It's a small world!

Development of Interfaces for Micro-Nano Satellite Systems

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8 different interfaces

Electrical contacts interface

BGA based electrical contacts between MCM or other units

Electrical Comp interface

Flip-chip based interconnection of bare FPGA dies and bare H-bridge dies

Electrical vias

Low ohmic electrical through silicon via based on metal connector and high yield robust design

Fluid Seal

Silicon based semi-hermetic package including electrical via

Fluid to Fluid interface

Pipe to silicon module interface

Filter & Channels

Fluid filters and channels based on bonded fish-bone structures

Functional Suspension

Corrugated membrane with larger stroke, for valve applications

Large Si Module interface

Silicon parts mechanically mounted and thermally connected to aluminum frame using silicon rubber

Example of small satellite concepts

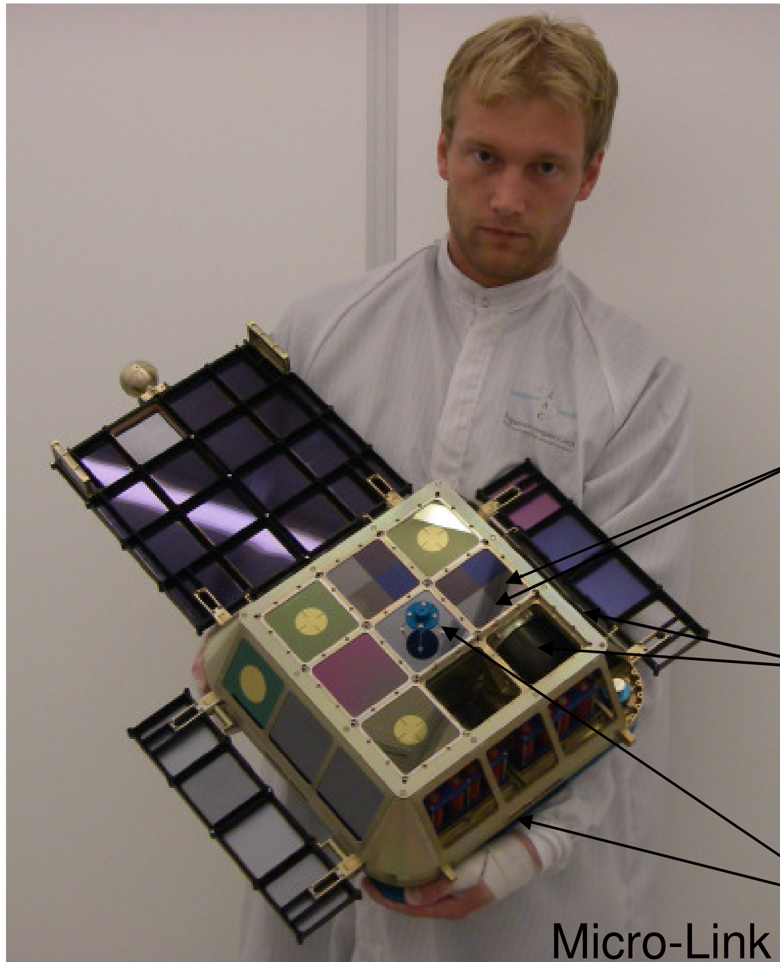
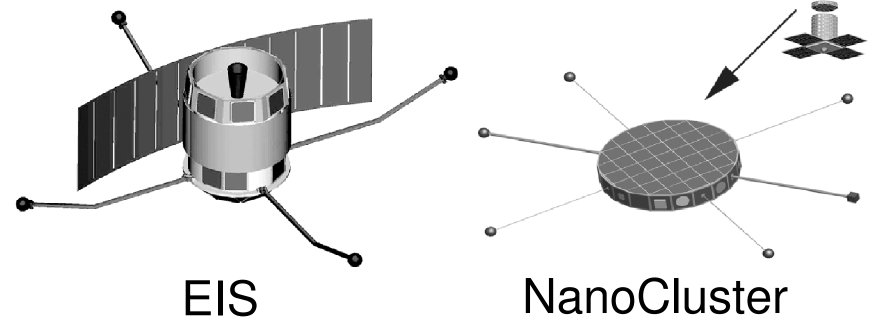


Photo: ÅAC. Satellite courtesy of Uppsala university.



Fluid to fluid interface, Functional suspensions, Fluid seal together with **Filters and channels** are to be used in fluid handling system parts for fuel cell feeding, cooling and micro-rocket engine propellant feeding

Electrical component interface, Electrical via interface together with **Electrical contacts interface** are to be used in handling electrical signals and power in Electronics miniaturization and 3-D stacking

Large silicon module interface are to be used for the standardized attachment of Si modules to nano-spacecraft

Interface requirements

Why small interfaces?

- Small components obviously need interface in same size, many of todays interconnections are not well suited for small system. Multifunctionality also gives an advantage in reduction of the number of interfaces (for example a combined mechanical and electrical interface)

Requirements comes from:

- Packaging and 3d-packaging
- Micro-fuel cells fuel feeding and cooling
- Micro-rocket engines
- LEO orbit
- Ariane 5 launch vehicle
- Design and testing has been adopted to ESA/ECSS-standards

Interfaces tested regarding:

- Vibration, thermal cycling, life-time cycling, mechanical fatigue, electrical fatigue

Electrical interface – Overview description

Electrical contacts interface

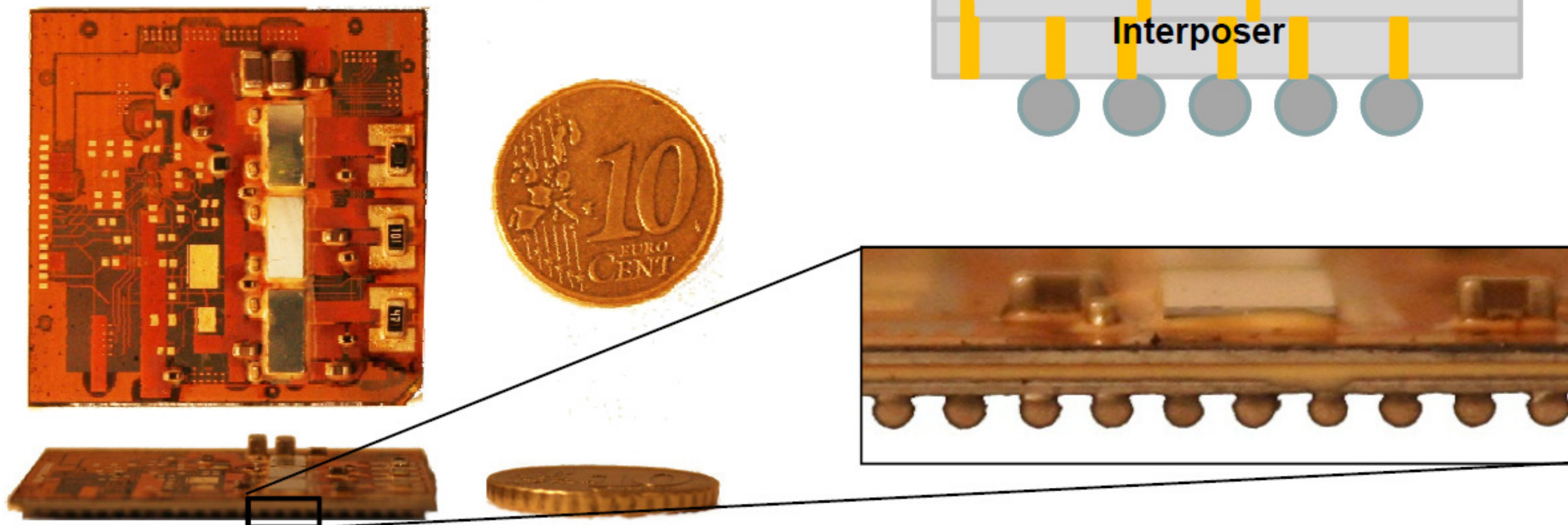
BGA based electrical contacts between MCMs or to other units

