

# Gold wire bonding performance and reliability of ENEPIG surface finishes.

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## INTRODUCTION

The expression „multifunctional PCB“, as a synonym for a PCB which is applicable with a variety of assembly techniques, is already established on the market. That means the PCB can be used for multiple reflow soldering and multiple assembly techniques like, Al-wire bonding, Au-wire bonding, conductive adhesives and other interconnection methods. In the mixed COB/SMT assembly, where mainly Al-wire bonding is used, the ENIG Surface finish with Ni thickness of 5-6  $\mu\text{m}$  and Au thickness of 50 – 100 nm, is a well established surface finish.

But the ENIG surface finish can not be used for Au-wire bonding which is used mainly in the packaging industry. On ENIG sometimes bond Lift off's were reported that are often caused by an exceeding amount of Ni oxides at the Au surface because of Ni diffusion. At the other side the surface finishes electrolytic Ni/Au or electroless Nickel with autocatalytic gold are working well with Au-wire bonding but because of the high Au thickness that hinders a Ni diffusion for a longer time period. In addition the solder joint integrity thick Au of the surface is not regarded as a reliable material combination because brittle AuSn<sub>4</sub> phases are formed.

ENEPIG (Ni/Pd/Au) offers an Au-wire bondable surface and in addition it has excellent solder joint integrity in combination with lead free solder. This is the reason why ENEPIG is regarded as a “Universal Finish”. In addition ENEPIG uses a low Au-Thickness (< 0.1  $\mu\text{m}$ ) which offers a cost advantage compared to Electrolytic Ni/Au and Autocatalytic Au over electroless Nickel using Au thicknesses from 0.3 to 0.5  $\mu\text{m}$ .

The aim of this investigation is to check the Au wire bonding and soldering performance based on an ENEPIG system of 4 – 6  $\mu\text{m}$  Ni, 100 nm Pd and 50 nm Au. Also the reliability of this system is investigated under defined ageing conditions

## DESCRIPTION OF TESTING

To evaluate the Au wire bonding capability of the ENEPIG surface, two different mechanical test methodologies were used: The Ball- Shear- and the Pull- Test. Afterwards the interface reliability between the Au wire bond and the ENEPIG surface was analyzed via e.g. thermal cycling test. Additionally surface roughness measurements, via confocal microscopy, were carried out. After this, the surface of some samples was prepared with a thin Pt-layer for FIB cuts in order to analyze the bonding interface region.

## Test Vehicle

Figure 1 shows an example of the test PCBs used with a detailed view on the utilized bond area.

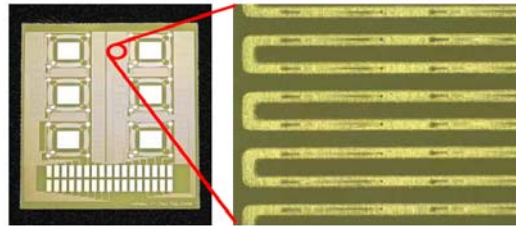


Fig. 1: Test vehicle for Au wire bond testing showing a detailed view on the utilized bond area.

The layout of the PCB board was developed by the Fraunhofer IZM Berlin.

## Surface Finish

The test PCBs were produced with the surface finish from the Atotech Deutschland GmbH: Electroless Nickel/ Electroless Palladium/ Immersion Gold (ENEPIG).

The following layer thicknesses were plated:

Table 1 – Summary of Surface Finish Specifications			
	Ni	Pd	Au
ENEPIG Thickness	4-6 $\mu\text{m}$	0.1 $\mu\text{m}$	0.05 $\mu\text{m}$
Deposit thickness variations: Ni: $\pm 5\%$ , Pd: $\pm 10\%$ Au: $\pm 10\%$			

## Test Equipment

For Au wire bonding the following bond equipment was used:

- 5610 Ball/Wedge Bonder from F&K Delvotec
- Max $\mu\text{m}$  Ultra Ball/Wedge Bonder from Kulicke&Soffa (K&S)

The capillary type was 41488-3823-R35 fabricated by K&S and the bonding temperature was set to  $\sim 125^\circ\text{C}$ . The used 25  $\mu\text{m}$  Au-RadixPlus wire (Heraeus) showed a breaking load of 10.8 cN and an elongation of  $\sim 4.6\%$  in initial (unbonded) state.

