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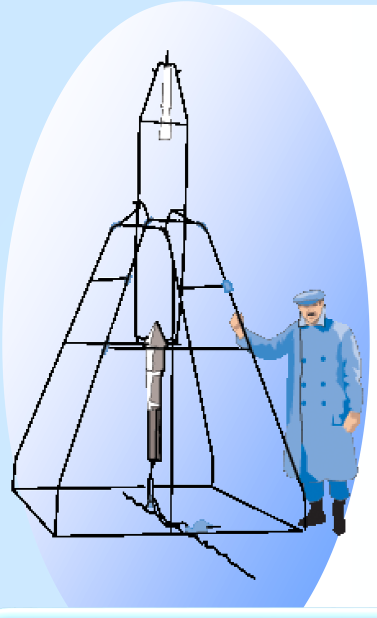
Starting TRL:_4_, Ending TRL: __5__



Advancing Next Generation Microshutter Arrays (NGMSA) for Future Astronomical Space-Based Observatories

Motivation / Problem Statement:

The existing array fabrication methodology resulted in a NGMSA with ~60% yield which would greatly reduce the field of view and thus the science deliverables from a space-based observatory. The motivation for the project is to resolve the identified process issues allowing near 100% yield large-format NGMSA.

Project Objective:

The main objective was to reduce front-to back run-out-error and minimize wafer bow. We focused on:

- DRIE recipe optimization
  - Gas flows
  - Etch timing
  - Power changes
- Test of different substrates
  - Pyrex
  - Sapphire
- Test of wafer adhesives

Results:

- We have reduced the DRIE run-out-error from ~5um to ~1.0 um with recipe changes and further improved it to ~0.5um with a stiffer sapphire substrate.
- We have reduced wafer bowing from ~+/-50um to ~+/-10um with improved wafer bonding techniques and using a stiffer sapphire substrate.
- Adhesive test are ongoing

Background:

