# An approach for fabrication of Quad Pixel Modules

## Definitions

***Hybrid:*** flexible printed circuit board with kapton as a base material.
***Silicon assembly:*** four FE-I4B readout ASICs bump bonded to silicon pixel sensor.
***Quad Pixel Module:*** hybrid and Silicon package glued together.

## Introduction

A special hybrid circuit board [1] has been designed to interface pixel readout chips [2] to data acquisition system of the ATLAS Detector [3]. Each of these hybrids attached to a silicon assembly comprising four FE-I4B integrated circuits flip-chip bump bonded to one planar silicon pixel sensor [4] forms a Quad Pixel Module.

Several methods have been considered for bonding hybrids and silicon assemblies [5], [6], [7] all with various degree of complexity, trade-offs and success rate. This paper describes what is believed to be the simplest and very reliable approach based on paper laminate. Detailed specs for necessary tooling are also given.

Semiconductor grade epoxy recommended for production of Quad Pixel Modules is Epolite FH 5313A [8]. It sets in approximately 6 hours at room temperature. The design of a jig for holding glued parts together considered long curing time with regards to risks of edge wetting associated with glue viscosity and possible temperature variations. Due to complexity and costs of components, especially bump bonded silicon assembly, it was decided to glue each module on an individual jig whose design simplicity allows for provision of sufficient number of jigs to cope with the module production schedule for the ATLAS upgrade [9].

## Gluing method

"Amplitude C6-99" paper impregnated with Epolite FH 5313A adhesive is being used to bind hybrid to the silicon assembly. Long staple fibres of this paper form a firm mesh to control the amount of adhesive near hybrid edges to avoid their wetting and contamination of wire bond pads. The uniform thickness of laminate material helps to keep the hybrid flat during glue curing period that in turn ensures high yield and reliability of bond wires connecting readout ASICs to the PCB. C6-99 paper benefits from moderate sodium ion content together with low extractable levels [10] with regards to radiation effects in constituents of the Quad Pixel Module.

Fibre-epoxy composite improves thermal performance of the Quad Pixel Module compared to gluing methods based on bare adhesive. Large mismatch in thermal expansion coefficient of epoxy resins (ranging between 50 and 100 ppm/K), kapton (20 ppm/K) and silicon (3 ppm/K) causes mechanical stress to the latter impacting its properties and performance. Irradiated sensors have to stand bias voltages in excess of 1 kV for bulk depletion sufficient enough to register ionising particles. Any strain-induced defects in the silicon crystal are likely to raise its leakage current resulting in early breakdown and thermal runaway. In addition, thermal cycling of Pixel Modules between -55 C and +60 C required by ATLAS Local Support Design

Parameters creates risk of PCB delaminating and as a consequence failure of bond wires due to shear strain from large mismatch in CTE of module's constituents. References [11] and [12] show that non-woven epoxy composite has its lateral CTE (in machine direction) just slightly above that of the laminate material in the broad range of its fibre volume. It suggests that low density C6-99 paper with 16 g/m2 basis weigh and CTE in order of 5..7 ppm/K should keep the CTE of epoxy composite under 20 ppm/K thus making it a perfect thermal interface between silicon assembly and kapton PCB. Thermal expansion of composite in transverse direction for approximately 50um thick paper could be neglected. Experimental tests are being prepared to compare peel strength of hybrids glued with and without paper laminate. Samples will be irradiated by 60 MeV protons to doses up to 1e16 cm-2 and thermally cycled in accordance with ATLAS design rules.

Depleting of the silicon pixel sensor requires bias voltage up to 1.5 kV applied to aluminised detector’s backplane to which the hybrid is glued. The glue layer should therefore provide adequate electrical insulation for the HV creepage. This could easily be achieved with epoxy composite material whose uniform thickness ensures insulation gap between hybrid and silicon. In addition, hybrid surface could be made sufficiently flat for wire bonding if some pressure were applied to the glued parts with fibre mesh as a spacer and for retaining glue between them.

## Gluing Jig

The tool for gluing contains 5 parts shown in figure 1. Base plate (part 1) with vacuum hold down nozzles for a silicon assembly is being used to support and align further components by means of two dowel pins. Aluminium alloy 6082 is recommended material for the base plate whose prototypes were made by the departmental workshop.

Guiding foil (part 2) resting directly on the base plate has a square cut for a silicon assembly. The foil thickness is chosen to be less or equal to that of readout ASICs so that any movement of the silicon assembly within this square aperture does not damage edges of the pixel sensor, figure 2. Once inside aperture, the silicon assembly has to be slid gently into the notched bottom left corner for alignment.

Vacuum will then be applied to hold the silicon assembly in place. Vacuum strength has to be adjusted to minimise mechanical stress to silicon. "Amplitude C6-99" paper liner is recommended between vacuum nozzles and silicon to diffuse air pressure and distribute it evenly over large area. Liner dimensions should be large enough to elevate both, the silicon assembly and the guiding foil above the base level by the same amount.

Paper frame (part 3) secures laminate sheet in exact position on top of the silicon pixel sensor. Contouring stencil (part 4) is being used for trimming laminate to hybrid dimensions. Parts 2, 3 and 4 were produced in 125um thin stainless steel by the PCBtrain company in their express laser stencil service with the overall cost under 50 Pounds.

Press plate (part 5) should be placed with some additional weight over hybrid to apply uniform force to glued parts. The plate features laser cut pockets to accommodate standing out surface mount components to be in a good touch with the rest of the PCB. The first few prototypes of the press plate have been produced by Qualitetch Ltd in 2.5 mm stainless steel at the price of 40 Pounds per piece dropping under 10 Pounds for 30+ order quantities.

