Testing alternative adhesives for the ATLAS Tracker Upgrade

Elin Bergeaas Kuutmann, Ingo Bloch, Conrad Friedrich, Heiko Lacker, Luise Poley, Laura Rehnisch, Dennis Sperlich

Humboldt University/DESY Zeuthen

PETTL WP4 17/10/2013

Outline

Issues with the current glue

Silver epoxy glue

used to glue read out chips on hybrids

- 6 hrs curing time (problem in mass production)
- silver (Z=47) leads to high radioactive activity
- $>$ 50% (mass) silver significantly reduces radiation length of glue
- limited evidence of carcinogenic effect
- silver epoxy glue corrodes aluminium (chips' backsides)

Requirements for replacement

Hard criteria

- radiation hardness
- good thermal conductivity
- strong connection on gold
- short curing time
- no corrosion of aluminium
- working temperature range from -20 to +80 C

Soft criteria

- no shrinking during curing process
- low cost
- low toxicity
- viscosity similar to currently used glue
- low activatability
- flexibility after curing

Candidates

Glues which match the criteria the most

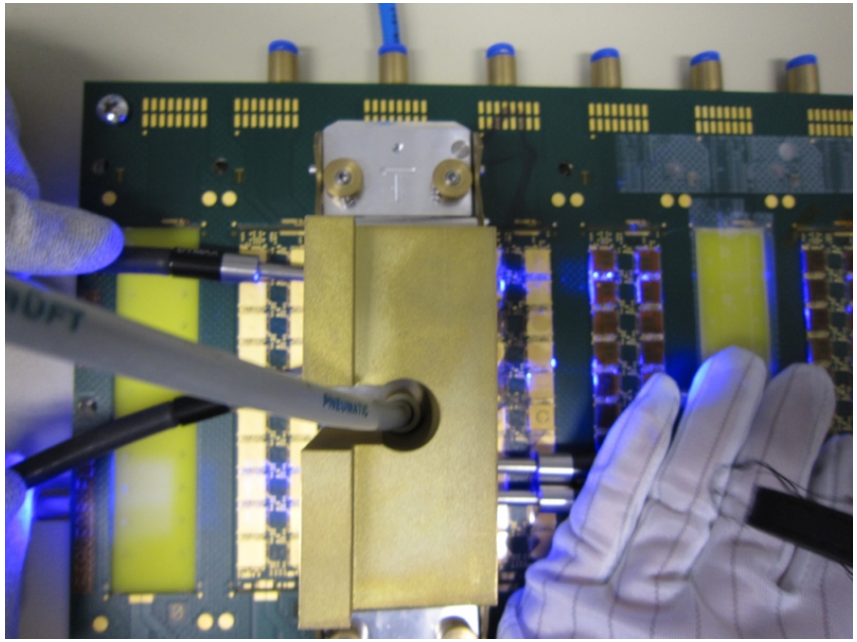
currently: Tra-Duct 2902 (curing after mixing within 6 hours, viscos)

- DYMAX 3013 (UV-curable, highly fluid)
- DYMAX 3025 (UV-curable, highly fluid)
- DYMAX 6-621 (UV-curable, highly fluid)
- Loctite 3525 (UV-curable, viscos)
- Loctite 3504 (UV-curable, viscos)
- Polytec UV 2133 (UV-curable, highly viscos)
- glueing film (no curing needed, thickness 3 mm)