The following test equipment was used for the mechanical testing:

- Dage4000 Pull- und Shear Tester
- Pull measurement unit: WP100
- Pull hook diameter: 75 µm
- Shear measurement unit: BS250
- Shear tool width: 150 µm

In addition equipment for cross-section preparation, FIB- and REM/EDX analyses was used.

### Test Procedure- Ball- Shear- Test

The Ball- Shear- Test is a mechanical method to evaluate the quality of a wire bond. A shear tool drives horizontal with constant speed and defined distance to the bonding surface towards the wire bond, until the bond will be destroyed. The measured shear force will be recorded. The wire bond shear area will be classified on the basis of the remaining bond material, the shear force and shear strength. Generally four different fracture modes are defined:

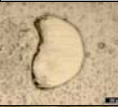


Mode	Description	
1	= remaining wire bond material 25%	
2	=remaining bond material 25 – 50%	
3	=remaining bond material 51% –75%	
4	=remaining bond material > 75%	

Fig. 2: Fracture modes – Ball Shear Test

The main objective is to maintain of more than 75% of the bond material on the substrate. For the basic bond optimization a limit of 50% remains material was classified as production standard.

### Test Procedure- Pull- Test

The Pull Test is another mechanical test method to evaluate the quality of a wire bond. During the test a hook stresses the wire strap with a constant speed. At the moment of destruction a sensor is recording the pull force. Depending on the position where the interconnection is destroyed the pull results will be evaluated on the basis of five different fracture modes and the pull force.

The following picture gives an overview of the different pull fracture modes.

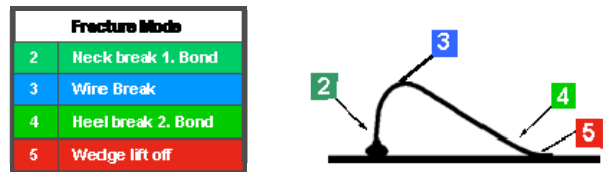


Fig. 3: Fracture modes – Pull Test

The occurrence of a “wedge lift of” was defined as the fail criteria of the test. According to DVS- data sheet 2811 (German industrial standard), neck, wire and heel breaks are allowed if a minimum pull force is reached (minimum pull force of a single bond > 4 cN, minimum average pull force >50% compared to breaking load of the wire in initial state, standard deviation <15% of average pull force).

### Test Procedure – Reliability Test

The reliability test contains three individual tests. During these tests the ENEPIG test samples were inspected after three different time intervals (250, 500, 1000h). The measurements were done in detail as follows:

- Thermal storage of bonded and non encapsulated samples at 150°C
- Moisture storage of bonded and non encapsulated samples at 85°C/ 85% rel. humidity
- Thermal cycling test of bonded and encapsulated samples at -55/125°C

After different thermal aging conditions (150°C & 85°C/ 85% rel. humidity) pull tests were carried out to evaluate the reliability of the interface between the surface and the Au-wire bond.

During the thermal cycling test the electric conductivity was measured after defined storage intervals up to 1000 cycles.

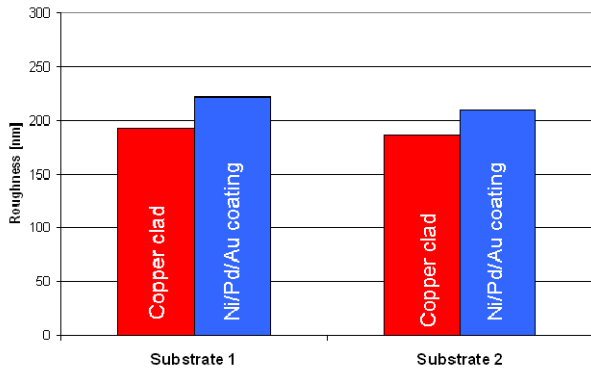
### TESTING RESULTS

In the following part of the article results obtained during the tests will be shown and discussed.

#### Testing Results- Surface roughness

To evaluate the first characteristics of the ENEPIG coating the roughness of the surface was measured via confocal microscopy.