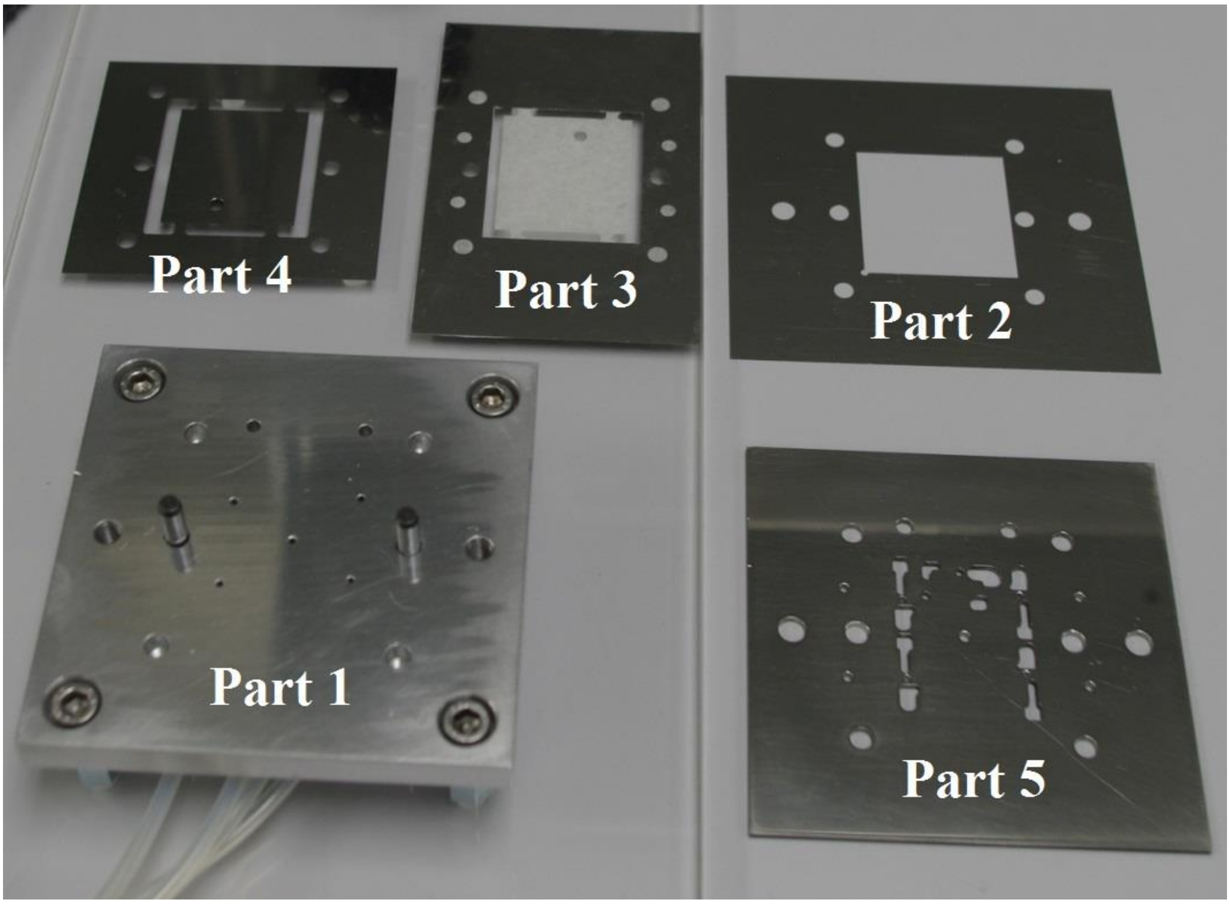
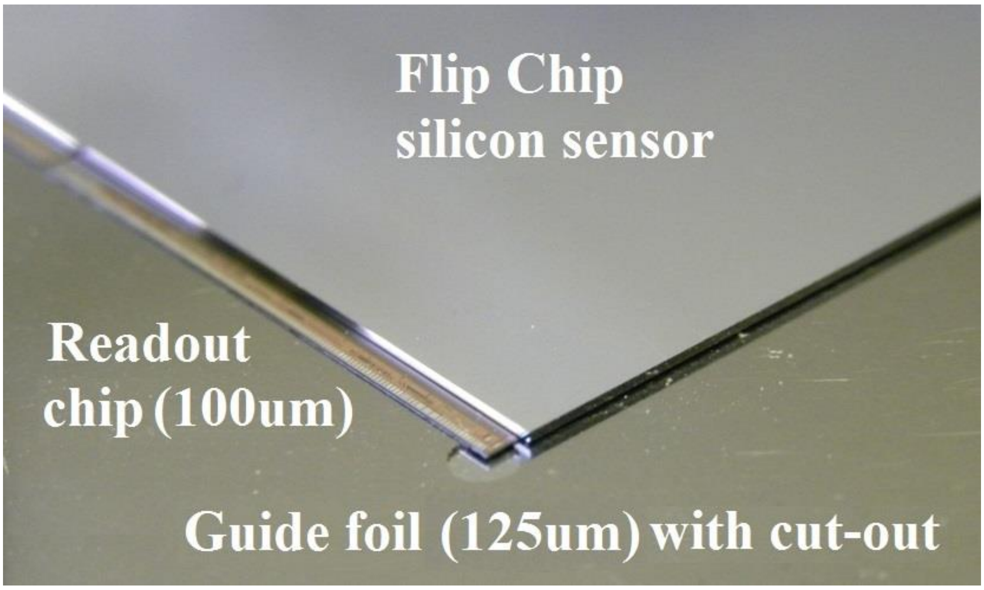


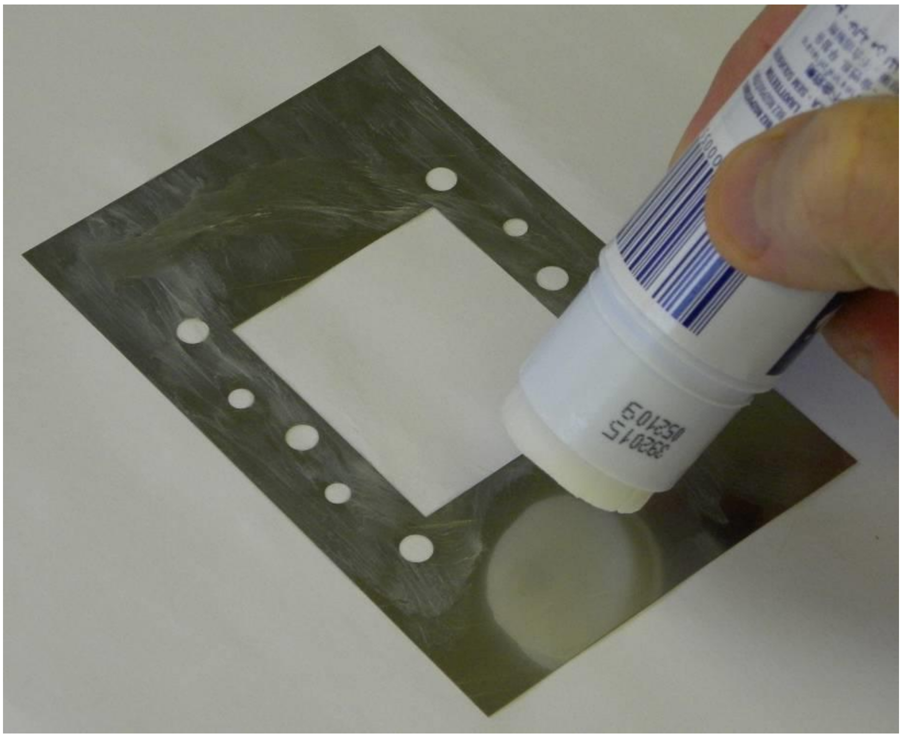

Figure 1. Parts of the gluing jig: base plate (1), guide foil (2), paper frame (3), contouring stencil (4), press plate (5).



