XYZTEC White Paper

Advanced Thin 3D & MEMS Die Bond Testing

Bob Sykes
July 2017

Whilst the quality and reliability of underside electrical and thermal interconnects is directly related to Die bond strength, die thinning and stacking together with advances in bonding make such analysis ever more challenging. Meaningful quality assurance then requires your bound testing methods to be fully optimised. This white paper explains solutions for the problems encountered.

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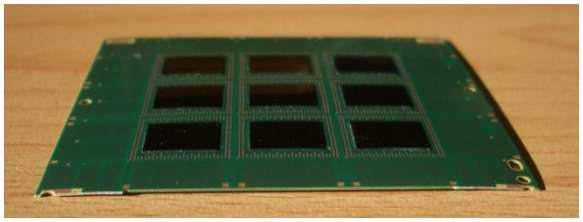
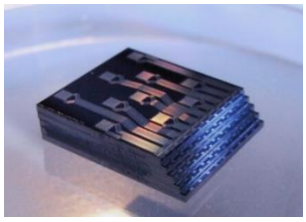
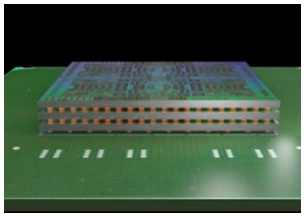
The challenges

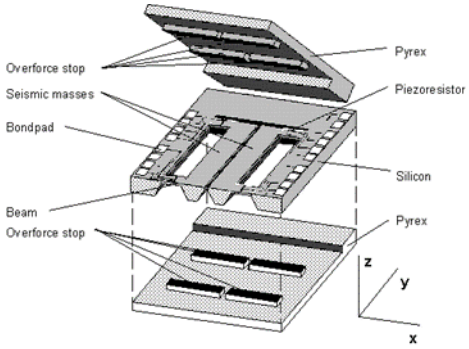


Thin die and warpage





Staked die, wire bonded and flip chip



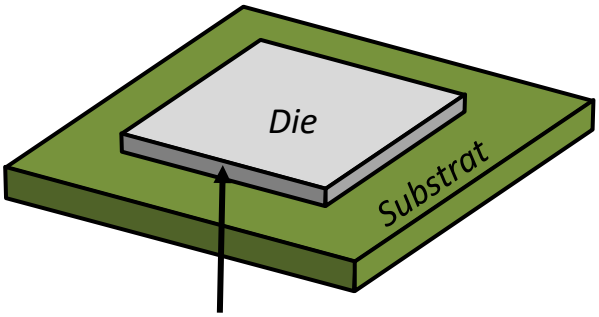
High strength and complex bonds

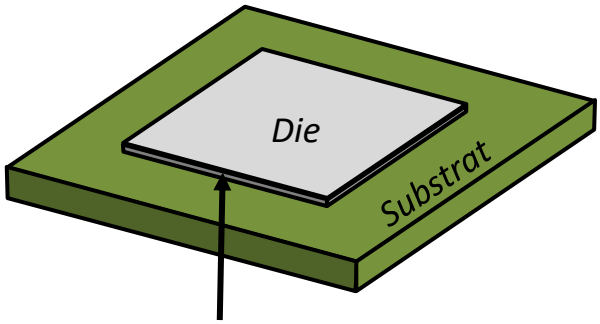
The fundamental difficulties

Reduced ratio of die thickness to die bond area

This is relevant to shear testing

The issue is the reduction in **test load area** to **bond area** as the die becomes thinner





The shear tool applies the test load to the side area of the die.

When the die is thinner there is less area to apply the test load to. As the die thickness reduces there comes a point when the test load stress between the tool and the die reaches its yield value before the bond reaches its yield stress.
The die then fails before the bond and the bond strength is not measured.

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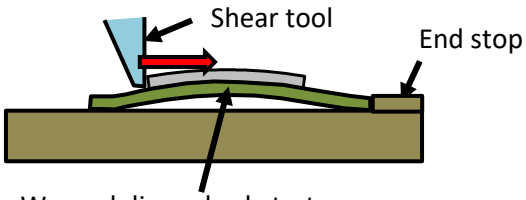
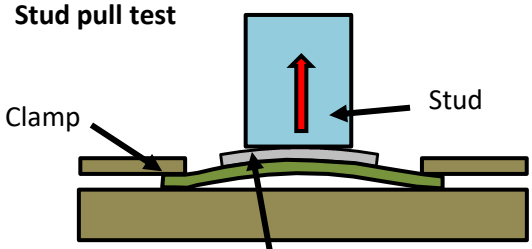
Die and substrate warpage with thin die

Shear test



Warped die and substrate increases buckling loads on die that can cause it to fracture before the bond fails

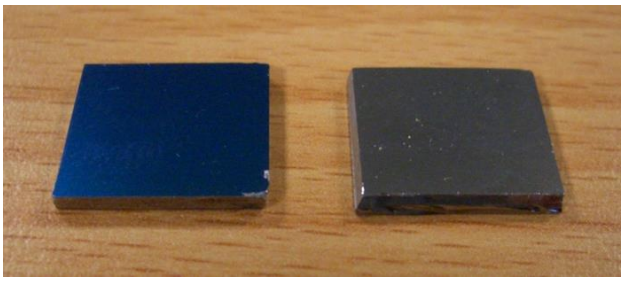
Stud pull test



Warped die and substrate makes a strong and consistent glue layer thickness between the stud and die difficult