Electrical components interface

Flip-chip based interconnection of bare FPGA dies and bare H-bridge dies

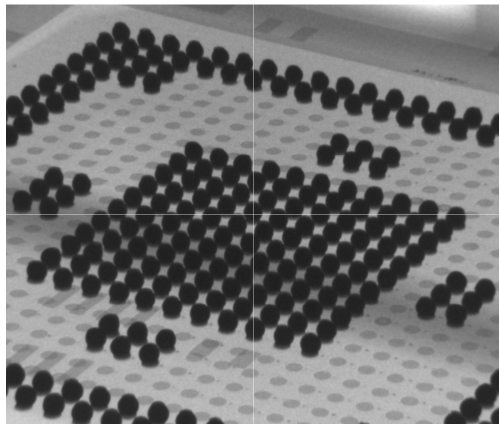
Electrical vias

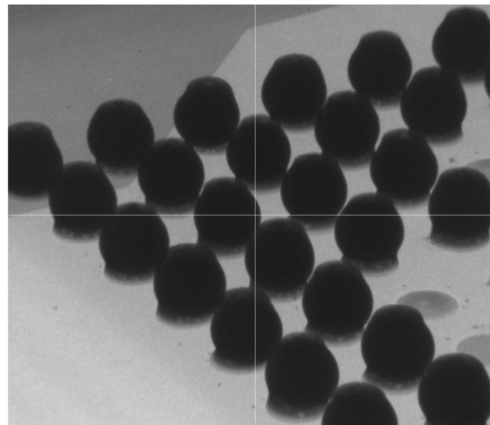
Low ohmic electrical through silicon via based on metal connector and high yield robust design

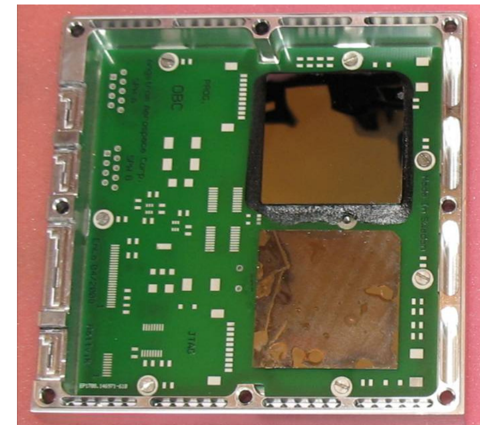


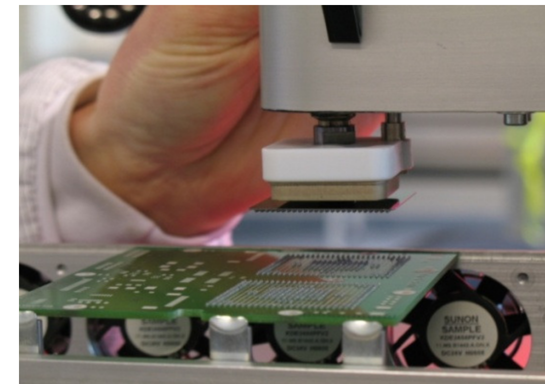
Electrical interface - Electrical contacts interface

BGA based electrical contacts between MCM or other units







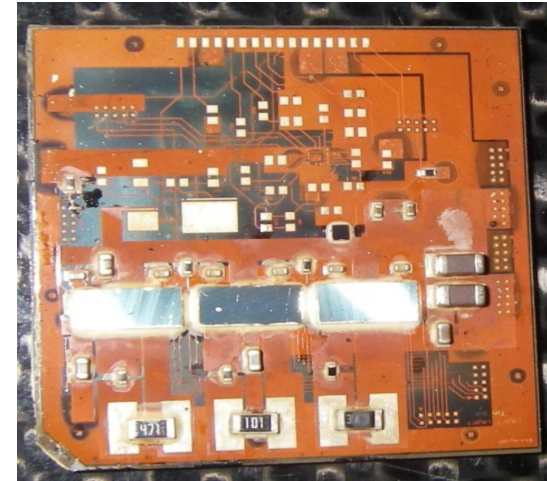


- *X-ray on flight EM BGA solder ball array between Si-substrate and PCB-substrate*

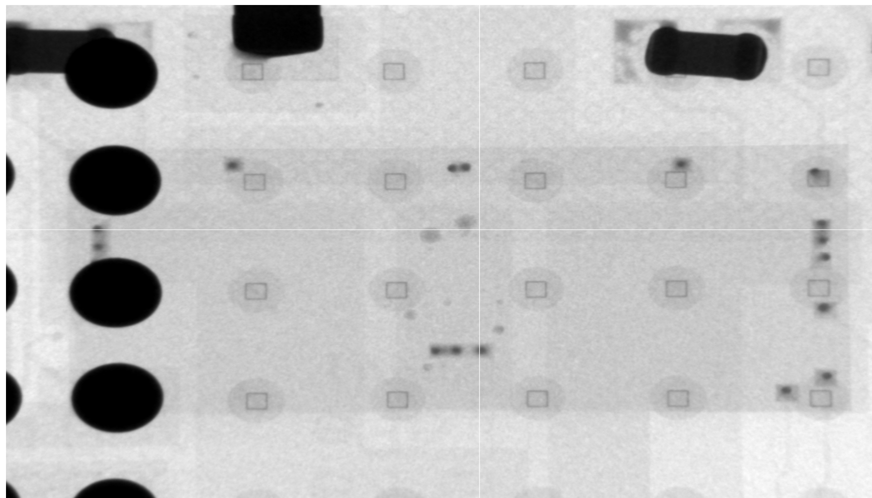
- *Flight EM with 2 BGA Si wafers soldered to PCB*

