New generation of wafer-scalable, hermetically sealed chip fuse for space

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Agenda

- > Intro: Motivation & Goal
- > Fuse Concept
- > Insights: Results, Findings
- > Summary

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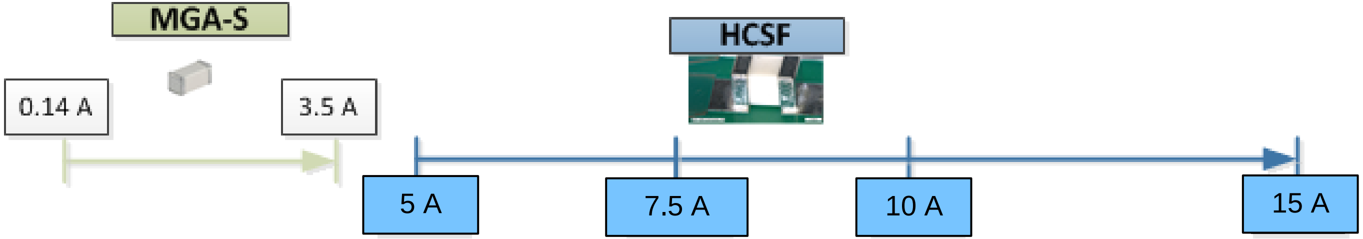
SCHURTER Space Fuses at a glance

ESCC qualified fuse families:

MGA-S: 
Small SMD fuse (SMD 1206), max. 125 V
Application: Overcurrent protection in “Low Power” module
QPL: 2008

HCSF: 
SMD fuse (SMD 3220), full range 125 V
Application: Overcurrent protection in “Low Power” and “High Power” module
QPL: 2016

IR Range:



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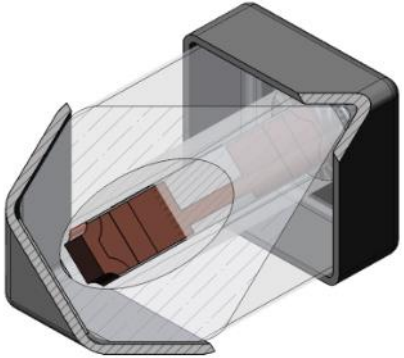
Motivation & Goal

Fuse with outstanding performance.

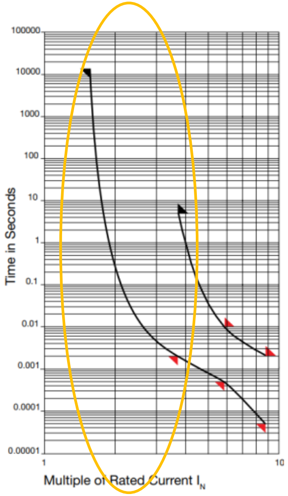
But it's a complex design => expensive manufacturing!



New generation of wafer-scalable, hermetically sealed chip fuse for space

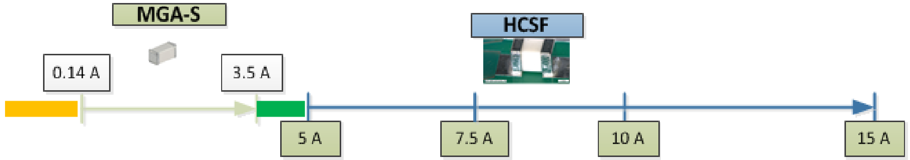
Motivation & Goal

Market Trends (dedicated to new space and related markets)



- Better **predictable fuse tripping time** at low overcurrent

- **Rated Currents (IR)** down to **50 mA & extend to 4 A, 5 A**



- Higher **Voltages (> 125 V)**

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Motivation & Goal

Market Trends (dedicated to new space and related markets)

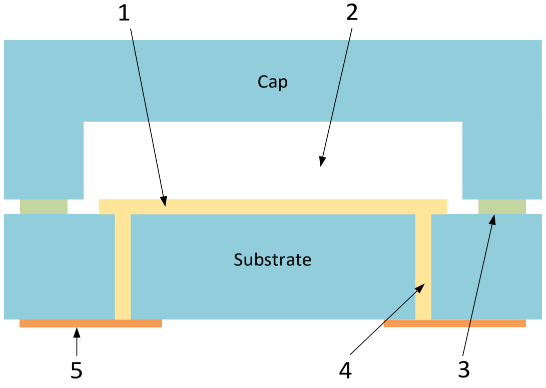
- Performance: **Breaking Capacity vs. Size**

- **Cost-competitiveness** (e.g. COTS in New Space)

- Narrowing regulatory restrictions on using hazardous substances (RoHS): **risk of banning HMP lead-solder in fuses**.