Increased bond strength, for example silicon is directly bonded to silicon

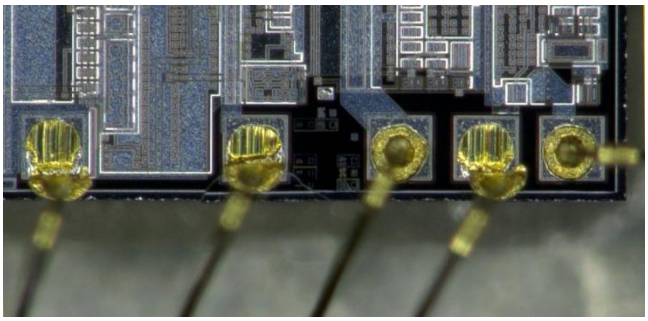
In this sample silicon is bonded to silicon with a similar yield stress to that of silicon



Shear test
As the area of the bond is much larger than the area for the test load the die will fail at the point of test load application before the bond

Stud pull test
The area to bond a stud is the same as the bond area but the bond is often stronger than that which can be achieved between the stud and the die

We should remember that not being able to obtain a bond failure is quite common
For example Bulk Gold failure is very common when shear testing the 1st bond



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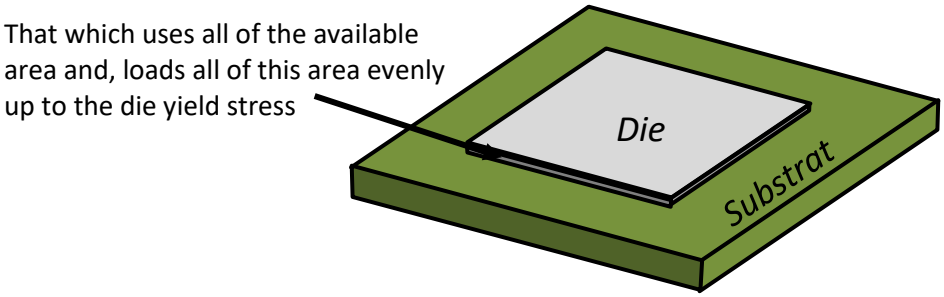
In cases like this we have not attained the **Failure Mode of Interest** because the bulk material (Gold ball) is weaker than the bond. The test still has recognized value as it proves the bond quality up to the test load applied.
A bond test though should always strive to obtain the Failure Mode of Interest which will be a bond failure of some kind and when this is not possible the highest test force possible. This principle is part of XYZTEC's "Science of Bond Testing" modules. More information being available on request.

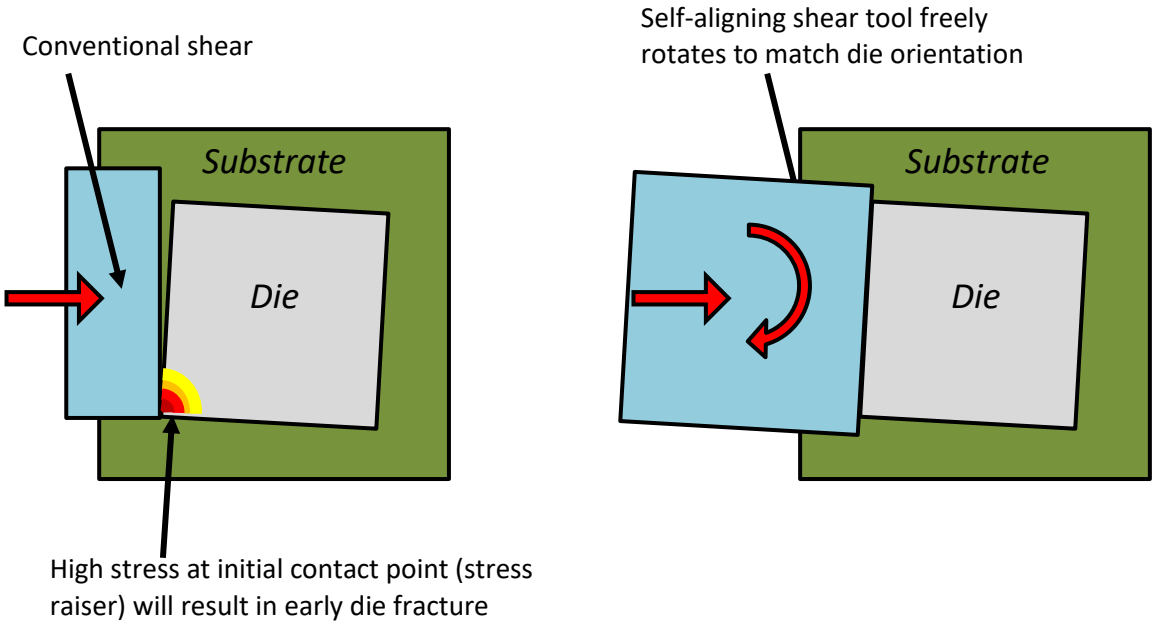
The most common die bond strength test is shear and for that reason it is this test that has received the most development. Many of the following aspects being the subject of XYZTEC patent PCT/NL2010/050545.