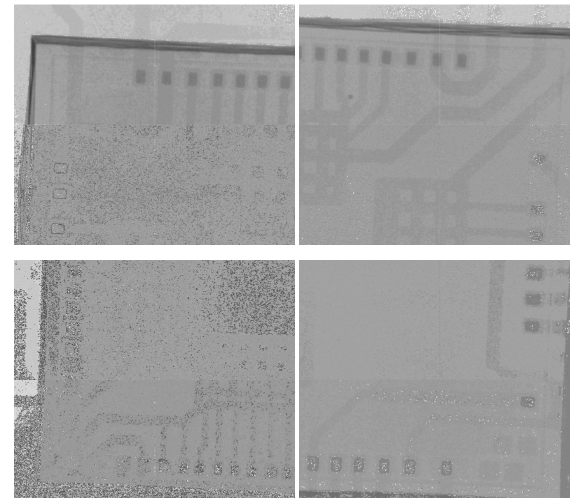
Electrical interface - Electrical component interface

Flip-chip based interconnection of bare FPGA dies and bare H-bridge dies are soldered to pyrex, LTCC and to silicon substrates



X-ray evaluation of solder joints

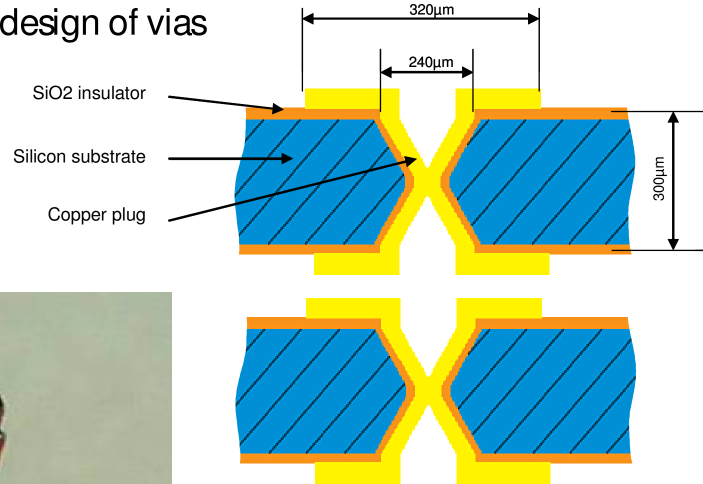


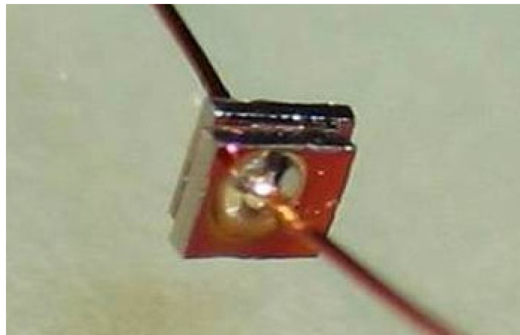


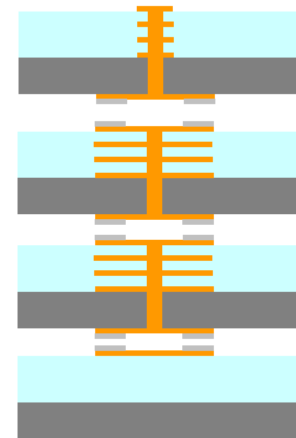
Electrical interface - Electrical through substrate vias (TSV)

Low ohmic electrical through silicon via based on metal connector and high yield robust design

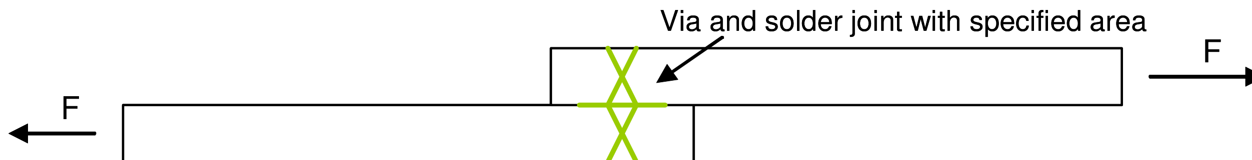
Detailed design of vias





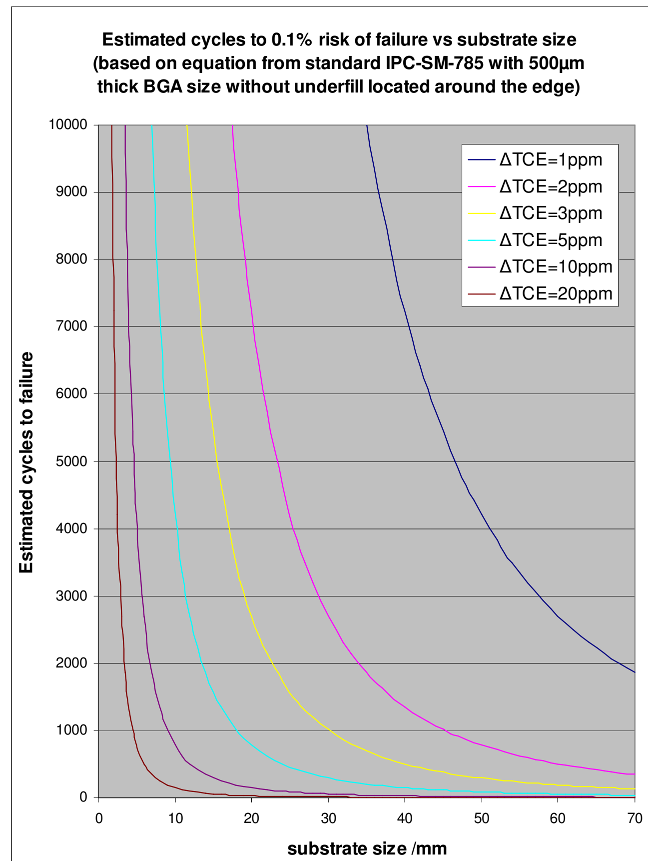


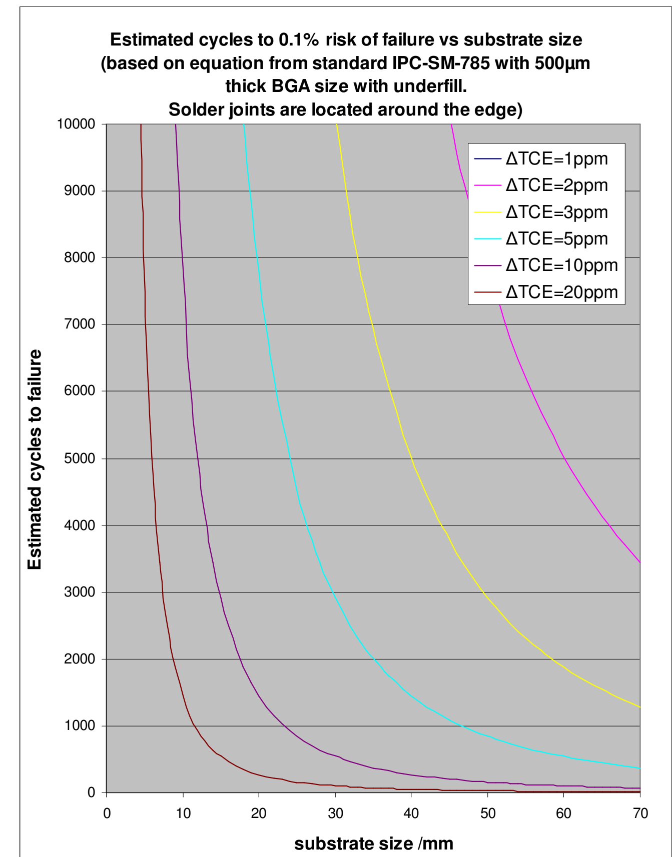
Wafer to wafer interconnects are solved by through substrate vias and wafer to wafer soldering