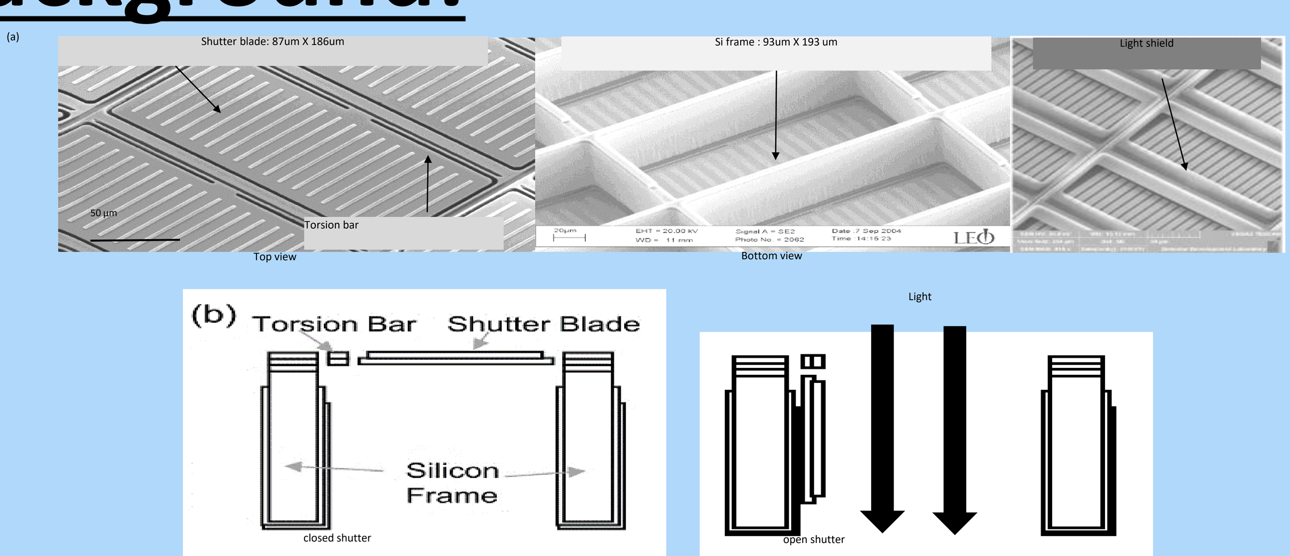


Figure 1.1(a) Scanning electron microscopy (SEM) image of a microshutter array with component details. The light shield covers the gaps between the shutter blade, torsion bar and the silicon frame.
(b) When actuated, the shutter blade rotates and opens the shutter.

Figure 1.2 MSA format development trend for Cosmic Origins is shown. Our pilot and JWST formats are shown on the left. A concept and manufacturing development array produced by our fiscal year FY18 Strategic Astrophysics Technology (SAT) project is shown in the center. Our FY18 SAT project also produced a ruggidized design that is sutable for spaceflight is shown on the right and is the subject of this SAT proposal. ***The design shown on the right has been demonstrated through test to general environmental verification standard (GEVS) vibration levels for evolved expendable launch vehicle (EELV) launch.*** *We propose this format for the Decadal Survey UVOIR stratigic mission aplication going forward.*