The measurements were done at two substrates with three measurements per substrate. The following chart gives an overview of the results

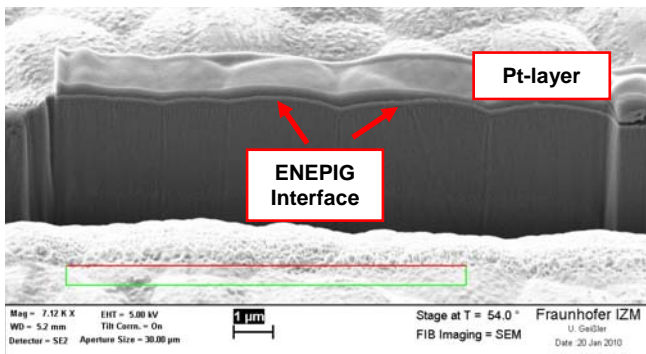


**Fig. 4:** Roughness of copper clad and ENEPIG surface

The results show for the copper clad surface a lower roughness as after ENEPIG coating. The measured roughness data of the ENEPIG surface finishes were within the typical range for Au-wire bonding.

**Testing Results - FIB Cuts**

The preparation of the PCB surface at the FIB (Focused Ion Beam) and the following documentation at REM/EDX allows a high-resolution analysis of the ENEPIG surface and especially the interface between the layers. In a first step a thin Pt-layer was plated to avoid redeposition effects during the cutting process. The following figure shows the FIB cut.

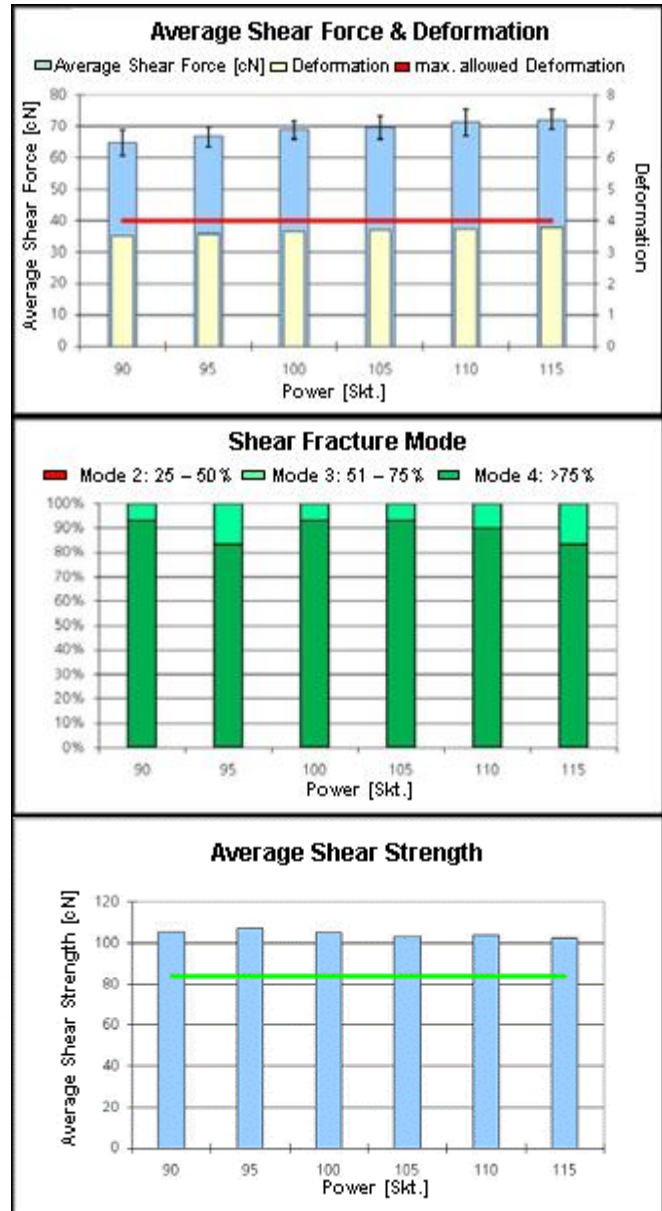


**Fig. 5:** FIB cut

Whether the analyses of the FIB cuts nor the REM/EDX documentation have shown any indications of corrosion on the ENEPIG surface. Also on the detail pictures no corrosion was recognized.