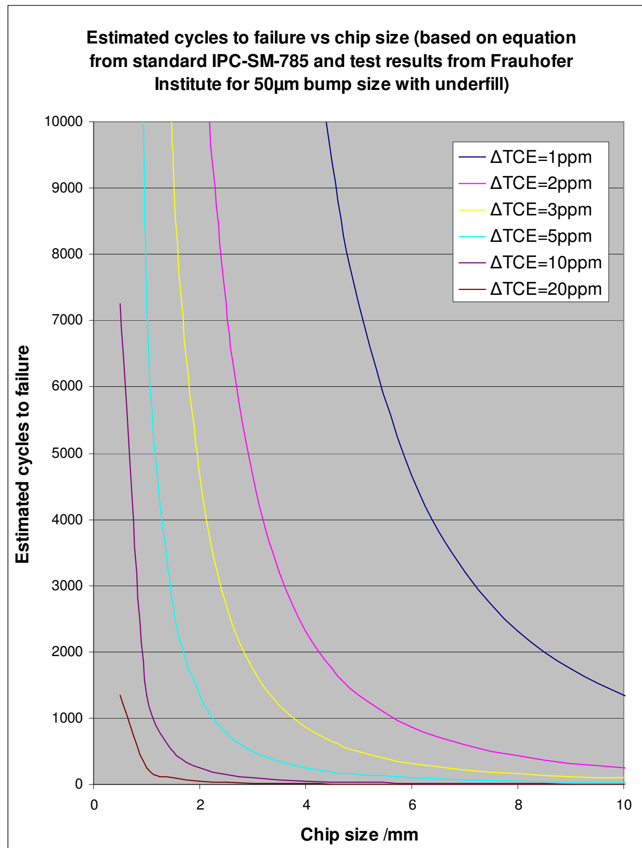
Electrical interface - Electrical contacts IF Design rules study

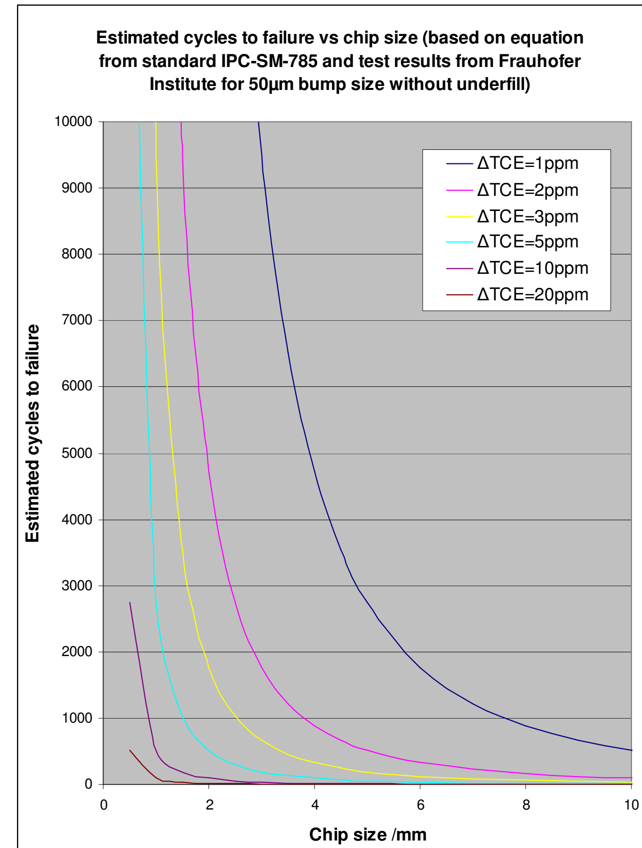
Guidelines for BGA-mounted carriers, with and without underfill, based on Standard IPC-SM-758 and results from Fraunhofer. Estimations are for -40 °C to +125 °C, time in extreme temperature t_D=15 minutes.





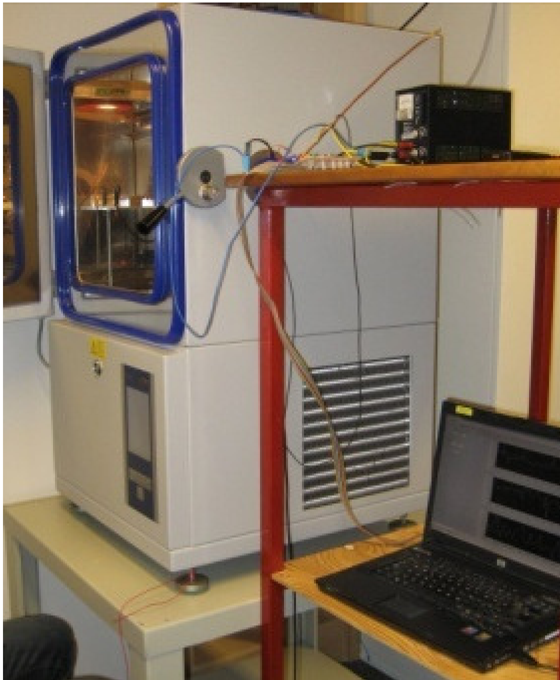
Electrical interface – Electrical componets IF Design rules study