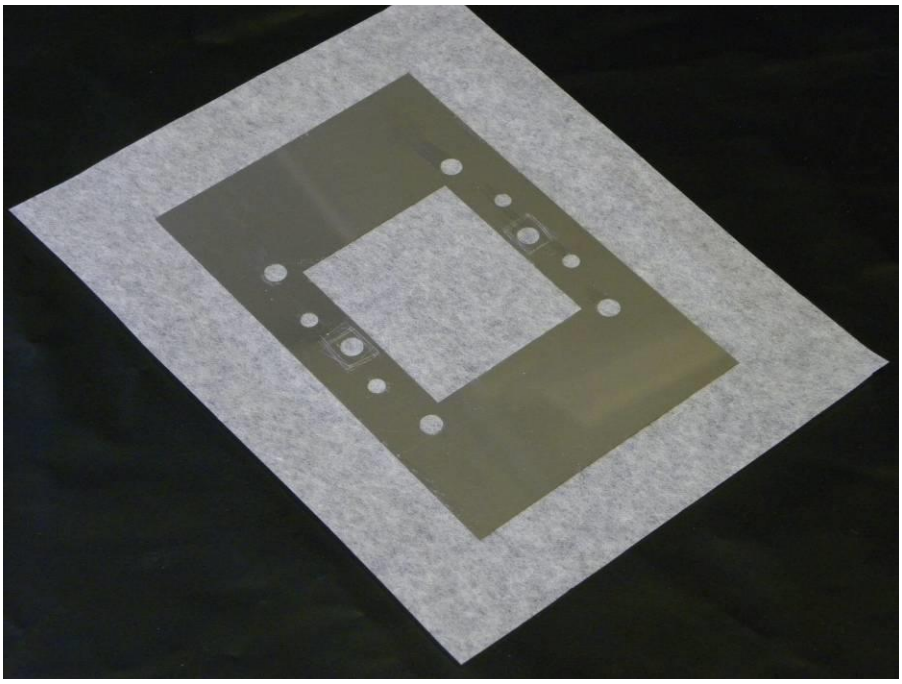

Picture 2 Alignment of silicon assembly by means of the guiding foil: readout chip sits in the notched corner of the cut-out whose edges are beneath the pixel sensor. Amplitude C6-99 paper (60um thin) placed under the chip diffuses vacuum and provides sufficient elevation of the silicon sensor above foil edges.

# Gluing Procedure

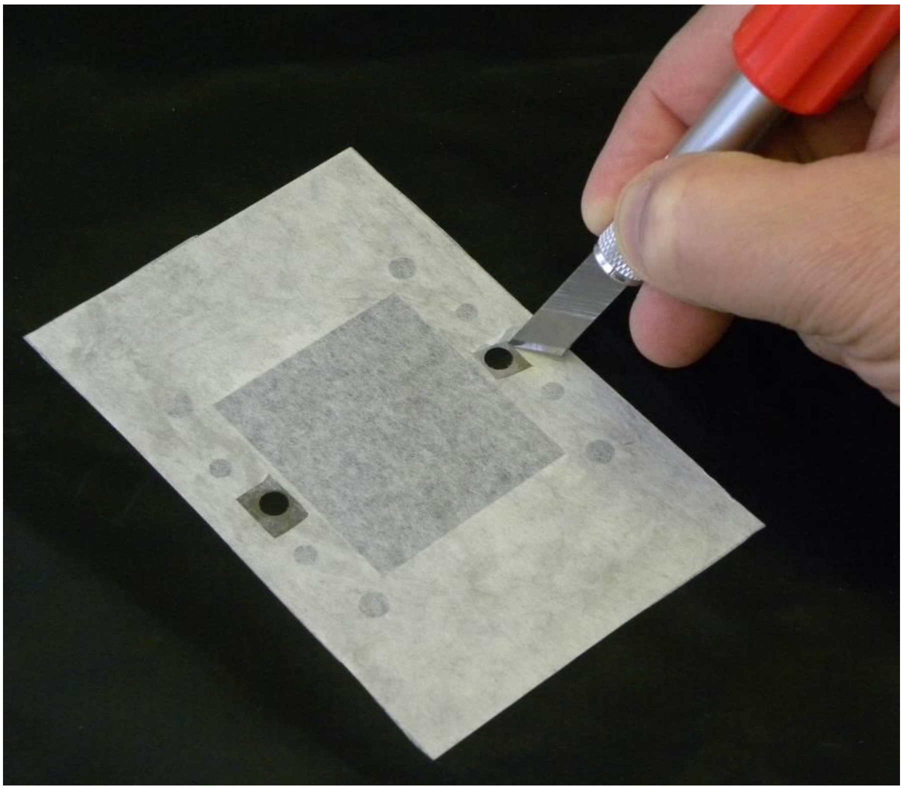
It is recommended to clean with alcohol all parts of the jig before making the new pixel module. The following pictures will demonstrate step by step assembly workflow:



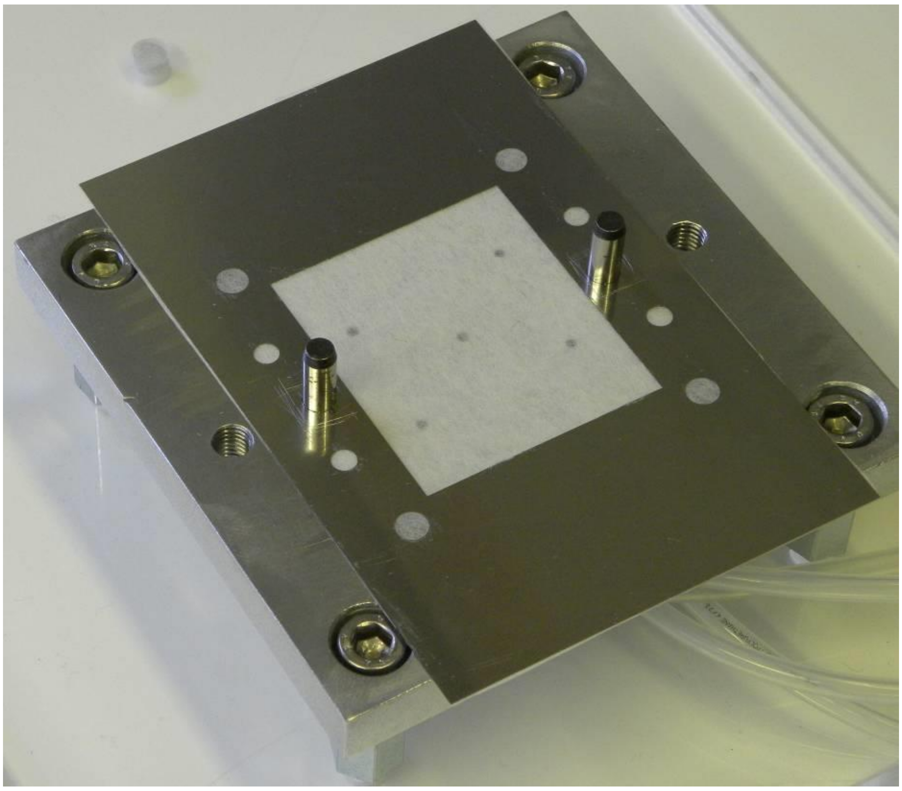
Step 1. Apply solid washable glue to paper frame (part 3).