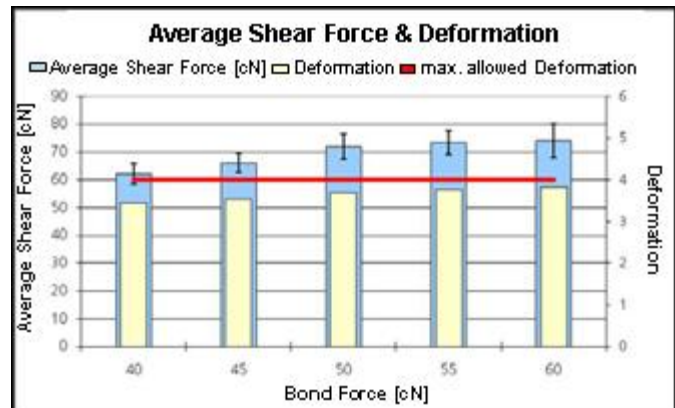
**Testing Results- Ball Shear Test**

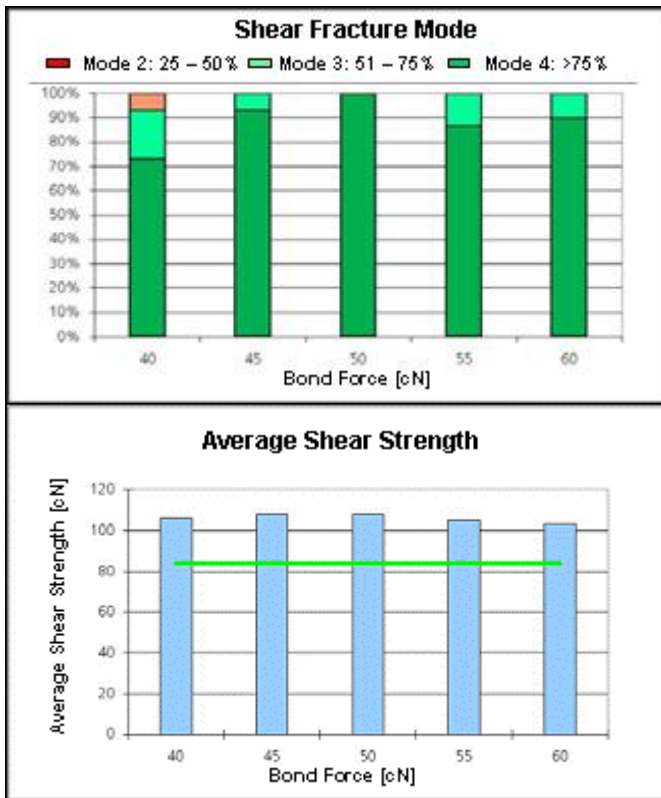
To achieve a comprehensive picture of the Au wire bond quality over the whole process window, the test was divided into two parts. In the first part the ultra sonic power was varied. Based on the optimized parameter of the first part, the bond force was varied in the second part. For every set of parameters 30 shear tests on the Dage4000 Bond-Tester were performed. The figure 6 gives a summarized overview of the results gained in the first part.



**Fig. 6:** Ball Shear Test – Variation of ultra sonic power (bond force: 50 cN; US-time: 25 ms)

The Figure 7 shows the shear test results of bonding force variation.





**Fig. 7:** Ball Shear Test – Variation of bond force (US-power: 105 Skt.; US-time: 25 ms)

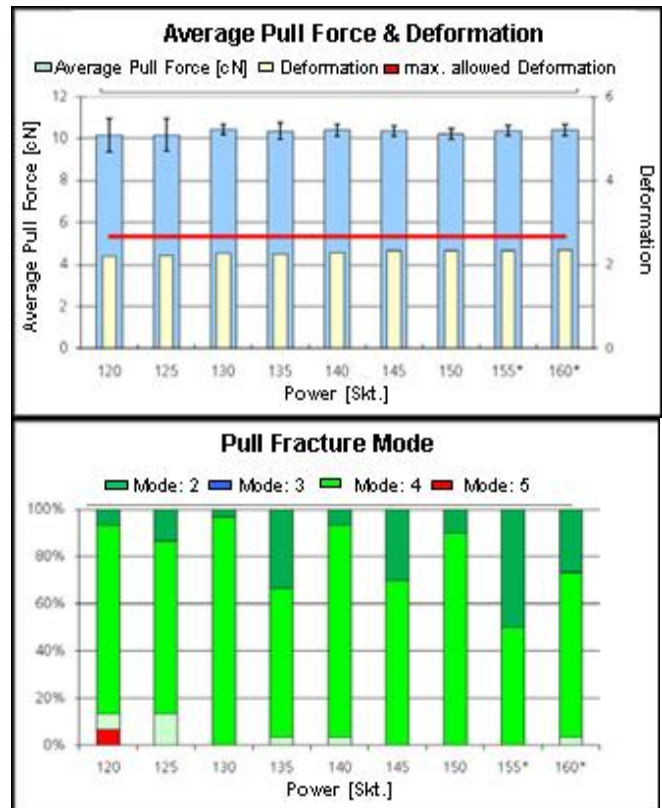
The pass-fail criteria of the average shear strength and shear force was set according to DVS-data sheet 2811 (average shear force: 40cN & shear strength: 84 MPa).