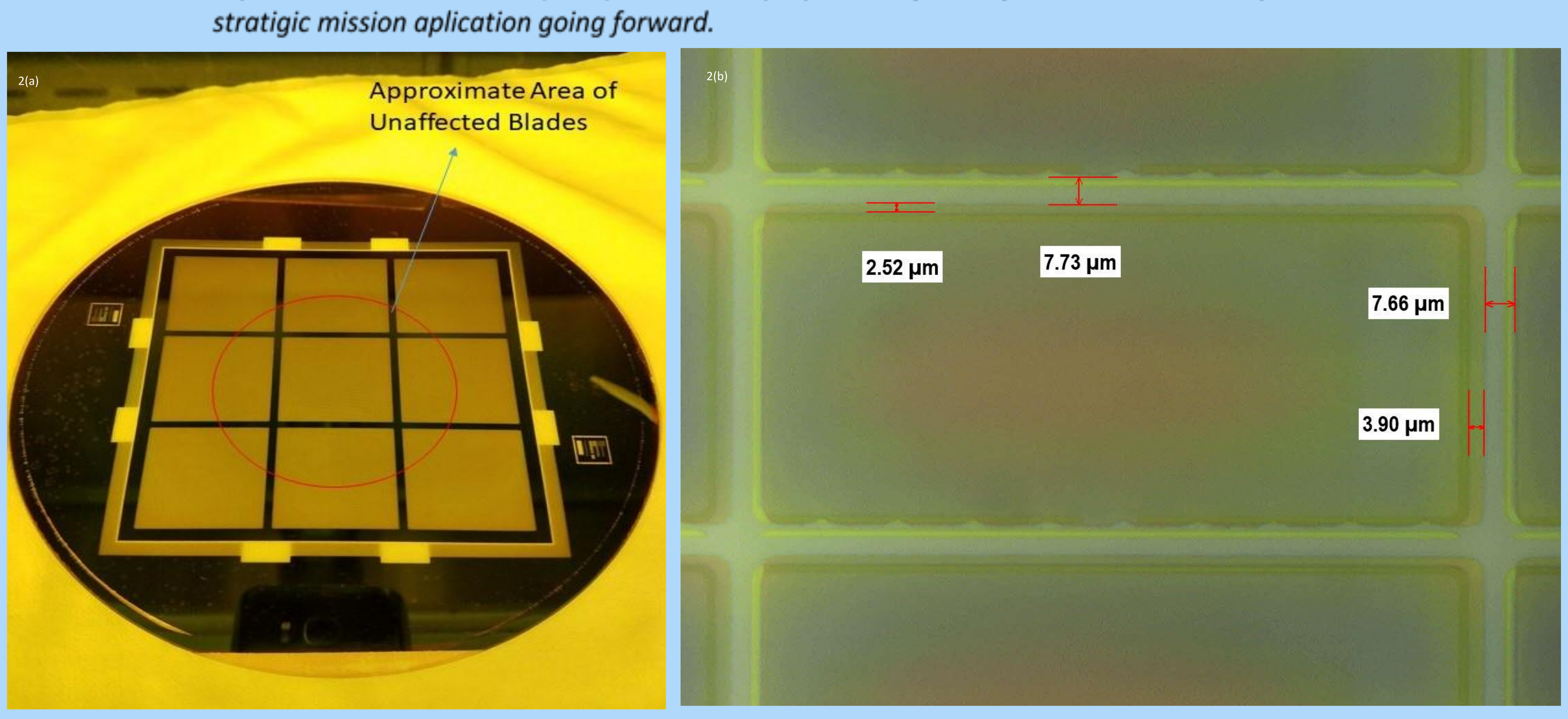
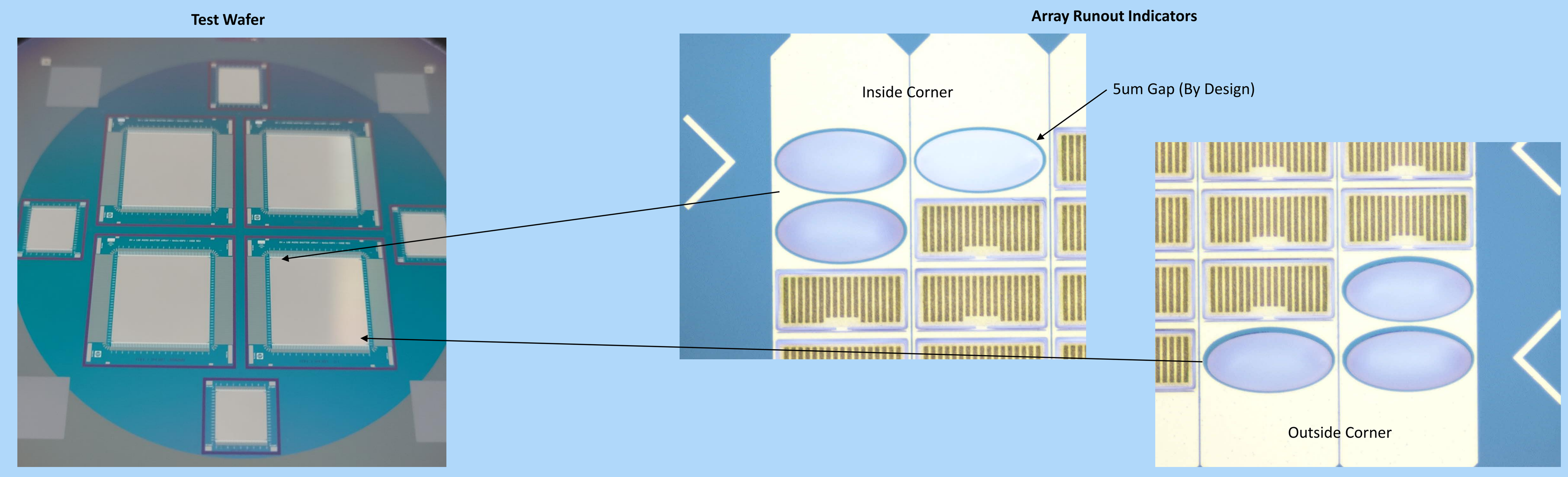