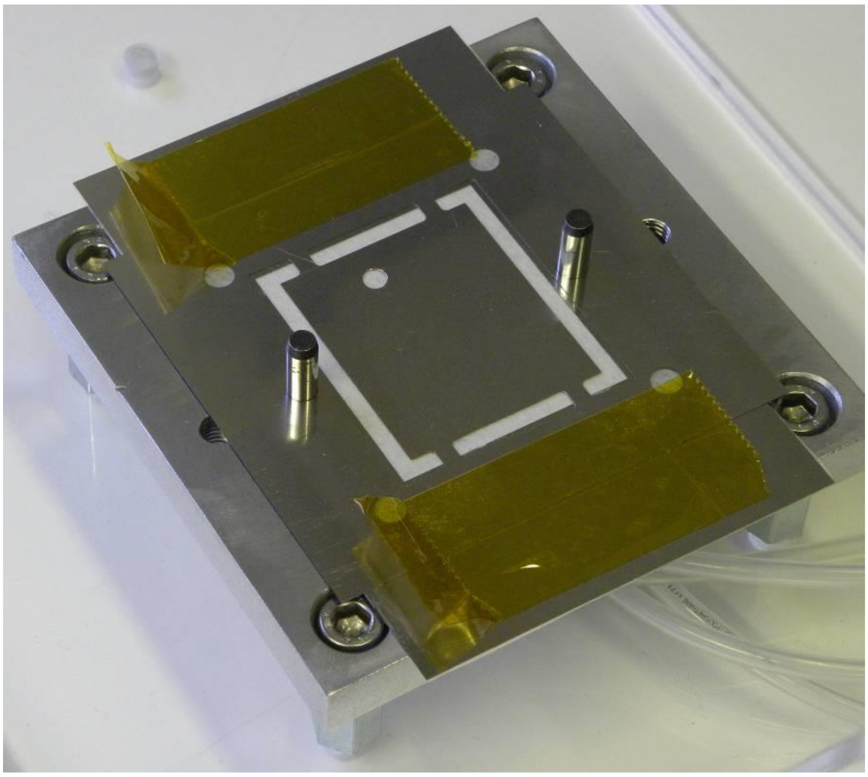
Step 2. Place frame with glue facing down onto C6-99 paper leaf.



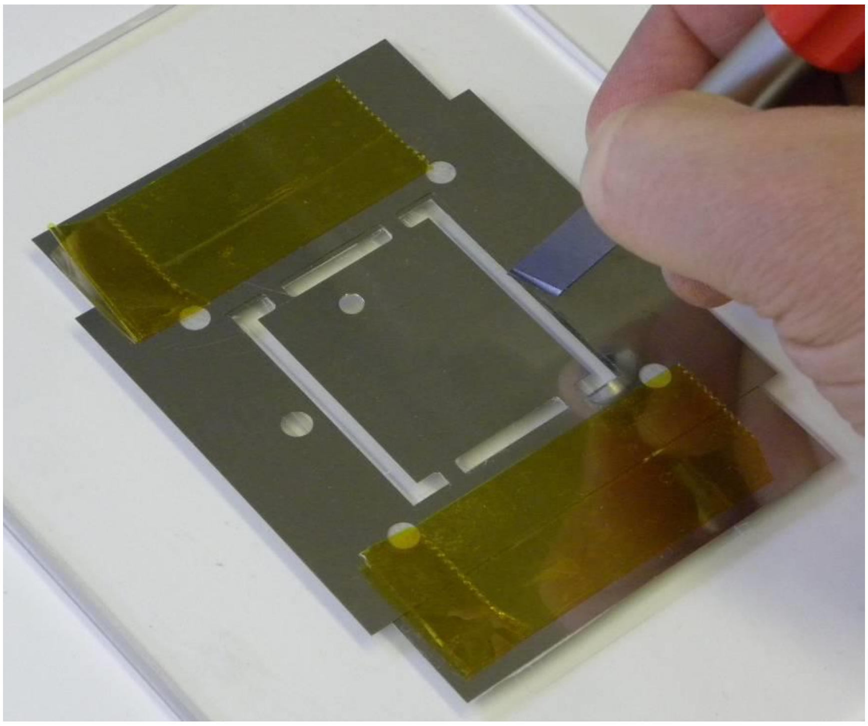
Step 3. Turn the frame over and cut paper with trimming knife to open alignment holes for the dowel pins



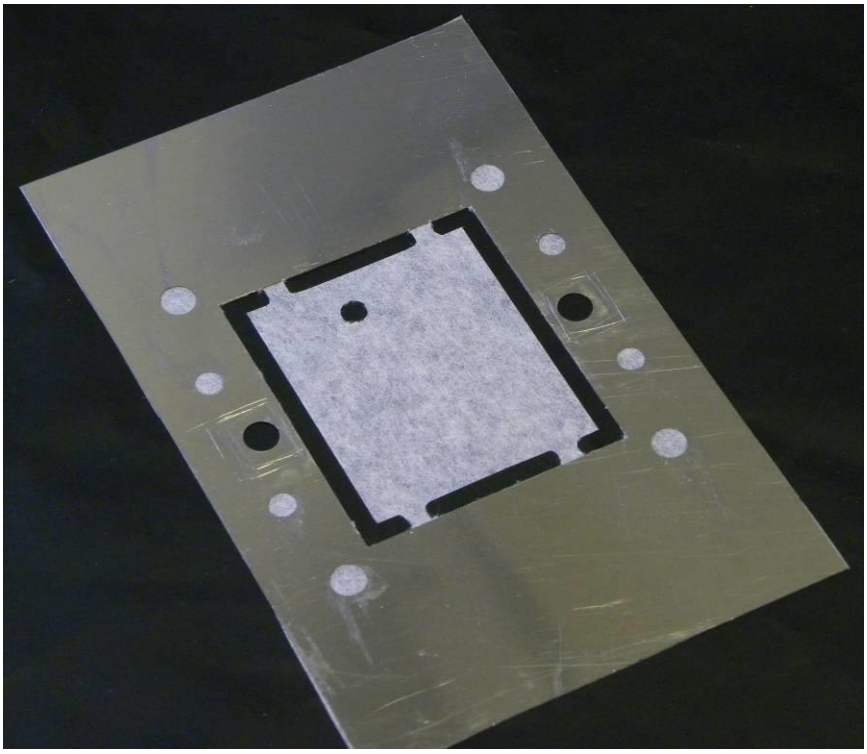
Step 4. Mount the frame onto base plate with paper facing down.



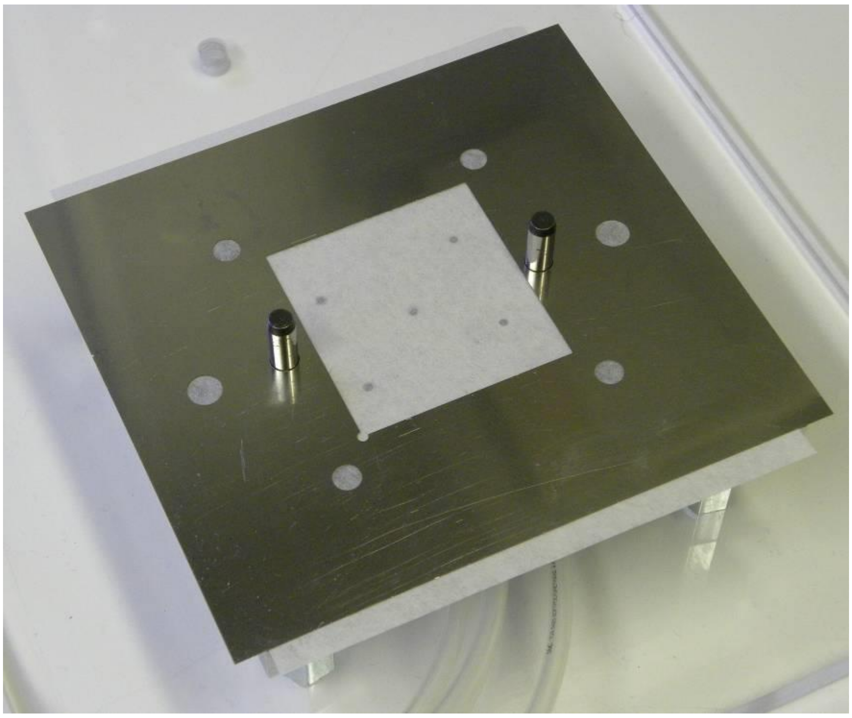
Step 5. Put contouring stencil (part 4) over paper frame and fasten two shims together using kapton or any other easy peel and low residue adhesive tape.