Shear Testing

To obtain the failure mode of interest i.e. a bond failure, we must be able to load the bond to the highest force possible.
The maximum load that can be applied to the side of a die is,



To load all of the side evenly a **Self-aligning** tool is needed,



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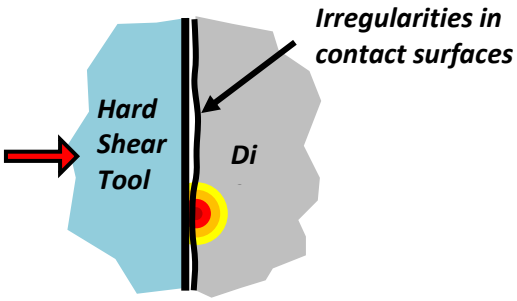
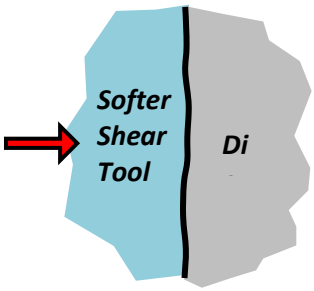
To load all of the side evenly you may need a **Soft/Compliant** tool



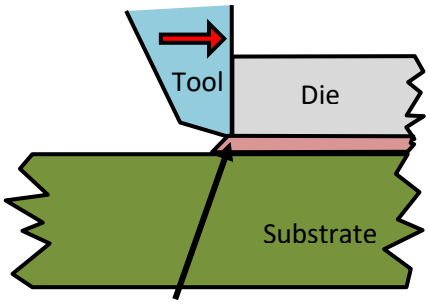
Stress concentration at point of contact



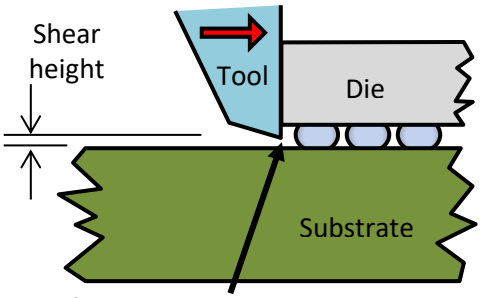
Soft tool deforms to die surface reducing stress concentrations

When soft tools are used they typically last for about 10 tests but this depends very much on the application.
It can be one test or 10s of tests.
They are wear parts but are low cost and very easy to remove and fit.

It is important to engage with the full available height along the edge of the die,

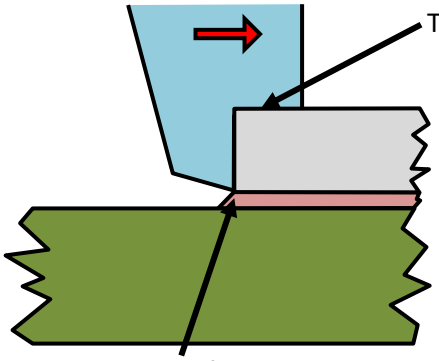


For bonds with a fillet the tool tip must be just above it



For flip chips the tool must descend lower than the bottom of the die to be sure of full engagement but still be above the substrate

To get an accurate engagement height and eliminate the effects of bond thickness a **Top Landing** tool is often better than the conventional shear height method



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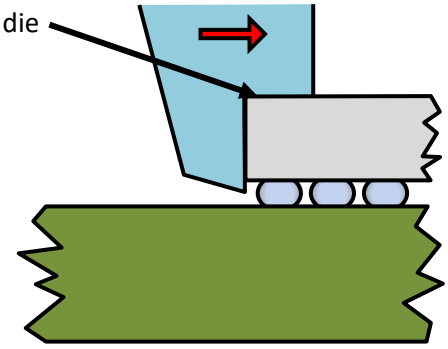

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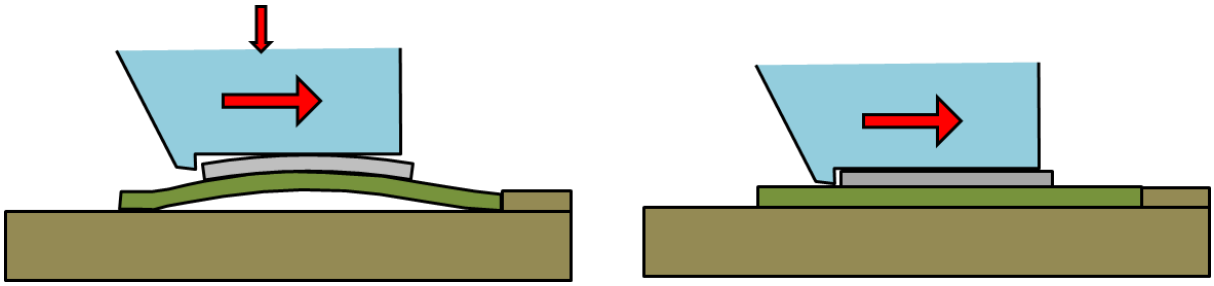
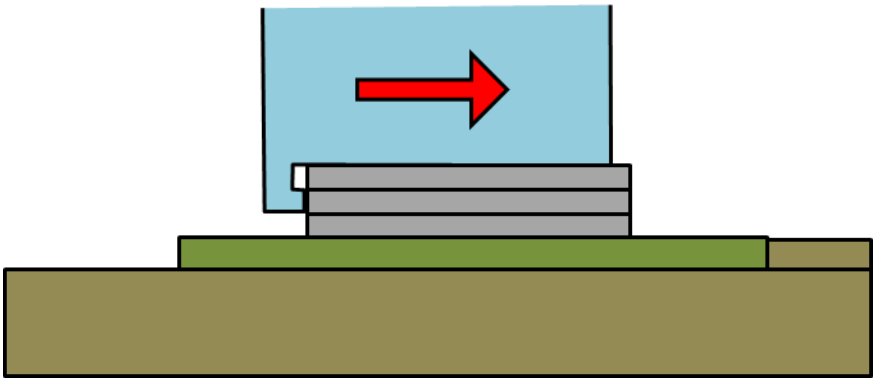
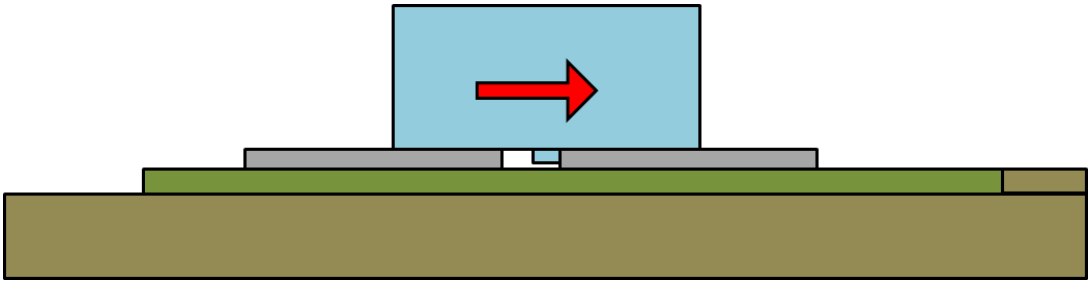
Landing on the top of the die with a slight landing force can also help minimize the effects of warpage by flattening the die between the tool and work holder base



