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Evaluation of Thermally Conductive Adhesive on the ‘p’ Side of Hamamatsu ATLAS Specified Silicon Detectors.

Background

A number of electrically and thermally functioning ATLAS barrel modules of various types, namely Z modules, End Tap and Centre Tap modules have been constructed at RAL, using various alumina loaded adhesives on a number of different jigs. Some have been 2 detector modules, while others have been complete 4 detector modules. They have been constructed with detectors from both Micron in the UK and Hamamatsu in Japan. All have exhibited the same worrying feature, that the bias current before and after construction has been grossly different by several orders of magnitude.
A thermally conductive adhesive is required for a real ATLAS module to transfer heat from both the hybrid and the detectors to the baseboard and hence the cooling system. It therefore became obvious that a detailed investigation was required before any more real modules should be constructed.

Detail

The only source of uncommitted typically processed, ATLAS specified detectors was Hamamatsu. Data that were available from the construction of the above modules are shown in table 1.
Two UK Hamamatsu detectors were therefore made available for adhesive evaluation. A specific set of tests were devised ranging from small areas of unloaded adhesive to gluing alumina tests pieces with loaded adhesives and to specified thickness.
The base epoxy was always Ciba Geigy 2011 (AW106 / HV953U) because a number of other modules are known to have been assembled using this epoxy and have had acceptable bias currents, and exist in radiation environments. Various thermal additive have been suggested as listed in table 2.
Boron Nitride is considered a favourite due to its high theoretical thermal conductivity of 300 W/mK compared to 30 W/mK for Alumina and also a reduced radiation length.

[1)] Radiation length of typical epoxy = 44.37 cm
Radiation length of Alumina = 7.55 cm
Radiation length of Boron Nitride = 20.80 cm

Assuming a typical adhesive mix of 2/3 adhesive to 1/3 filler then
Radiation length of Alumina loaded epoxy = 18.79cm
Radiation length of Boron Nitride loaded epoxy = 33.50cm

Boron however is a good absorber of thermal neutrons which then decay emitting α's
[2)] There are two reactions with thermal neutrons

a) $B^{10}(n,\alpha)Li^{7}$ with a cross section of 3837 barns @ room temperature

b) $B^{10}(n,\gamma)B^{11}$ with a cross section of 0.5 barns @ room temperature

Boron ^{10} is 20% of natural Boron

The α from reaction (a) has an energy of approximately 2.8 MeV with a range of approximately 1.77 x 10^{-3} g/cm^{2}

The density of the adhesive is approximately 2gm cc.

The range of α's is therefore approximately 11.3 μm.

Reaction (b) emits γ's of the following energies
1) 4.443 MeV (76.0%)
2) 4.710 MeV (34.0%)
3) 6.759 MeV (39.5%)
4) 7.005 MeV (47.85%)

All α's produced in the adhesive used in the construction of the baseboard will be absorbed by the Beryllia baseboard which is 380 microns thick, before they reach the silicon.

Only those α's produced in the adhesive between the baseboard and the detector will reach the silicon
And since the adhesive is 100 microns thick only 5.6% will escape and reach the detector.

The flux of thermal neutrons in the inner detector varies from [3] 1.8×10^6 n/cm^2/s in the barrel and first forward wheel to 2.5×10^6 n/cm^2/s in the most forward wheel at the nominal luminosity of 10^{34}

Rate of α's is given by

$N_p = (N_0\rho)/A\ N_A 1\ t\ a\ \sigma$

where	N_0	= Avogadro's Number	$6.02\ 10^{23}$
	ρ	= Density of target (gm/cc)	2.33
	A	= Atomic weight of target (Boron 10)	10
	N_A	= Natural abundance of isotope	100%
	1	= Thickness of target (cms)	2.73×10^{-4}
	t	= Irradiation time (secs)	1
	a	= Area of target (cms)	1
	σ	= Cross section (cms)	$3.8 \text{ X } 10^{-21}$

$N_p = 0.15$/cm^2/sec which is negligibly small.

