



*LIGO Laboratory / LIGO Scientific Collaboration*

LIGO-E1000277-v10

**ADVANCED LIGO**

28<sup>th</sup> January 2013

Preparation of an end or input penultimate mass  
(ETM/ITM PM)  
(Hydroxide-Catalysis Bonding of ears and gluing prisms  
and magnet flags)

Mariëlle van Veggel, Helena Armandula, Nicola Beveridge, William Cunningham, Russell Jones,  
Gerardo Moreno, Mark Barton

Distribution of this document:  
DCC

This is an internal working note  
of the LIGO Project.

California Institute of Technology

LIGO Project – MS 18-34

1200 E. California Pkwy

Pasadena, CA 91125

Phone (626) 395-2000

Fax (626) 304-9800

E-mail: [info@ligo.caltech.edu](mailto:info@ligo.caltech.edu)

LIGO Hanford Observ

P.O. Box 19708

Mail Stop S9-00

Richland WA 99115

Phone 509-372-8106

Fax 509-372-8137

**Institute for Gravitational  
Research**

**University of Glasgow**

**Kelvin Building**

**Glasgow G12 8QQ**

Phone: +44 (0)141 330 3340

Fax: +44 (0)141 330 6833

Web: [www.physics.gla.ac.uk/igr/](http://www.physics.gla.ac.uk/igr/)

Massachusetts Institute of Technology

LIGO Project – NW22-295

185 Albany St

Cambridge, MA 02139

Phone (617) 253-4824

Fax (617) 253-7014

E-mail: [info@ligo.mit.edu](mailto:info@ligo.mit.edu)

LIGO Livingston Observatory

P.O. Box 940

Livingston, LA 70754

Phone 225-686-3100

Fax 225-686-7189

<http://www.ligo.caltech.edu/>

Table of Contents

<b>1# Introduction.....</b>	<b>4#</b>
<b>1.1# Purpose and Scope .....</b>	<b>4#</b>
<b>1.2# Low detail time schedule .....</b>	<b>5#</b>
<b>1.3# Required lab-settings.....</b>	<b>5#</b>
<b>1.4# Equipment and Materials .....</b>	<b>6#</b>
<b>1.5# References.....</b>	<b>7#</b>
<b>1.6# Version history .....</b>	<b>8#</b>
<b>2# Main procedure for bonding the ears .....</b>	<b>10#</b>
<b>2.1# Set jig for the relevant side (“S3” or “S4”) of the mass.....</b>	<b>10#</b>
<b>2.2# Set-up mass and ear for cleaning.....</b>	<b>10#</b>
<b>2.3# Prepare bonding solution .....</b>	<b>11#</b>
<b>2.4# Clean the relevant side (“S3” or “S4”) of the mass .....</b>	<b>11#</b>
<b>2.5# Clean ear .....</b>	<b>13#</b>
<b>2.6# Bonding.....</b>	<b>14#</b>
<b>2.7# Initial curing and inspection .....</b>	<b>16#</b>
<b>2.8# Bond the other side .....</b>	<b>17#</b>
<b>2.9# Curing .....</b>	<b>18#</b>
<b>3# Main procedure for gluing the wire break-off prisms.....</b>	<b>18#</b>
<b>3.1# Set jig for the relevant side (“S3” or “S4”) of the mass.....</b>	<b>18#</b>
<b>3.2# Set-up mass and prism for cleaning .....</b>	<b>19#</b>
<b>3.3# Clean the relevant side (“S3” or “S4”) of the mass .....</b>	<b>19#</b>
<b>3.4# Clean prism .....</b>	<b>19#</b>
<b>3.5# Prepare the adhesive.....</b>	<b>20#</b>
<b>3.6# Gluing the prism onto the side.....</b>	<b>21#</b>
<b>3.7# Glue the prism on the other side.....</b>	<b>22#</b>
<b>4# Procedure for attaching the magnet flag bases .....</b>	<b>23#</b>
<b>5# Final air-bake and return to storage.....</b>	<b>25#</b>
<b>6# Back-up and other procedures .....</b>	<b>26#</b>
<b>6.1# De-bonding - procedure for when the bond quality is too low within 8 hours after bonding .....</b>	<b>26#</b>
<b>6.2# De-bonding procedure for when the bond quality is too low after a longer time (&gt;8 hr)</b>	<b>28#</b>

**6.3# Removing a prism and magnet base ..... 29#**  
**6.4# Applying/removing First Contact..... 29#**  
**6.5# Drag-wiping..... 30#**  
**6.6# Disposal of old sodium silicate solution..... 30#**  
**7# Remarks..... 30#**

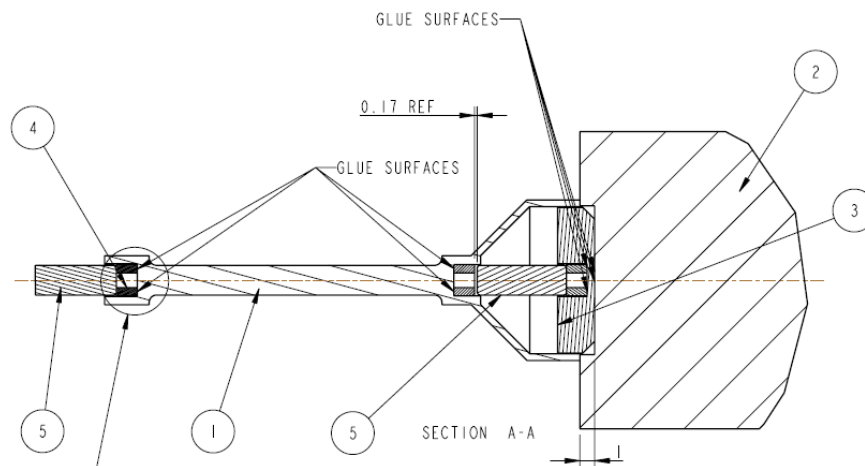
## 1 Introduction

### 1.1 Purpose and Scope

This document goes through the procedure for preparing an ETM/ITM penultimate mass (D080128-v1 and D080117-v1) for installation into the quadruple suspension structure. The procedure consists of three steps:

- 1) Hydroxide catalysis bonding on a fused silica ‘ear’ (suspension element according to D090007-v1) to each of the surfaces S3 and S4 in a well-defined location. General hydroxide-catalysis bonding procedures are detailed in E050228.
- 2) Attaching a sapphire wire break-off prism (D080479-v3) to each of the surface S3 and S4 in a well-defined location using EP30-2 adhesive.
- 3) Attaching 4 magnet-flag bases with magnets for the magnet flag assemblies into the counter-bored holes on surface S2. The magnet assemblies for the penultimate mass consist of 7 parts:
  1. Magnet flag - D070235
  2. (Mass)
  3. Magnet base – D1001124
  4. 3x Steel disc – D070238
  5. 2x Magnet - D0901345

The steel rings serve as attraction base for the magnets and are to be glued into the magnet flags on both ends and into the magnet base (Figure 1.1).



**Figure 1.1 Cross-section of the magnet assembly (D070234)**

The procedure ends with storing the mass. The procedure assumes the penultimate mass has been fully prepared. It includes handling the mass using the ergo-arm. Mirror handling procedures with the ergo-arm are detailed in T1000082.

It assumes that the mass has been stored in a COC ETM storage container or ‘cake-tin’ (D0902146). The procedure starts from the point of removing the mass from the ‘cake-tin’ using

the ergo arm. The procedure includes the 4-week curing period needed to cure the ears. The test mass is stored back into the cake-tin container during this curing period.

The adhesive Masterbond EP30-2 is used to glue the prisms and the magnets and magnet flag bases to the penultimate mass as per the 3<sup>rd</sup> November 2010 in E960050-v9. The adhesive procedure is detailed in E1000386 (as stated in E960022).

The procedure does not include cleaning and/or baking procedure prior to inserting the mass into the structure. On the date this update was written this was not considered as part of the procedure for the silica masses.

The document starts with giving an overview of the required lab-settings and tooling followed by giving the relevant documentation.

It then discusses the detailed steps of the procedure including location, timing, number of personnel needed and tooling needed.

### 1.2 Low detail time schedule

	Day 1	Day 2	4 Weeks	Day 31	Day 32	Day 33	People required
<b>Unpack mass and measure width</b>							Yes
<b>Bond ear 1</b>							Yes
<b>Bond ear 2</b>							Yes
<b>Curing</b>							No
<b>Glue prism 1</b>							Yes
<b>Initial cure glue</b>							No
<b>Glue prism 2</b>							Yes
<b>Initial cure glue</b>							No
<b>Glue magnet flag base plates</b>							Yes
<b>Full cure</b>							No

### 1.3 Required lab-settings

The surfaces must be free of particles, thus, the bonding must take place under a Class 100 laminar flow bench or in a Class 100 clean-room.

Operator must be dressed in clean room attire: overall, boots, head cover, facemask, and approved cleanroom gloves are required.

While handling undiluted sodium silicate solution safety goggles must be worn.

This clean-room has a sink with running DI water with a resistance of 18 MΩ. It also has two tables of normal height (between 70 and 75 cm).

## 1.4 Equipment and Materials

- Filtered dry nitrogen
- Air gun or unplugged de-ionizing gun (de-ionizing gun must be unplugged for at least 5 minutes prior to use near flammable liquid)
- High intensity light source (ideally handheld battery supported)
- DI water 18 M $\Omega$  resistance
- Pipettor with tip ejector - variable volume, 2-20  $\mu$ l, Eppendorf 2000 - (VWR Cat. No. 53511-588)
- Microcentrifuge tubes - Eppendorf, 1.5 ml - (VWR Cat. No. 20901-551)
- VWR® MiniFuge Microcentrifuge - 120V, 50/60Hz - (VWR Cat. No. 93000-196)
- Microcentrifuge tubes storing rack - (VWR Catalog No. 20901-675)
- Centrifuge tubes - polypropylene, graduated, 15 ml – (VWR Cat. No. 21008-103)
- Centrifuge tube's rack – (VWR cat. No. 21008-485)
- Medical Filter: Whatman Filter Uniprep 0.2UM PK50 UN113ENYL Filter
- Eppendorf\* epTIPS\* Pipette Tips – Sterile PCR Clean Filter Tips, 2-20  $\mu$ l, 10 Racks of 96 Tips – (VWR Cat. No. 47745-092)
- Alpha 10 wipes - case – (VWR Cat. No. TWTX1010)
- Gloves - VWR Certi-Clean Class 100 Latex Gloves or Accu Tech Ultra Clean 91300 Gloves.
- Methanol – Spectroscopic grade
- Acetone – Spectroscopic grade
- Sodium bicarbonate (= Bicarbonate of soda)
- Cerium oxide polishing compound
- Sodium Silicate Solution – from Sigma-Aldrich 338443-1L (~10.6% NaOH, ~26.5% SiO<sub>2</sub> by weight)
- Ultrasonic cleaner - BRANSON 8510
- 2x V-block - D1001685
- Bonding jig - D1001592
- Prism holder assembly – D1001623
- Metric slip gauges
- Allen key for #2-56 socket-head cap screw
- Digital calipers – with metric setting
- EP30-2 Adhesive and gun-kit applicator

- UHV aluminium foil
- Uncoated copper wire  $\varnothing$  0.5 mm
- Glass petri dishes
- Magnifying glass
- First contact
- Ergo-arm
- Safety goggles
- SYS-approved air-bake oven large enough to accommodate PUM and capable of temperature and ramp rates called out in M1200294.