In the case of stacked die top landing can also be used to load the sample at a specific layer



Top landing can also be used to test die placed close to each other **(2.5D)**



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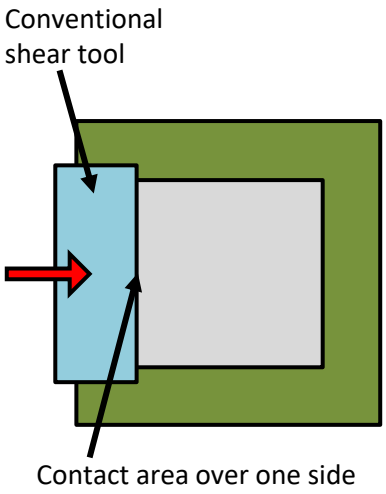
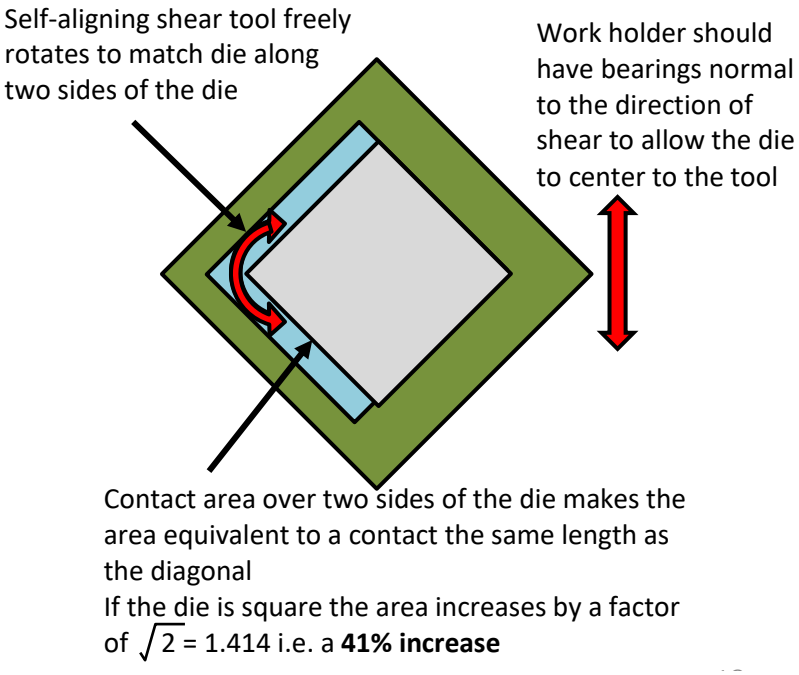
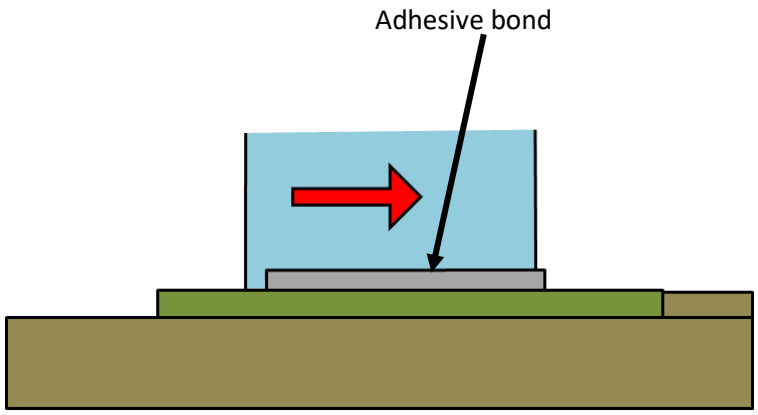
The shear tool contact area can be further increased by using a **45° Tool**