The adhesive test data are shown in tables 3 and 4. In all cases the adhesive is mixed by hand and not pumped down to remove any trapped air. From the beginning to the end of the test sequence, the detector was kept in air. Picture 1 shows Scanning Electron Micrographs of both alumina and Boron Nitride.
Since the conclusion of this series of tests a number of other points have been raised .

1) All fillers are hydroscopic at some level due to their particle dimensions.
2) All epoxies are hydroscopic at some level too.

Advice from experienced epoxy manufacturing departments highlighted the fact that they always store their "next batch" of adhesive in a warm oven to drive off any water, and all additives are heated and /or pumped down for the same reason. Although there is no indication from the above tests that this is a concern it would seem reasonable that one might adopt this as a standard practice.

Conclusion

From table 1 it is obvious that all of the modules which were constructed using adhesives with Alumina as the filler, ether as commercially supplied or as a self mix additive to increase their thermal conductivity showed marked increases in bias current. All of the adhesive tests on the two detectors using Boron Nitride as a filler failed to show any marked increase in current as did the single sample of Aluminium Nitride loaded epoxy. Final tests with Alumina as the additive for each of the detectors show a increase of 2 orders of magnitude of the bias current.

Module type	Detector Manufacture	Detector Type	Adhesive Side	Basic Adhesive	Adhesive Description	Particle Size	Inital Currents	Final Currents
1/2 Z Module	Micron Semiconductors	n' in 'n'	'n'	Epotecny E708 room temp cure	2 component epoxy resin filled with alumina	< 60 microns	1 microamp @ 30v	
1/2 Z Module	Micron Semiconductors	n' in 'n'	'n'	Epotecny E708 room temp cure	2 component epoxy resin filled with alumina	< 60 microns	1 microamp @ 30v	
End Tap Module	Micron Semiconductors	n' in 'n'	'p'	Ciba -Geigy 2011 (AW106 / HV 953U)	2 part epoxy with alumina (Baco MA 1 LS) added at RAL	< 50 microns	30 microamps @ 50v	240 microamps @ 50v
Center Tap	Hamamatsu semiconductors	n' in 'n'	'p'	Ciba -Geigy 2011 (AW106 / HV 953U)	2 part epoxy with alumina (Baco MA 1 LS) added at RAL	< 50 microns	0.5 microamp @ 50v	200 microamps @ 50v

TABLE 1

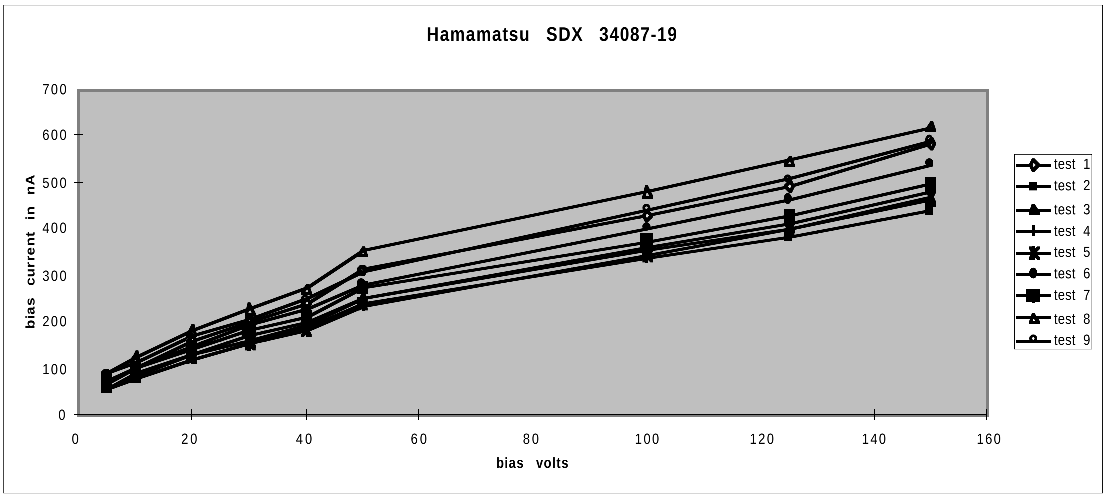
Filler	Part Number	Particle Size (Microns)	Maximum Theoretical Thermal Conductivity (W/mK)
Alumina	Baco MA1 LS	55	30
Boron Nitride (BN)	PT 140 S	8 to 14	250 to 300
Aluminium Nitride (AlN)	A 100 WR	3 to 4	160