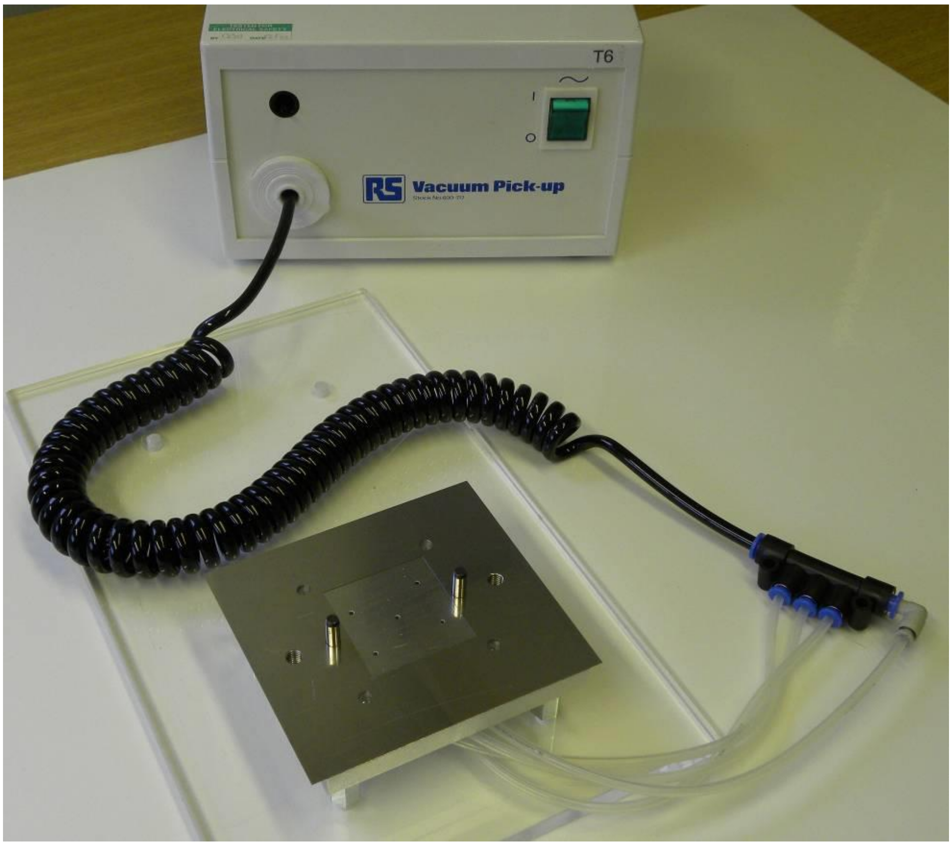
Step 6. Take both stencils off the base plate and cut paper through apertures using trimming knife. 2mm thin Perspex sheet is recommended as a single use cutting mat to ensure accurate paper edges.



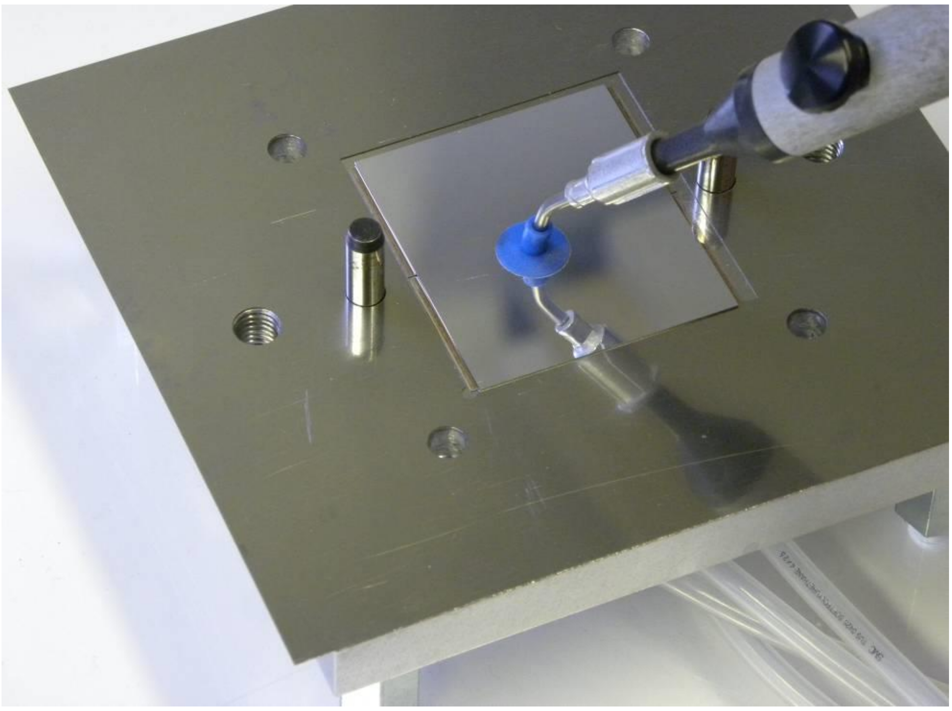
Step 7 Remove contouring stencil from the paper frame and inspect visually the quality of prepared laminate sheet whose edges should look clean, otherwise repeat steps 1 to 6 for good result.



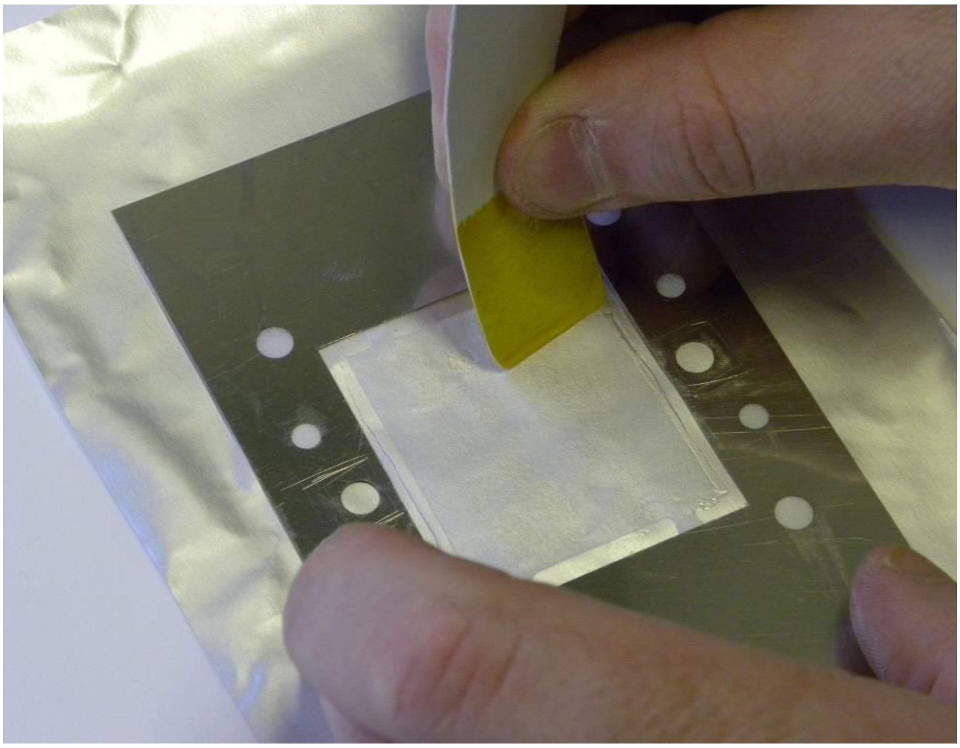
Step 8. Place guiding foil (part 2) on the base plate. C6-99 paper sheet between the base plate and guiding foil is recommended as a vacuum diffuser for very thin (under 100um) readout chips.