In summary it could be found out, that the ENEPIG surface of the Atotech Deutschland GmbH achieved excellent bond test result, although only a very limited parameter optimization was performed.

**Testing Results- Pull Test**

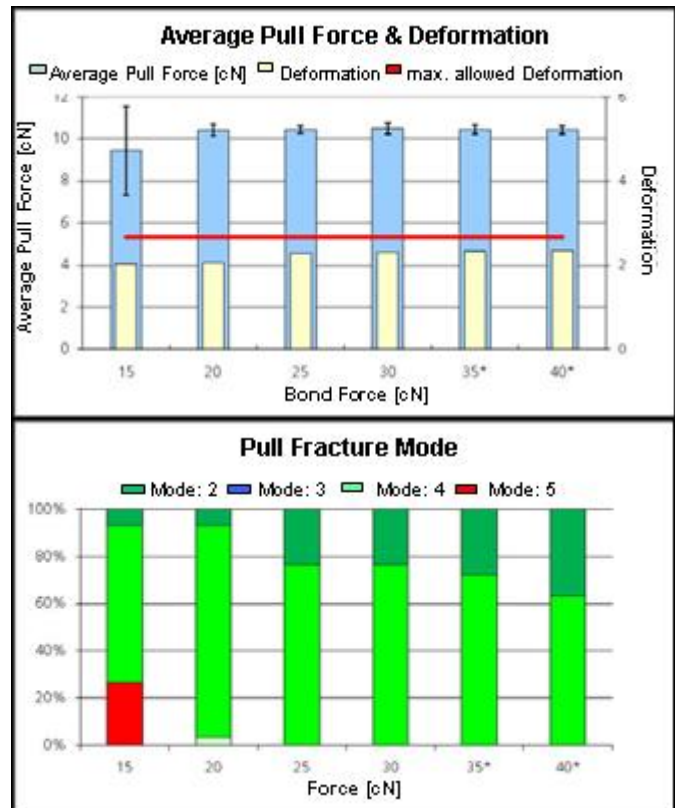
During the Pull Tests comprehensive parameter variations were done. The aim was to evaluate the optimal bonding range.

The occurrence of pull lift offs was defined as the lower and clear capillary prints as upper bound of the parameter window. The bonding parameter optimization for the wedge bond was similar to the optimization of the ball bond. (first step: variation of US-power, second step: variation of pull force). For every set of parameters 30 tests on the Dage4000 pull tester were carried out. The pull angle at both bonds was 30°. The Figure 8 gives a summarized overview of the results gained at constant bond force and bonding time.



**Fig. 8:** Pull Test – Variation of ultra sonic power (bond force: 25 cN; US-time: 20 ms)

The Figure 9 shows the pull test results of bonding force variation.



**Fig. 9:** Pull Test – Variation of bond force (US-power: 140 Skt.; US-time: 20 ms)

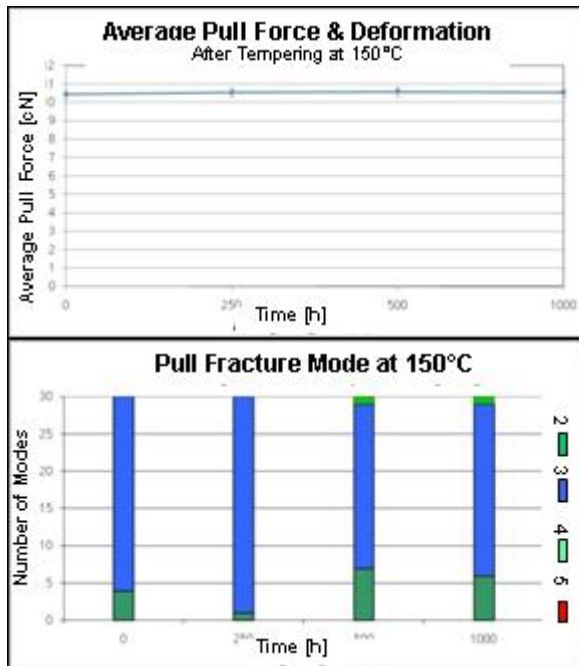
At low US level a few not acceptable wedge lift offs did occur. In the range of 125 – 150 Skt. (US-power) high quality bonds could be produced. In this region only some wire breaks were noticed. Single neck and heel breaks were monitored only at higher pull forces.