Concept

Schematic on chip level – cross-sectional sketch



1:	Fuse link
2:	Arc-extinguishing space
3:	Bonding layer
4:	TGV
5:	Under Bumb Metallization (UBM)

Target figures

- Fast-acting, better predictable tripping time
- IR 50 mA to 5 A, 125 Vdc
- High BC
- Hermetically sealed
- No inner-solderjoint (intrinsically no Pb)
- Cost-effective

Key technologies considered:

> State-of-the-art Thin-Film fuse link

> Glass substrate considering metal filled-vias or through-glass-vias (TGV)

> Advanced bonding technology

Insights: Results & Findings

Introduction to the results of the low current prototypes:

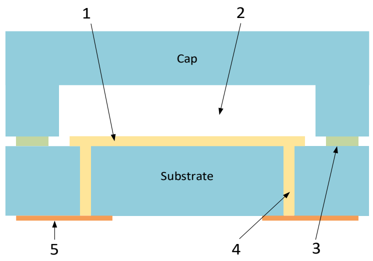
- fast-acting
- **Rated Current = 50 mA and 250 mA**

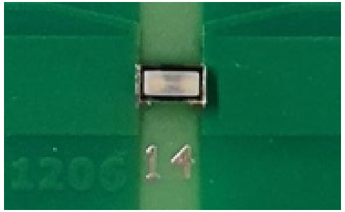
Tests:

- Breaking Capacity
- “Most critical” ESCC 4008 Tests:
  - Thermal Vacuum
  - Operating Life
  - Rapid Change of Temperature
  - Robustness of Termination
- Hermetically sealing: Fine-He Leak Test

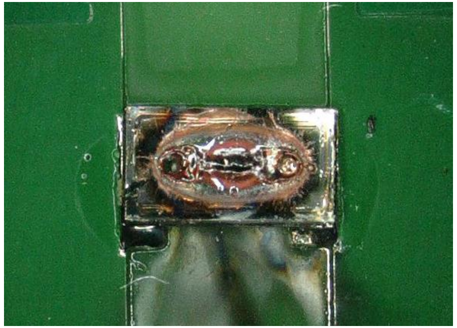
Breaking Capacity

Goal: Same BC as MGA-S (up to 300 A at 125 Vdc), or better!





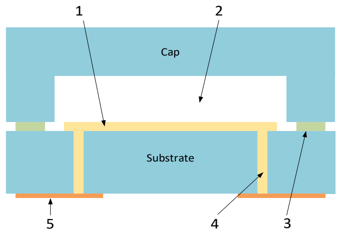
Result at 125 Vdc, 300 A



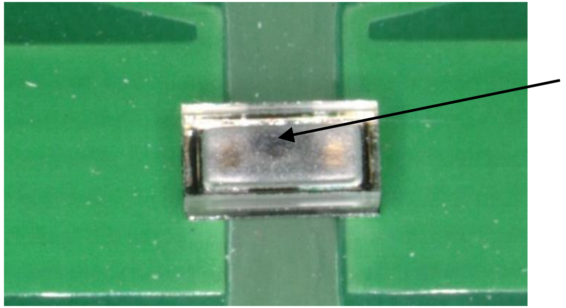
Sample without arc-extinguishing agent.
Bad result! Fuse body exploded, strong outgassing residuals.

=> As expected, an arc-absorbing material is needed!

Breaking Capacity



Result at **200** Vdc, 300 A



Dark spot inside the body represents vaporized metal and arc-extinguishing material.

Sample **with** arc-extinguishing agent.
Good result!