Contact area over two sides of the die makes the area equivalent to a contact the same length as the diagonal
If the die is square the area increases by a factor of $\sqrt{2}$ = 1.414 i.e. a **41% increase**

In some cases where the bond strength is high and the die very thin a sacrificial top landing tool can be glued to the top of the die



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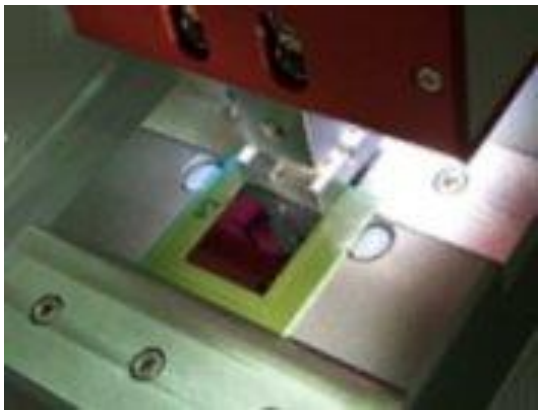
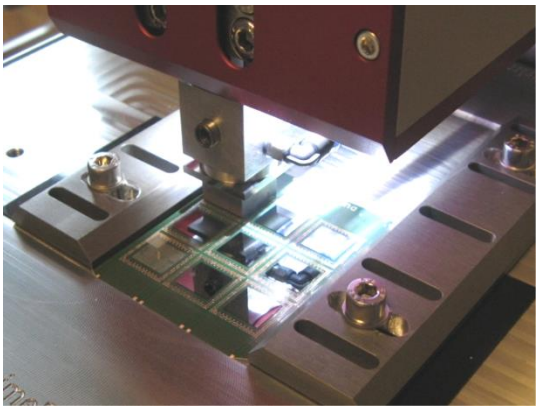
Any one or all of the shear test features can be incorporated in the XYZTEC patented design.
Here are some examples,

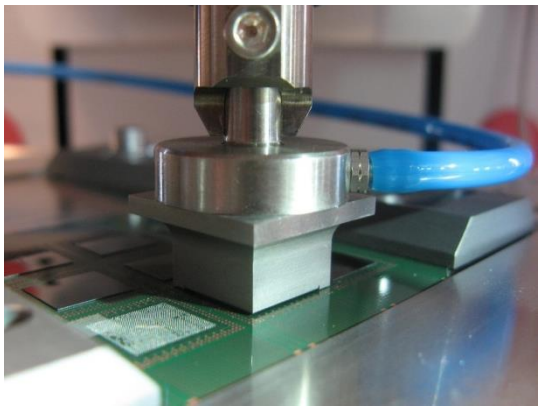


Compliant self-aligning tool

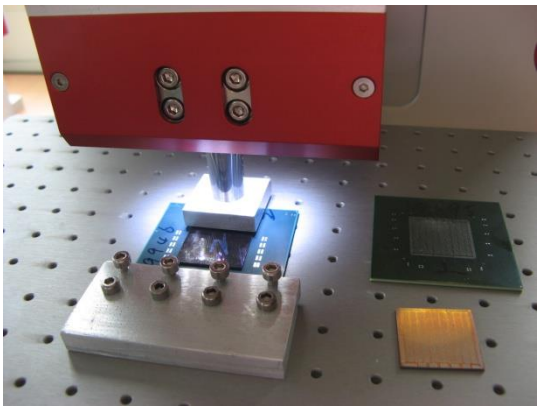
45° Self-aligning top landing tool



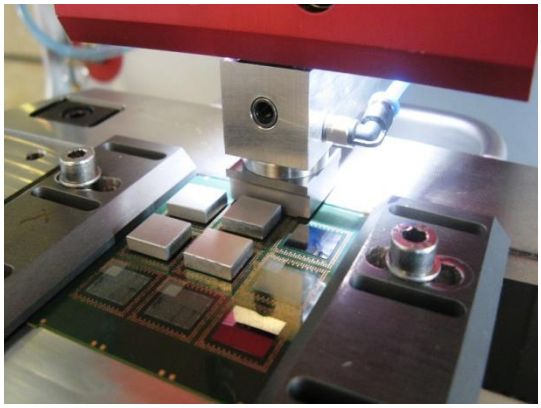
None compliant self-aligning tool



45° Self-aligning top landing tool



280kg Test result



Block glued to die and tested with a self-aligning block

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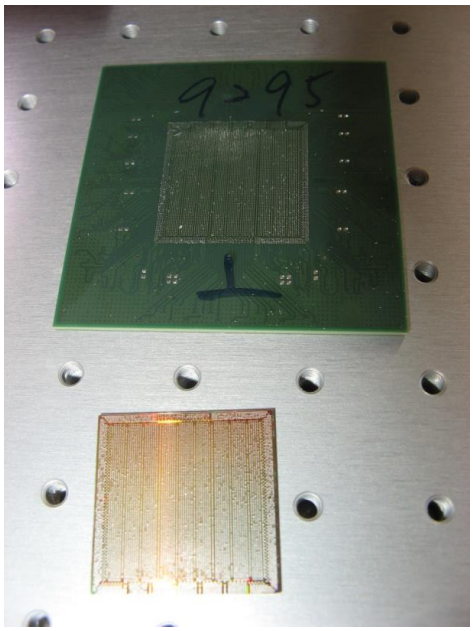
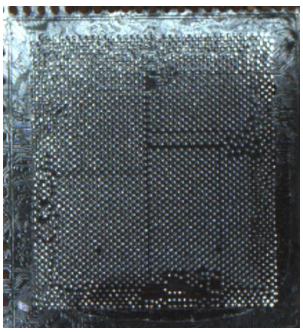
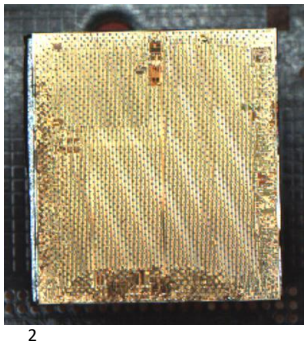
Some typical results – Flip Chip



