLOGY

• TRANSFERRED TECHNOLOGY TO APPLICATIONS IN SPACE TELESCOPE, GALILEO AND AXAF PROGRAMS

MERCURY IODIDE

• DEMONSTRATED 7% SPECTRAL RESOLUTION FOR 0.661 KeV GAMMA RAYS AT ROOM TEMPERATURE

INFRARED TO MILLIMETER WAVE

• DEMONSTRATED ADVANCED DETECTOR ARRAY TECHNOLOGY BASED ON SILICON (DARK CURRENT <10 e^-/sec, NOISE <50 e^-)

• PIONEERING DEVELOPMENT OF GERMANIUM BIB TECHNOLOGY FOR SUBMILLIMETER

• DEMONSTRATED EXTENSION FROM 3.5 TO 5.0 μm IN COBALT SILICIDE INFRARED DETECTOR SPECTRAL RESPONSE CUTOFF
OBJECTIVES

• MAP THE DISTRIBUTION OF WIND VELOCITY, WATER VAPOR AND TRACE GASES IN THE ATMOSPHERE OF THE EARTH

TECHNOLOGY NEEDS

• SOLID STATE LASERS WITH HIGH PULSE POWER AND FREQUENCY

• CARBON DIOXIDE LASERS FOR MEASUREMENT OF DOPPLER SHIFTS OF SCATTERED RADIATION
ACTIVE REMOTE SENSING
SOLID STATE LASER DEVELOPMENT

REQUIREMENTS:
- PULSE ENERGIES (~1 JOULE)
- REPETITION RATE (10 Hz)
- EFFICIENCY (>5%)
- SPECTRAL RANGE (1\textmu m-20\textmu m)
- SPECTRALLY TUNABLE

TITANIUM: SAPPHIRE LASER

<table>
<thead>
<tr>
<th>AlGaAs laser diodes</th>
<th>Neodymium YLF</th>
<th>Second harmonic crystal</th>
<th>Titanium sapphire crystal</th>
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OPTICAL PARAMETRIC OSCILLATOR

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<tr>
<th>AlGaAs laser diodes</th>
<th>Ho: YAG master oscillator</th>
<th>AgGaSe$_2$ parametric oscillator</th>
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<td>Ho: YAG oscillator amplifier</td>
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LASER DIODE-PUMPED NEODYMIUM:YAG LASER

- HIGH-REFLECTION COATING
- Nd:YAG SLAB
- AIGaAs LASER DIODE ARRAY
- OPTICAL ISOLATOR
- Q-SWITCHED LD PUMPED Nd:YAG OSCILLATOR
ACTIVE SENSOR RESEARCH ACCOMPLISHMENTS

CO₂ LASERS

• DEVELOPED CATALYST TECHNOLOGY FOR LONG LIFE TIME APPLICATIONS. PLANNED FOR USE IN LAWS PROGRAM

SOLID STATE LASERS

• PIONEERED DEVELOPMENT OF TITANIUM SAPPHIRE TECHNOLOGY

• CONCEIVED NEW APPROACHED FOR ACTIVE SENSING IN MID INFRA RED
NASA

SPACE COOLER TECHNOLOGY PROGRAM GOALS

NEEDS:
- SENSOR COOLING FROM 150K TO SUBKELVIN (<1K) TEMPERATURE

CONSTRAINTS:
- POWER AND MASS BUDGETS OF SPACECRAFT EXTREMELY TIGHT
- LONG LIFETIME AND RELIABILITY PARAMOUNT
- ULTRA LOW VIBRATION AND EMI ARE CRITICAL FOR MANY APPLICATIONS

APPROACH:
- STRESS ADVANCES IN COMPONENT TECHNOLOGY WITH ORDER-OF-MAGNITUDE PERFORMANCE IMPACT
- EXPLORE INNOVATIVE SYSTEM CONCEPTS FOR SOLVING PROBLEMS IMPOSED BY SPACE ENVIRONMENT
SPACE COOLER TECHNOLOGY
LOW VIBRATION COOLER (65-80K)

REQUIREMENTS

• Cooling to the range from 10 - 150K
• Loads up to 5W
• Ultra low vibration
• High efficiency, power less than 200W
• Life times > 5 years

APPROACH

• Develop key components of systems with potential of meeting these requirements

Diagram:

- Low Vibration Mechanical Compressor
- Sorption Compressor
- Pulse Tube Refrigeration
- Recuperative Heat Exchanger
SPACE CRYOCOOLER TECHNOLOGY
SEPARATION OF LIQUID HELIUM ($^3$He AND $^4$He) AND VAPOR PHASE IN ZERO-G

REQUIREMENTS:

- EFFICIENT SEPARATION OF LIQUID AND GAS PHASES FOR
  - $^3$He–$^4$He DILUTION REFRIGERATION
  - ON ORBIT TRANSFER OF LIQUID HELIUM

APPROACH:

- INVESTIGATE AND CHARACTERIZE NON-GRAVITATIONAL PHASE SEPARATION PHENOMENA
- FABRICATE AND DEMONSTRATE DEVICES FOR ACHIEVING PHASE SEPARATION FOR REFRIGERATOR AND CRYOGEN TRANSFER APPLICATIONS
NEW PROGRAM INITIATED IN FY 88

FORMULATED A COHERENT MULTICENTER NASA PROGRAM TO ADDRESS SPACE SCIENCE NEEDS

CONCEIVED SEVERAL INNOVATIVE APPROACHES FOR SUBKELVIN APPLICATIONS
SENSORS RESEARCH AND TECHNOLOGY

KEY POINTS OF CONTACT

POINT OF CONTACT

| PROGRAM MANAGEMENT | M.M. SOKOLOSKI | NASA/CODE RC | (202) 453-2748 |

| TECHNICAL |

| CO-CHAIRMAN, SENSOR WORKING GROUP | C. McCREIGHT | AMES RESEARCH CENTER | (415) 694-6549 |

| PASSIVE COHERENT SENSING | M. FRERKING | JET PROPULSION LABORATORY | (818) 354-4902 |

| PASSIVE NON-COHERENT SENSING | C. McCREIGHT | AMES RESEARCH CENTER | (415) 694-6549 |

| ACTIVE SENSING | F. ALLARIO | LANGLEY RESEARCH CENTER | (804) 865-3601 |

| SPACE COOLER TECHNOLOGY | S. CASTLES | GODDARD SPACE FLIGHT CENTER | (301) 286-8986 |
SENSOR RESEARCH AND TECHNOLOGY
FUTURE PLANS

- IMPLEMENTATION OF THE CSTI SCIENCE SENSOR PROGRAM

- IDENTIFY SCIENCE SENSOR NEEDS DRIVEN BY FUTURE PROGRAMS

  - PATHFINDER - PLANETARY AND LUNAR SURFACE EXPLORATION
  - GLOBAL CHANGE TECHNOLOGY

- IDENTIFY OPPORTUNITIES CREATED BY NEW TECHNOLOGIES

  - OPTICS
  - PHOTONICS
  - HIGH Tc SUPERCONDUCTIVITY