## 1.5 References

<i>Design documentation 'glass' essentials</i>	
D080128	ALIGO ITM Quad penultimate mass
D080117	ALIGO ETM Quad penultimate mass
D090007	aLIGO SUS ETM/ITM Quad PM Production Ear with Recess
D1001035	aLIGO SUS ITM Production Penultimate Mass WITH PRISMS AND EARS ASSEMBLY
D080479	aLIGO SUS ETM ITM QUAD PM Wire Break-off Prism
<i>Design documentation metal essentials</i>	
D070234	Pen Re Mass Magnets (External Shielded Magnets)
D070235	Pen Re Mass Magnets, Magnet Holder (External Shielded Magnets)
D1001124	Pen Re Mass Magnets, Magnet Base (External Shielded Magnets)
D070238	Pen Re Mass Magnets, Steel Disk (External Shielded Magnets)
D0901345	2MM DIA X 6MM MAGNET
<i>Design documentation of the alignment jigs</i>	
D0901592	ASSEMBLY DRAWING – NP-type bonding jig
D0901591	Baseplate – NP-type bonding jig
D1000128	Penultimate mass prism holder
<i>Measurement reports on 'glass' essentials</i>	
Q10xxyy	Relevant penultimate mass control measurements
Q10xxxx	Relevant ear control measurements of ears
Q10zzzz	Relevant prism control measurements of prisms
<i>Back ground documents</i>	

E050228	(Specification) Silicate Bonding Procedure
T0900402	Enhanced LIGO core optic drag wipe cleaning procedure
E0900394	aLIGO Optic Container Shipping Procedure
E1000079	Advanced LIGO First Contact procedure for large optics
T1000114	ALIGO NP-type: - Report on Ear Bonding at LASTI 27 <sup>th</sup> August – 31 <sup>st</sup> August
T0900447	Ear fabrication readiness review
M080134	ETM/ITM and BS/FM pitch frequencies and d-values
T1000534	Ergo-arm users manual
T1100238	Report on hydroxide catalysis bonding done at LHO in March and April 2011
D0902146	ASSEMBLY, ETM, COC OPTIC CONTAINER, ADVANCED LIGO
D1100555	Metrology baseplate for ear and prism position measurements
E1000079	First Contact Application and Removal Procedure
F1000006	Bond quality monitoring form
E1000265	Jig-settings calculation sheet
E1000386	Material Qualification RGA Test Results: MasterBond EP30-2 epoxy
E960022	LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures
E960050	LIGO Vacuum Compatible Materials List
M1200294	Stop Work for Adhesive Bonding of Elements to Optics
T1200130	Ion gun use and safety eyewear training
T1200321	Guidelines on protecting the Cavity Optics in chamber wrt First Contact
E1200821	Guidelines for use in de-bonding of epoxy bonds from optics

## 1.6 Version history

04/08/10: Requested DCC number for the document

08/04/10: Release v1 onto DCC

02/19/11: Release v2 onto DCC

31/03/11: Release v3 onto DCC – added a small overview schedule at the start of the document

02/08/11: Release v4 onto DCC – added procedural steps to check the position of the ears and prisms on the mass, a flag to slant the mass slightly to prevent the ear from drifting away from the jig

26/08/11: Release v5 onto DCC - Correction of step 2 in the procedure on which side of the jig to use for which surface

31/08/11: Release v6 onto DCC – correction of equation in step 43.



09/03/12: Release v7 onto DCC – Added a requirement to unplug the de-ionizer gun for 5 minutes before use around flammable liquids, or use an air gun.

28/08/12: Release v8 onto DCC – Added requirement to wear safety goggles during the use of undiluted bonding solution.

20/9/12: v9 - New guidance on use of EP30 from M1200294. New guidance on de-gluing from E1200821.

28/01/13: v10 – Added information in section 2.9 on when a bonded mass is ready for shipping and insertion into a suspension.

-

## 2 Main procedure for bonding the ears

### 2.1 Set jig for the relevant side (“S3” or “S4”) of the mass

Step	What	Where	Time	People	Tools
1	Select the mass, which side (surface “S3” or “S4”), ear and bonding jig that will be used for the bonding. Calculate the required settings for $D_{\text{slider}}$ and $D_{\text{screw1}}$ for the bonding jig using the excel spreadsheet (E1000256) and copy onto clean-room paper	in office	30 min	2 (one calculator, one checker)	Quality control documentation of mass, ear and bonding jig.
2	Set $D_{\text{screw}}$ on the left side of the jig (side 1 on the assembly drawing) for bonding onto surface “S4” or the right side of the jig (side 2 on the assembly drawing) for bonding onto surface “S3”	in bonding cleanroom	5 min	1	Bonding jig assy, slip gauges of the right thickness
3	Set $D_{\text{slider}}$ on both sliders of the jig	in bonding cleanroom	5 min	1	Bonding jig assy, calipers, Allen key for #2-56 cap screw
			<b>40 min</b>		

### 2.2 Set-up mass and ear for cleaning

Step	What	Where	Time	People	Tools
4	Take the mass out of its ‘cake-tin’ and place onto the V-block on the washing table/sink. This is done using the ergo-arm. Follow instructions for cake-tin. <b>The bonding sides are placed vertically to minimize risk of rinsing water and methanol over the coated surfaces of the mass and to give easier access.</b>	in bonding cleanroom	15 min	2	Ergo-arm (T1000082), mass in ‘cake-tin’ with tooling to open, V-block, isopropanol, optical wipes
5	Take the ear out of its packaging and place in a petri dish on an optical cloth	in bonding cleanroom	2 min	1	Ear, petri dish, cleanroom wipes
6	Change gloves	in bonding cleanroom	1 min	2	Gloves
			<b>18 min</b>		

### 2.3 Prepare bonding solution

Step	What	Where	Time	People	Tools
7	Wear a pair of safety goggles. Pour 2 ml of sodium silicate solution and put the lid on a 15 ml centrifuge tube. Close the sodium silicate bottle promptly to prevent contamination and for safety reasons and store the bottle in the chemicals cabinet. Then add 12 ml of DI water into the tube, close the lid, and shake thoroughly for 30 seconds (this gives a 1:6 volumetric ratio of sodium silicate solution to DI water).	in bonding cleanroom	1 min	1	15 ml centrifuge tube, sodium silicate solution, DI water, safety goggles
8	Transfer the solution into 3 1.5 ml centrifuge tubes. Take care you don't hover with any gear above the tubes at any time. Then close lids. Transfer to centrifuge and let them spin for 30 seconds.	in bonding cleanroom	1 min	1	Rack for 1.5 ml centrifuge tubes, 1.5 ml centrifuge tubes, centrifuge
9	Open up two of three centrifuge tubes and transfer to the outer shell of a medical filter. Leave a bit in the centrifuge tubes as this bit will contain the larger particles. Also, stay below the stepped edge of the medical filter (this is the maximum amount the filter can effectively filter). Then place the (closed) filter piece into the outer shell and press down until it clicks into the outer shell edge.	in bonding cleanroom	1 min	1	0.2 µl medical filter
10	Transfer the medical filter with solution to the bonding table and change gloves	in bonding cleanroom	1 min <b>4 min</b>	1	Gloves