Already tested

Basic Issues

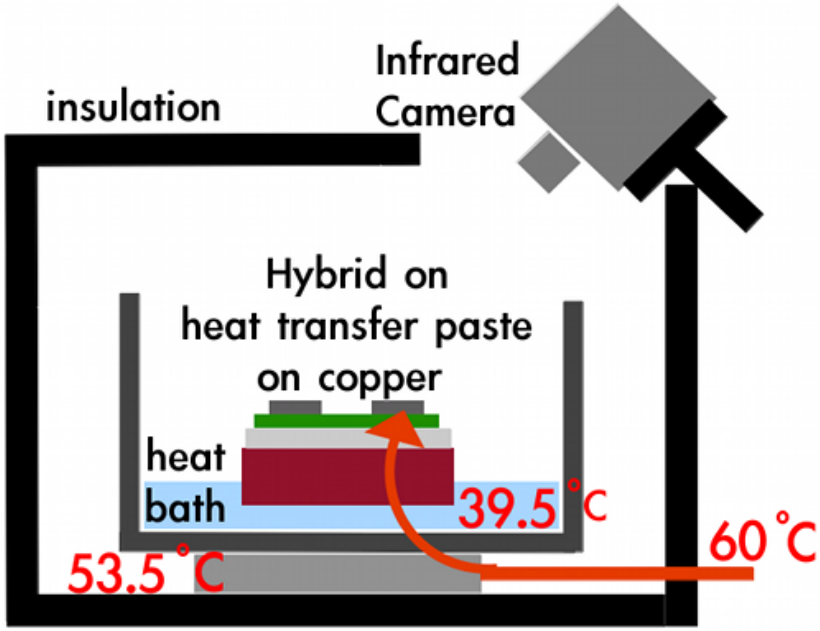
- lower toxicity
- can be applied
- can be cured with current curing setup
- strong connection on gold
- stays flexible after curing
- can be bonded

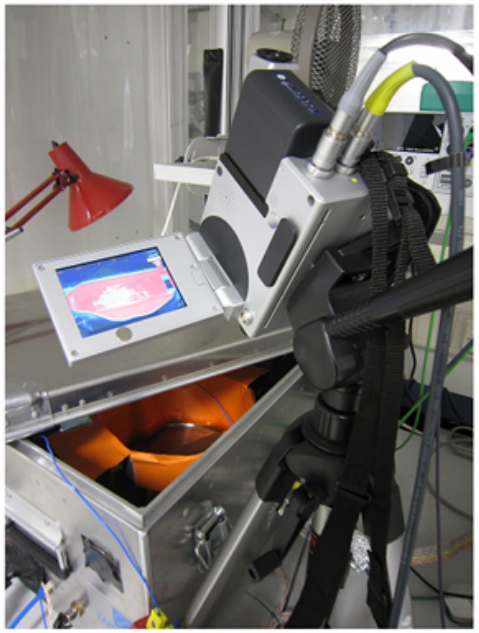


Thermal conductivity tests

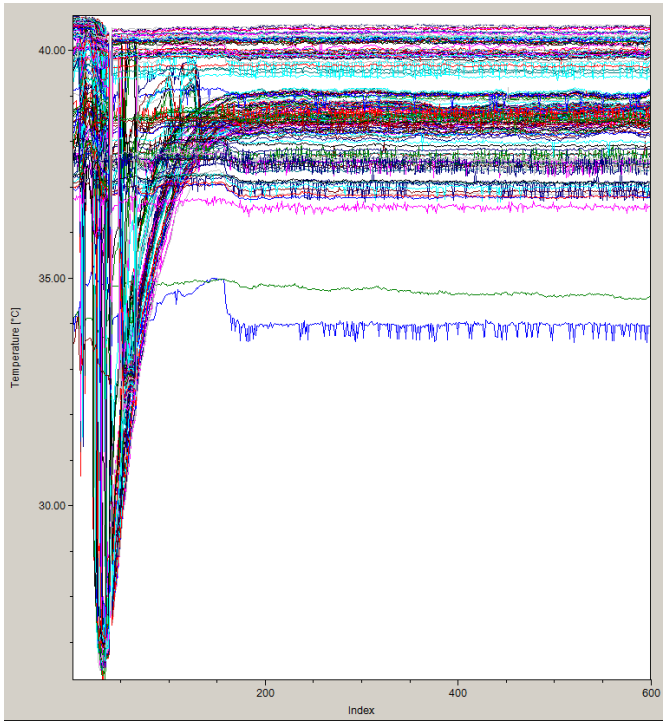
Measurement issues

- no data given for tested glues
- comparison of thermal conduction of silver epoxy and UV curable glues in thermal equalization curves
- tested in setup comparable to operation in detector