25 mm^2 100µm thick die
Bond strength up to 280kg
4.4MPa on bond area
1100MPa on side edge





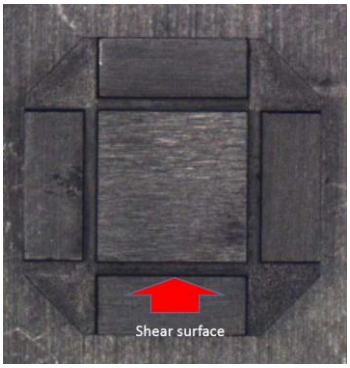
9 mm^2 70µm thick die
Bond strength up to 70kg
8.5MPa on bond area
1090MPa on side edge

Tensile yield strength of Silicon 5000 – 9000MPa
Bending strength of Silicon 500- 1000MPa
Stress concentrations at the tool contact surface and buckling loads due to die warpage prevent loads equivalent to the maximum possible strength of the silicon being achieved
However these techniques significantly increase the maximum loads possible

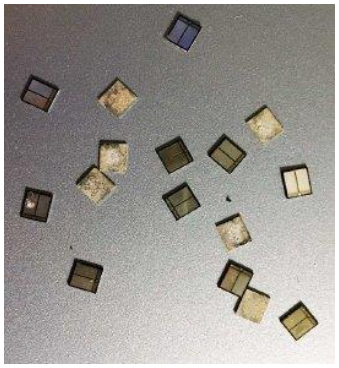
Another typical result – Soldered Die

Sample

Test



Underside of tool



Tested die

4.9 mm^2 210µm thick die
Bond strength up to 127kg
51.7MPa on bond area
1200MPa on side edge

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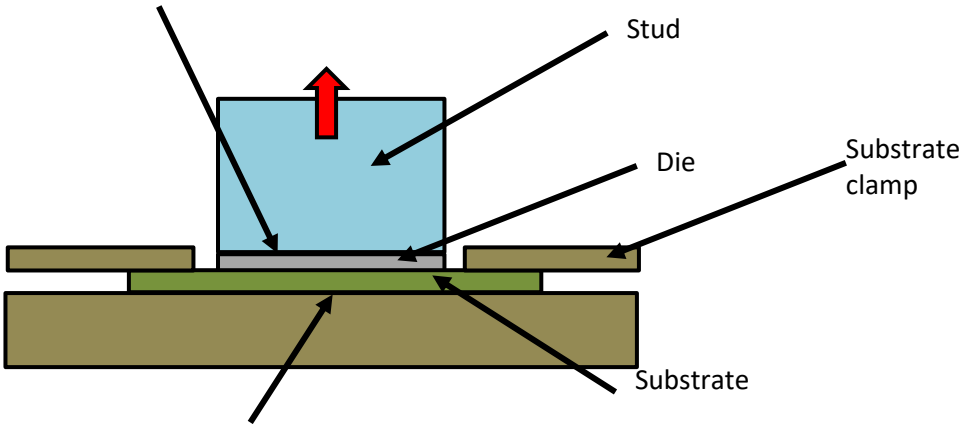
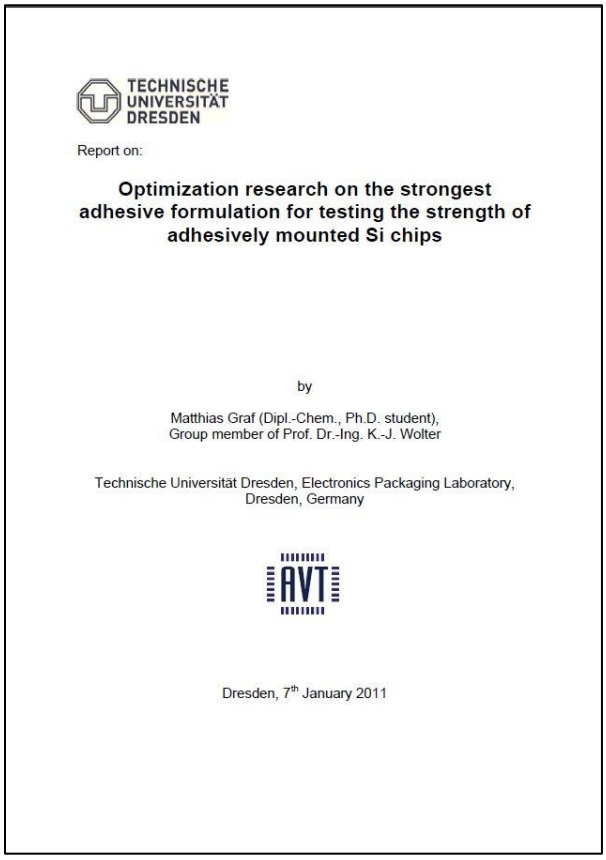
Stud pull testing