### 2.4 Clean the relevant side ("S3" or "S4") of the mass

Step	What	Where	Time	People	Tools
11	Make sure the dry nitrogen supply is open and air gun can blow a gentle consistent and well controlled flow.  Make sure methanol and optical wipes are ready.  Get the DI water running gently but solidly through the flexible hose	in bonding cleanroom	1 min	1	Dry nitrogen

Step	What	Where	Time	People	Tools
	Open petri dish with bicarbonate of soda. Put that at the back to minimize risk of contaminating with cerium oxide				
	Open petri dish with cerium oxide. Put that in front of the bicarbonate of soda.				
12	Rinse DI water over side “S3” or “S4” of the TM. Rub the surface with a folded wet optical wipe embedded with cerium oxide paste in a random motion with moderate pressure. Make sure the actual bond area is rubbed best but extend the area to about three times the width and height. The cerium oxide paste should start sticking uniformly over the cleaned surface. The surface should become hydrophilic. Typically 30 seconds of rubbing is enough. Rinse again with DI water and rub with a clean optical wipe to get rid of most cerium oxide.	in bonding cleanroom	1 min	2	DI water, cerium oxide, optical wipes
13	Throw away the cerium oxide cloth and rinse fingers thoroughly.	in bonding cleanroom	1 min	2	
14	Rub side “S3” or “S4” with a folded wet optical wipe embedded with a copious amount of bicarbonate of soda paste with moderate pressure. Work from the inside out to work remainders of cerium oxide from inside out. Typically 30 seconds of rubbing is enough. Make the cleaning area slightly bigger than was done for the cerium oxide. Rinse with water to wash away bicarbonate of soda.	in bonding cleanroom	1 min	2	DI water, bicarbonate of soda, optical wipes
15	Repeat step 14.	in bonding cleanroom	1 min	2	DI water, bicarbonate of soda, optical wipes
16	Rinse the cleaned area with methanol and blow dry gently with de-ionized nitrogen. Once again work from the clean inner area outward and cover a larger area. Wipe away as many water drops that have run along the barrel away with a cloth soaked in methanol.	in bonding cleanroom	1 min	2	Methanol, dry nitrogen, optical wipes
17	Inspect the cleaned surface: it is verified as cleaned when no particles or	in bonding cleanroom	1 min	2	Fiber optic light source, magnifying

Step	What	Where	Time	People	Tools
	films are present when viewed without optical aid at a viewing distance of 5"- 6" while the surface is illuminated by a fiber optic light source against a dark background.				glass (optional)
18	Change gloves	in bonding cleanroom	1 min	2	Gloves
19	Lift up the test mass using the ergo-arm and wipe carefully and thoroughly with a cloth soaked in methanol underneath the mass, where water ran.	in bonding cleanroom	5 min	2	Ergo-arm, methanol, optical wipes
20	Turn the mass 90°, such that the cleaned side is pointing upward ready for bonding and cover with an optical wipe.	in bonding cleanroom	1 min	2	Optical wipes
21	Transport the mass on the ergo-arm to the bonding table and put it down onto the V-block for bonding. <b>Make sure that the bonding flat is slightly slanted down towards the reference edge of the bonding jig when it is placed on the mass later, so that the ear will not have a tendency to drift away from the jig in the first minute after placing down the ear.</b>	in bonding cleanroom	5 min	2	
			<b>19 min</b>		

## 2.5 Clean ear

Step	What	Where	Time	People	Tools
22	Make sure the air gun, the DI water gun and the supply of methanol and wipes described in step 11 are still available.	in bonding cleanroom	1 min	1	Contact, clean room wipes
23	Take the ear into an optical cloth and rinse with DI water. Embed another optical wipe with cerium oxide and rub the entire ear with moderate pressure. Make sure all edges and corners are covered. Take about 1 minute. Rinse again with DI water to get rid of most cerium oxide.	in bonding cleanroom	1 min	1	DI water, cerium oxide, optical wipes
24	Transfer the ear to another optical wipe embedded with cerium oxide and	in bonding	30 sec	1	DI water, cerium

Step	What	Where	Time	People	Tools
	rub the bonding surface in particular. Do this for 30 seconds.	cleanroom			oxide, optical wipes
25	Transfer the ear to another clean optical wipe and rub to remove most cerium oxide. Make sure gloved hands are rinsed thoroughly as well.	in bonding cleanroom	1 min	1	
26	Transfer the ear to an optical wipe embedded with copious amounts of bicarbonate of soda and rub it with moderate pressure for about 1 minute. Rinse.	in bonding cleanroom	1 min	1	DI water, bicarbonate of soda, optical wipes
27	Transfer the ear to a fresh optical wipe embedded with copious amounts of bicarbonate of soda and rub in particular the bonding surface with moderate pressure for about 30 seconds.	in bonding cleanroom	30 sec	1	DI water, bicarbonate of soda, optical wipes
28	Thoroughly rinse the ear and gloved hands with DI water while the ear is lying in a hand upside down, ensuring to never touch the bonding surface with the gloves.	in bonding cleanroom	30 sec	1	
29	Rinse the ear with methanol and cover with an optical wipe.	in bonding cleanroom	30 sec	1	Methanol, optical wipe
30	Transfer part back to petri dish on bonding table lined with a fresh optical wipe	in bonding cleanroom	30 sec	1	Petri dish, optical wipe
31	Clean gloves	in bonding cleanroom	30 sec	1	Gloves
			<b>7 min</b>		