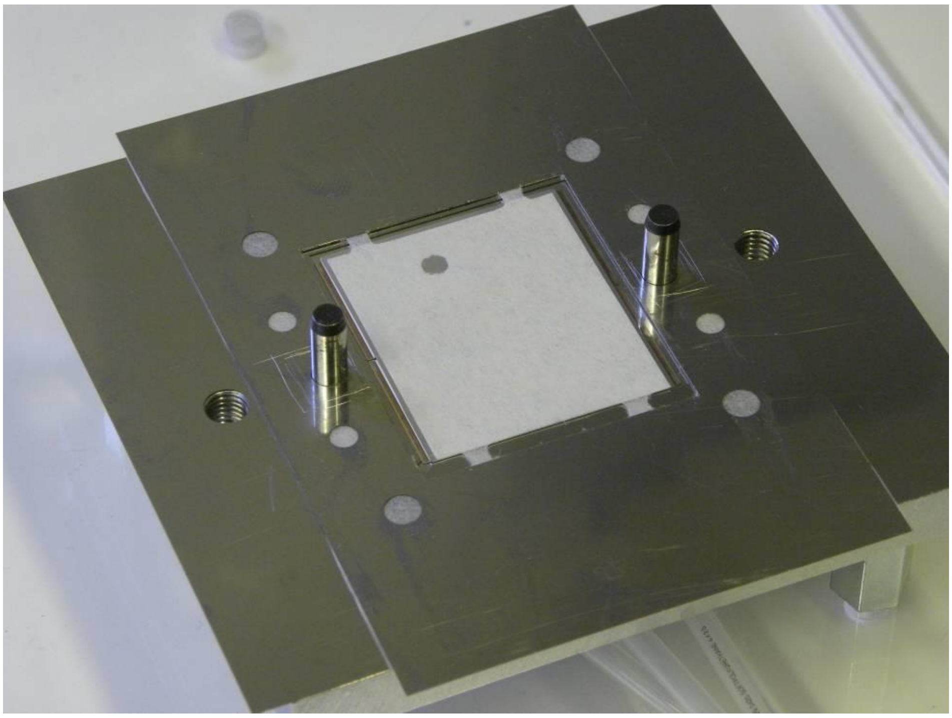

Step 9. Prepare vacuum system



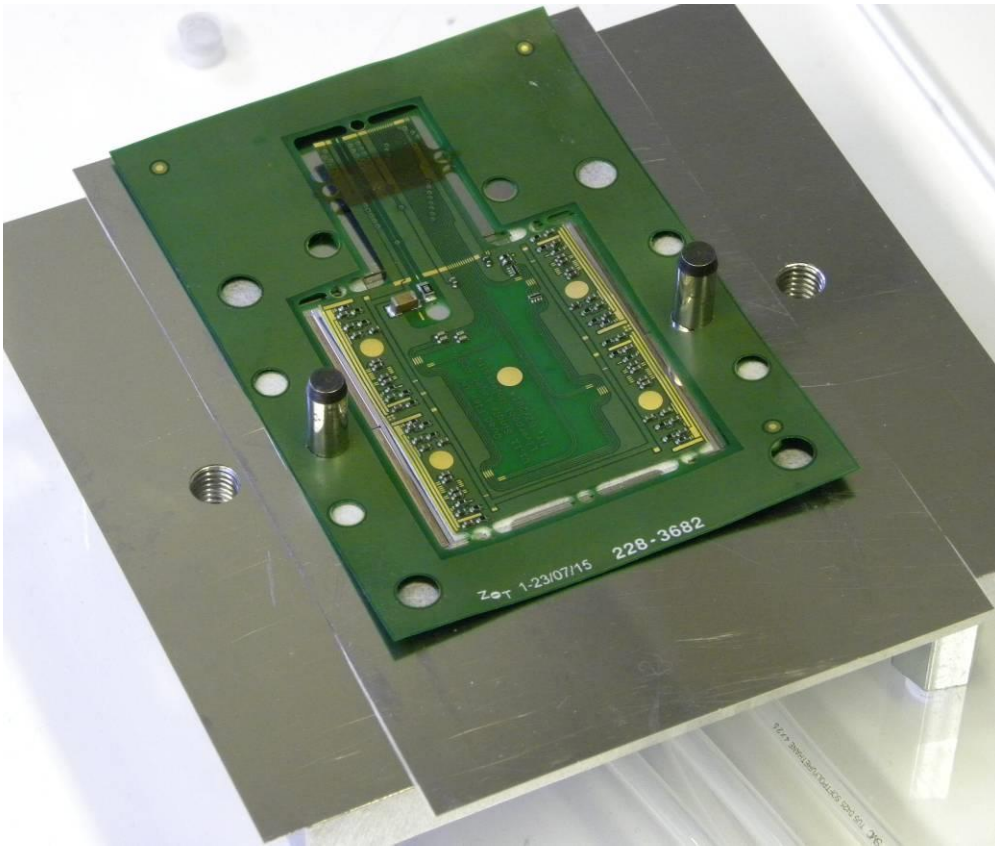
Step 10. Put silicon assembly inside rectangle aperture of the guiding foil. Gently slide silicon assembly into the notched bottom left corner. Apply vacuum to hold silicon assembly down.



