# Reworking of Indium bump bonded pixel detectors

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## 1 Abstract

Yield maximization in multichip hybrid pixel sensors is a crucial issue in large volume productions planned for future High Energy Physics experiments. Bump bonding process optimization can guarantee statistical single bump failure rates at the acceptable level of 10-100 ppm; nevertheless, systematic effects connected to process repeatibility can affect the functionality of a full chip in a module to a much larger extent. Because of this, the reversibility of the bonding procedure has been investigated. A feasibility study on single chip assemblies for the ATLAS experiment has been succesfully completed, proving on a test beam the possibility of reworking. As a result of it, a dedicated facility has been conceptually designed, engineered and commissioned. The characteristics of the facility in terms of motion, temperature and tensile strength control are outlined, together with the main results.

## 2 Introduction

For pixel detectors, due to the contact density, minimum pitch and the required bump failure rate, the only interconnection technique is bump bonding on flipped chips.

The choice of the metal bump determines the process characteristics in terms of the under bump metallization (UBM), the bonding mechanism and parameters, the mechanical properties and the bump aspect ratio.

Indium bumping technology has been developed for infrared sensor assemblies as Indium retains its mechanical properties also at liquid nitrogen temperatures where the sensors are operated. Indium bumps are in general grown by evaporation through a patterned photoresist, after a proper UBM, which may be simple and limited to a single Cr adhesion layer and bump pitches in the $20-30$ $\mu m$ are standard [1]. Chemical etching of the photoresist and evaporation are critical parameters in the process, as a bad control may result in Indium attachment to the via walls, making the lift-off not effective. As a result of it, Indium bumps have a small height/pitch ratio (e.g. 7 $\mu m/50$ $\mu m$) and bumping on both sides of the assembly is necessary [1]. Flip chip occurs at moderate pressure ($10^{-2} N/bump$) and temperature ($20-100$ $°C$), but it requires excellent planarity (at the 0.1 mrad level) and bump uniformity.

Moving from a detector prototype to a full scale system, integrated in a large experimental facility, requires a full production chain optimization where hybridization plays a crucial role. Moreover the requirements on the new detectors are more and more stringent. Nowadays the DELPHI pixel detector, that represents a succesfull project, appears as being simple compared to the detectors planned for the future experiments at LHC or at the Tevatron where the number of pixels increases by two orders of magnitude, the dose is expected to be three orders of magnitude higher and the electronics will be clocked up to 8 times faster.

Nevertheless the final production yield of the DELPHI pixels was at the 40% level [2] while the future pixel detectors have a 70% producion yield benchmarck: achieving it and fitting the time scale is a real challenge of hybridization.

In current HEP applications up to 16 chips are connected to the same sensor: replacing a faulty chip ("reworking") could considerably improve the yield. For instance, in the DELPHI pixel detector the module production yield after bump bonding of 16 known good chips was 80% and a good part of the faults were on a single chip [3].

## 3 Feasibility study

As introduced in the previous chapter, hybridization is a critical step in the pixel module production chain and the possibility of reworking a module with other chips already bonded on it could greatly help in time and money saving: it allows to strip a not properly working chip (badly bonded or not working after it has been bonded) and to replace it with a new one without descarding the whole module.

A feasibility test on the reversibility of the Indium bump bonding process has been perfomed giving good results and showing which are the important parameters that have to be taken into account during the stripping itself [4] [5] [6].

The tests have been performed at Politecnico di Milano, using a dynamometer operating in a temperature controlled environment shown in Figure 1. The chip is held by vacuum grooves in the holders; the upper holder may be pulled by a string coupled to a load cell to measure the stripping force and is connected to three slides to absorb any shear stress. The dynamometer, or "sandglass", can turn around its central axis so that, after the stripping, the two chips can easily be picked-up.

The measurements of the stripping force shown in Figure 1 helped also in the optimization of the bump bonding parameters.