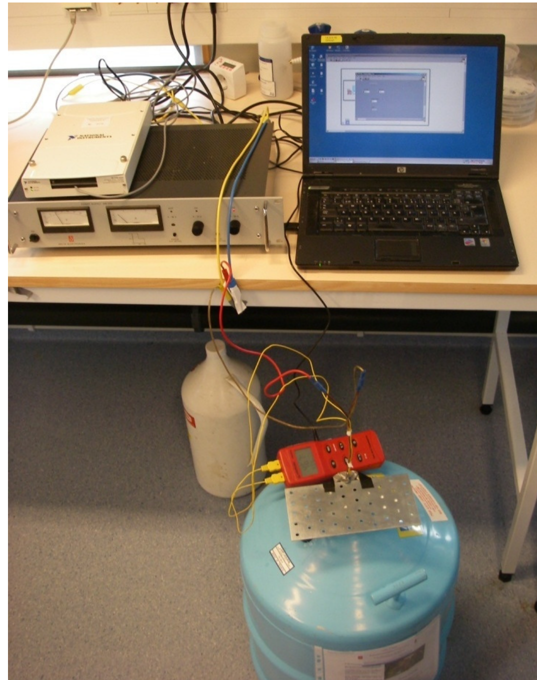


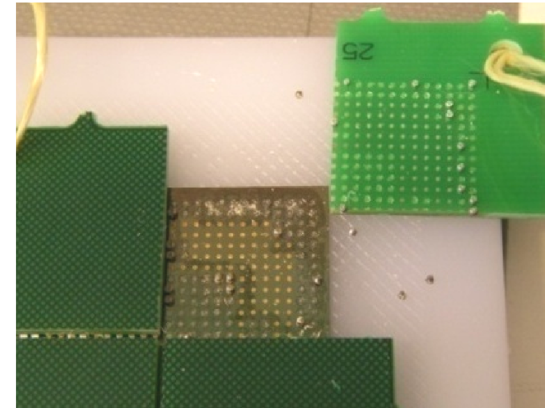


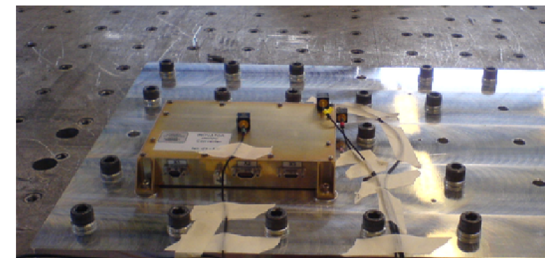
Guidelines for flip-chip mounted dies on various substrates, based on IPC-SM-758 standard and test results from IZM Fraunhofer. The left graph shows the amount of cycles before failure for solder joints with underfill, the right graph shows the same for joints without underfill.

Electrical interface - Testing









Electrical interface - Results

Electrical contacts IF

34x34 mm BGA based electrical contacts between MCM or other units passed following tests:

X-ray evaluation acceptance

Vibration similar to ECSS-Q-70-08A Table 6

500 thermal cycles (-40 to +125 C)

Thermal shock 10 min at -160 C

Low force shear load 25700 cycles at 1.4MPa

Electrical life-time: U=14V, Ia=0.03A, Ib=0.14A and Ic=0.47A up to 300s

68x68 BGA LTCC to PCB tested at Saab Space

Electrical tests show no issues at room temperature and no symptoms at -30 C or +70 C.

Electrical interface - Results

Electr Comp IF

Flip-chip based interconnection of bare FPGA dies and bare H-bridge dies passed following criterias:

X-ray evaluation acceptance

Vibration similar to ECSS-Q-70-08A Table 6

500 thermal cycles (-40 to +125 C)

Thermal shock 10 min at -160 C

H-bridge solder joint tested for 3 A and 14 V with 50% duty cycle (= 21 W)

Smallest pitch ca 57 µm for FPGA

Bump height ca 15 µm for FPGA

Electrical interface - Results

<u>Electrical vias</u>

Low ohmic electrical through silicon via based on metal connector and high yield robust design passed following tests:

Life-time testing for 500 thermal cycles -40C to +125C

Thermal shock to -160 C for 10 min

-30 to +70 C, 6 cycles with in-situ electrical validation

Electrical resistance less than 10 Ohm

Electrical cycling 0-1A at 10V for 29000 cycles

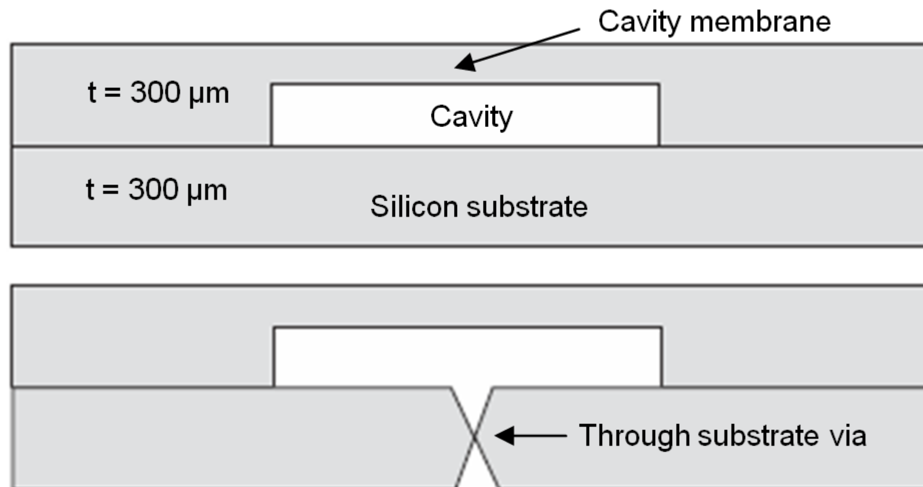
Low force shear load tested at 4MPa for 17 000cycles (~1Hz)