## 2.6 Bonding

Step	What	Where	Time	People	Tools
32	Set the pipette to 9.6 $\mu$ l and lock.		1 min		
33	Take the optical wipe off side 1 of the mass. Take a folded optical wipe soaked with methanol and wipe the bonding surface. Blow dry with dry nitrogen from the air gun. Use the fibre optic light to thoroughly inspect	in bonding cleanroom	1 min		

Step	What	Where	Time	People	Tools
	the surface for small specks from a distance of 5-6". Wipe and/or blow any specks away.				
34	Wipe down the bonding jig with methanol to remove any dust and place it on the bonding surface by referencing the front surface ("S1") of the mass and lining the sliders up with the fiducials on surface ("S3"). Tighten the spring-loaded screw onto surface "S2".	in bonding cleanroom	3 min	1	Optical wipe, methanol
35	Pick up the ear and wipe the bonding surface in one stroke with a folded optical wipe soaked with methanol. Gently blow dry with dry nitrogen using the air gun. Use the fibre optic light to thoroughly inspect the surface for small specks from a distance of 5-6". Wipe and/or blow any specks away. Lay the ear back down.	in bonding cleanroom	1 min	2	Dry nitrogen, air gun, high intensity light source, optical wipe soaked in methanol
36	Put a pipette point onto the pipette and extract the required solution from the medical filter, making sure not to touch the pipette tip to anything except the solution and making sure to close the filter again. Give the surface of the mass one more glance to ensure no more specks have landed and then place the drop of bonding solution down about 3 cm from the left reference edge and 1 cm from the top reference edge of the bonding jig (middle of the ear). Remove the pipette tip and place the pipette back.	in bonding cleanroom	1 min	2	Pipette, pipette tips bonding solution
37	Pick up the ear. Give the surface of the mass one more glance to ensure no more specks have landed. Place the ear carefully onto the mass, while lining it up with the top-left corner of the bonding jig hole. <b>Gently push the ear into the top left corner of the jig for the first minute after placing it, to ensure the ear does not drift away.</b>	in bonding cleanroom	1 min	1	High intensity light source
38	Inspect how the bonding solution spreads. It should spread readily over the entire bonding surface. Viewing at a shearing angle of $\sim 30^\circ$ one should see coloured fringes. There might also be bubbles visible. These should be moving towards the edges.	in bonding cleanroom	5-10 min	2	High intensity light source

Step	What	Where	Time	People	Tools
	Note down on the inspection sheet all relevant information including the state of the bond initially (bubbles and fringes). Keep on checking for about 5 to 10 minutes.				
			<b>18 min</b>		

## 2.7 Initial curing and inspection

Step	What	Where	Time	People	Tools
39	Inspect the bond every 30 minutes for the first 2 hours and note down on the inspection sheet.		25 min 5 min 25 min 5 min 25 min 5 min 25 min	0 1 0 1 0 1 0	Fibre optic light, pen, inspection sheet F1000006
40	Remove the bonding jig carefully after 2 hours		10 min	1	Fibre optic light, pen, inspection sheet F1000006
41	Place slip gauges on top of the PFA440 flat template (D1100555) against the left side of the ear. Touch another slip gauge gently against the face of the mass (closest to the left side of the ear) and stick it out to show if there is a gap between the slip gauges on the flat. If there is, change the width of the slip gauges on the flat until the gap is closed to the closest 10 $\mu\text{m}$ and the slip gauge against the face of the mass is flat against both the flat and the slip gauges on the flat.  Check the total width of the slip gauges with digital calipers and note down the width. The value is denoted $A$ .  Look up $x_{hl}$ and $z$ for the ear used in E1000265.	In bonding clean room	10 min	2	Slip gauges, E1000265 file to hand, D1100055 flat template.



Make the following calculation:

$$d_{S-center\ ear} = A + z$$

Compare this value to  $w_{mass}/2$ . If the values are equal to each other within 0.1 mm, the ear has been bonded on with satisfactory accuracy (see T1100238 for more details).

If these values are not equal within 0.1 mm, the ear will have to be debonded and a new ear rebounded.

42	Inspect the bond every hour for the following 3 hours.	55 min 5 min 55 min 5 min 55 min 5 min	0 1 0 1 0 1	Fibre optic light, pen inspection sheet F1000006
43	Leave bond to cure for at least 12 hours before starting the other side.	7 hrs <b>12 hrs</b>		

### 2.8 Bond the other side

Step	What	Where	Time	People	Tools
44	Use the ergo-arm to move the mass back to the sink to allow for starting the bonding procedure for the other side of the mass	in bonding cleanroom	10 min	2	First Contact, clean room wipes
45	Repeat steps 1 through 38.	In office/ in bonding cleanroom	1 hr 46 min	1,2	See above
46	Repeat the curing steps 39 through 43	In bonding cleanroom	12 hrs	0,1	See above

Step	What	Where	Time	People	Tools
47	Use the ergo-arm to store the mass back into it's cake-tin and move the cake-tin to mass storage	In bonding cleanroom/ mass storage place	30 min	2	Ergo-arm, cake-tin

## 2.9 Curing

Step	What	Where	Time	People	Tools
48	Leave the ears to cure in storage for at least 4 weeks before commencing with attaching prisms and magnet flags.  The mass with bonded ears can be shipped after one week of curing has been completed for optical testing for example.	Mass storage	28 days	0	

## 3 Main procedure for gluing the wire break-off prisms

### 3.1 Set jig for the relevant side ("S3" or "S4") of the mass

Step	What	Where	Time	People	Tools
49	Choose which side (surface "S3" or "S4") to bond the prism, select a prism, prism holder and bonding jig that will be used for the bonding. Calculate the required settings for $D_{\text{slider}}$ and $D_{\text{screw1}}$ for the bonding jig using the excel spreadsheet (E1000256) and copy onto clean-room paper	In office	30 min	2 (one calculator, one checker)	Quality control documentation of mass, ear and bonding jig.
50	Set $D_{\text{screw}}$ on the left side of the jig for bonding onto surface "S3" or the right side of the jig for bonding onto surface "S4"	in bonding cleanroom	5 min	1	Bonding jig assy, slip gauges of the right thickness
51	Set $D_{\text{slider}}$ on both sliders of the jig	in bonding cleanroom	5 min	1	Bonding jig assy, calipers, Allen key size #2-56
			<b>40 min</b>		

