LWIR HgCdTe - INNOVATIVE DETECTORS IN AN INCUMBENT TECHNOLOGY

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ABSTRACT

HgCdTe is the current material of choice for high performance imagers operating at relatively high temperatures. Its lack of technological maturity compared with silicon and wide-band gap III-V compounds is more than offset by its outstanding IR sensitivity and by the relatively benign effect of its materials defects. This latter property has allowed non-equilibrium growth techniques (MOCVD and MBE) to produce device quality LWIR HgCdTe even on common substrates like GaAs and GaAs/Si. Detector performance in these exotic materials structures is comparable in many ways with devices in equilibrium-grown material. Lifetimes are similar. RoA values at 77K as high as several hundred have been seen in HgCdTe/GaAs/Si with 9.5 μm cut-off wavelength. HgCdTe/GaAs layers with ~15 μm cut-off wavelengths have given average 77K RoA of >2. Hybrid focal plane arrays have been evaluated with excellent operability.
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APRIL 24, 1990

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OVERVIEW

- PACE BACKGROUND AND MATERIALS
- TEST DIODE PERFORMANCE AND TECHNOLOGY LIMITS
- PRELIMINARY LWIR ARRAY DATA
- DIRECTIONS AND CONCLUSIONS
DEFINITIONS

- **CONVENTIONAL TECHNOLOGY**
  -- MCT GROWN BY LIQUID PHASE EPITAXY ON CdTe OR SIMILAR COMPOUND

- **PACE (PRODUCIBLE ALTERNATIVE TO CdTe FOR EPITAXY)**
  -- ROCKWELL APPROACH TO OVERCOME MCT PRODUCIBILITY ISSUES
  -- **PACE-1**: MCT GROWN BY LIQUID PHASE EPITAXY ON VAPOR PHASE EPITAXIAL CdTe/SAPPHIRE -- SUITABLE FOR SWIR (1-3 MICRONS) AND MWIR (3-5+) MICRONS
  -- **PACE-2**: MCT GROWN BY VAPOR PHASE EPITAXY ON GaAs (OR EVENTUALLY Si) -- SUITABLE FOR ALL IR WAVELENGTHS

**PACE-2 HAS BETTER COMPOSITIONAL UNIFORMITY THAN LPE**

\[
\begin{align*}
\text{3" DIA GaAs WAFER} & \\
\max \frac{\Delta x}{x} &= 3.3\%, \quad \max \frac{\Delta d}{d} = 29\% \quad \text{OVER 3" DIA} \\
\max \frac{\Delta x}{x} &= 2.2\%, \quad \max \frac{\Delta d}{d} = 17\% \quad \text{OVER 2" DIA}
\end{align*}
\]

**LEGEND**
- COMPOSITION, X VALUE
- THICKNESS, µm
- CRYSTALLINITY, ARC-SEC

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LWIR TACTICAL MCT DETECTOR PERFORMANCE

RADIATIVE LIMIT (10μm THICK DETECTOR)

RANGE OF BEST MCT DETECTORS AND SMALL ARRAYS

MCT ION IMPLANTED (LETI) PHOTODIODES

MCT S.A.T. DIFFUSED HOMOJ (BULK)

MCT DIFFUSION LIMITED TREND LINES

D* (cm Hz 1/2/W) (ASSUMING λ_c = 8μm, QE = 0.5)

R_0A (Ω·cm^2)

10^{16} cm^{-2} s^{-1}

PACE-2

n/P

P/m

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n⁺/p TEST DIODES IN HgCdTe/GaAs (PACE-2)

MTD DATA FOR 3-623 BASELINE LAYER
n ON p DEVICES, ION IMPLANTED

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ORIGINAL PAGE IS OF POOR QUALITY
LWIR HgCdTe/Pace-2 p/n Devices Show Higher Performance Than LPE Devices

- ARSENIC IMPLANTATION
- OMVPE HgCdTe ON GaAs

RECENT p ON n MTD PERFORMANCE CONFIRM EARLIER RESULTS

ARSENIC IMPLANT/DIFFUSION IN DOUBLE LAYER HETEROSTRUCTURE

3-576 GaAs

- MEAN: 122
- MEDIAN: 55.5
- DIODES: 9
- \( \lambda_c: 9.48 - 9.53 \mu m \)
- \( T: 77K \)