During this feasibility study we realized that care has to be taken both in removing the chip with the same planarity it has been attached ($\sim 0.1$ $mrad$) to prevent shear

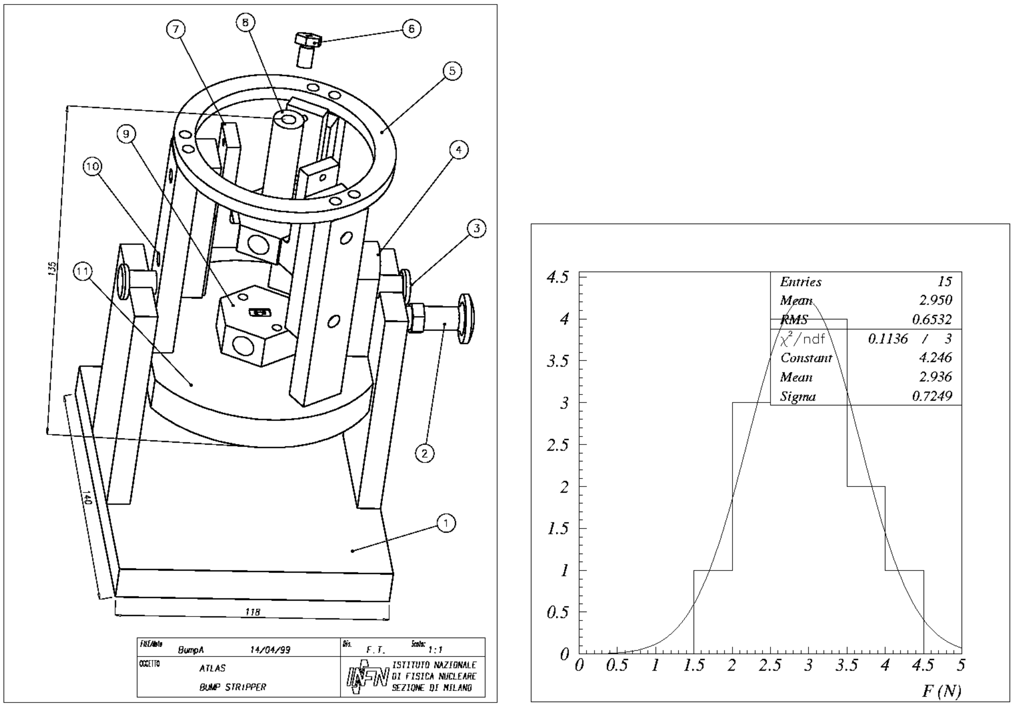

Figure 1: The ”sandglass” used for the stripping tests on the left and the distribution of stripping force at 100 °$C$ on the right.

stress to cause asymmetric bump breaks and in warming up the bonds to exploit the Indium plastic characteristics: stripping at room temperature the Indium bond breaks along the weak lines of the bond itself and this does not guarantee a symmetric stripping. Indium cannot be re-grown on the module when other chips are present and if we want to strip a not properly working chip and re-attach a new one in a given position we have to make sure that the ”left-over” indium allows a new flip-chip. Figure 2 shows asymmetric bump breaks, with a typical ”half moon” shape, that do not guarantee the reworkability of the module and a bump stripped at 100 °$C$ where the Indium plastic filaments are visible.

These tests lead us to a conceptual design of the chip stripping machine:

-Micrometric positioning both for the x-y stage to position the chip to be stripped and for the Z axis where a not well controlled move could damage the module.

-Good planarity ($\sim 0.1\ mrad$) to prevent and shear stress on the bumps and to have symmetric breaks

-Module heater to exploit the Indium plastic characteristics at 100 °$C$

-Vacuum holders for both the module and the chip to prevent any left over glue on the silicon