### 3.2 Set-up mass and prism for cleaning

Step	What	Where	Time	People	Tools
52	Take the mass out of its ‘cake-tin’ and place onto the V-block on the washing table/sink. This is done using the ergo-arm. Follow instructions for cake-tin. The bonding sides are placed vertically to minimize risk of rinsing water over the coated surfaces of the mass and to give easier access.	in bonding cleanroom	15 min	2	Ergo-arm (T1000082), mass in ‘cake-tin’ with tooling to open, V-block, isopropanol, optical wipes
53	Take the prism out of its packaging and place in a petri dish on a clean room wipe	in bonding cleanroom	2 min	1	Ear, petri dish, optical wipe
54	Change gloves	in bonding cleanroom	1 min	2	Gloves
			<b>18 min</b>		

### 3.3 Clean the relevant side (“S3” or “S4”) of the mass

Step	What	Where	Time	People	Tools
55	Make sure the dry nitrogen supply is open and air gun can blow a gentle consistent and well controlled flow. Make sure acetone, methanol and optical wipes are ready.	in bonding cleanroom	1 min	1	Dry nitrogen
56	Use the drag wiping procedure to carefully wipe the relevant side (“S3” or “S4”) with acetone. Repeat with isopropanol or methanol	in bonding cleanroom	1 min	1	DI water, cerium oxide, clean room wipes
57	Use the air gun to gently blow dry the bonding area	in bonding cleanroom	1 min	1	
			<b>3 min</b>		

### 3.4 Clean prism

Step	What	Where	Time	People	Tools
------	------	-------	------	--------	-------

Step	What	Where	Time	People	Tools
58	Take the prism into a clean room cloth. Apply some acetone to another wipe and wipe the surface to be bonded carefully.	in bonding cleanroom	1 min	1	DI water, cerium oxide, optical wipes
59	Repeat with isopropanol or methanol	in bonding cleanroom	30 sec	1	DI water, cerium oxide, optical wipes
60	Transfer part back to petri dish on bonding table lined with a fresh optical wipe	in bonding cleanroom	30 sec	1	Petri dish, optical wipe
61	Take the prism holder and wipe with methanol to remove any dust particles.	In bonding cleanroom	30 sec	1	Prism holder, optical wipe, methanol
62	Turn the grub screw on the prism holder back so that the prism can easily be put into the holder. Pick up the prism and carefully put it in the prism holder ensuring it sits comfortably against all three support rods. Then tighten the grub screw such that it is just tight enough to prevent the prism from falling out of the prism holder.	In bonding cleanroom	1 min	1	Fingers should be enough, Allen key for #2-56 socket head cap screw
63	Clean gloves	in bonding cleanroom	30 sec	1	Gloves
			<b>3 min</b>		

### 3.5 Prepare the adhesive

Step	What	Where	Time	People	Tools
64	Make a boat of clean UHV aluminium foil	in bonding cleanroom	1 min	1	UHV aluminium foil
65	Prepare a couple of applicator wires (0.3 mm uncoated copper wire). Wipe them with acetone followed by a wipe with isopropanol or methanol	in bonding cleanroom	1 min	1	0.3 mm uncoated copper wire, acetone, methanol or isopropanol
66	Put an EP30 adhesive cartridge into the applicator gun, remove (but save) the end cap, and fit a new mixing tube. Dispense at least a full trigger-pull's worth of adhesive onto scrap foil until the adhesive appears	in bonding cleanroom	2 min	1	EP30 gun

Step	What	Where	Time	People	Tools
	to be coming out well-mixed, and then dispense a small amount into the boat. Remove and discard the mixing tube and replace the end cap.		4 min		

### 3.6 Gluing the prism onto the side

Step	What	Where	Time	People	Tools
67	Take the optical wipe off side 1 of the mass. Take a folded optical wipe soaked with methanol and wipe the bonding surface. Blow dry with dry nitrogen from the air gun. Use the fibre optic light to thoroughly inspect the surface for small specks from a distance of 5-6". Wipe and/or blow any specks away.	in bonding cleanroom	1 min	1	Optical wipe, methanol
68	Wipe down the bonding jig with methanol to remove any dust and place on the bonding surface by referencing off the front surface ("S1") of the mass and lining the sliders up with the fiducials in surface ("S3"). Tighten the spring-loaded screw onto surface "S2".	in bonding cleanroom	3 min	1	Optical wipe, methanol
69	Check the prism for dust and wipe with methanol if there is any. Blow dry with dry nitrogen.				
70	Dip the copper applicator wire into the adhesive in the aluminium boat. Draw a cross of adhesive from corner to corner onto the prism. Stay about 1 mm from the edge of the corner though. The thickness of the adhesive should be approximately 0.5 mm.	in bonding cleanroom	1 min	1	Uncoated copper applicator wire
71	Pick up the prism holder and put the prism down onto the mass while referencing the prism holder against the bottom left corner of the bonding jig. Apply some mild pressure to make the adhesive spread. The cross pattern helps to get the adhesive in the corners and prevent it from escaping from underneath the edges at the same time.	in bonding cleanroom	1 min	1	
72	Leave the remainder of the adhesive in the boat beside the mass. Leave the adhesive to cure overnight (12 hrs). Contrary to earlier versions of	In bonding cleanroom	12 hrs	0	

Step	What	Where	Time	People	Tools
	this procedure do not use a heat lamp.				
73	On return, check the adhesive in the boat has cured by breaking it. It should break in a brittle way.	In bonding cleanroom	1 min	1	
74	Loosen the grub screw on the prism holder and carefully remove it. Then loosen the spring loaden screw on the jig and carefully remove the jig from the mass.	In bonding cleanroom	2 min	1	
75	Use the CMM to measure the position of the prism with respect to the front and back and the fiducial lines to confirm the prism is in the correct position	In bonding cleanroom	1 hr	2	
			<b>8 min</b>	<b>1</b>	
			<b>12 hrs</b>	<b>0</b>	
			<b>63 min</b>	<b>2</b>	

