SENSORS RESEARCH AND TECHNOLOGY

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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

PHOTONS

EM RADIATION

ELECTRICAL SIGNAL

NON-COHERENT (DIRECT) SENSING

NATURAL RADIATION

LOCAL OSCILLATOR

RADIATION COLLECTOR AND MIXER

INTERMEDIATE FREQUENCY

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
NASA 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
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
APPLICATIONS

- Imaging and Spectroscopy of Astrophysical Objects
- Imaging and Spectroscopy of Atmospheres
- Moisture and Temperature Sounding
- Surfaces of Earth and Planets
- Multispectral Imaging of the Earth

MARINER MARK-II SPACECRAFT

NON-COHERENT SENSORS

SPACE STATION
NON-COHERENT SENSORS
KEY TECHNOLOGIES

DETECTOR ARRAYS
- SILICON CCDs
- DEEP DEPLETION DIODES
JPL/GSFC

DETECTORS ARRAYS
- SILICON EXTRINSIC
- SILICON BIB
- SILICON SSPM
ARC

DISCRETE DETECTORS
- MERCURY IODIDE
GSFC

NEW MATERIALS AND DEVICES
- SILICON-SILICIDE
- MERCURY ZINC TELLURIDE
JPL/ARC

SPECTRAL REGION
- GAMMA RAY
- X-RAY
- ULTRA VIOLET
- VIS
- IR
- FAR IR
- SUBMM
- MM WAVE
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
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
ACTIVE REMOTE SENSING

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\mu m-20\mu m)
• SPECTRALLY TUNABLE

TITANIUM: SAPPHIRE LASER

| AlGaAs laser diodes | Neodymium YLF | Second harmonic crystal | Titanium sapphire crystal |

OPTICAL PARAMETRIC OSCILLATOR

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<th>Ho: YAG master oscillator</th>
<th>AgGaSe2 parametric oscillator</th>
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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
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
SPACE CRYOCOOLER TECHNOLOGY
SEPARATION OF LIQUID HELIUM (³He AND ⁴He)
AND VAPOR PHASE IN ZERO-G

REQUIREMENTS:

- EFFICIENT SEPARATION OF LIQUID AND GAS PHASES FOR
  
  → ³He–⁴He 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
SPACE COOLER RESEARCH ACCOMPLISHMENTS

- NEW PROGRAM INITIATED IN FY 88

- FORMULATED A COHERENT MULTICENTER NASA PROGRAM TO ADDRESS SPACE SCIENCE NEEDS

- CONCEIVED SEVERAL INNOVATIVE APPROACHES FOR SUBKELVIN APPLICATIONS
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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 $T_C$ SUPERCONDUCTIVITY