-Everything has to be PC controlled to allow an automatic procedure

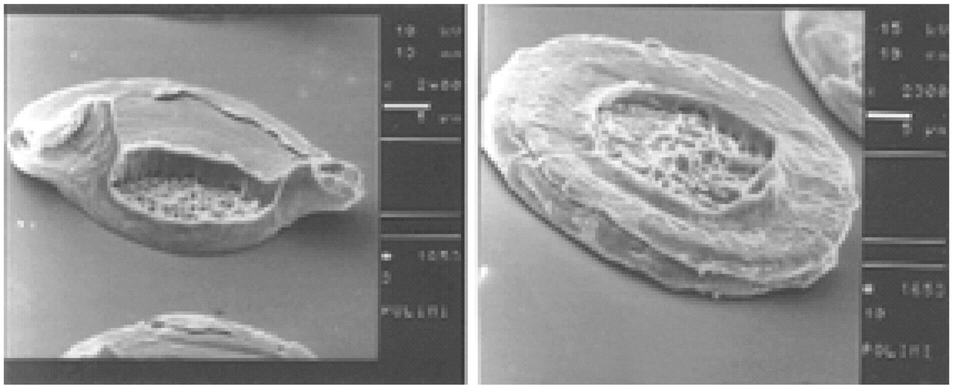

Figure 2: An asymmetric detachment with the "half moon" shape on the left and a plastic one on the right.

# 4 The chip stripping machine

The conceptual design outlined in the previous section lead us to the actual facility shown in Figure 3: a Venturi vacuum pump is on the top of the Z axis with the pick up tool installed on the other end. The hot plate with the Peltier cell to hold and to heat the module with the chip to be stripped is mounted over the X-Y moving stage. On the bottom the PC, the motion control power unit and the Peltier power supply can be seen. The structure of the facility is a granite coordinate measuring machine (CMM) by Poli (Varallo, Italy) with pneumatic guides on the moving axis and a maximum travel of 400x300x250 mm (X, Y, Z); optical encoders guarantee the needed resolution.

The motion of the axis is controlled by a National Instruments NI 7344 card and is powered by a Mini Maestro servo motor Pulse Width Modulation (PWM) power unit. The performances of the system after the Proportional, Integral, Derivative (PID) parameters have been optimized (see [7] for more details) are shown in Figure 4. It can be noticed how stable the system is, after the target position has been reached: this is very important because any minimal move of the pick up tool after touching the chip would reflect in stress, deformation of the bumps or even break of the chip itself. To achieve this, a double PID has been introduced: the approaching PID is software changed to the stationary PID after being within few microns from the target position for at least 300 ms.

To heat up the module, a Peltier cell has been used as a heat pump between a heat sink connected to the X-Y moving stage and the hot surface where the module will be positioned. To maximize the thermal connection, the Peltier cell has been sandwiched and pressed with optimized force between the hot and the cold surface and a silicon gel has been used in the contacting areas. On the other end, to prevent