### 3.7 Glue the prism on the other side

Step	What	Where	Time	People	Tools
76	Use the ergo-arm to turn the mass 180° to allow for bonding the prism onto the other side.	in bonding cleanroom	10 min	2	First Contact, clean room wipes
77	Repeat steps 49 through 51 and 53 through 73.	In office/ in bonding cleanroom	26 min	1,2	See above
78	Repeat the curing steps 74 through 77.	In bonding cleanroom	12 hrs + 63 min	0,1	See above
79	Use the ergo-arm to put the mass onto surface S1 onto a patch of cleanroom wipes.	In bonding cleanroom/ mass storage place	10 min	2	Ergo-arm, cake-tin
			<b>36 min</b>	<b>2</b>	
			<b>12 hrs</b>	<b>0</b>	
			<b>73 min</b>	<b>2</b>	

## 4 Procedure for attaching the magnet flag bases

Steps 81 through 89 can be executed with the same adhesive and in conjunction with the gluing of one of the prisms.

Step	What	Where	Time	People	Tools
80	Prepare 12 steel rings, 4 magnet bases and 4 magnet flags by wiping them with acetone followed with a wipe with isopropanol or methanol (for one mass).	in bonding cleanroom	1 min	1	12 steel rings (D070238), 4 magnet bases (D1001124), 4 magnet flags (D070235), cleanroom wipes, acetone, methanol or isopropanol
81	Prepare the adhesive as described in steps 64 to 66.	in bonding cleanroom	7 min	1	UHV aluminium foil, EP30 adhesive, razor blade or scissors, backing pump, vacuum vessel
82	Dip the applicator wire in the EP30 with an effort to create a small a drop as possible on the end.	in bonding cleanroom	1 min	1	0.3 mm uncoated copper wire, acetone, methanol or isopropanol,
83	Pick up a steel disc with a pair of tweezers and apply the adhesive to the back	in bonding cleanroom	1 min	1	Steel tweezers
84	Glue the steel disc into one end of the magnet flag or into a magnet base still using the tweezers. As the discs are hollow, make sure that no excess adhesive protrudes at the front of the discs as this would prevent the magnets from properly adhering to the steel rings.	in bonding cleanroom	1 min	1	
85	Repeat steps 82 to 84 until the discs have been glued into one end of all 4	in bonding	8 min	1	

Step	What	Where	Time	People	Tools
86	magnet flags and into all 4 magnet bases. Leave the remainder of the adhesive in the boat beside the mass. Leave the adhesive to cure overnight (12 hrs). Contrary to earlier versions of this procedure, do not use a heat lamp.	cleanroom in bonding cleanroom	12 hrs	0	
87	On return, check the adhesive in the boat has cured by breaking it. It should break in a brittle way.	in bonding cleanroom	1 min	1	
88	Prepare more EP30 as described in steps 64 to 66.	in bonding cleanroom	7 min	1	
89	Wipe the counter bores in surface S2 of the mass thoroughly with acetone and methanol or isopropanol using cleanroom swap sticks. Blow dry with dry ionized nitrogen.	in bonding cleanroom	2 min	1	Cleanroom swap sticks, acetone, methanol or isopropanol
90	Clean the magnet bases with methanol on the back	in bonding cleanroom	30 sec	1	Cleanroom wipes, acetone, methanol or isopropanol
91	Clean the copper wire with acetone and methanol or isopropanol using cleanroom wipes.	in bonding cleanroom	30 sec	1	0.3 mm copper wire, cleanroom wipes, acetone, methanol or isopropanol
92	Dip the copper wire in the EP30 creating a small drop of adhesive on it's end.	in bonding cleanroom	30 sec	1	
93	Hold the magnet base upside down using a pair of tweezers and apply the EP30 to the back, spreading it out to a uniform thin layer with the copper wire.	in bonding cleanroom	30 sec	1	
94	Glue in the magnet base into on of the counterbore holes on surface S2 of the mass. Remove the tweezers and apply some mild pressure to make the adhesive spread.	in bonding cleanroom	30 sec	1	
95	Repeat steps 94 through 97 for the remaining three magnet bases.	in bonding cleanroom	6 min	1	



Step	What	Where	Time	People	Tools
96	Dip the applicator wire in the EP30 with an effort to create a small a drop as possible on the end.	in bonding cleanroom	1 min	1	0.3 mm uncoated copper wire, acetone, methanol or isopropanol,
97	Pick up a steel disc with a pair of tweezers and apply the adhesive to the back	in bonding cleanroom	30 sec	1	Steel tweezers
98	Glue the steel disc into the other end of the magnet flag.	in bonding cleanroom	30 sec	1	
99	Repeat steps 96 through 98 for the remaining three magnet flags	in bonding cleanroom	2.5 min	1	
100	Leave the glue to cure overnight (12 hrs). Contrary to ealier versions of this procedure, do not use heat lamps.	in bonding cleanroom	12 hrs	0	2 Heat lamps on stands
101	On return, check the adhesive in the boat has cured by breaking it. It should break in a brittle way.	in bonding cleanroom	1 min	1	
			<b>12 hrs 6 min</b>		

## 5 Final air-bake and return to storage

Step	What	Where	Time	People	Tools
102	Set up the V-block in a cold (room-temperature) airbake oven.	In bonding cleanroom	1 min	1	V-block, airbake oven
103	Use the ergo arm to pick up the optic and move it onto the V-block in the oven.	In bonding cleanroom	5 min	2	ergo-arm
104	Remove First Contact from both sides of the optic.		30 min	1	ion gun, Berkshire lint free wipes, acetone