Data analysis



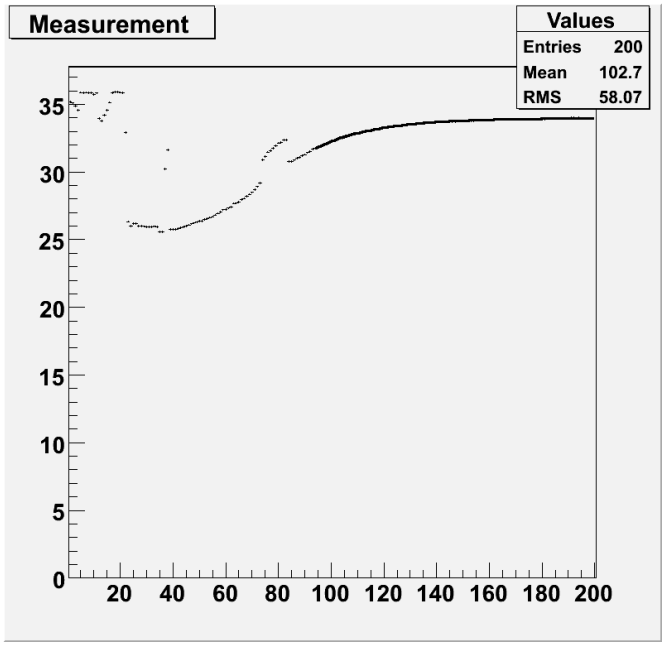
4 measurement points per chip, at least two measurements per hybrid (before/after thermal cycling, irradiation)

theoretical description:

$$T_m = T_{hb}(1 + (\frac{T_{m,0}}{T_{hb}} - 1) \cdot \exp^{-\frac{t}{\tau}}),$$

T_m = temperature measured on chip, T_{hb} = temperature of heat bath, $\tau = R \cdot C$ with C = unknown heat capacitance of the system, $R = \frac{l}{A \cdot \lambda}$ with l = glue layer height, A = glue cross section, λ = thermal conductivity of glue

Data analysis



fit function
$f(t) = \alpha(1 + \beta \cdot \exp^{-\frac{t}{\gamma}})$,

$\gamma = \tau = R \cdot C$ = thermal time constant of the system

results were averaged over four measurement points per chip, several measurements per hybrid and three chips glued with the same type of glue

Results

thermal time constants τ, in s

	TRA-DUCT 2902	DYMAX 6-621	DYMAX 3025	DYMAX 3013
after gluing	2.5 $\pm$ 0.02	3.0 $\pm$ 0.1	3.2 $\pm$0.3	3.0 $\pm$0.3
irradiated	2.2 $\pm$1.8	1.4 $\pm$0.03	2.5 $\pm$0.2	1.5 $\pm$0.04
after gluing	2.6 $\pm$0.02	2.5 $\pm$0.1	2.9 $\pm$00.7	2.2 $\pm$0.06
thermocycled	2.7 $\pm$0.4	2.6 $\pm$0.2	3.5 $\pm$0.5	2.2 $\pm$0.1

Uncertainties are statistical, from the combined fit result uncertainties, systematic uncertainty estimated with $\pm$1.0 s from measurements

Results

thermal time constants τ, in s

	LOCTITE 3525	LOCTITE 3504	POLYTEC UV 2133	3M 5590H
after gluing	3.0 $\pm$0.3	3.0 $\pm$0.3	3.0 $\pm$0.9	2.7 $\pm$0.3
irradiated	1.4 $\pm$0.1	2.0 $\pm$0.2	1.6 $\pm$0.07	2.0 $\pm$0.3
after gluing	2.3 $\pm$0.2	2.6 $\pm$0.2	2.1 $\pm$0.1	3.1 $\pm$0.2
thermocycled	2.5 $\pm$0.1	2.6 $\pm$0.1	2.3 $\pm$0.1	2.7 $\pm$0.6

