Rockwell's Large Infrared Detector Arrays for Astronomy

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1st Annual NGST Technology Challenge Review

NASA Goddard Space Flight Center

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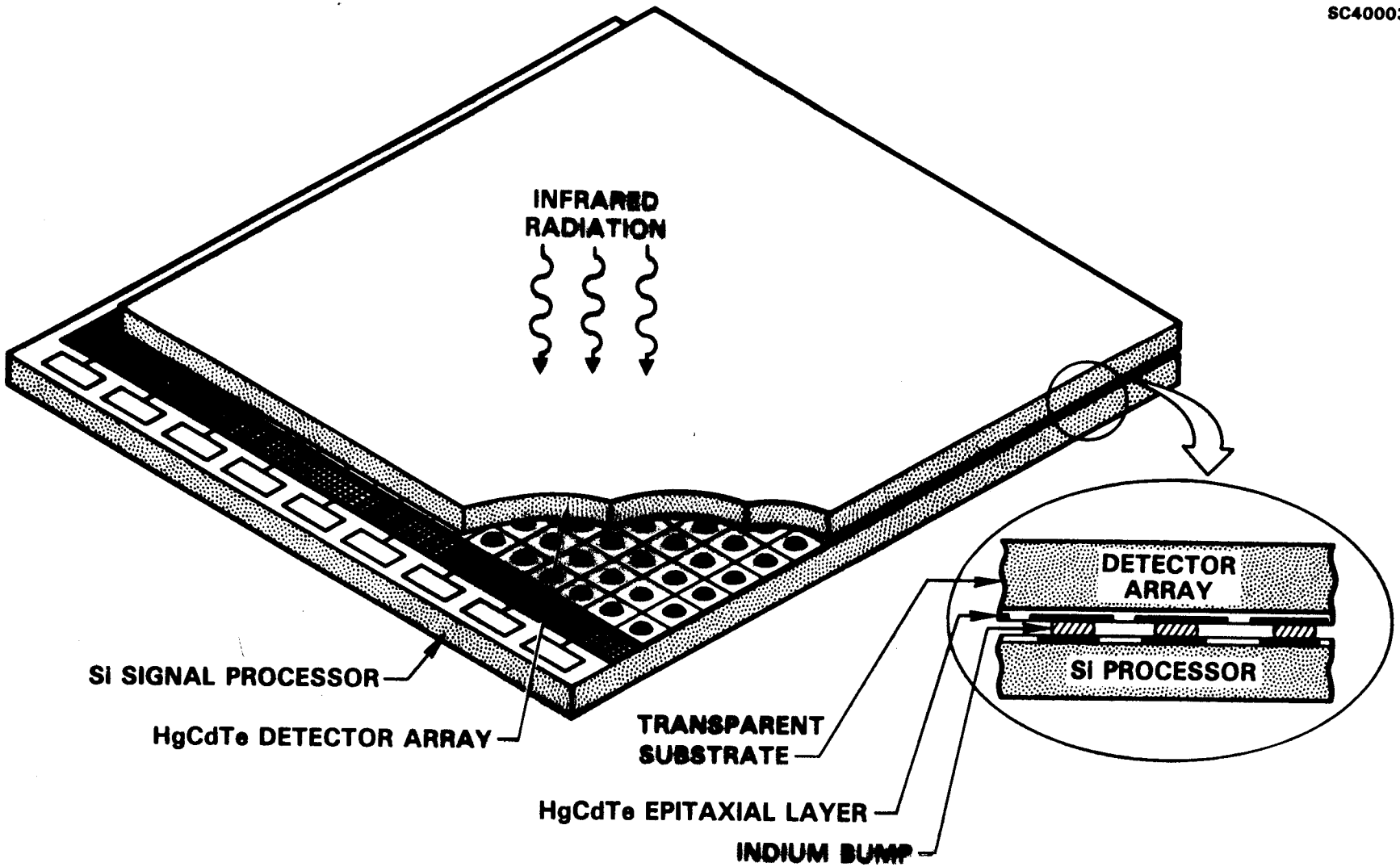
Rockwell
Science Center

Agenda

- **This presentation will provide an overview of Rockwell capabilities in large HgCdTe Infrared FPAs covering 0.9 μm to 10.0 μm**
- **Multiplexers**
- **Detectors**
- **Hybrid focal plane arrays**

HgCdTe HYBRID FOCAL PLANE ARRAY

SC40003



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Large, High Sensitivity Hybrid FPAs

- FPAs **DEVELOPED**, CURRENTLY IN FAB, OR *IN DESIGN*

[illegible]	Form	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Gain (pV/e-)	Noise (e-)	Power (mW)
HAWAIIX4	*2048²*	*SFD*	*Ripple*	*4/16*	*<2*	*18*	*0.01*	*0.4-0.7*	*4-6*	*<10*	*<2*
HAWAII	**1024²**	**SFD**	**Ripple**	**4**	**<2**	**18.5**	**0.01**	**0.4-0.7**	**4-6**	**<10**	**<1**
TCM8050	1024²	p-PCDI	Window Snap/Rip	4	20	18	>0.6	2.4	Variable	<600	<150
TCM8000	**1024²**	**n-CTIA**	**Ripple**	**2**	**>15**	**18.5**	**0.058**	**2.5**	**3.6**	**27**	**45**
TCM6600	**640×480**	**p-CTIA**	**Snapshot**	**1**	**>12**	**27**	**0.1**	**2.5**	**16**	**<100**	**<60**
TCM6050	*640×480*	*p-PCDI*	*Window Snap/Rip*	*4*	*20*	*27*	*>2.5*	*2.4*	*Variable*	*<600*	*<100*
TCM6000A	**640×480**	**n-DI**	**Ripple**	**4**	**>10**	**27**	**2.2**	**1.5-2.0**	**0.077**	**<600**	**<60**
SCM6000	**640×480**	**n-RHBDI**	**Window&Ripple**	**1**	**>10**	**27**	**0.5**	**2.5**	**1.0**	**<150**	**<100**
SCM5000	*512×512*	*p-RHCTIA*	*Snap/Window*	*1*	*>10*	*35*	*0.2*	*>2.5*	*4.0*	*<150*	*<100*
TCM3100	**320×240**	**n-BDI**	**Snap/Rip**	**1**	**>8**	**30**	**1.2**	**2.2**	**Variable**	**<500**	**<50**
TCM3000B	**320×240**	**n-DI**	**Ripple**	**1**	**>20**	**30**	**>3**	**1.8**	**0.048**	**<500**	**<50**
NICMOS3	**256²**	**SFD**	**Ripple**	**4**	**0.2**	**40**	**0.025**	**0.4-0.7**	**1.5-2.5**	**25**	**<1**
PICNIC	**256²**	**RHSFD**	**Ripple**	**4**	**0.2**	**40**	**0.025**	**0.4-0.7**	**1.5-2.5**	**<15**	**<1**
TCM2900	**256²**	**p-ESBDI**	**BEST**	**1**	**<5**	**40**	**>5**	**2.0**	**0.04**	**<1000**	**25**
TCM2800	**256²**	**n-ESBDI**	**BEST**	**1**	**<5**	**40**	**>9**	**≥4.2**	**0.045**	**<1000**	**18**
2620UHG	**256²**	**p-CTIA**	**Snapshot**	**4**	**>8**	**40**	**0.01**	**2.4**	**48/4.8**	**<120**	**<40**
TCM2620	**256²**	**p-CTIA**	**Snapshot**	**4**	**>8**	**40**	**0.1**	**2.4**	**7.7/0.8**	**<120**	**<40**
TCM2550	**256²**	**p-PCDI**	**Window Snap/Rip**	**1**	**>8**	**40**	**>4**	**2.4**	**Variable**	**<600**	**<50**
TCM2100	**256²**	**n-PCBDI**	**Snapshot**	**1**	**≥8**	**40**	**>1.5**	**2.2**	**0.18-1.1**	**350**	**45**
TCM2001	256²	p-PCDI	Window Snap/Rip	1	>10	40	>8	2.4	Variable	<1000	<50
TCM2000C	**256²**	**n-DI**	**Ripple**	**1**	**<6**	**40**	**2.8**	**2.1**	**0.05**	**650**	**<50**
SCM1400	**112×224**	**n-DCTIA**	**MultiSnap**	**1**	**<3**	**56.5**	**0.96**	**2.8**	**0.31**	**280**	**20**