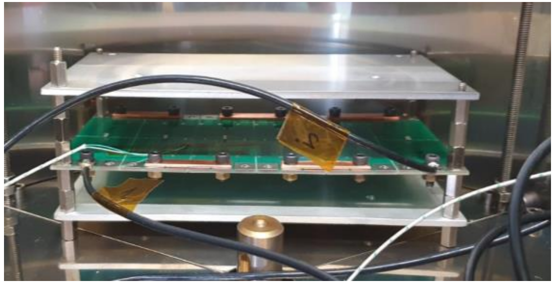
Overview Results

Design	Arc-Extinguishing Agent	300 A at 63 Vdc	**300 A at 125 Vdc**	300 A at 150 Vdc	300 A at 200 Vdc	Insulation Resistance at 500 Vdc
A	no	passed	failed	not tested	not tested	> 500 MΩ
B	yes	passed	passed	passed	passed	> 500 MΩ

Thermal Vacuum

According to ESA ESCC 4008, Para. 8.15

- *Sample size: 6*
- *Samples are powered with 90% of IR*
- *p = 0.00007 mbar, at 125 °C for 48 h*



Test setup at SCHURTER

RESULTS:

No.	**Cold Resistance drift in %**	Overload Operation under Vacuum	Overload Operation after TV test at Atmosphere	Insulation Resistance at 250 Vdc
1	-0.27	passed	-	> 220 MΩ
2	1.34	passed	-	
3	1.01	passed	-	
4	1.35	-	passed	
5	7.73 (1)	-	passed	
6	-0.02	-	passed	
MIN	-0.27	-	-	> 220 MΩ
AVG	1.06	-	-	> 220 MΩ
MAX	7.73	-	-	> 220 MΩ

(1) The root cause was narrowed down to the intermetallic joining between the UBM and the TGV

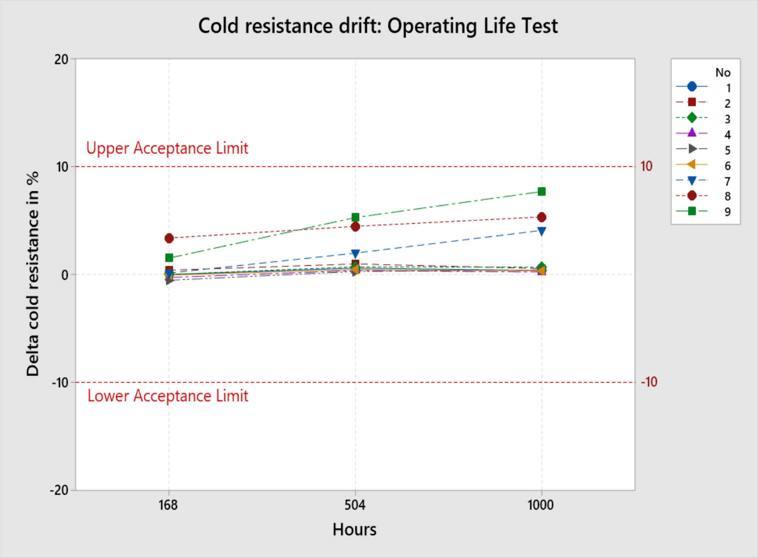
Insights: Results & Findings

Operating Life Test

According to ESA ESCC 4008, Para. 8.8

- *Sample size: 9*
- *Samples are powered with 90% of IR*
- *125 °C for 2’000 h*

Intermediate RESULTS:



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Rapid Change of Temperature

According to ESA ESCC 4008, Para. 8.9

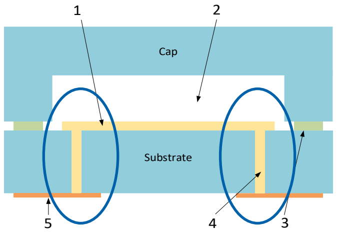
- *Sample size: 9*
- *Samples unpowered*
- *-55 °C to 150 °C, 200 cycles*