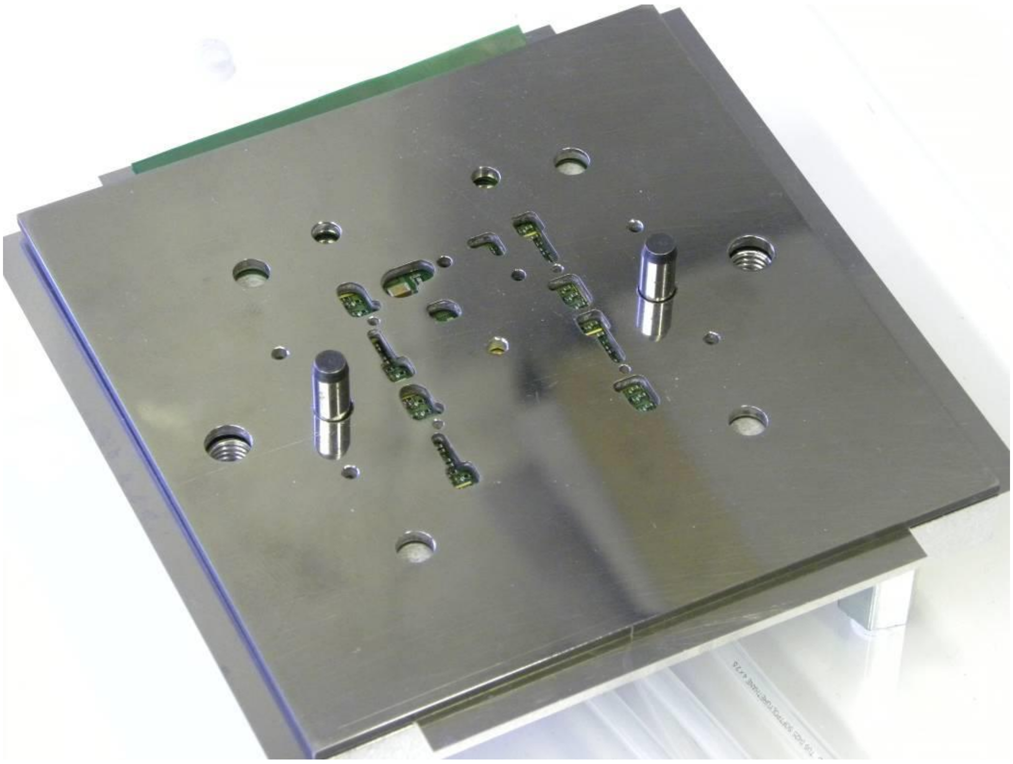
Step 11 Prepare epoxy and apply it to laminate material whose tabs should be kept free of glue. Aluminium foil (kitchen foil) is recommended as a single use mat under the frame for a tidy job. Aluminium is chemically neutral thus it will not contaminate glue and it will also be easy to peel foil off soaked paper with high surface tension. Squeegee excessive glue into gaps between laminate and its frame.



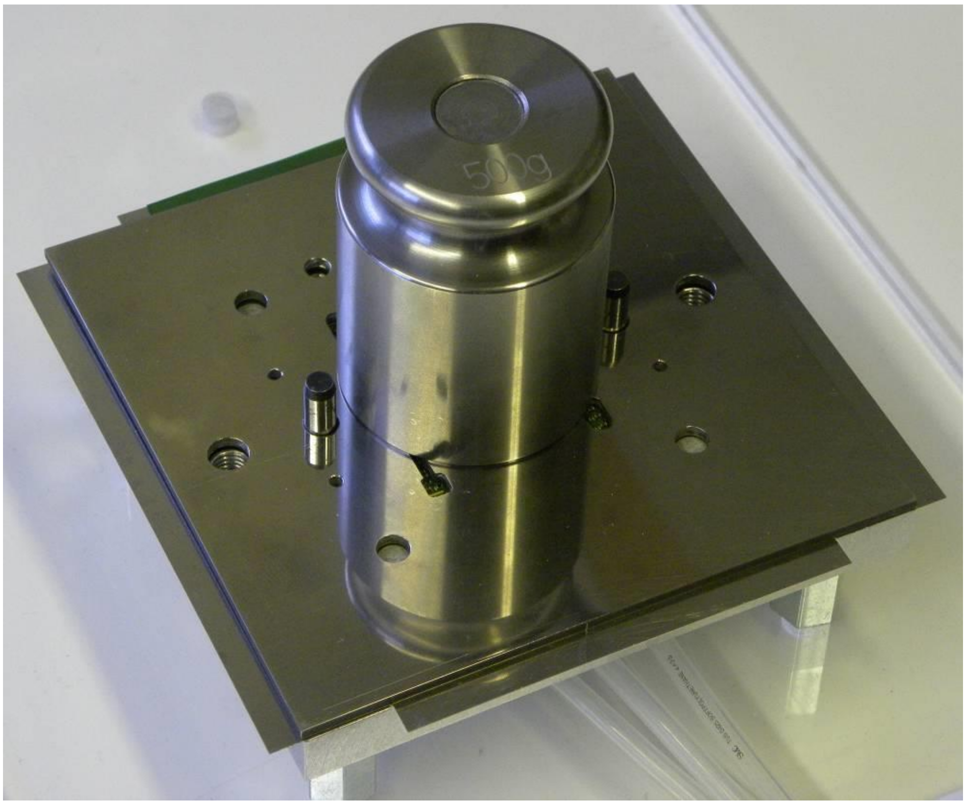
Step 12. Place impregnated laminate on top of silicon package.




Step 13. Place hybrid over laminate



Step 14. Place press plate over hybrid.




Step 15. Put some weight onto press plate. The maximum safe pressure will depend on quality of surfaces in contact with silicon (base plate and hybrid) cushioned by C6-99 paper. Good PCB planarity has been achieved with 5kg metal bar fitted between two dowel pins.

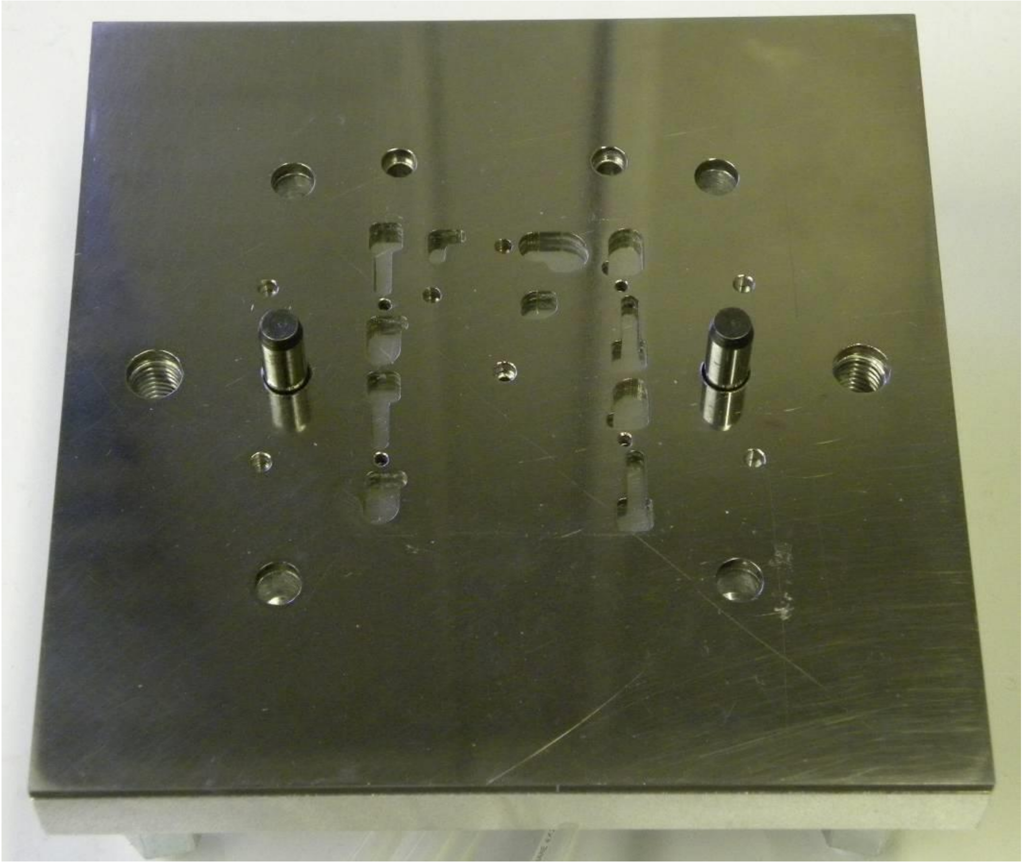
The pixel module should now be left on a jig for epoxy curing which could be accelerated by elevating ambient temperature. FH 5313A resin will set in about 2 hours at 40 degrees Celsius. Its hardening could be tested using control samples, for example dab of glue on an aluminium chuck undergoing same temperature treatment as the pixel module itself. It is worth noting that this gluing method is tolerant to speedy curing because expanding parts will simply lift up the pressure plate and the glue thickness defined by laminate material will remain uniform.