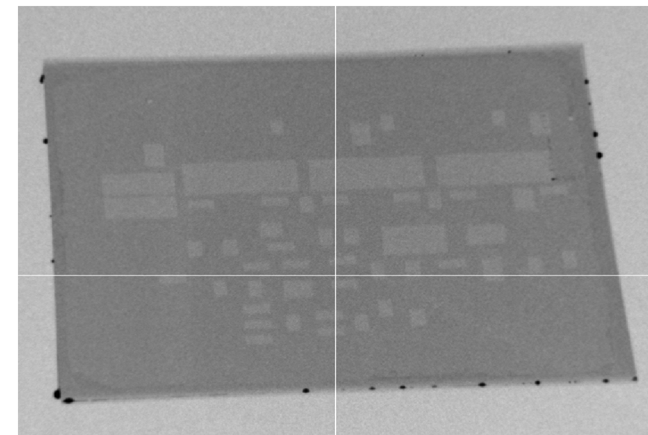
Pull strength test > 20MPa

Pull-fatigue test 4MPa for 17000cycles

Fluid interface - Fluid Seal

Silicon based semi-hermetic package including electrical via

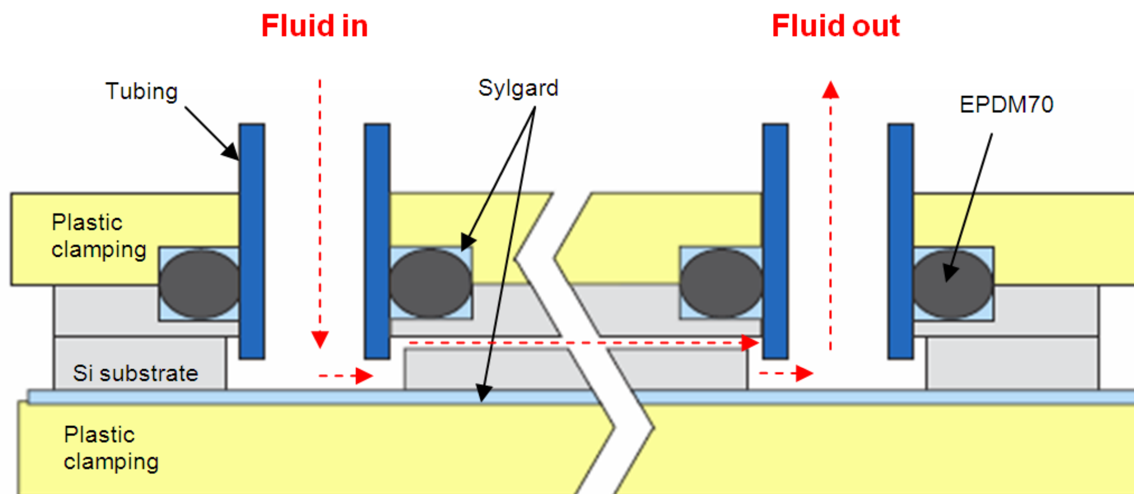


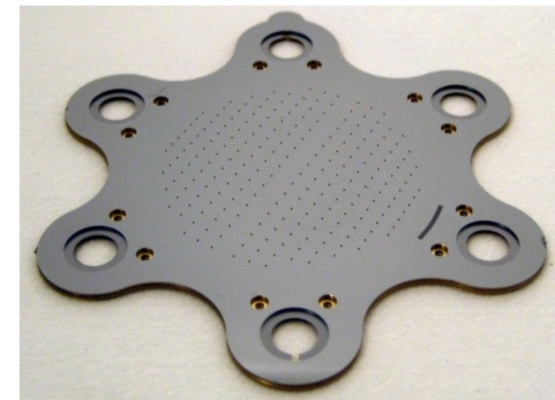


Low resistive electrical metal via
Process compatible with flip-chip technology (1 reflow)
Wafer-to-wafer solder joint leak tight for 1atm external pressure
Via not leak-tight for 1atm external pressure
Thermal shock to -160 C for 10 min
Storage 2 years

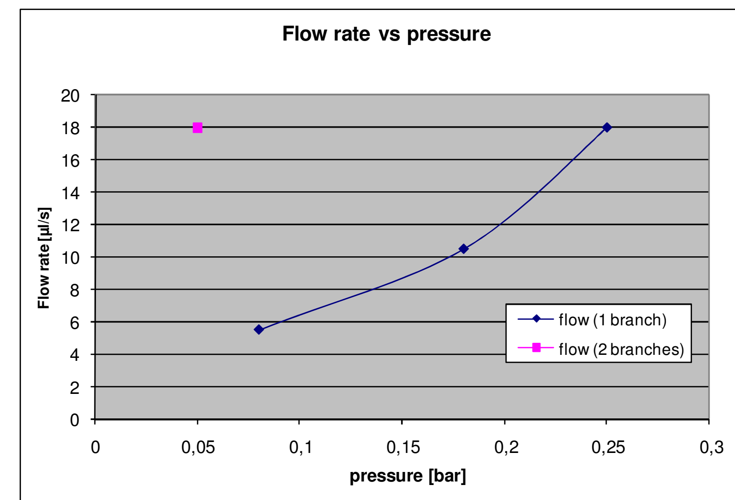
Fluid interface - Fluid to Fluid interface

Pipe to silicon module interface



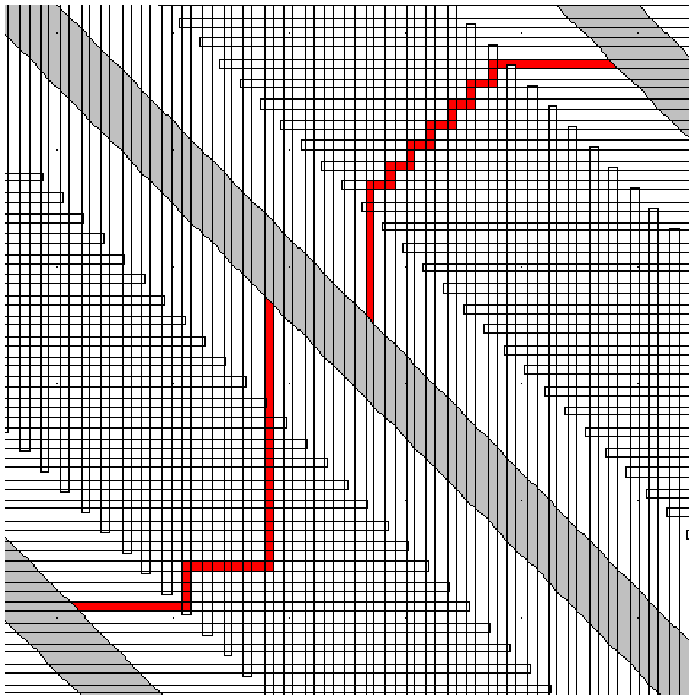


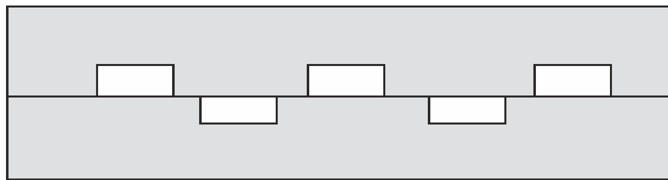
Tested with water
Flowrate 18 µm/s
Tested to PVC (not to Delrin®)
EPDM 70 O-rings
5 mm in diameter
Life-time tested for > 500cycles