3-579 GaAs/Si

- MEAN: 150
- MEDIAN: 4
- DIODES: 10
- \( \lambda_c: 9.51 - 9.81 \mu m \)
- \( T: 77K \)

BEST DIODE
- \( R_0A = 308 \Omega \cdot \text{cm}^2 \)
- AT 9.48 \( \mu m \)

BEST DIODE
- \( R_0A = 544 \Omega \cdot \text{cm}^2 \)
- AT 9.73 \( \mu m \)

\* n ON p DIODES HAVE BETTER UNIFORMITY
EXCELLENT DIODE PERFORMANCE IN VLWIR MOCVD MCT/GaAs p ON n DIODES

Minority Carrier Lifetime

4-334, N-Type, Undoped, x=0.235, Nd=1.1 \times 10^{15} \text{cm}^{-3}

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LIFETIMES IN SOME VACANCY DOPED PACE-2 APPROXIMATE THEORY

Layer 3-581
P-Type, Vacancy Doped
x = 0.226
Na = 3.7E16 cm\(^{-3}\)

Auger + Radiative

Layer 1-1316
P-Type, Arsenic Doped
x = 0.25
Na = 4E15 cm\(^{-3}\)

Auger + Radiative

BEST IMPURITY DOPED PACE-2 SAMPLES SHOW THEORETICAL LIFETIMES
Performance of an LWIR MCT/GaAs Array at 50K

LWIR MOCVD HgCdTe/GaAs DIODES
BEST PERFORMANCE IS AT TOP
LPE LEVELS FOR 77 AND 40K
VLWIR I-V Characteristics for MOCVD Grown MCT/GaAs Detector

\[ T = 30K \]
\[ R_0A = 30 \Omega \text{ cm}^2 \]
\[ \lambda_c(30K) = 15.8 \mu \text{m} \]

\[ x = 0.226 \quad (Ic = 9.22 \mu \text{m at 77K}) \]
\[ N_a = 3.7 \times 10^{16} \text{ cm}^{-3}, \quad d = 13 \mu \text{m} \]
Temperature Dependence of the R₀A Product of a P/N Diode Fabricated from PACE-2 Material

![Graph showing temperature dependence of R₀A product](image)

**STRATEGIC APPLICATIONS REQUIRE CONTROL OF DISLOCATION DENSITY**

**ETCH PIT DENSITY MCT/GaAs**

- MADE GOOD DIODES IN DIFFUSION REGIME
- CURRENT TYPICAL
- POTENTIAL

**LOW TEMPERATURE OPERATION IS MOST DEMANDING APPLICATION**

- EPD > 5 x 10⁵ cm⁻²
- EPD < 5 x 10⁵ cm⁻²

Λ > 9.1 - 10.3μm AT 40K FOR 38 LAYERS

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SAMPLE DIODES FROM PACE II 128 x 128 WAFER (ROCKWELL IR&D)

FULL PLANAR PROCESS: n/p, B-IMPLANTED, ZnS/SiC>2 PASSIVATED

Pace-2 Shows D* Uniformity and Operability of LWIR Hybrid
CONCLUSIONS

- MCT HAS DEMONSTRATED THE HIGHEST PERFORMANCE OF ANY INTRINSIC AT ALL IR WAVELENGTHS

- NOVEL, ALTERNATIVE-SUBSTRATE, VPE APPROACHES CAN MEET PROGRAM GOALS WHILE ENHANCING PRODUCIBILITY AND MAKING POSSIBLE ADVANCED ARCHITECTURES

- THE PRESENT LIMITATIONS OF THE TECHNOLOGY ARE NOT FUNDAMENTAL BUT DUE TO IMMATURITY

- WE EXPECT LWIR/PACE-2 (GaAs) OR 3 (Si) TO FOLLOW A SIMILAR PATH TO PRODUCIBILITY AS THAT OF MWIR PACE-1 WHICH HAS RESULTED IN THE LARGEST (256X256) INTRINSIC IR FPA TO DATE