The difficulty with stud pull is getting a strong adhesive joint between the stud and the die



The substrate can be clamped but sometimes will also need to be glued
If the stud is securely glued to the die and the substrate securely held the pull test is relatively easy

XYZTEC commissioned the Technical University of Dresden to research the strongest stud bond possible



TECHNISCHE UNIVERSITÄT DRESDEN

Report on:

Optimization research on the strongest adhesive formulation for testing the strength of adhesively mounted Si chips

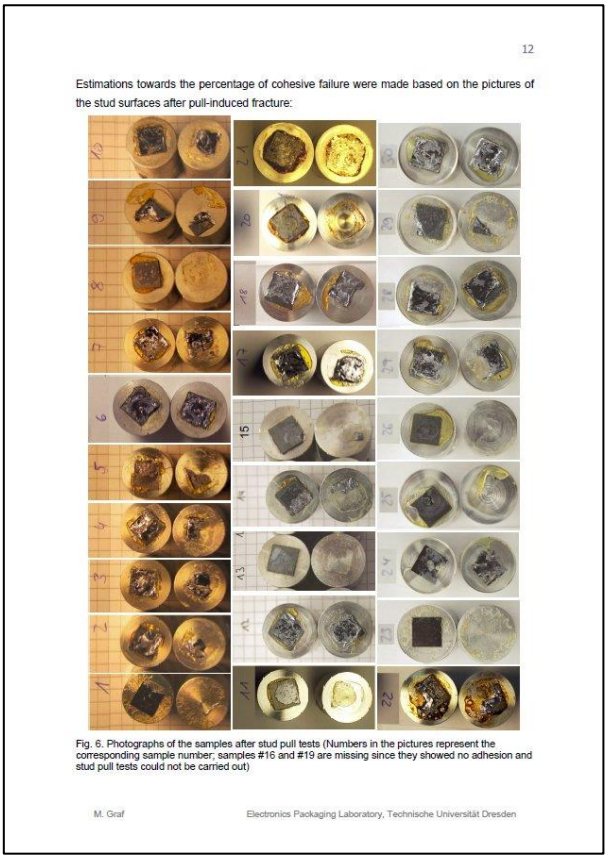
by

Matthias Graf (Dipl.-Chem., Ph.D. student),
Group member of Prof. Dr.-Ing. K.-J. Wolter

Technische Universität Dresden, Electronics Packaging Laboratory, Dresden, Germany

AVT

Dresden, 7th January 2011



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Estimations towards the percentage of cohesive failure were made based on the pictures of the stud surfaces after pull-induced fracture:

Fig. 6. Photographs of the samples after stud pull tests (Numbers in the pictures represent the corresponding sample number; samples #16 and #19 are missing since they showed no adhesion and stud pull tests could not be carried out)

M. Graf Electronics Packaging Laboratory, Technische Universität Dresden

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TUD results: Strongest bond 32.7MPa Typical max in stud pull: 5-20Mpa

Table 2. Overview of results (files marked in grey highlights the respectively varied parameter)

#	Al Pretreatment	AP	Si Thickness [µm]	AP	Adhesion Adhesive	Ballotini [µm]	Cure for [h], at [°C]	Pull Test Tensile Strength [MPa]	Test Success Cohesive Failure [%]
1	anod. Ox. 15 min	AP2b	150	AP1	Epoxy	40	4, 140	30,6	0
2	anod. Ox. 30 min	AP2b	650	AP1	Epoxy	40	4, 140	17,4	50
3	anod. Ox. 45 min	AP2b	650	AP1	Epoxy	40	4, 140	27,8	70
4	anod. Ox. 60 min	AP2b	650	AP1	Epoxy	40	4, 140	19,1	30
5	Plasma	AP2b	650	AP1	Epoxy	40	4, 140	32,7	30
6	Pickling	AP2b	650	AP1	Epoxy	40	4, 140	18,8	100
7	an. Ox. 30 + Plasma	AP2b	650	AP1	Epoxy	40	4, 140	15,6	70
8	Pickling + Plasma	AP2b	650	AP1	Epoxy	40	4, 140	8,5	0
9	Pickling + Plasma	AP2b	650	AP1	Epoxy	70	4, 140	31,0	30
10	Pickling + Plasma	AP2b	650	AP1	Epoxy	180	4, 140	4,9	60
11	Plasma	no	650	AP1	Epoxy	40	4, 140	19,1	0
12	Plasma	AP2b	650	no	Epoxy	40	4, 140	20,8	90
13	Plasma	AP2b	650	AP1	Epoxy	40	6, 140	23,2	0
14	Plasma	AP2b	650	AP1	Epoxy	40	5, 140	30,9	40
15	Plasma	AP2b	650	AP1	Epoxy	40	3, 140	13,0	20
16	Plasma	AP2b	650	AP1	Epoxy	40	2, 140	no adhesion	
17	Plasma	AP2b	650	AP1	Epoxy	no	4, 140	10,5	90
18	Plasma	AP2b	650	no	Epoxy	no	4, 140	21,2	80
19	Plasma	AP2b	650	AP1	PI	40	30min, 300	no adhesion	
20	Plasma	AP2b	650	AP1	PI/Epoxy 75:25	40	4, 180	no adhesion	
21	Plasma	AP2b	650	AP1	PI/Epoxy 50:50	40	4, 180	no adhesion	
22	Plasma	AP2b	650	AP1	PI/Epoxy 25/75	40	4, 180	27,6	40
23	Plasma	AP2b	150	AP1	PCy/Epoxy 50/50	40	4, 140	2,0	0
24	Plasma	no	150	no	PCy/Epoxy 50/50	40	4, 140	22,3	70
25	Plasma	no	650	no	PCy	no	30min, 135; 60min, 177	no adhesion	
26	Plasma	AP2b	650	AP1	PCy	40	30min, 135; 60min, 177	no adhesion	
27	Plasma	no	650	AP1	PCy	40	30min, 135; 60min, 177	3,2	80
28	Plasma	AP2b	650	no	PCy	40	30min, 135; 60min, 177	4,1	60
29	Plasma	AP2b	650	AP1	PCy/Epoxy 50/50	40	4, 140	2,5	20
30	Plasma	no	650	no	PCy/Epoxy 50/50	40	4, 140	7,1	90