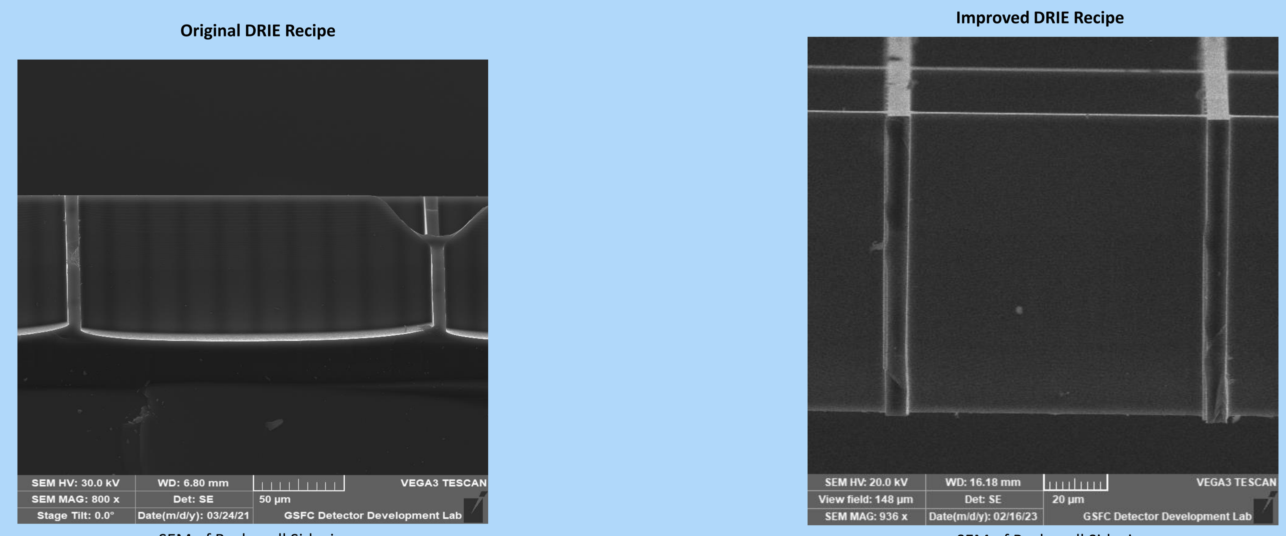
Figure 2 (a) 736 X 384 micro-shutter array on 150mm substrate after DRIE back etch. The circled region indicates where shutter blade operation is possible. (b) Plan view micrograph showing mis alignment of a single microshutter blade due to run-out-error. Misalignment >3um prevents shutter blade operation.

DRIE Runout Improvement:

Test Wafer **Array Runout Indicators**



Original DRIE Recipe **Improved DRIE Recipe**



SEM of Back-well Sideview.
Runout ~5um

SEM of Back-well Sideview
Runout ~ 1um

DRIE Recipe Data / Runout Measurements

	Pass Dep. Pres. (mT)	Etch Pres. (mT)	ICP Power (W)	Pass Dep Time (s)	Pass Etch Time (s)	Si Etch Time (s)	Pass Etch Power (W)	Si Etch Power (W)	Etch/Pass Gas (sccm)	Etch Step Ar (sccm)	Total Etch Cycles	Circle Runout (Avg)	Oval Runout (Avg)	He P (T)
TW8	30	25	1200	2.2	2.2	1.3	125	5	170	10	280	1.81	1.96	16
TW9	30	25	1250	2.2	2.2	1.3	125	12.5	170	10	265	1.39	1.39	8
TW10	30	25	1250	2.2	2.2	1.3	125	12.5	170	10	265	0.924	0.852	4
TW11-S1 (sapphire)	30	25	1250	2.2	2.2	1.3	125	12.5	170	10	265	0.528	0.302	4
TW12	30	25	1250	2.2	2.2	1.3	125	12.5	170	10	265	1.05	0.876	4

Conclusion: The addition of Ar to the recipe reduced runout from ~5um to ~2um. The reduction of He pressure reduced runout to ~1um. The addition of a stiffer sapphire substrate reduced the runout to ~0.5um.