DI - Direct Injection
CTIA - Capacitive Transimpedance Amplification
DCTIA: Differential CTIA

ESBDI - Electronically Scanned Buffered DI
SPECTRUM - Self-correcting Production-ready Enhanced Capability Temperature-tolerant Revolutionary Universal Multiplexer

SFD - Source Follower per Detector

MLGM - MOSFET Load Gate Modulation
BGM: Buffered Gate Modulation

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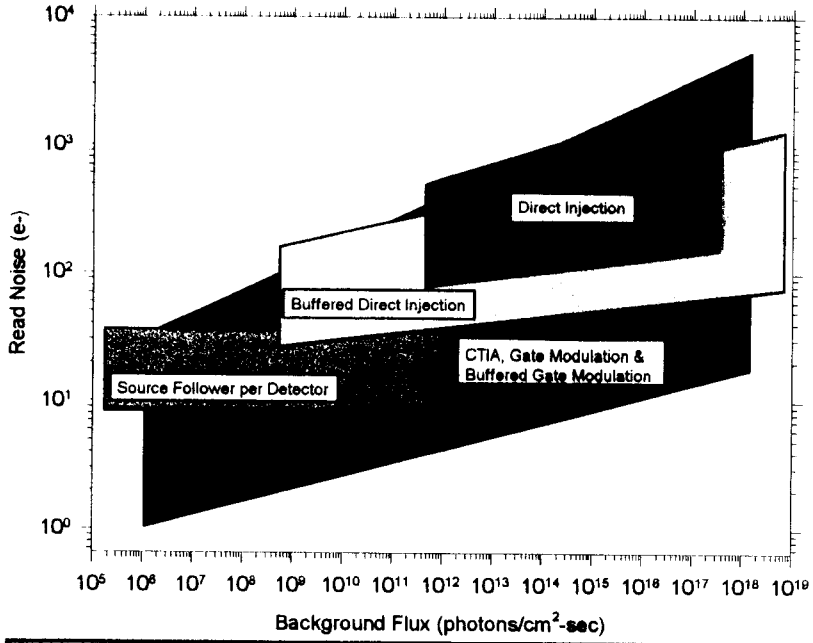
Small Format & Scanning FPAs

Part #	Format	Input Circuit	Imaging Mode	Video Taps	Rate (MHz)	Pitch (μm)	Capacity (10^7)	ΔV (V)	Gain (μV/e-)	Noise (e-)	Pow (mW
TCM1900	*128×128*	*HABDI*	*Snapshot*	*1*	*10*	*60*	*>6.5*	*2.5*	*0.045*	*<1000*	*<5*
TCM1800	*128×128*	*CNDI*	*Snapshot*	*1*	*10*	*60*	*>7.8*	*2.5*	*0.038*	*<1000*	*<5*
1717/BGM	128×128	p-BGM	Ripple	1	10	60	5.95	1.8	A_i×0.0302	Var.	<4
1700/GMOD	128×128	p-CMGM	Ripple	1	10	60	15.42	2.5	A_i×0.0162	Var.	<1
1050/MMAD	128×128	p-PCDI	Window Snap/Rip	1	10	40	5.5	2.5	Selectable	<400	<2
1040/MMAD	128×128	p-PCBDI	Window Snap/Rip	1	10	40	2.7	2.5	Selectable	<400	<5
SCM1600	*128×128*	*RH DCTIA*	*Window Ripple*	*1*	*10*	*60*	*0.05*	*2.5*	*Selectable*	*<100*	*<2*
SCM1640	*128×128*	*RH DCTIA*	*Window Snapshot*	*1*	*10*	*60*	*0.2*	*2.5*	*Selectable*	*<100*	*<2*
SCM1000	140×140	RHDiff. BDI	Window Ripple	1	2	100	0.1	2	3.49/0.6	100	<2
1500	128×128	n-DI	Ripple	1	10	60	2.1	2.0	0.093	350	<5
1000C	128×128	n-DI	Ripple	1	2	60	1.5	2.0	0.064	<450	<2
DIN	128×128	p-DI	Ripple	1	4	60	14.9	2.8	0.0188	700	<5
TNT	128×128	p-ESBDI	Ripple	1	4	60	52,70,100	2.4	4.4-12nV	<1300	<10
GNP	128×128	p-CMGM	Ripple	1	4	60	5.2	2.0	A_i×0.029	Var.	<2
GPN	128×128	MLGM	Ripple	1	4	60	5.2	1.7	A_i×0.025	Var.	<2
NIC2	128×128	SFD	Ripple	1	0.5	60	0.04	0.4-0.8	1.1-1.5	50	<1
IRFPA	128×128	ESBDI	Ripple	1	<10	40	>50	2	0.004	<500	<5
SCM-640	64×64	DCTIA	Ripple	1	<4	50	0.8	3.5	0.537	<250	<2
IRFPA	64×64	ESBDI	Ripple	1	<10	60	100	1.8	0.018	<500	<2
TCM128	*1×128*	*CTIA*	*Snapshot*	*2*	*>5*	*100*	*0.56-22.0*	*2.5*	*0.016-0.53*	*<100*	*<1*
IRFPA	480×4	CTIA	TDI	16	8	76×82	3.4	1.7	0.05	300	17
SCM113	2×64	CSBDI	Snapshot	1	1	100	3.2	4.3	0.136	195	5
SWIR-I	10×132	CTIA	TDI	1	10	25×75	0.0077	2	26	TDI:<40	<2
SWIR-II	20×132	CTIA	TDI	1	10	25×50	0.02	2	10	TDI:<60	<5
SCM-111	16x16	CSDI	Ripple	16	2	125	7.0	2	0.0287	500	1
MATS1	8×16	CTIA	Snapshot	8	10	160	0.02	3	Var to 2.2	<60	<5
MATS2	8×16	CTIA	Snapshot	8	10	160	0.01,0.05	3	Var to 2.2	<60	<5
142	8×8	CTIA	Snapshot	8	10	160	0.02,2.03	3	Var to 2.2	<60	<5
SW2D	48×48	CTIA	Snapshot	16	2	125	0.05	3.5	5-8	<100	<1

Application Breadth Requires Diverse ROICs & Circuits



DI: Direct Injection
PCDI: Push-Clocked DI
CNDI: Current-Nulling DI
SPECTRUM: "Universal" High Perf. Input
BDI: Buffered DI
PCBDI: Push-Clocked BDI
HABDI: Hole-Annihiliating BDI
ESBDI: Electronically Scanned BDI
CTIA: Capacitive Transimipedance Amplifier
SFD: Source Follower per Detector
GM: Gate Modulation
BGM: Buffered Gate Modulation

Format	DI	PCDI	CNDI	BDI	PCBDI	HABDI	ESBDI	CTIA	SFD	GM	BGM	SCBGM	
2048^2									①				
1024^2		①						❶	❶				
640×480	❶	①		❶				①					
512×512								1					
320×240	❶	❶								❶			
256^2	❶	❶,①	①		❷		❷	❷	●				
140×140				❶									
128^2	❶	❷	❶		❷	❶	❶	❶	❶	❶	❶	1	
64^2								❷					
48^2								❷					