The fact that neck breaks predominantly occur, shows the good Au wire bonding capability of the ENEPIG surface. Single heel breaks are most probably caused by fluctuations during the bonding process (e.g. because of local higher roughness of the surface). The detected neck breaks could be classified as non critical because they only occurred at high pull forces. Finally a neck break mainly depends on the structural conditions in the neck region, formed during the recrystallization of this region during the cooling process after the ball forming process. Neck breaks are not connected to the Au wire bonding capability of the ENEPIG surface.

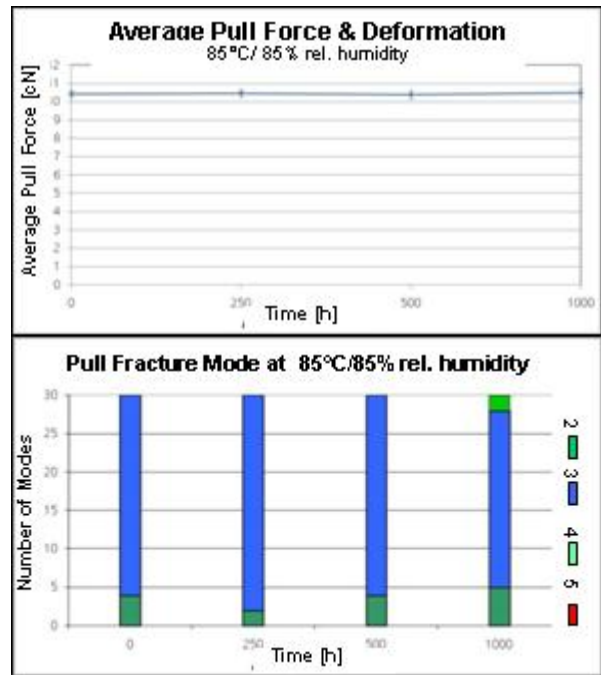
The process stability of a bonding process on an ENEPIG surface was tested at tempered PCBs (150°C for 4h). For the test 1000 bonds were produced (Maxum Ultra Ball/Wedge Bonder from Kulicke&Soffa) and tested mechanically. The analyzed data showed consistently good/excellent bonding results.

**Testing Results- Reliability Test**

In the following figures the pull test results after temperature and moisture storage are summarized.



**Fig. 10:** Pull test results after temperature storage at 150°C after 0, 250, 500 and 1000h



**Fig. 11:** Pull test results after moisture storage at 85°C/85% rel. humidity after 0, 250, 500 and 1000h

In summary it can be stated, that the reliability tests showed no noticeable problems of the Au wire bonds on ENEPIG surface. Also the results of the electric conductivity measurements of encapsulated devices after temperature cycling detected no systematic failures. Therefore it can be stated that the ENEPIG finish is a very reliable Au-wire bonding surface finish.

**SUMMARY**

The aim of this investigation was to check the Au wire bonding and performance based on an ENEPIG system of 4 – 6 µm Ni, 100 nm Pd and 50 nm Au. Also the reliability of this system was investigated under defined ageing conditions.

The roughness measurements of the copper clad and the ENEPIG surface showed typical results of PCB surface finishes.

The analysis of the bonding interface, via FIB and REM/EDX, showed no indications of corrosion.

In comprehensive bonding tests the good Au wire bonding capability of the ENEPIG surface was confirmed. Ball as well as wedge contact showed a high quality in a wide bonding range. The Pull Tests of 1000 bond connections showed no noticeable problem.

Also the reliability test of the interface between the surface and the Au-wire bond showed no noticeable failures.

Finally it can be stated, that the ENEPIG finish is a very reliable surface with an excellent and reliable Au wire bonding capability.