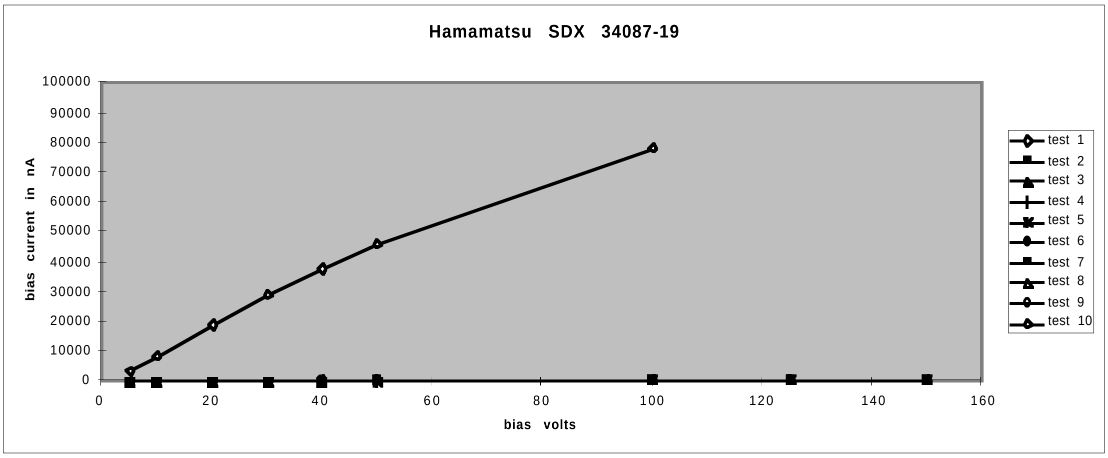
T ABLE 2

SDX 34087-19 (Hamamatsu)

bias volts	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)
	initial conditions	Small area of 2011 (5mm2)	Small area (5mm2) of 2011 + Boron Nitride 140S mix ratio 2.5g/2g/2g	2011 No filler, thin strip of adhesive only, small area (17.5mm2) mix ratio 2.5g/2g	2011 + Boron Nitride 140s thin strip of adhesive only small area (18mm2) mix ratio 2.5g/2g/2g	2011 no filler alumina strip with undefined gap, alumina under vacuum, Adhesive area (46,2mm2) mix ratio 2.5g/2g	2011 + Boron Nitride 140S, alumina strip with undefined gap, alumina under vacuum, area (46,2mm2) mix ratio 2.5g.2g/2g	2011 no filler, alumina strip with defined gap of 100 microns, alumina under vacuum, area (46,2mm2) mix ratio 2.5g/2g/2g	2011 no filler alumina strip with defined gap of 100 microns, alumina and detector under vacuum, area (46,2mm2), mix ratio 2.5g/2g	2011 +alumina, alumina strip with defined gap of 100 microns, alumina and detector held under vacuum, area (50mm2), mix ratio 2.5g/2g/2g
		Temp 21 ^{0}C RH 33%	Temp 21 ^{0}C RH 36%	Temp 21 ^{0}C RH 44%	Temp 21 ^{0}C RH 45%	Not Measured	Temp 21 ^{0}C RH 44%	Temp 21 ^{0}C RH 49%	Temp 21 ^{0}C RH 46%	Temp 21 ^{0}C RH 40%
	test 1	test 2	test 3	test 4	test 5	test 6	test 7	test 8	test 9	test 10
5	70	56	60	60	59	72	76	90	89	3600
10	103	83	88	93	84	104	105	128	117	8900
20	162	122	129	132	125	150	147	182	170	19000
30	205	157	161	171	156	193	182	229	206	29000
40	244	187	197	200	184	228	210	272	250	38000
50	315	242	255	252	236	283	272	352	310	46000
100	430	340	355	360	342	404	375	481	442	78000
125	494	385	404	414	400	465	429	546	507	
150	582	440	464	483	471	540	497	620	590	