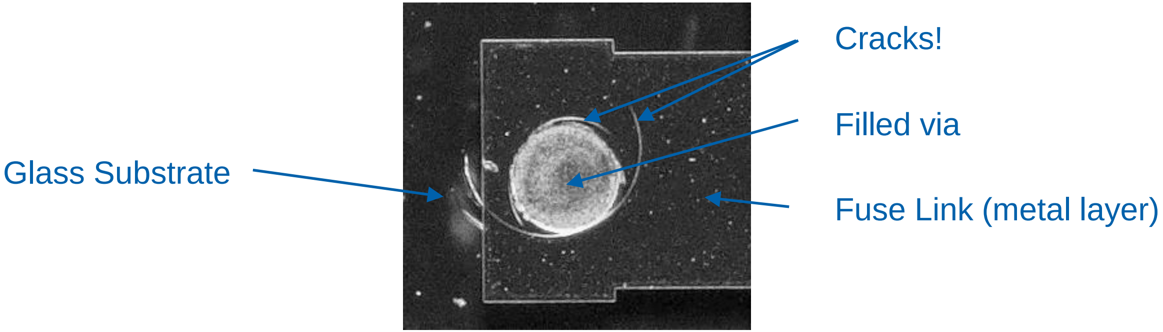
RESULTS:

No.	**Cold Resistance drift in %**	Visual Inspection (mechanical damage, glass cracks)	**Result**
1	1.65	No damage or crack	passed
2	5.26	No damage or crack	passed
3	5.57	No damage or crack	passed
4	60.02	Cracks on glass surrounding TGV	failed
5	32.43	Cracks on glass surrounding TGV	failed
6	38.06	Cracks on glass surrounding TGV	failed
7	2.71	No damage or crack	passed
8	5.71	No damage or crack	passed
9	1957.3	Cracks on glass surrounding TGV	failed

Rapid Change of Temperature

Noticeable glass cracks surrounding the TGVs were observed in all failed samples.





These cracks mainly cause detachment and partial disconnections between the filled via and the fuse link (metal layer).

Insights: Results & Findings

Robustness of Termination

According to ESA ESCC 4008, Para. 8.14

- *Sample size: 4*
- *Samples unpowered*
- *Displacement max 1.5 mm*

RESULTS:

No.	**Displacement = 1.5 mm** (ESCC 4008 para. 8.14)		Displacement = 2.5 mm	
	Cold Resistance drift in %	Result	Cold Resistance drift in %	Result
1	0.55	passed	42.6	Failed (1)
2	-0.2	passed	-	-
3	0.18	passed	-	-
4	1.06	passed	52.28	Failed (1)

(1) The root cause was narrowed down to the UBMs. Partial detached areas between the glass substrate/via and the metal pad were noticed

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Insights: Results & Findings

Fine Helium Leak Test

- *Sample size: 36*
- *He-bombing for 72 hours at 5 bars, then leaking He was measured using a fine He leak tester*
- *Acceptance limit: 1*10-9 mbar*l/s*

RESULTS:

	Leak rate in 10^{-09} mbar*l/s	Comments
MIN	0.00104	-
AVG	0.00394	-
MAX	0.02	Four samples with values in the range of $0.01*10^{-09}$ to $0.02*10^{-09}$ mbar*l/s

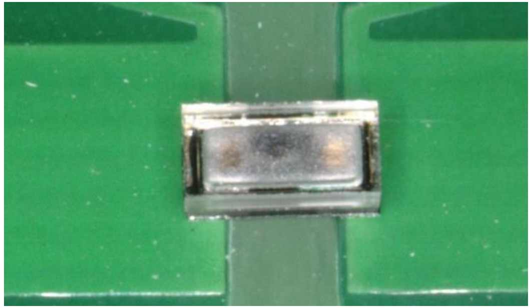
All samples passed. 4 Samples showed slightly higher values than the others.

Summary

Overall Test Summary:

- Breaking Capacity Test — ✓
- "Most critical" ESCC 4008 Tests:
  - Thermal Vacuum — ✓
  - Operating Life — test ongoing, 1'000 h passed
  - Rapid Change of Temperature — failed
  - Robustness of Termination — ✓
- Hermetically sealing: Fine-He Leak Test — ✓

Summary



Overall, the **concept is promising**. **But!**

Two serious weaknesses noticed:

1.) Insufficient performance and quality of the TGV (thermal expansion mismatch: glass vs filled-vias)

2.) Under-Bump-Metallization: the adhesion layer sticking to the filled-vias must be improved

Thank you for your attention

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