Note: Encircled Numbers Indicate Quantities of Each Type and Development Status

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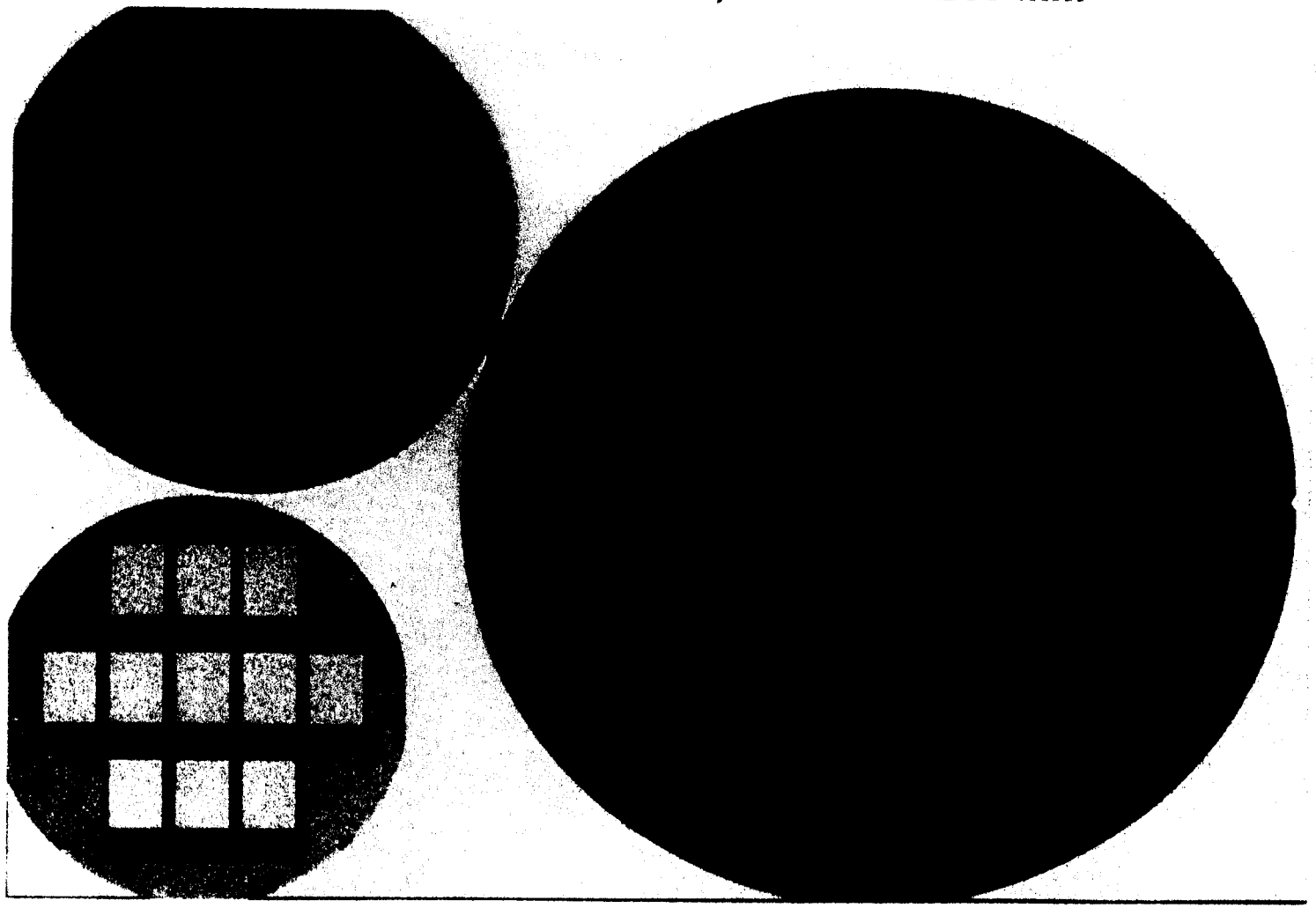
Impact of Leveraging Commercial CMOS

- 640x480 ROIC: 100 mm, 125 mm & 200 mm



CMOS ROIC Development Methodology is Very Successful (45/50)

Proven Readouts: 45	SWIRSCAN-A (10 ×132) SWIRSCAN-B (20 ×132) GaAs-1 (2 × 64) SWIFT-2C (48 ×48) SWIFT-2D (48 ×48) IRFPA (4 × 480) TCM6000A (640 ×480): RSS TCM2800 (256 ×256) TCM3000 (320 ×240) SCM640 (64 ×64) TCM2610 (256 ×256) TCM2900 (256 ×256) TCM2510 (256 ×256) GMOD (128 ×128) TCM8000 (1024 ×1024) PICNIC (256 ×256) TCM1040 (128 ×128) SCM6000 (640 ×480) TCM2620 (256 ×256) TCM1800 (128 ×128) SWARM-II (2×10×256) VCI356 (356 ×292) SCM1240 (128 ×128)	SC104 (4 32 ×128) KADRI (256 ×256) NICMOS1 (128 ×128) NICMOS2 (128 ×128) NICMOS3 (256 ×256) MATS1 (8 ×16) MATS2 (8 ×16) DIN (128 ×128) GNP (128 ×128) GPN (128 ×128) TNT (128 ×128) HAWAII (1024 ×1024) TCM2700 (256 ×256) BGM (128 ×128) SCM1400 (112×224) TCM1050 (128 ×128) SCM1000 (140 ×140) TCM2620V (256 ×256) TCM1900 (128 ×128) TCM128 (128 ×1) TCM3700 (320 ×240) SCM1020R (128 ×128)
Performance-Limiting Design Flaw(s): 5	TCM6000 (640 ×480): TRW TCM2100 (256 ×256) TCM2550 (256 ×256)	TCM2600RH (256 ×256) VCI648 (648 ×488)
***Designed* or In Fabrication: 5**	TCM2001(256 ×256) TCM6050 (640 ×480)	TCM8050 (1024 ×1024)
Currently in Test: 4	SCM1020 (128 ×128) TCM1150 (128 ×128)	TCM1140 (128 ×128) TCM6600 (640 ×480)

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Rockwell HgCdTe Detector Technologies

- N/P LPE "PACE-1" (Sapphire substrate)
- P/N MBE (CZT substrate)
- P/N MBE (Si substrate)

PACE-I MATERIAL

- THE SUBSTRATE IS MOCVD CdTe ON SAPPHIRE
- LIQUID PHASE EPITAXY HgCdTe
- SAPPHIRE IS MECHANICALLY STRONG AND AVAILABLE IN SIZES UP TO 4" COMMERCIALLY
- BETTER CTE MATCH WITH SILICON COMPARED TO CdTe
- DETECTORS IN THE 0.8-5.5 μm BAND (UP TO 7 μm WITH THINNING OF SAPPHIRE)
- PACE-I IS IN PRODUCTION AT ROCKWELL ~~ELECTRO-OPTICAL~~ SCIENCE CENTER ~~(EOC).~~ (RSC)