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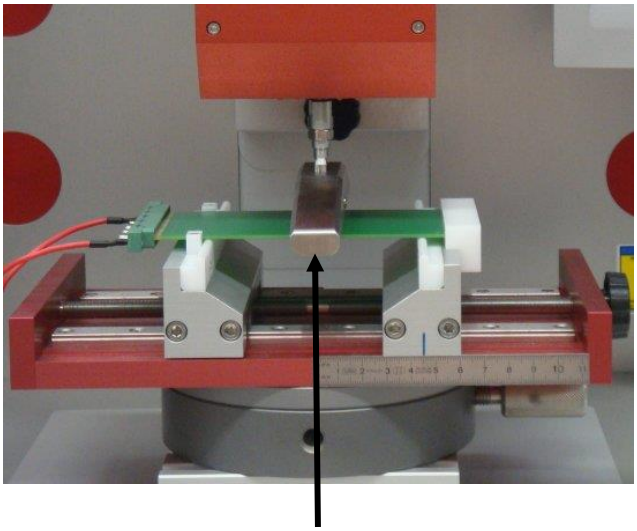
Bend testing

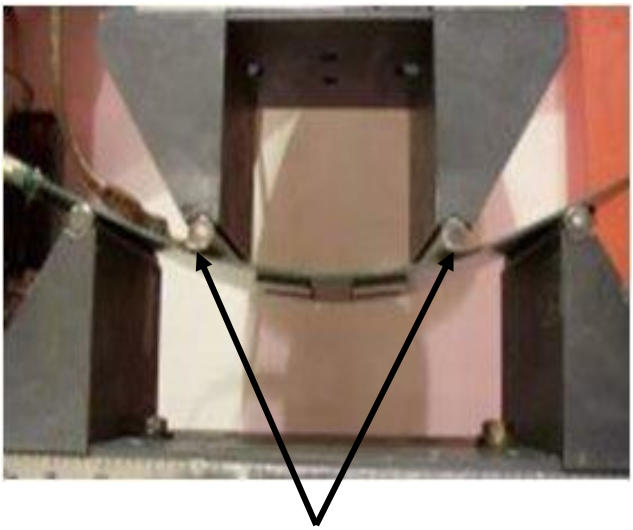
There are two types of bend test

Three point



Three point puts a stress concentration in the center of the sample

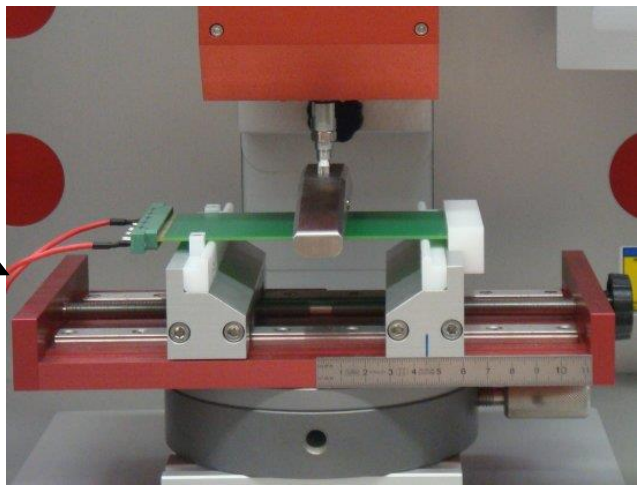
Four point



Four point creates a bend but the stress concentration at the load points can be outside the area of interest

Bend testing does not give a bond strength
Typically electrical continuity is measured as the sample is bent
Bond resilience is then a function the amount of bend before connection failure
The test can be a single bend or multiple bend events

Continuity measurement



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Advantages & Disadvantages of Test Types

	SHEAR	STUD PULL	BEND
ADVANTAGES	Easy to do Quick to do	Clean bond separation for easy failure mode analysis.	Bending can be the root cause for die interconnect failure, in which case the test more closely replicates the true load
DISADVANTAGES	Limited to the load that the side of the die can withstand although block can be gluded When bond breaks the separated surfaces rub on each other which can make failure mode analysis difficult Short life compliant tooling may be required	Limited to the strength of the stud bond (and substrate when applicable). Disposable studs needed. Time consuming and difficult. Stud adhesive process requires tight control. Special clamping required when gluing stud if the sample is warped	Difficult to correlate a point of bond failure to a specific test load or degree of bend In lead frame constructions individual die may not easily be separated out for testing

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