Uncertainties are statistical, from the combined fit result uncertainties, systematic uncertainty estimated with $\pm$1.0 s from measurements

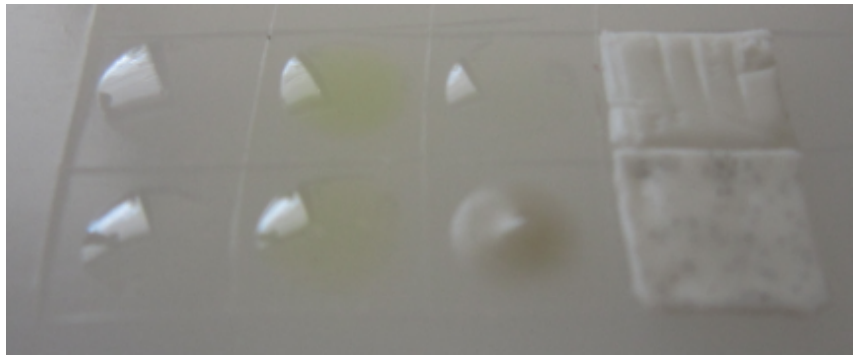
Results

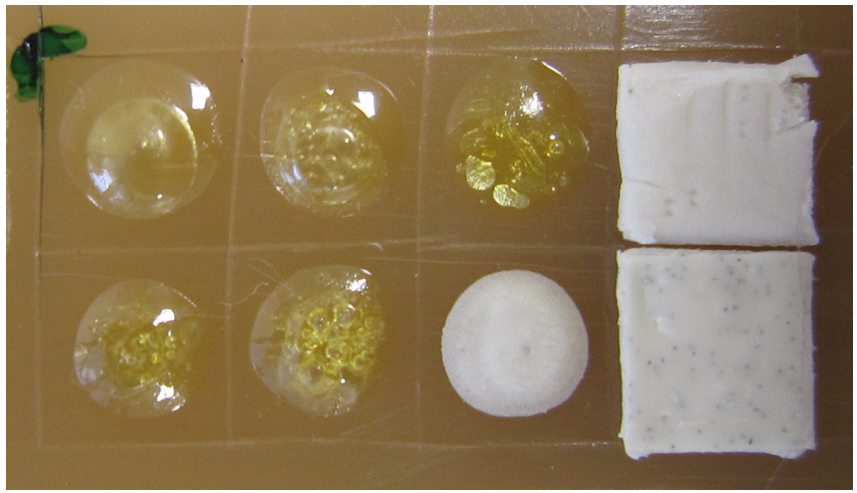
- result for silver epoxy after irradiation is not reliable (several chips were loose after transport, worse thermal conduction)
- UV curable glues show improved thermal conductivity after irradiation
- results before and after thermal cycling are the same within statistical uncertainties
- all glues under investigation show results which are comparable to the silver epoxy glue (larger glue cross-sections compensate worse thermal conductivity)
- notably worse results (DYMAX 3025) used for the selection of the final candidates
- further investigations will be conducted

Irradiation tests

Tests conducted at Karlsruher Kompaktzyklotron (KAZ)

- twice the dose expected in ATLAS Tracker ($2 \cdot 10^{15}$ n_{eq})
- 23 MeV protons in cooled environment
- three pieces tested: one hybrid glued with silver epoxy glue, one hybrid with UV curable glues, polyethylene plate with glue spots
- visible change: POLYTEC UV 2133 turned from brown to white