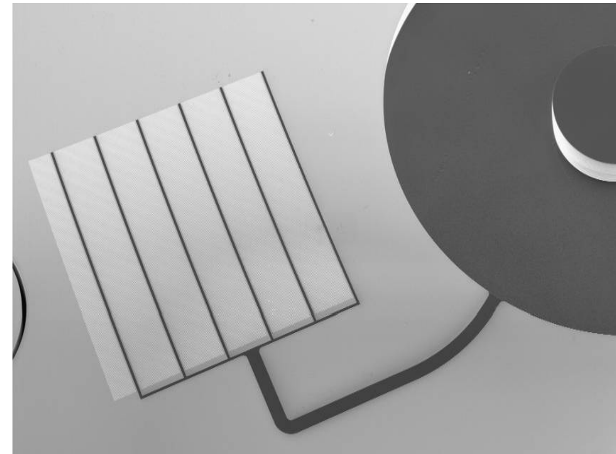


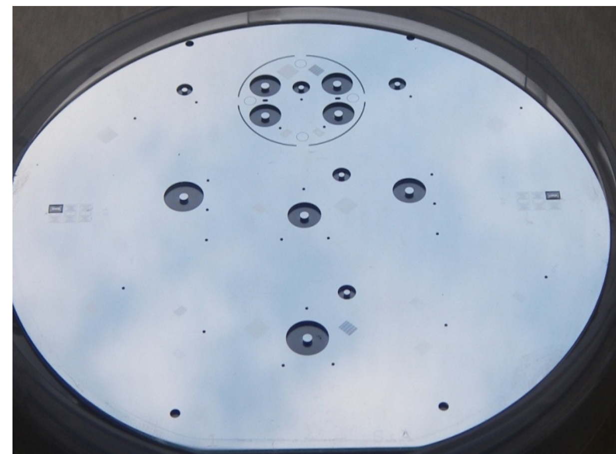
Fluid interface - Filter & Channels

Fluid filters and channels based on bonded fish-bone structures









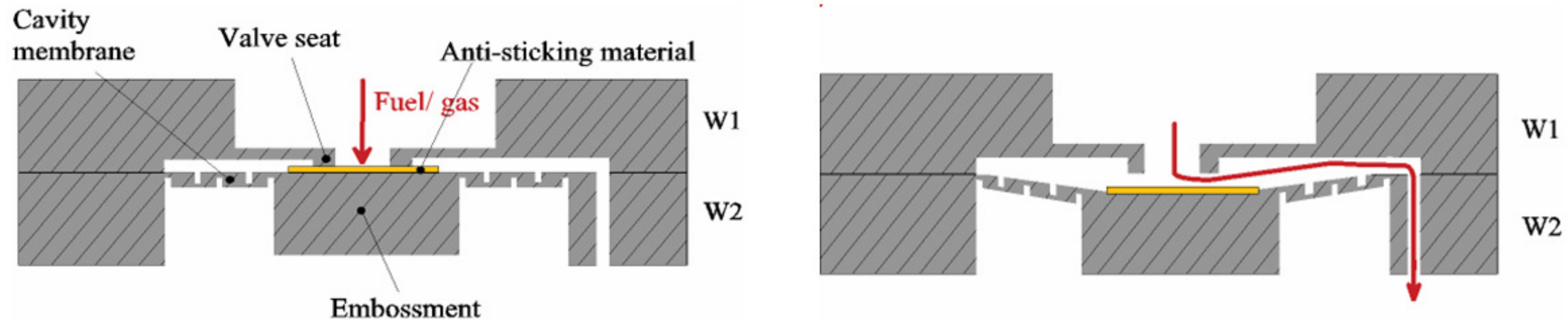
Fluid interface - Filter & Channels

Fabrication is based on std MEMS processing (DRIE and KOH)
Recommended maximum working pressure (bar) for crossed v-groove filters according to results from ÅSTC/Uppsala University.
Note! These guidelines are extrapolated from ÅSTC results and not experimentally verified

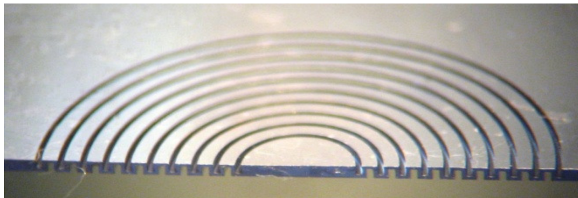
		Aspect ratio $A_1 : A_2$ (bonded : non bonded area)				
Bond yield strength σ_{bond}	**FOS**	**1:5** $P_{gas, max}$	**1:1** $P_{gas, max}$	**2:1** $P_{gas, max}$	**5:1** $P_{gas, max}$	**10:1** $P_{gas, max}$
1MPa	4	0,5bar	2,5bar	5bar	12,5bar	25bar
5MPa	4	2,5bar	12,5bar	25bar	62,5bar	125bar*
10MPa	4	5bar	25bar	50bar	125bar*	250bar*
20MPa	4	10bar	50bar	100bar*	250bar*	500bar*

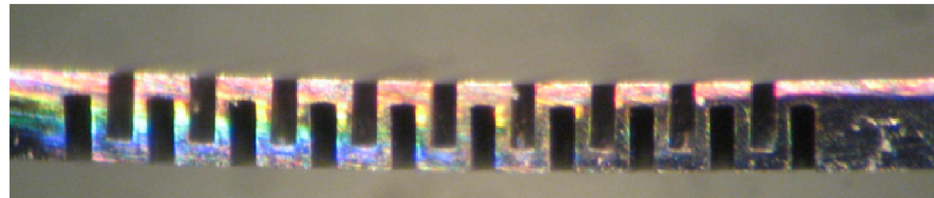
** Other phenomena may occur making this table invalid for very high pressure.*

Mechanical interface – Functional Suspension



Corrugated membrane with larger stroke, for valve applications



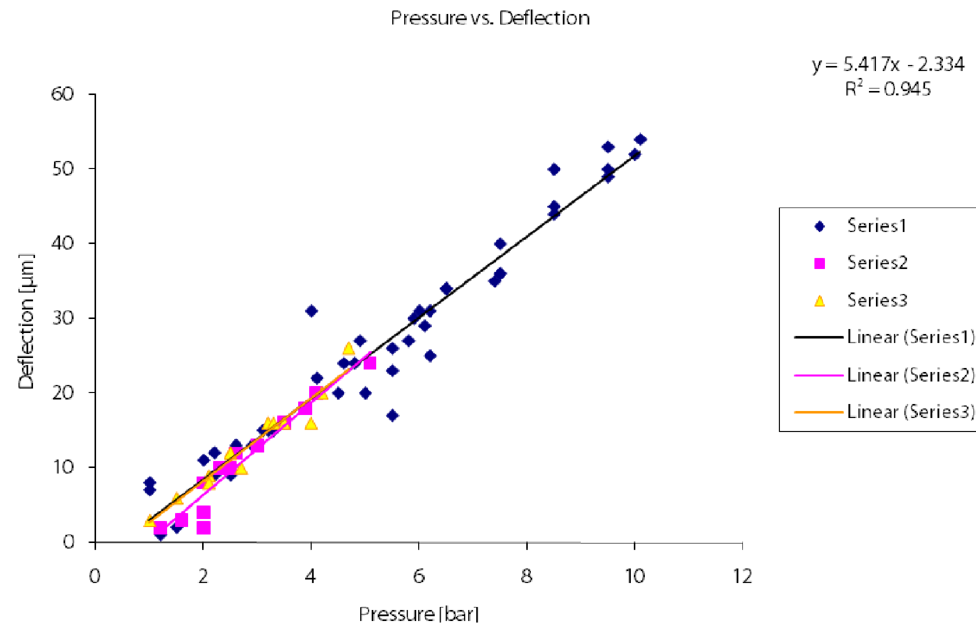


Left: Corrugated membrane chip cut in center to show the cross section as well as top-view.
Right: *Cross section of corrugated membrane, same dimensions as the chips tested.*

Mechanical interface – Functional Suspension

Tested up to 10 bar, deflection measured to 12µm, tested 2000cycles 0 to 3bar with no damage noticed

Simulations from TN3 showed 11 resp. 38µm deflection at 3 resp. 10bar pressure. Measurements show ~12 resp. ~50µm for same pressure.



Measured deflection vs pressure for 3 different functional suspension chips.