TABLE 3

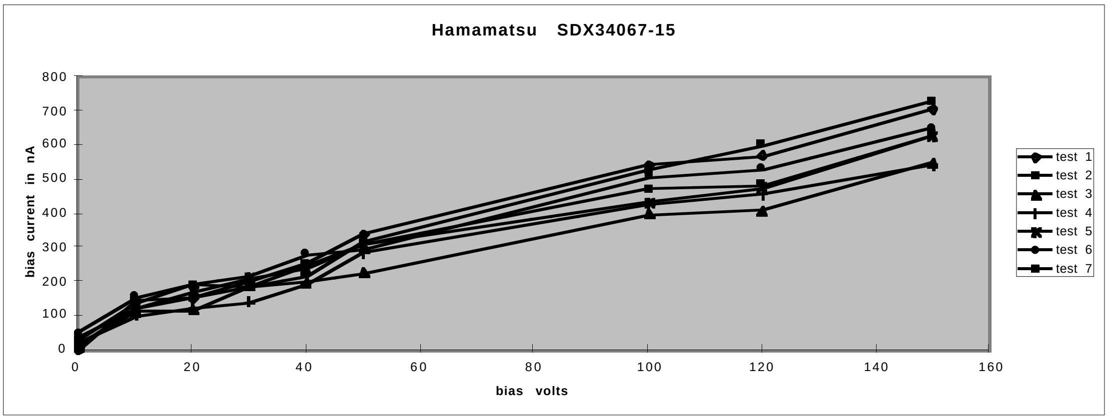


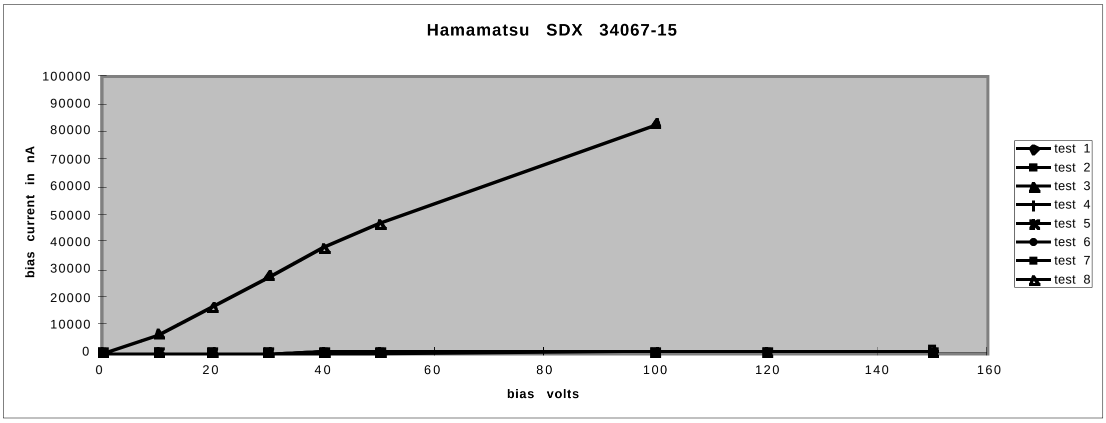