Activation

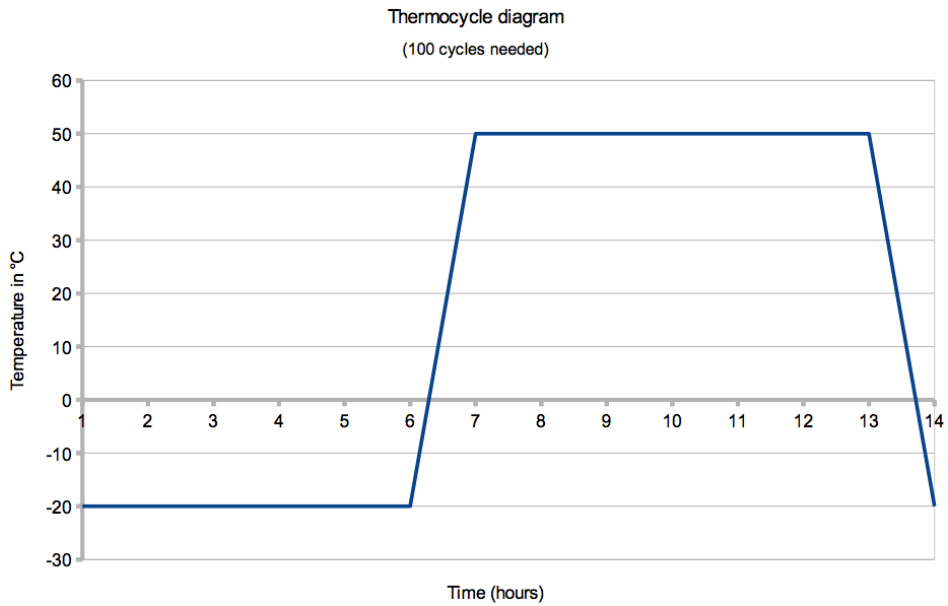
Results

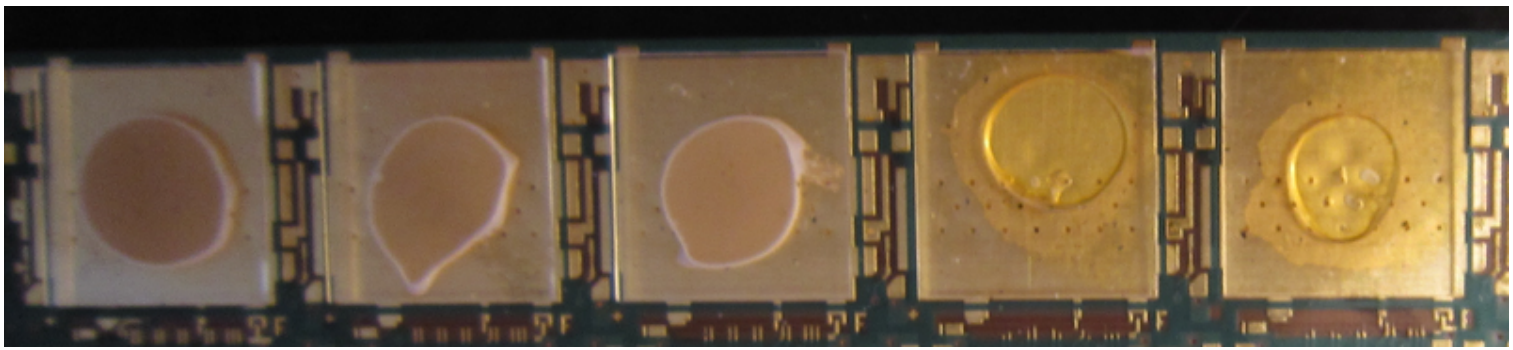
- structures were measured "not radioactive" (German guidelines) after 25 days
- similar activations of hybrids glued with silver epoxy glue and UV curable glues (main part from copper in hybrids), measured after 38 days
- hybrid glued with silver epoxy glue shows a signal for antimony (Sb^{124})