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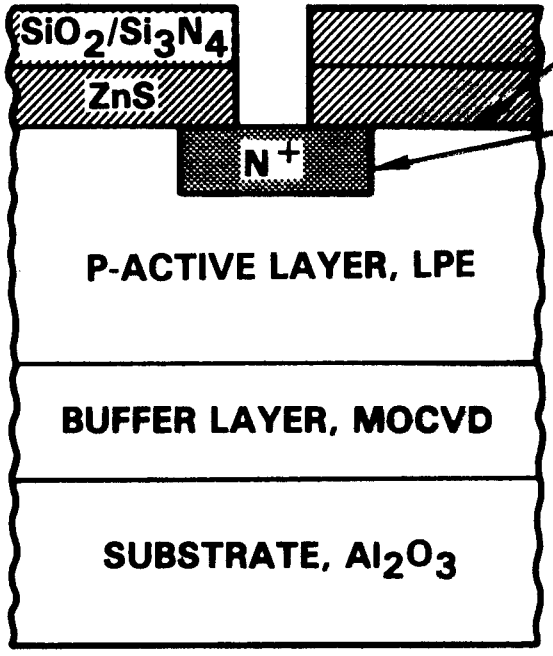
EVERY STEP OF PROCESS EFFECTS PERFORMANCE AND YIELD

SC46360A



- NATIVE OXIDE
- STOICHIOMETRY
- IMPURITIES

- PERFORMANCE
- UNIFORMITY
- REPRODUCIBILITY

- ELECTRICAL PROPERTIES
- STRUCTURAL PROPERTIES
- OPTICAL PROPERTIES

- DISLOCATION DENSITY
- CRYSTALLINITY
- PURITY

- SMOOTH SURFACE
- SCRATCH FREE
- ORIENTATION

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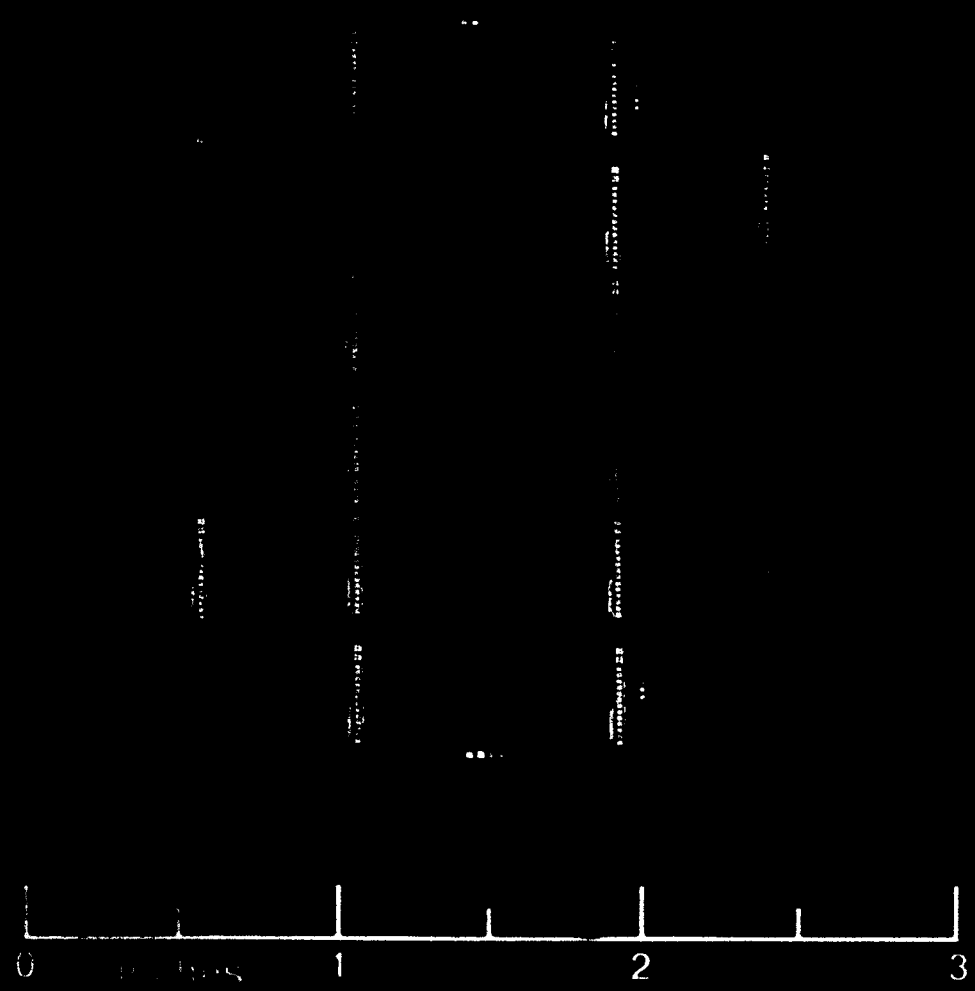
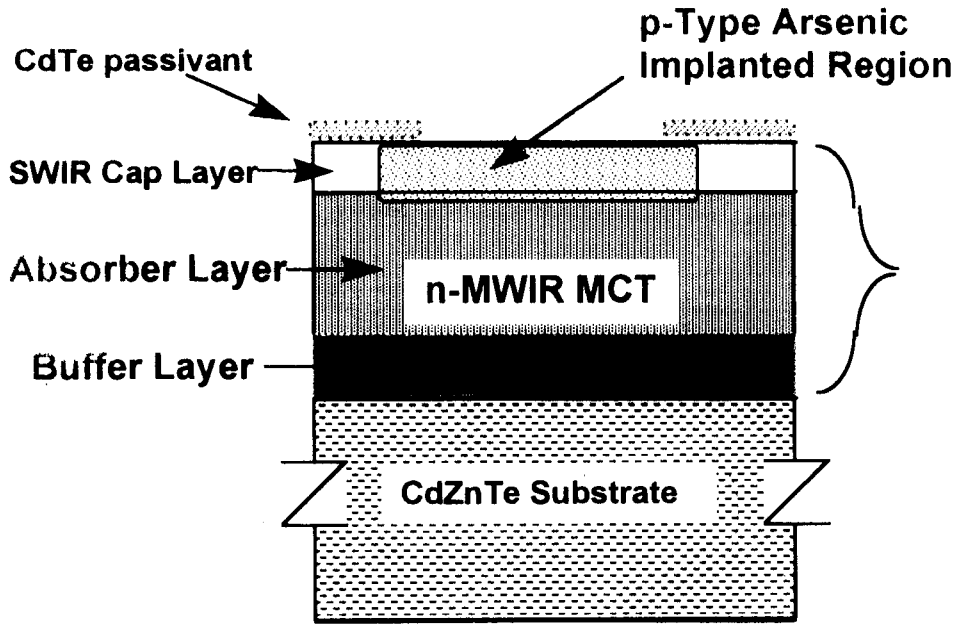
1024 X 1024 HgCdTe Detector Arrays

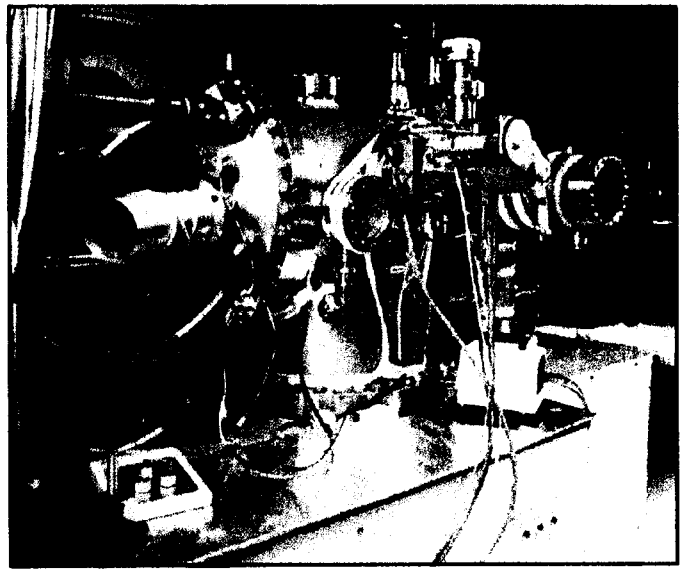


P/N Double Layer Planar Heterostructure--
Offers Performance and Manufacturing Advantages