Mechanical interface - Large Si Module interface

Silicon parts mechanically mounted and thermally connected to aluminum frame using silicon rubber

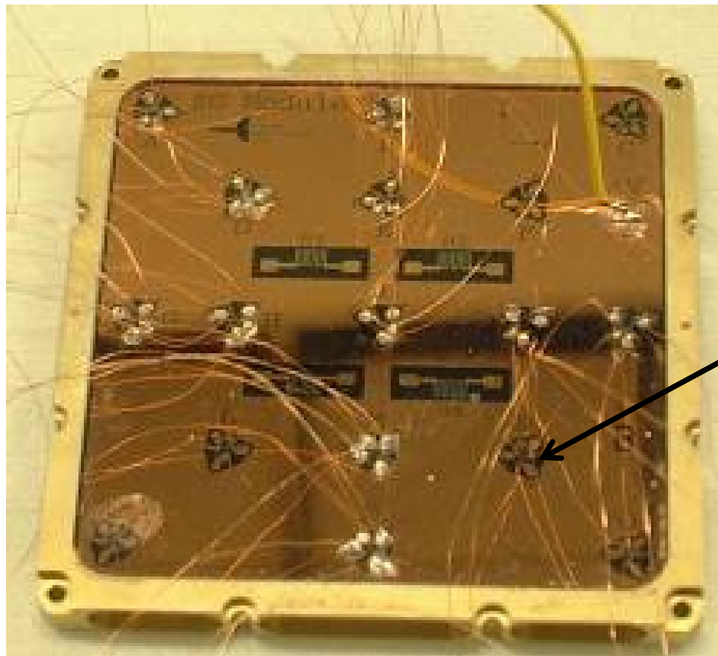
- Elastosil rt 675 Tested at ESA with acceptance for standard use in space
- Aluminum AA7075 (6000 series if doing black anodization)
- Alodine 1200S

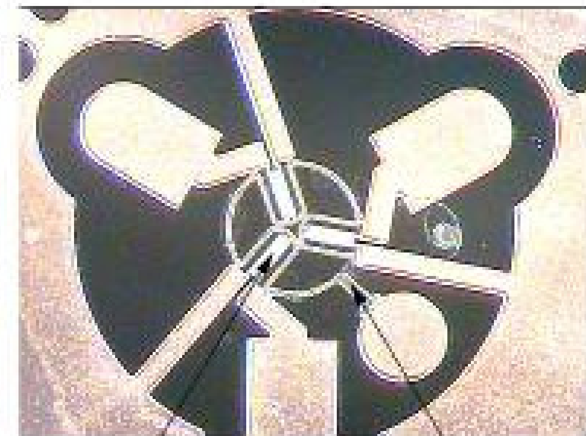
Dimensions:

- The outer dimensions of the silicon module are 68x68 mm
- The outer dimension of the frame are 74.6x74.6x7.5 mm

Mechanical interface - Large Si Module interface

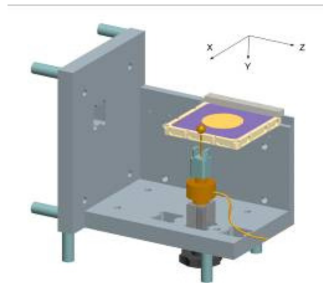
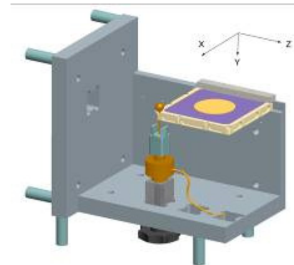
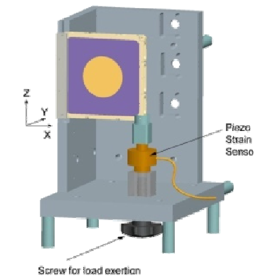
Silicon parts mechanically mounted and thermally connected to aluminum frame using silicon rubber (68x68 mm)

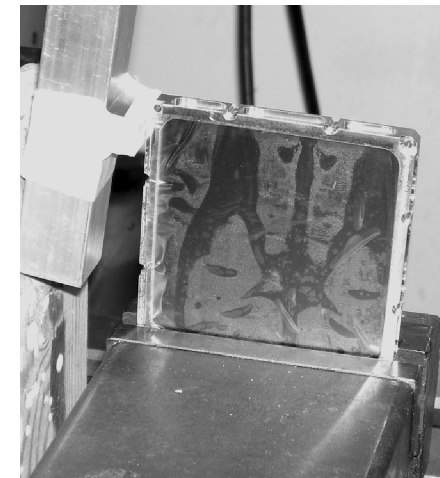




Mechanical interface - Large Si Module interface

From ÅSTC; The destructive bending, warping and shearing tests, yielded 246, 239 and 865 N, respectively, with the module allowed to twist slightly in the shearing mode. The maximum displacement of the loading point and in the loading direction was measured to 7 mm in the warping case.



Bending Warping Shearing

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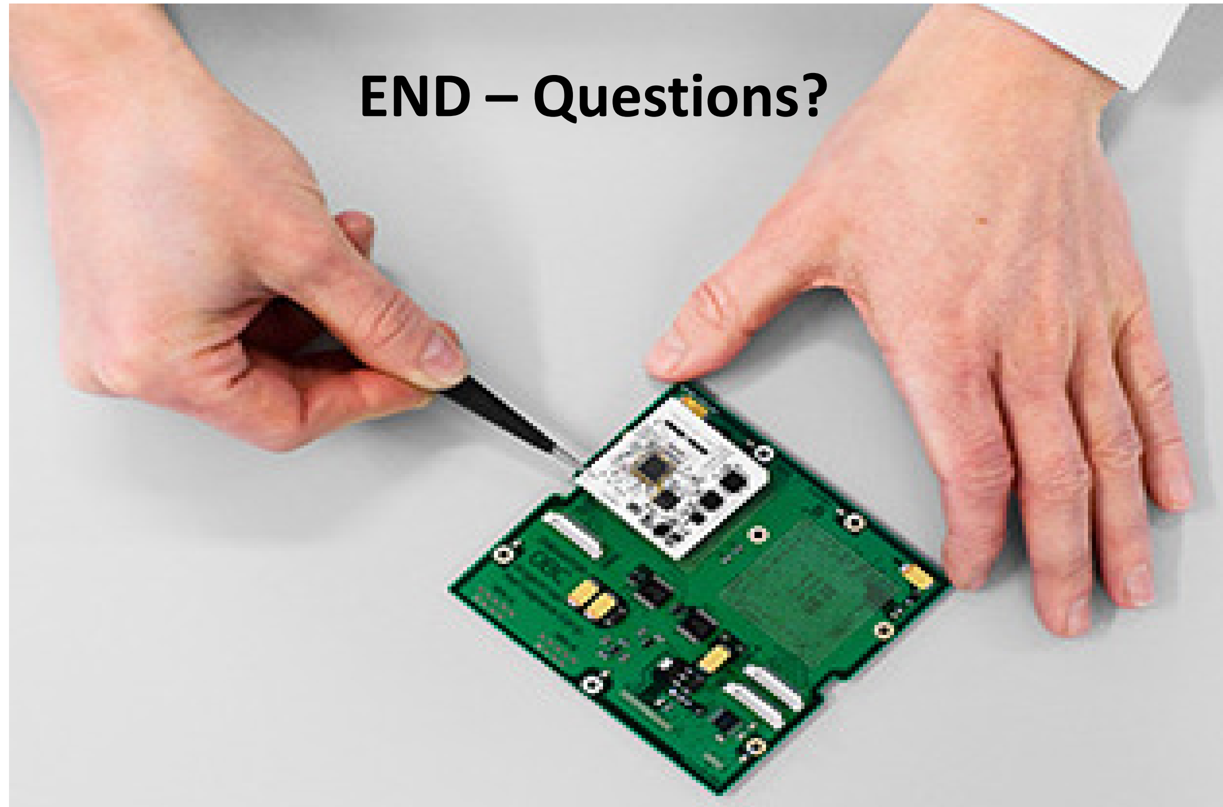

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