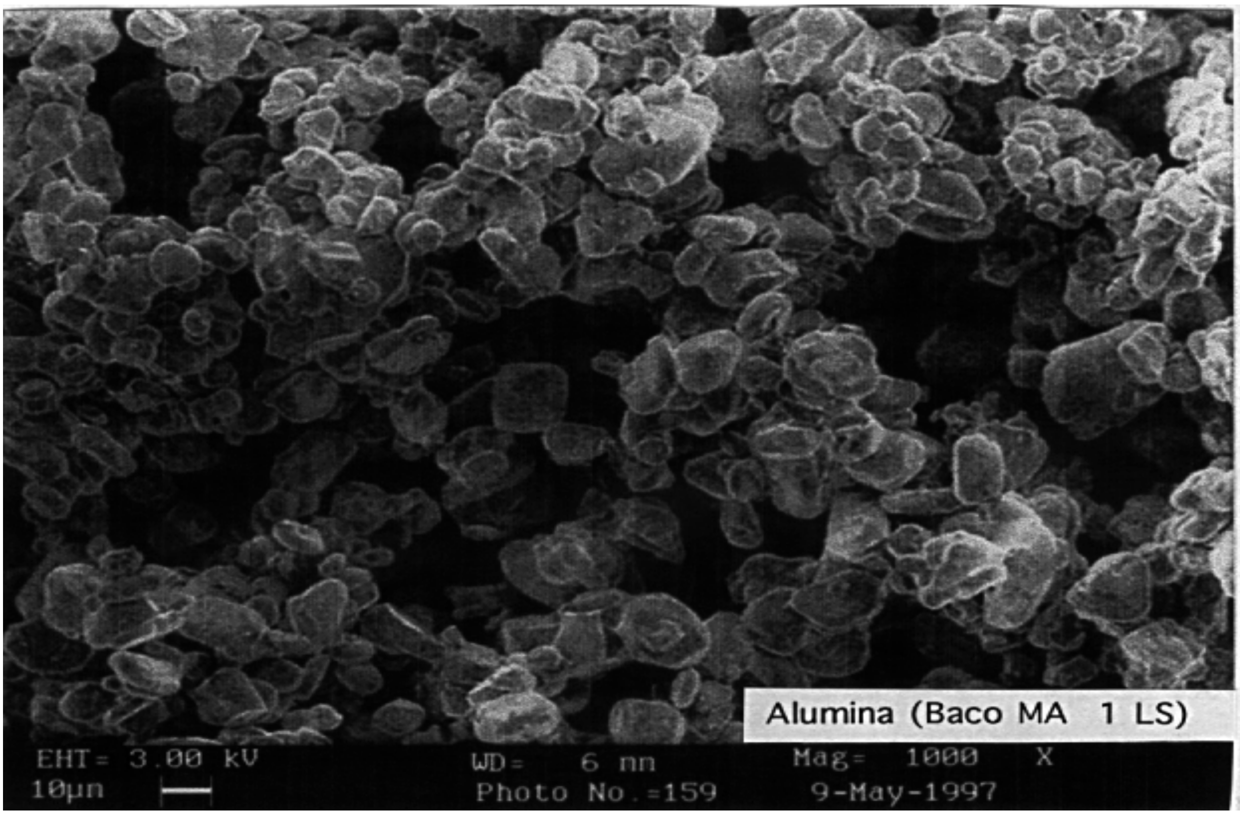
SDX 34067-15 (Hamamatsu)