Thermal cycling

Tests conducted in climate chamber at CERN

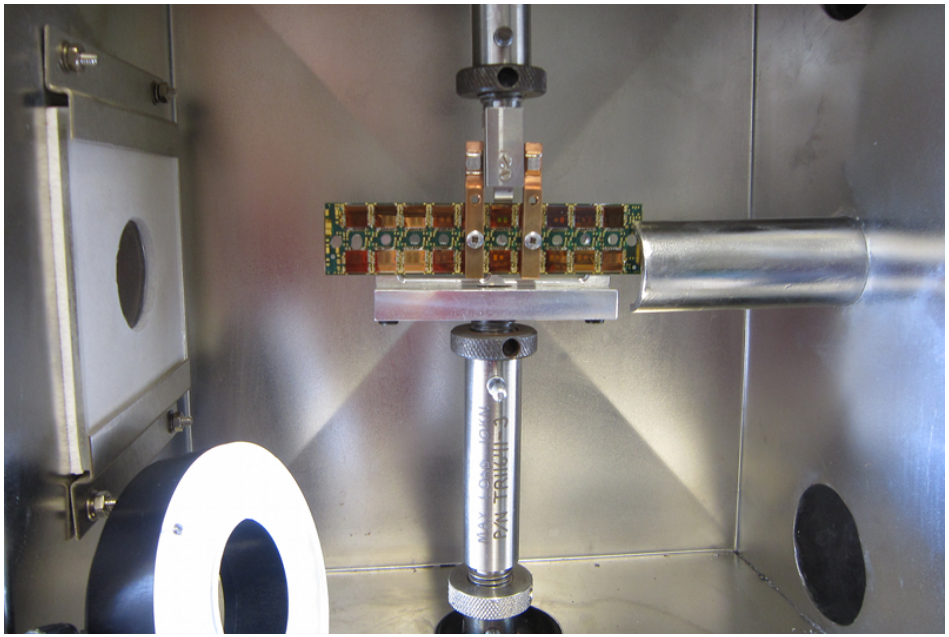
- 100 cycles of dry cold and dry heat
- only POLYTEC UV 2133 showed visible changes (oxidized layer)



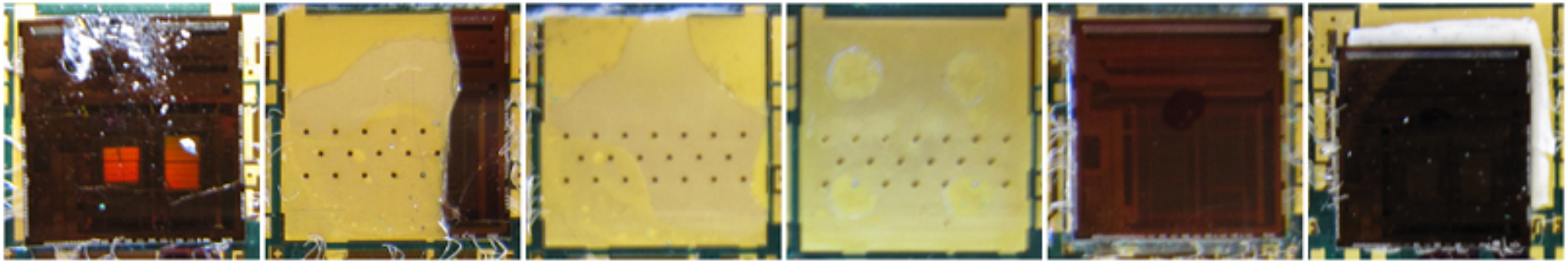


Shear tests

- performed at IZM with an INSTRON 5848 MicroTester
- hybrids screwed on bracket structure and positioned in the tester
- shear tester moved down at constant rate of 0.5 mm/min and measured the force needed to continue
- test stopped when the force dropped below 80 % of its maximum
- maximum force was taken as quality criterion for the glue type



Results



1. chip splintered (b-grade chips were used for the tests, i.e. edges could be cracked), chip stayed on hybrid
2. chip broke
3. chip was removed, glue stayed (partially) on hybrid
4. chip and all of the glue was removed from hybrid
5. hybrid was moved by a small distance and was stuck again
6. the chip was moved over hybrid at a constant rate with force of 1 N