The whole assembly process takes approximately 10 minutes per module after mastering steps 6 and 11. Production of laminate material for a large number of modules could be contracted out to printing companies who can prepare contoured laminate on a card frame. It has been discussed whether or not should Quad Pixel Modules be kept on a frame after assembly for all their tests until final mounting onto half-ring supports. Industry-made laminate with single use card frame has one big advantage in this case as it could easily be trimmed for convenient handling.

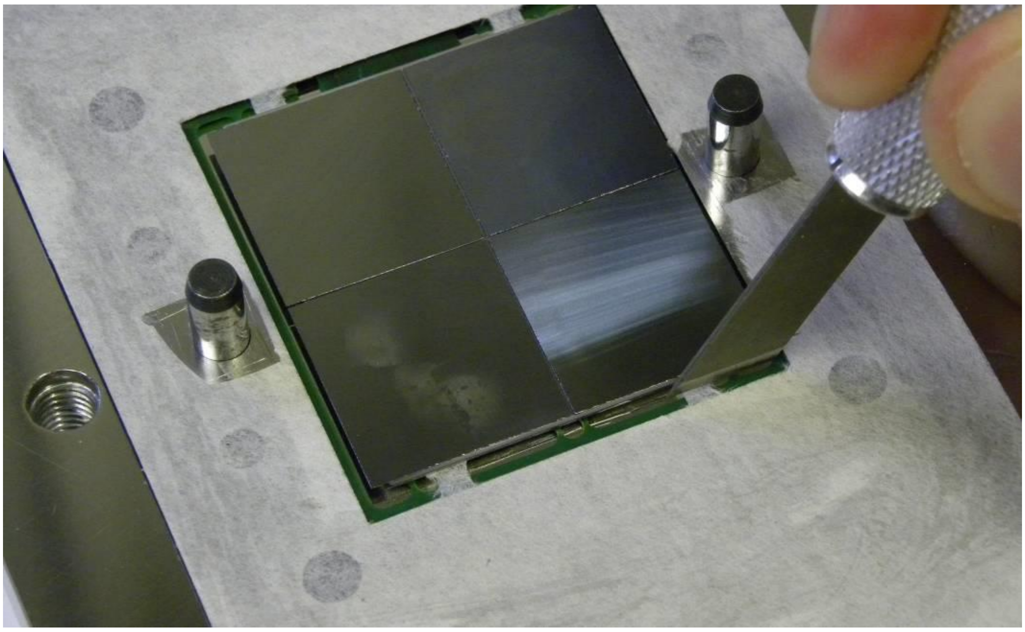
Drawings of jig parts together with DXF and Gerber data for their production and also uncompressed high-resolution photographs and a video clip of the Quad Pixel Module assembly process could be found at:

http://hep.ph.liv.ac.uk/~tsurin/POOL/Atlas/Pixel/Jig/
(Liverpool HEP twiki page would be better)

# Detaching Quad Pixel Module from the frame



Step 16. Put pressure plate upside down onto base plate to match vacuum holes.



Step 17. Place frame with PCB facing down onto pressure plate, apply strong vacuum to keep Quad Pixel Module static after its detaching, clip paper and kapton tabs using trimming knife.

## List of recommended commercial parts for the gluing jig

RS components Ltd is a preferred supplier of all complementary parts for making a jig. Below is a list of components for a single unit although most positions feature large minimum order quantity so they could be shared between several jigs. The same is true for tools and services, for example vacuum pump. Acrylic sheets or cutting mat could be sourced from any local hardware store.

| Pos. | Order Nr. | Q-ty | Description |
|---|---|---|---|
| 1 | 188-321 | 1 | 10mm thick 6082 aluminium alloy sheet 300mm x 500mm |
| 2 | 264-7279 | 1 | 2.5mm thick 316 A4 stainless steel sheet 300mm x 500mm |
| 3 | 245-2015 | 1 | Coil tubing OD=6mm |
| 4 | 744-0786 | 1 | Flexible pipe OD=4mm (length 20m, need per unit 1m) |
| 5 | 400-3299 | 1 | Manifold In OD=6mm, Out OD=4mm |
| 6 | 771-5327 | 1 | Elbow adapter A OD=4mm B OD=6mm (bag of 5, need 1) |
| 7 | 812-308 | 1 | Elbow push-in fitting OD=4mm (bag of 5, need 4) |
| 8 | 270-619 | 1 | Dowel pins D=5mm, L=20mm (bag of 20, need 2) |
| 9 | 603-536 | 1 | 20mm spacers M6 (bag of 10, need 4) |
| 10 | 600-717 | 1 | Powered Vacuum PickUp tool (could serve several assembly jigs) |
| 11 | 381-4868 | 1 | Trimming knife set (could be shared) |

## References


1. **Development of hybrid for EndCap Quad Pixel Module**, contribution to Atlas Upgrade Week in Freiburg 2014, http://indico.cern.ch/event/311426/contribution/8/material/slides/0.ppt

2. **The FE-I4 pixel readout integrated circuit**, M.Garcia-Sciveres et all, NIM A 636 (2011), pages S155-S159.

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4. **Development of planar pixel modules for the ATLAS high luminosity LHC tracker upgrade**, P.P. Allport et al, NIM A 765 (2014) pages 109-113

5. **Building CMS Pixel Barrel Detector Modules**, S. Koenig at al, NIM A 582 (2007) pages 776-780

6. **Design and assembly of double-sided silicon strip module prototypes for the ATLAS upgrade strip tracker**, ATLAS UPGRADE-PUB-2011-002

7. **High bandwidth pixel detector modules for the ATLAS Insertable B-Layer**, CERN-THESIS-2013-303 page 42

8. **Silicon strip staves and petals for the ATLAS Upgrade tracker of the HL-LHC**, S.Diesz on behalf of the ATLAS collaboration, NIM A 699 (2013) pages 93-96

9. **ATLAS Phase-II Upgrade Scoping Document**, CERN LHCC Report 2015-020

10. **Amplitude(TM) optical-grade paper datasheet**
www.contecinc.com/media/datasheets/amplitude%20optic%20wipe.pdf

11. **Electronic materials handbook Volume 1: Packaging** (1989) by Merrill L. Minges
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12. **Thermal Expansion Properties of Composite Materials** R.R. Johnson, G.B. Mackey, NASA Contractor Report 165632 (1981) via Google search