Detector Cross Section:



RIBER MBE 32 P Growth Reactor



- **Inherently High Radiation Hardness**
- **Inherently Easy to Passivate**
- **Few Critical Steps Give Reliable Processes**
- **Excellent Device Performance**
- **Exploits MBE's Outstanding Materials Control**

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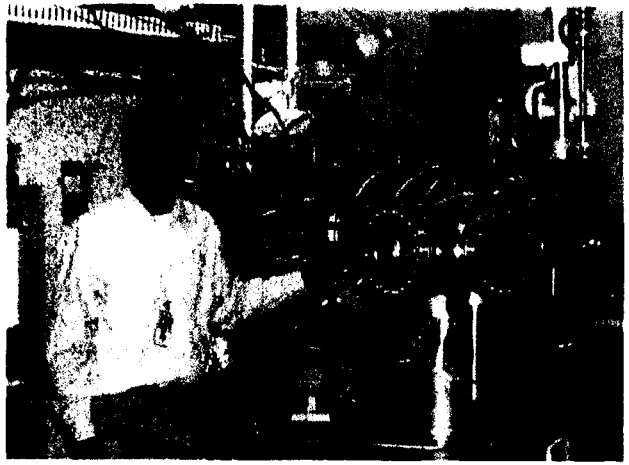
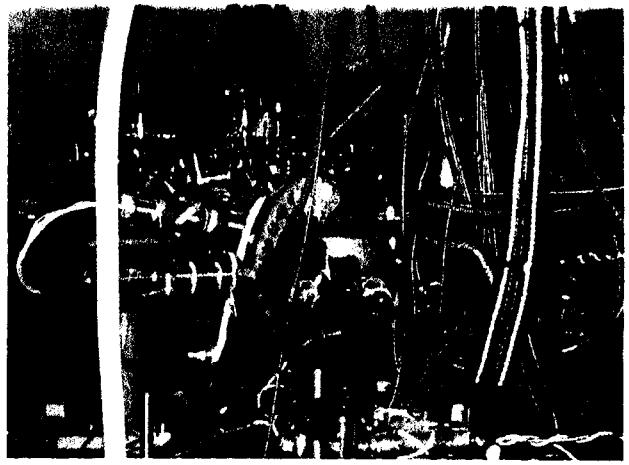
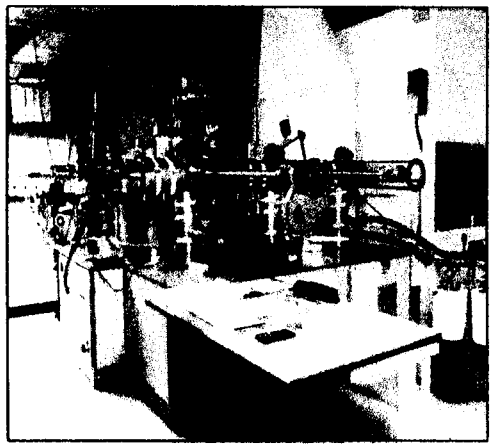
MBE Material growth



MBE System 1



MBE System 2



MBE System 3

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M8G Hybrid Mating Apparatus

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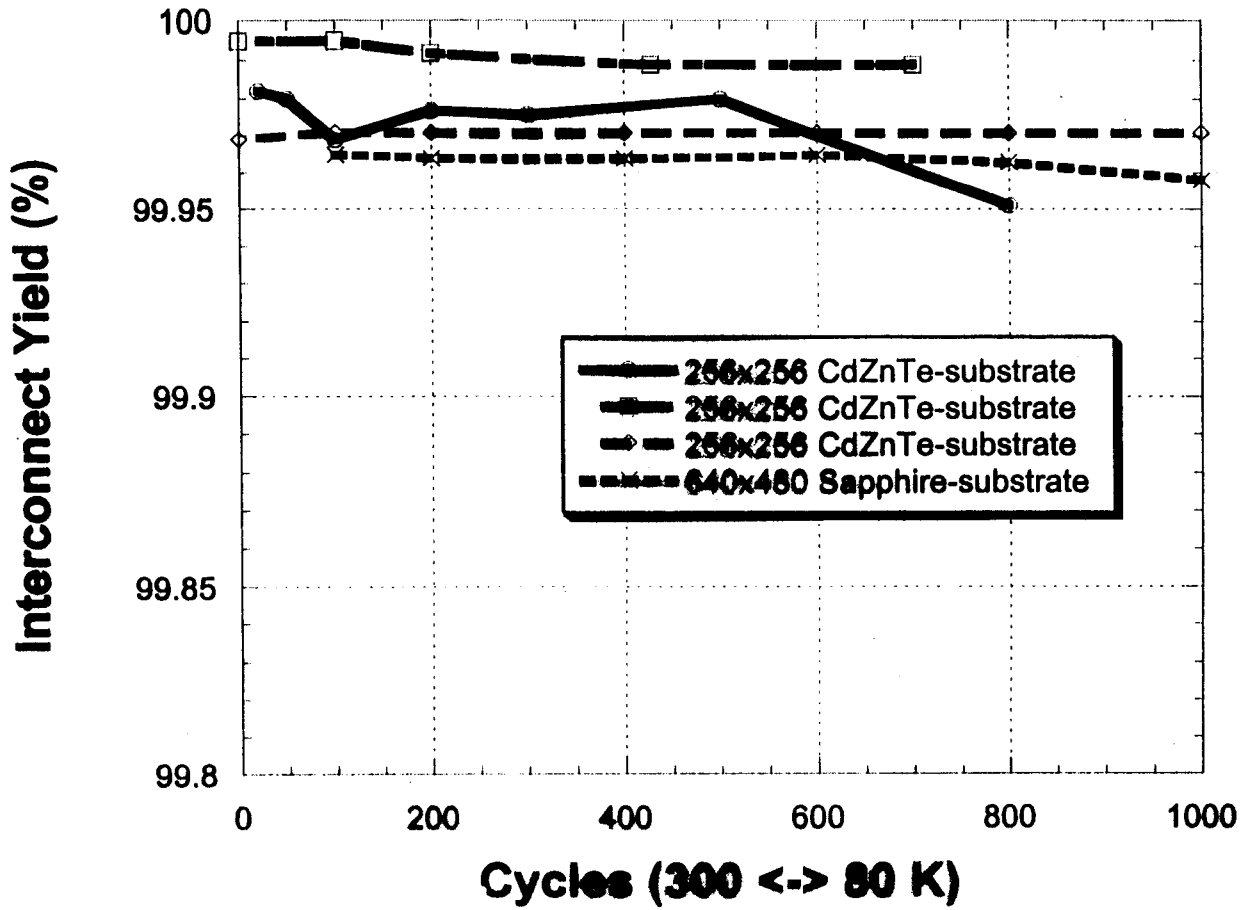
HgCdTe FPAs can be made reliable to thermal cycling