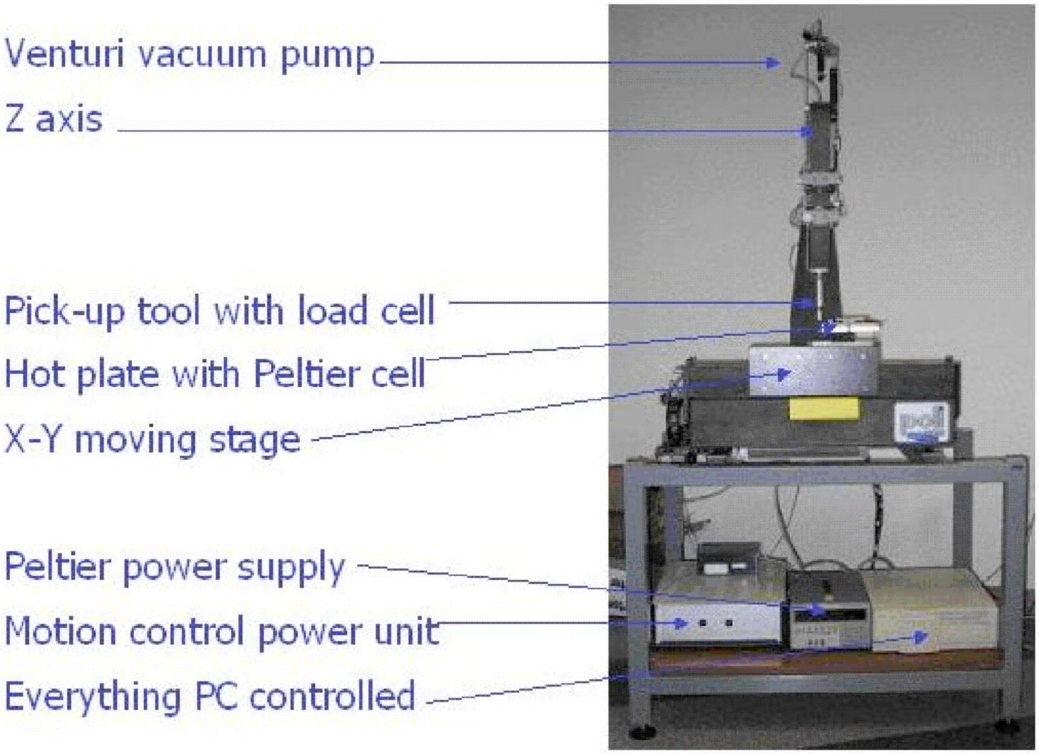

Figure 3: The chip stripping machine with all its components.

a thermal short circuit, the hot and the cold surfaces have been screwed together by Macor insulators that have been built on purpose. To hold the module, grooves have been digged in the hot surface and connected to a vacuum pump. The Peltier cell is biased by a GPIB controlled power supply: the hot plate temperature is read by PT 100 devices and a PID loop reaches and maintains the needed temperature.

A stainless steel long, thin pipe inside the empty granite structure of the Z axis takes the vacuum from the Venturi pump on the top of the Z axis down to the teflon touching tool: connected to this pipe there is a spring with k = 0.6 N/mm laying on the load cell inside the pick up tool. This pipe is free to move just along the Z direction: in normal conditions the load cell measures the weight of the pipe and the teflon touching tool ($\sim 1N$). While touching the chip to be stripped, the output of the load cell decreases to the point when the pipe weight is completely on the chip: the good resolution of the load cell allows us to set a threshold to stop the Z axis. As a further safety step, the pipe can go inside the Z axis by $\sim 2\ cm$: there is a stop on the Z axis position independent on the load cell measurement to prevent the Z axis to crasch the module. The whole touch down process, a very critical step, is shown in Figure 5: it can be noticed the pick up tool weight measurement first, the soft touch

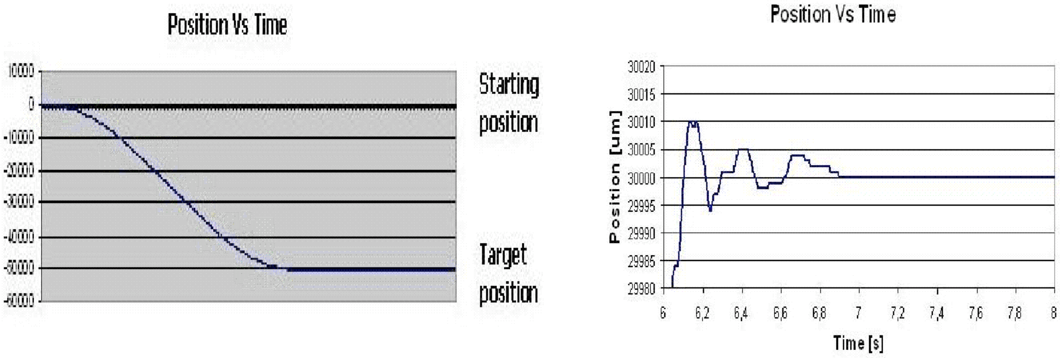

Figure 4: Motion control performances: on the right how the target position is reached and maintained.

down and the "no load" condition that could go on for several more mm. In a real stripping process, the Z axis is stopped during the touch down, vacuum is given to the teflon tool (the surface has been shaped and excavated to mate the chip shape and maximize the possible pulling force) and the load cell measures the stripping force (and the pipe weight) while the Z axis is moving upwards.