Wafer Bow Reduction / Adhesive Tests:

WAX	Substrate	ID	Bow (µ)	Spin	HPB Bake 1	HPB Bake 2	Vac Oven Bake	Wax Thick (µ)	Bow (µ)	Si (µ)	ID	Bow (µ)	Bond 1	Bow (µ)	Bond 2	Bow (µ)	HPB 1	Bow (µ)	HPB 2	Bow (µ)	Net Change
509	650 um Sapphire	S LS1	5.2	870 X 4. 2 each	115C - 60s ea	115C - 10m	-	-	-	512	W5	1.5	115C	-	115C	14.1	-	-	-	-	8.9
509	650 um Sapphire	S LS2	-0.11	870 X 4. 2 each	115C - 60s ea	115C - 10m	-	-	-	516	W6	-10.3	115C	-	115C	10.8	-	-	-	-	10.9
Ait	500 um Pyrex		4.3	2K X 1	75C - 10m	-	-	12	10.6	-	-	-	-	-	-	-	125C - 60s	9.83	110C - 60s	13.6	9.3
AiT	650 um Sapphire	S LS2	-0.202	1K X 4	75C - 60s ea	75C - 10m	-	87	-0.359	-	-	-	-	-	-	-	120C - 10m	-0.359	-	-	0.157
AiT	650 um Sapphire	S LS2	-0.202	1.25K X 4	75C - 60s ea	75C - 10m	~110C: 5m soak, 10m Vac Oven	75	0.006	-	-	-	-	-	-	-	-	-	-	-	0.208
AiT	650 um Sapphire	S LS1	5.1	1.25K X 5	75C - 60s ea	-	145C: 5m soak, 10m Vac Oven '8'	90	0.59	-	-	-	-	-	-	-	-	-	-	-	4.51
AiT	650 um Sapphire	S LS1	5.1	1.25K X 4	75C - 60s ea	-	135C: 1m soak, 10m Vac Oven '7'	75	5.7	114	-	49.6	130C	29.7	130C	-2.3	110C - 60s	-5.7	110C - 60s	-5.8	10.9
AiT	650 um Sapphire	Slot 18	0.183	1.25K X 2	75C - 60s ea	-	125C: 5m soak, 10m Vac Oven '6'	33.4	1.9	-	-	-	-	-	-	-	-	-	-	-	1.717
509	650 um Sapphire	Slot 18	0.183	870 X 4	115C - 60s ea	115C - 10m	-	22.5	-2.1	115	-	37.9	115C	6.6	115C	-8.3	110C - 60s	-5.1	110C - 60s	-3.7	3.88
509	500 um Pyrex	P1	2.7	870 X 2	115C - 60s	115C - 10m	-	11.4	4.6	-	-	-	-	-	-	-	-	-	-	-	1.9
509	500 um Pyrex	P1	2.7	870 X 4	115C - 60s ea.	115C - 10m	-	24.7	9.3	100	-	64.9	115C	-29.5	115C	-13.8	110C - 60s	-23.4	110C - 60s	-23.3	26
AiT	500 um Pyrex	P3	18.3	1.25K X 2	75C - 60s ea	-	125C: 3m soak, 10m Vac Oven '6'	33.8	19.3	100	-	53.3	130C	-29.1	130C	-22.7	110C - 60s	-42.1	110C - 60s	-40.2	58.5
AiT	500 um Pyrex	P20	18.3	1.25K X 4	75C - 60s ea	-	135C: 5m soak, 10m Vac Oven '7'	73.3	10.6	114	-	0.7	135C	-36.6	135C	-26.5	-	-	-	-	44.8
509	500 um Pyrex	P21	2.7	870 X 8	115C - 60s ea.	115C - 10m	-	70.5	11.1	115	-	-1.4	115C	-22.7	115C	-3.2	110C - 60s	-0.026	110C - 60s	0.209	2.49

Conclusion: Sapphire backing wafers dominate the stress introduced by the adhesive leading to reduced wafer bow. Tests of Crystalbond 509 wax vs. AiT BGL7120 wax indicate 509 wax is less stressed and easier to work with.