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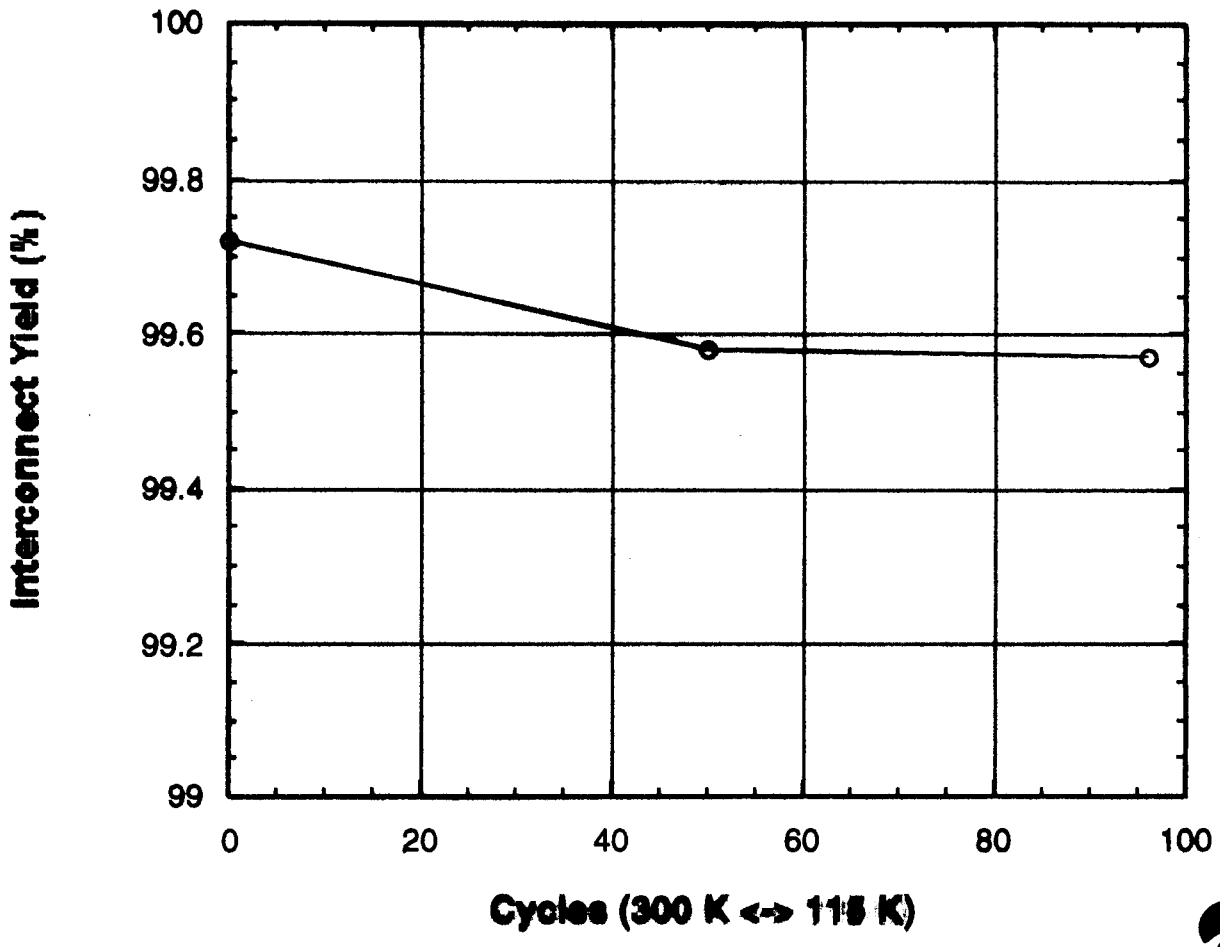
Mega-pixel PACE-I FPA Survives Thermal Cycling

- 1024x1024 PACE-I FPA for strategic applications
- 100 cycle reliability meets system requirements



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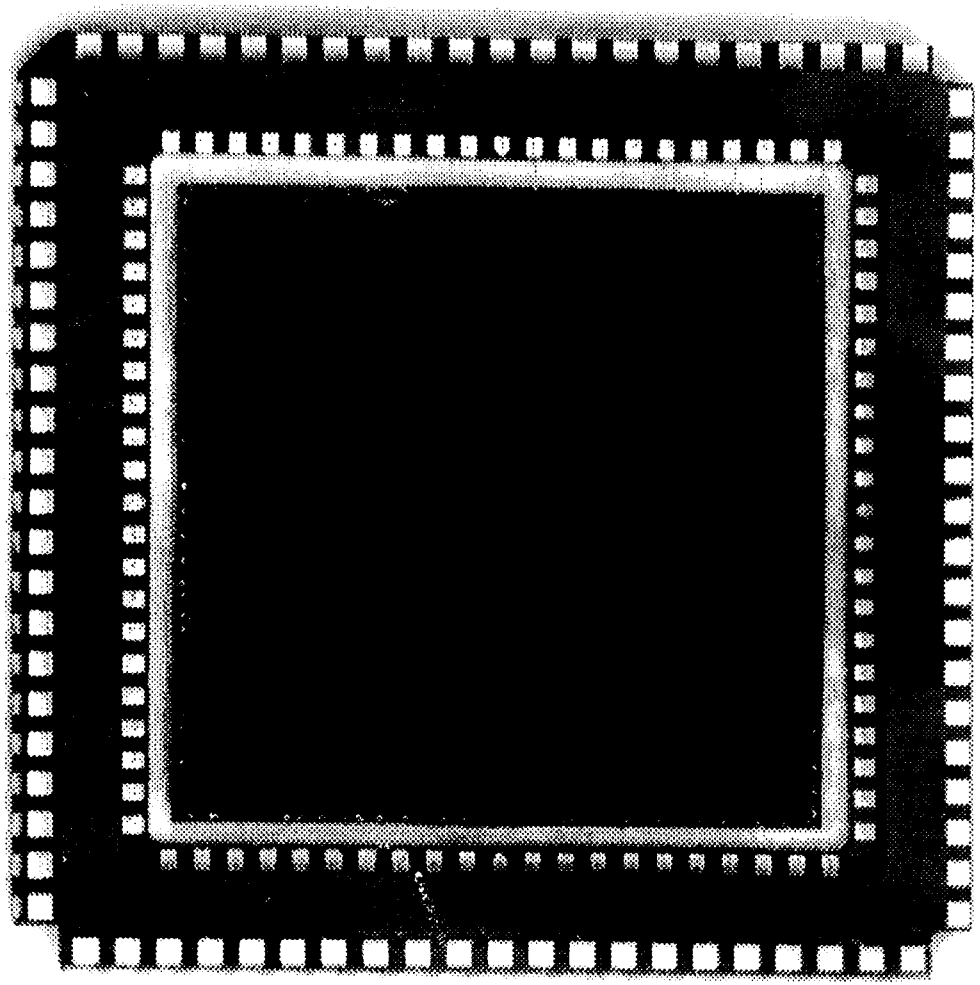
HAWAII 1024 × 1024 Hybrid FPA