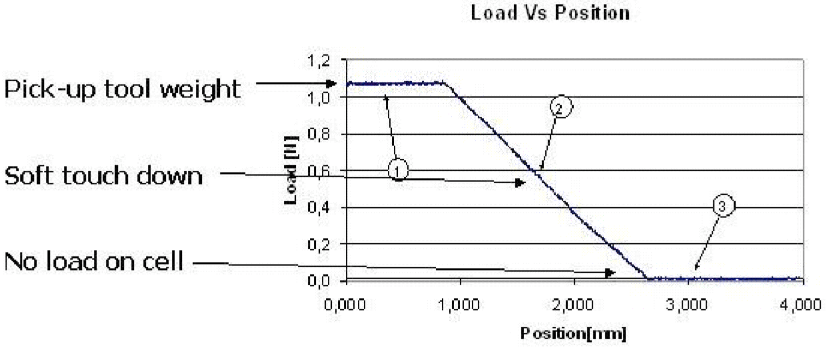

Figure 5: The touch down output of the load cell.

The whole stripping process is controlled by a Labview code: first, few parameters of the motion control and the load cell have to be checked and calibrated. The module support is then moved towards the operator to allow the module to be positioned: vacuum is given to the support to hold the module and the X-Y stage moves to set the chip to be stripped under the pick up tool. The module is heated and when the temperature is stable at the needed value, the stripping procedure starts. The Z axis comes down until the teflon tool touches the chip: the Z axis is stopped, vacuum is given to the teflon tool and the Z axis starts moving up slowly. The pulling force is monitored and the chip strip is seen as a sudden change in the load cell output that goes back to the touching tool weight. The Peltier cell is turned off and after cooling down, the stripped chip can be picked up by the operator. The whole process takes about 30 minutes: most of the time is needed to heat up the module while the stripping step itself takes few minutes.

# 5 Conclusions

The first chips have been recently stripped: the dummy module we had, unfortunately already suffered some injuries and the results may be affected by this. On the left side of Figure 6 the setup is shown: the Peltier cell is between the heat sink (bottom) and the hot surface. On the right the vacuum pipe, while on the left and on the back the PT 100 devices to measure the temperature of the hot surface are shown. The two missing chips are not the stripped ones and another visible damage of the module is the broken left top corner.

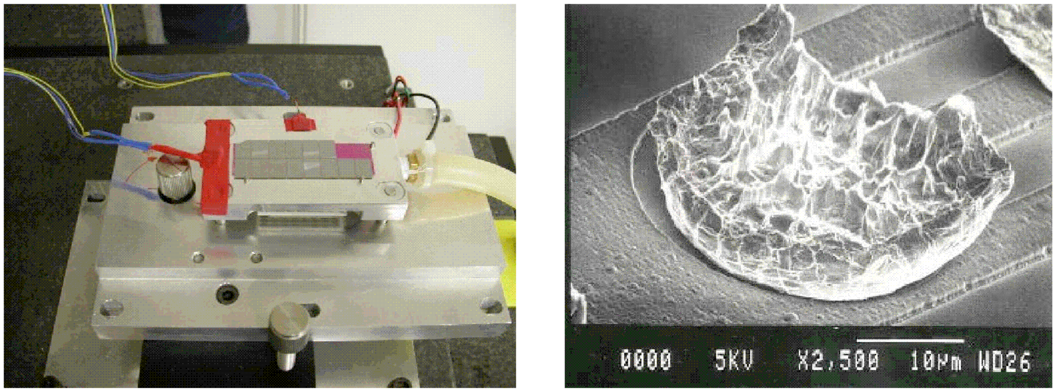

Figure 6: On the left the setup for the first chip strip with the facility and on the right an Indium bump of the stripped chip.

Figure 6 on the right shows a stripped Indium bump: very nice and thin filaments can be seen showing that the Indium plastic characteristic have been exploited working at the right temperature and with the correct pulling force, not breaking the bump along weak lines. Unfortunately the typical "half moon" shape is present telling us that probably (this has not been investigated yet) the needed planarity has not been obtained: some parameters have to be carefully re-checked.

I would conclude that a chip stripping facility has been realized, it is working and it is almost ready!

# 6 Acknoledgements

I'd like to thank Prof. Milani, University of Milano, for being so open to give us free access to his laboratory SEM that allowed us a prompt analysis of the sripped bumps and a very special thank to Dr. Barborini who, despite his wife was giving birth to their new child, was available to use the SEM, otherwise a useless tool in my unskilled hands! An hero of ancient times!

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