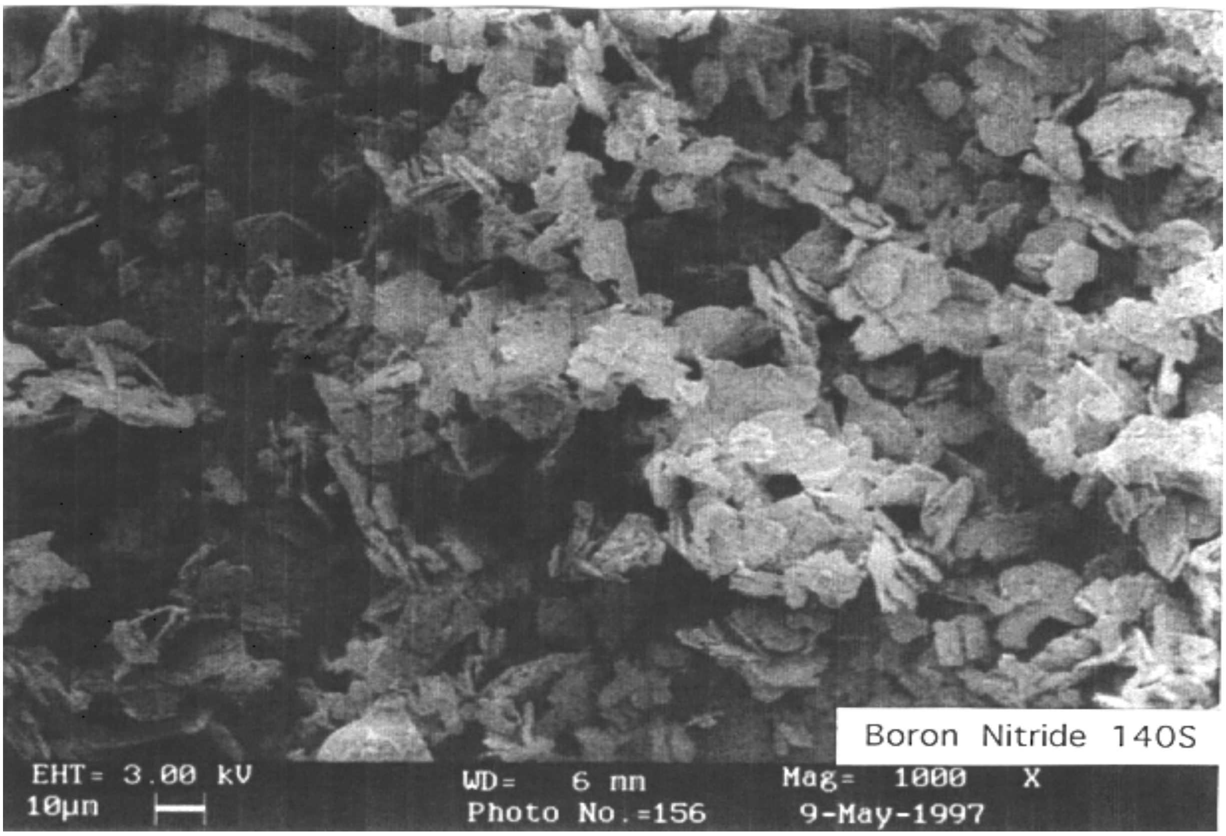
bias volts	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)	bias current (nA)
	initial conditions	2011 alumina strip with defined gap of 100 microns, alumina and detector under vacuum, adhesive area (175mm2), mix ratio 2.5g/2g	2011 + Boron Nitride 140S alumina strip with defined gap of 100 microns, alumina and detector under vacuum, adhesive area ($175mm^2$), mix ratio 2.5g/2g/1g	2011 + Boron Nitride 140S alumina strip with defined gap of 100 microns, alumina and detector under vacuum, adhesive area ($175mm^2$), mix ratio 2.5g/2g/1.5g	2011 + Boron Nitride 140S alumina strip with defined gap of 100 microns, alumina and detector under vacuum, adhesive area ($175mm^2$), mix ratio 2.5g/2g/2g	2011 + Boron Nitride 140S alumina strip with no defined gap, alumina and detector under vacuum, adhesive area ($175mm^2$), mix ratio 2.5g/2g/1.5g	2011 + Aluminium Nitride A100WR alumina with defined gap of 100 microns, alumina and detector under vacuum, adhesive area ($280mm^2$), mix ratio 2.5g/2g/2g	2011 + alumina alumina and detector under vacuum with defined gap of 100 microns Adhesive area ($175mm^2$), mix ratio 2.5g/2g/2g		
	Temp 23 ^{0}C RH 51%	Temp 21 ^{0}C RH 61%	Temp 18 ^{0}C RH 60%	Temp 19 ^{0}C RH 67%	Temp 20 ^{0}C RH 74%	Temp 20.4 ^{0}C RH 69%	Temp 22 ^{0}C RH 53%	Temp 21 ^{0}C RH 52%		
	test 1	test 2	test 3	test 4	test 5	test 6	test 7	test 8	test 9	test 10
0	0	15	14.9	23	36	52	28	27		
10	144	124	119	101	123	156	140	6800		
20	154	153	116	123	172	193	190	17000		
30	204	183	187	142	209	215	182	28000		
40	255	251	198	195	238	282	220	38000		
50	339	314	228	283	308	294	320	46700		
100	543	473	400	426	432	506	525	83000		
120	571	483	410	458	475	530	602			
150	708	633	551	544	630	653	729			

TABLE 4









ADHESIVE FILLERS

picture 1

References

[1] Private correspondence from R Apsimon
[2] Private correspondence from M Edwards
[3] Private correspondence A Ferrari to M Edwards