Results

- glue pad was rejected (chip was moved by small forces)
- POLYTEC UV 2133 was rejected (too brittle after irradiation, broke when holes were drilled in hybrid)
- chips glued with silver epoxy fell off the hybrid after irradiation (happened already before irradiation, presumably a problem happened during gluing)
- all of the other glues' results were as good or better than the silver epoxy (results were the chip broke at small forces were not considered)
- five remaining candidates

Results

	2902	3025	5590H	3504
	compressive force, in N			
irradiated	11 (3)	171 (4)	(5)	49 (3)
	9 (3)	146 (2)	(5)	23 (2)
thermal cycled	17 (2)	53 (4)	(5)	118 (1)
	104 (3)	146 (2)	(5)	53 (2)

	2133	3013	6-621	3525
	compressive force, in N			
irradiated	-	89 (3)	124 (3)	109 (4)
	-	127 (3)	123 (2)	136 (2)
thermal cycled	20 (3)	68 (4)	44 (2)	83 (4)
	85 (3)	-	72 (2)	163 (4)

(1) and (2) - chip broke, (3) - chip was removed, (4) - chip was moved by small distance, (5) - chip was constantly pushed forward

Aluminium corrosion

Silver epoxy glue is known to corrode aluminium (combination of a noble and a less noble metal leads to oxidation of the less noble material)

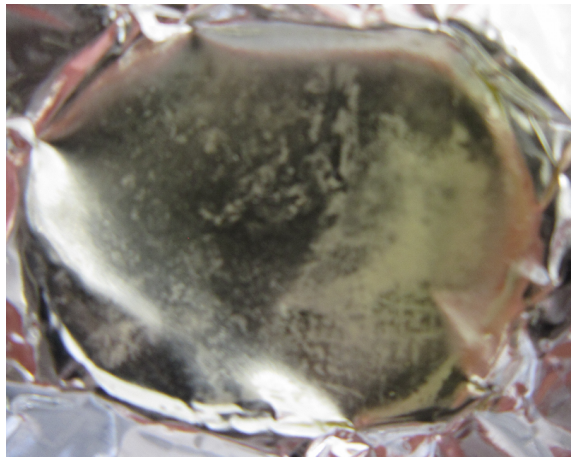
Long term tests

1. glues on aluminium foil in clean room climate
   - constant temperature and humidity, light exposure
2. inspection of chips' backsides after irradiation
   - constant temperature and humidity, full ATLAS Upgrade dose
3. inspection of chips' backsides after ageing
   - changing temperature and humidity, no irradiation, no light exposure

Aluminium corrosion

Results

- silver epoxy glue could not be removed from the chips' backsides without damaging them
- no direct comparison between corrosion effects
- chemical reaction found for one type of glue (LOCTITE 3504), was subsequently rejected



Conclusion

Three types of glues rejected

- POLYTEC UV 2133 (brittle after irradiation)
- 5590H (glue pad) did not withstand shear test
- LOCTITE 3504 (chemical reaction with aluminium)

Conclusion

	DYMAX 3013	DYMAX 3025	DYMAX 6-621	LOCTITE 3525
Toxicity	Xi - irritant N - harmful to environment	T - toxic Xn - harmful	Xi - irritant	Xi - irritant Xn - harmful
Thermal time constant	average	high after irradiation	average	average
Shear test results	good	lower after thermal cycling	good	lower after thermal cycling
Application	microliter pipette	microliter pipette	microliter pipette	not trivial

- DYMAX 3025 was excluded because of toxicity
- DYMAX 3013 and 6-621 remain most promising candidates
- LOCTITE 3525 will be investigated if DYMAX 3013 and DYMAX 6-621 should be rejected (requires glue dispenser)

Outlook

To be investigated

- radiation lengths (before and after irradiation)
- molecular structure changes after irradiation (Raman spectroscopy)
- chemical purity, outgassing during curing
- corrosion of silicon (in case of cracks in the aluminium layer on the chips)
- thermal conductivity for a hybrid during operation