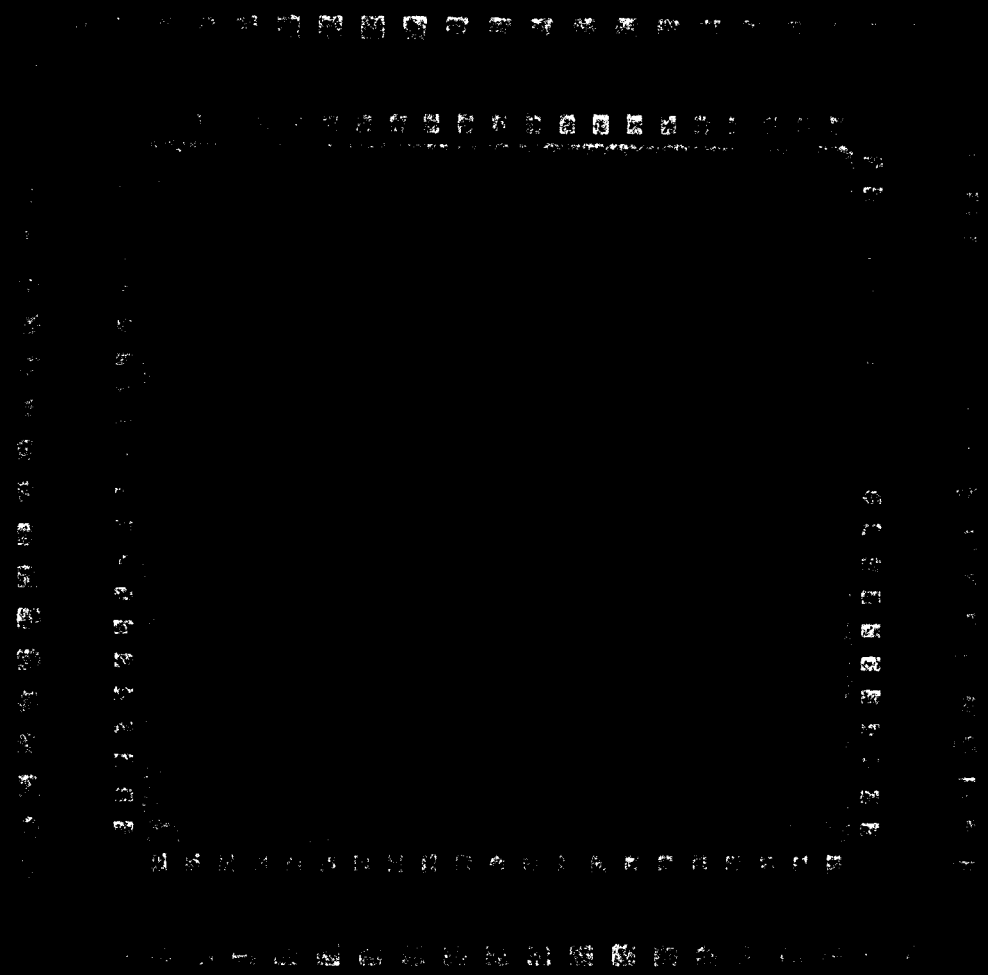
Features

- PACE-I HgCdTe/Al_2O_3
- λ_c=2.5 μm
- <120K Operation
- 18.5 μm Pitch
- Readout: 0.8 μm CMOS
  – 19.8 mm × 19.8 mm
- 4 Outputs
- Low Voltage Design
- 84-pin LCC

Achievements

- Capacity ≥100,000 e-
- I_{dark}<0.1 e-/sec
- Read Noise ≈9 e-
- Negligible "Glow"
- ≤1 MHz Data Rate

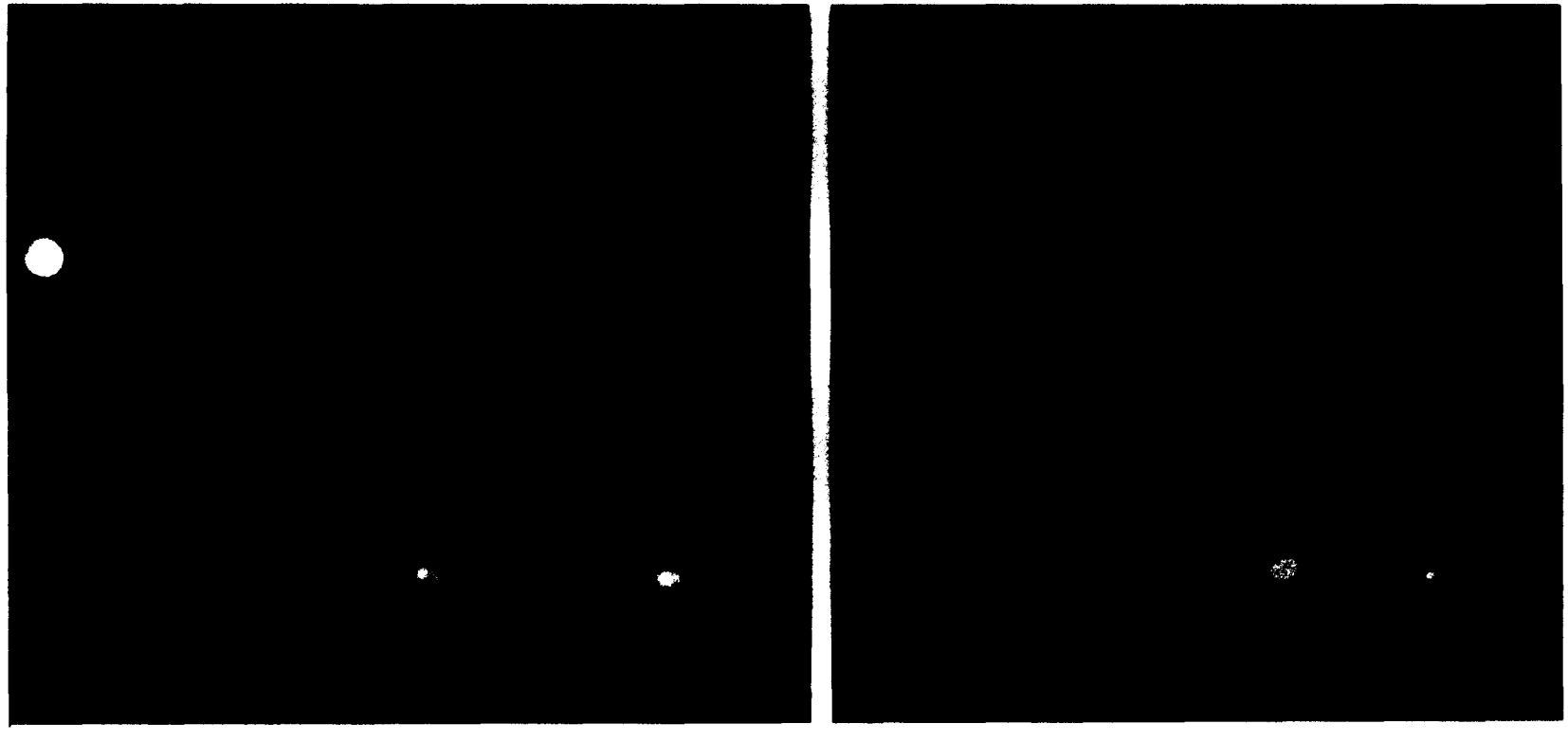
1024 x 1024 HgCdTe FPA



HAWAII 1024 x 1024 FPA Characteristics

Parameter	Value	Units
Array Format	1024^2	
Pixel Pitch	18.5	μm
Pixel Yield	>99	%
Detector Type	$HgCdTe/Al_2O_3$	
Quantum Efficiency	>50	%
Cutoff Wavelength	2.5	μm
Detector Dark Current	<0.01	e-/sec @ 78K
Jdark @	10^5	Ω-cm^2 @ 150K
Optical Fill Factor	>95	%
FPA Dark Current	<0.1	e-/sec @ 78K
Mean D* at T<120K	$\geq 10^{14}$	cm-Hz$^{1/2}$/W
Maximum Frame Rate	3.8	Hz
Minimum Read Noise	≤8.6 (CDS) <4 (Fowler)	carriers
Charge-Handling Capacity	$\geq 10^4$	carriers
Maximum Usable Dynamic Range	0.91	10^4
Responsivity Nonuniformity	<10	%
Output Channels	4	
Power Dissipation	<3	mW
Maximum Data Rate per Output	1	MHz

Rockwell 1024 X 1024 HgCdTe FPA at 2.2 meter Hawaii Telescope



Shoemaker-Levy 9 Comet Collision with Jupiter

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SCP.0651A.072594

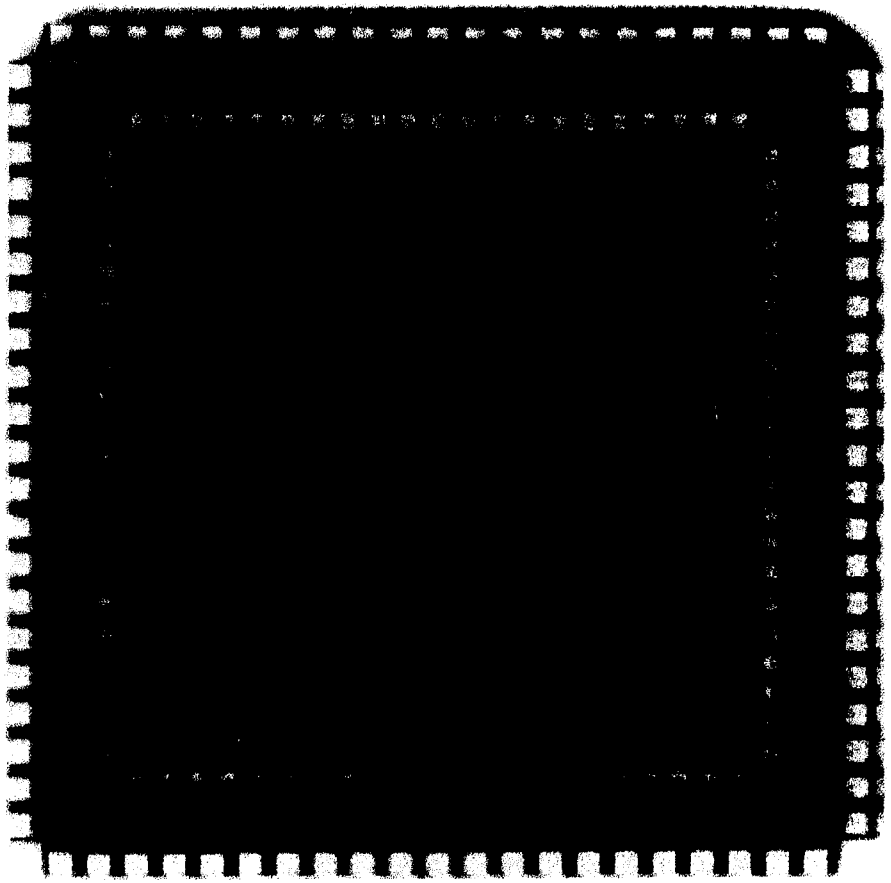
TCM8000: CTIA 1024×1024 Hybrid FPA

Readout

- 0.8 µm CMOS
- 4.4 million transistors
- CTIA Input Circuit
- >5x10^5 e- Linear Capacity
- 25 e- Read Noise
- ≥13 MHz Data Rate
- Two Outputs
- Very Low Power & Glow
- Simple Electronics
  - 3 Clocks, 1 Variable Bias

Detector

- PACE-I (HgCdTe/Al_2O_3)



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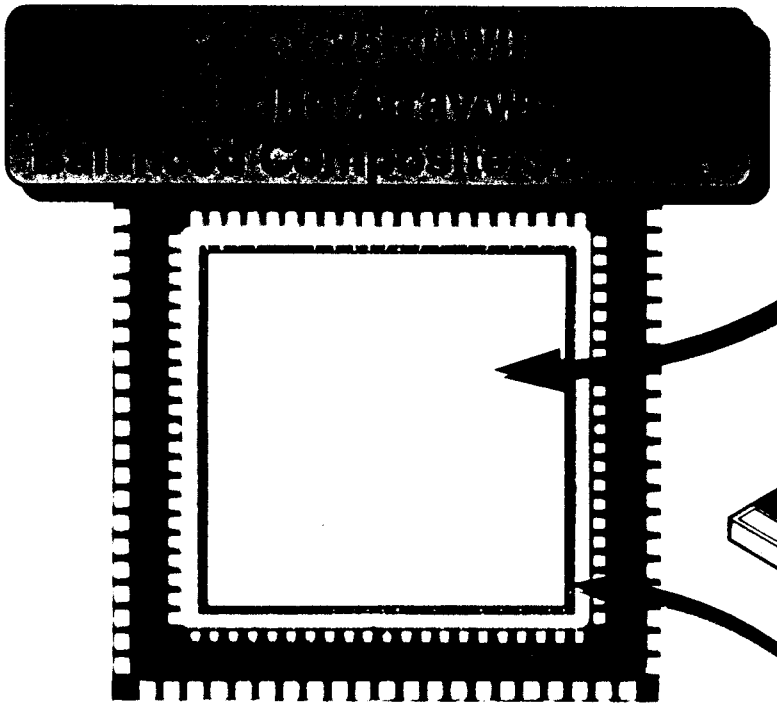
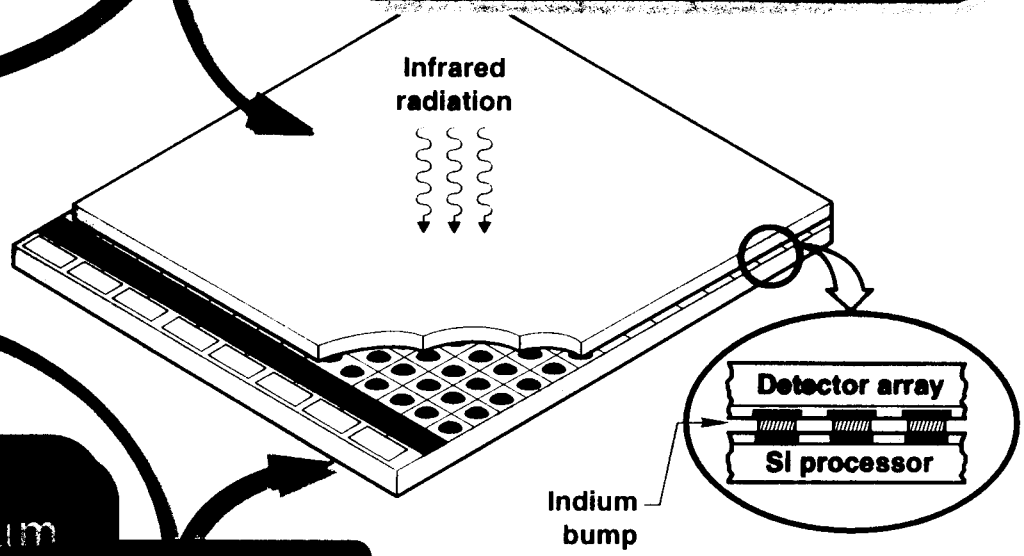
Rockwell's 256x256 LWIR MCT Focal Plane Array



Detector Array Chip

Double layer planar heterostructure MBE P/N MCT on CdZnTe



256x256 MMAD ROIC

- Commercial Rockwell 0.6 μm Silicon CMOS process
- Direct Injection input cell
- 8 MHz data rate output
- Windowing & ripple snapshot imaging

Readout IC Chip

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Summary

- Rockwell is currently unique in delivering 1024 x 1024 arrays to astronomers

- Rockwell's 0.9 μm to 2.5 μm HgCdTe FPAs are mature
  - 1024 x 1024 demonstrated, many delivered to astronomers, producing excellent results
  - 2048 x 2048 arrays in development

- 0.9 μm to 5 μm HgCdTe FPAs rapidly maturing to 2.5 μm performance levels
  - 640 x 480 arrays demonstrated
  - 1024 x 1024 arrays are under development
  - Expected to exceed InSb performance due to tunable (wider) bandgap and high material quality from MBE

- 0.9 μm to 10 μm HgCdTe FPAs under development for astronomy performance levels
  - 256 x 256 demonstrated
  - anticipate very high performance for low-temperature applications