Step	What	Where	Time	People	Tools
105	Set the oven for a maximum temperature of 34°C with a ramp rate of 1.5°C per minute or less.	In bonding cleanroom	1 min	1	
106	Bake the optic for 6 hours, monitoring the temperature with a thermocouple from time to time to check that it does not exceed the above ramp rate or maximum temperature.	In bonding cleanroom	6 hrs	0	thermocouple
107	Switch off the oven and allow the optic to cool.	In bonding cleanroom	30 min	1	
108	Once the optic has reached room temperature, use the ergo-arm to move it into the storage container	In bonding cleanroom	5 min	2	ergo-arm
109	Reassemble the storage container around the optic and take the optic to storage.	In bonding cleanroom/ mass storage place	10 min	2	ergo-arm, storage container
110			<b>6 hrs 46 min</b>		

## 6 Back-up and other procedures

### 6.1 De-bonding - procedure for when the bond quality is too low within 8 hours after bonding

Defining too low quality:

If after bonding an ear it becomes obvious that:

1. (despite every caution) a particle is trapped in the bond, which is visible by the eye without magnifying aids, causing a clear dark speck with fringes around it.
2. an area of more than 50 mm<sup>2</sup> (area of ~ 7 x7 mm or ¼" x ¼") part of the bonding area is not covered by bonding solution. This can be seen by the fact that the area not bonded is reflective in nature, whereas the area bonded is transparent. The total bonding area is approximately 1185 mm<sup>2</sup>, which means that the area not bonded can be maximally 4.2%. Bond loss measurements performed by Peter Murray (P0900053) were performed with a bond in which approximately the same percentage of bond area was not bonded.

3. If there is a number of small bubbles in the bond initially they can make up a slightly larger percentage of the bond area (up to 8% as it is likely that some or most of the bubbles will move to the sides and disappear. It is not necessary to debond immediately in that case.

It will take approximately 50 to 60 seconds for a bond to settle initially in a laboratory at 20 °C (humidity unknown but typically 30-50% in the laboratory) (Reid et al., Phys. Lett. A, 2007). Initial settling means that with minor force applied it will not move. In the first 8 hours after bonding it is possible to break to bond using a combination of rinsing with copious amounts of DI water and applying a moderate amount of manual force (preferably in a rotation around the axis perpendicular to the bond surface, effectively shearing it). For 1 inch bonded discs a 100% de-bonding success rate was achieved using this method up to 13 hours after the bond was made (T1000464). As the ear bonds cover a larger surface area a shorter time period is recommended. The procedure for this is discussed below.

Step	What	Where	Time	People	Tools
1	Observe that the bond quality is unlikely to meet requirements.	In clean-room	10 min	2	High intensity light source
2	Carefully remove the bonding jig, by releasing the spring-loaded bolts and lifting it carefully off the surface.	In clean-room	1 min	1	
3	Lift up the mass using the ergo-arm, transport to the washing table and rotate the mass 90° back before placing it down onto the V-block on the basin.	In clean-room	10 min	2	Ergo-arm
4	Run copious amounts of DI water along the bonded ear. Apply a moderate amount of manual force in a shearing direction or rotation. This combination should allow the ear to come off the side of the mass within 3 minutes.	In clean-room	1 min	2	DI water
5	Gently place the ear in a beaker with DI water.	In clean-room	1 min	1	Beaker with DI water
6	Keep on rinsing both the flat of the mass with copious amounts of water. Then clean the side of the mass again with cerium oxide and bicarbonate of soda as discussed in section 2.4 in the procedure.	In clean-room	19 min	2	DI water, cerium oxide, bicarbonate of soda, methanol, optical wipes, dry

Step	What	Where	Time	People	Tools
7	Clean the ear again as discussed in section 2.5.	In clean-room	7 min	2	nitrogen, air gun DI water, cerium oxide, bicarbonate of soda, methanol, optical wipes
8	Repeat the remainder of the bonding procedure discussed in sections 2.6 and 2.9.	In clean-room	1 hr 46 min 12 hrs	2  0	See above.

## 6.2 De-bonding procedure for when the bond quality is too low after a longer time (>8 hr)

In case no abnormalities were observed within the initial period where debonding by rinsing with copious amounts of water is still possible, there is still the possibility of debonding using ultrasonic stimulation in DI water up to (T1000464 and T1000465) 48 hours after the bond has been made. It is extremely unlikely the bond will change significantly for the worse after 12 hours.

Step	What	Where	Time	People	Tools
9	If the bonding jig has not removed yet, remove the bonding jig carefully, by releasing the spring-loaded bolts and lifting it carefully off the surface.	In clean-room	1 min	1	
10	Set-up the ultrasonic bath. Put blocks in the bottom to ensure the ear will be submerged completely, but the mass will be submerged by 1 cm at the most. Fill with DI water. Place the stiff lid onto the bath. Attach handles to the V-block and set-up the V-block on top of the ultrasonic bath lid.	In clean-room	15 min	2	Ultrasonic bath with lid, DI water, V- block plus handles
11	Lift up the mass from the bonding table using the ergo-arm, transport to the V-block on ultrasonic bath. Rotate the mass 180° so that the ear to be de-bonded is facing down and place it carefully on the V-block.	In clean-room	10 min	2	Ergo-arm, V-block, Ultrasonic bath
12	Carefully lift up the V-block (with mass) with 2 people while a third person removes the lid. Lower the V-block with mass down into the ultrasonic bath.	In clean-room	3 min	3	

Step	What	Where	Time	People	Tools
13	Switch on the ultrasonic bath: temperature setting: 50° C, running the ultrasonic indefinitely until the ear falls off. If the procedure is commenced within 12 hours after bonding, it should take maximally 30 minutes for the ear to come off. Switch off the ultrasonic bath.	In clean-room	30 min	1	
14	If possible remove the ear from the bath and deposit in a beaker with DI water.	In clean-room	1 min	1	Beaker with DI water
15	Use the handles on the V-block to carefully lift the mass out of the bath with two people and a third person places the lid back onto the bath, before the two people put the mass back down onto it.	In clean-room	3 min	3	Lid
16	Use the ergo arm to lift the mass onto the V-block on the washing table and rotate 90°. Also dry the barrel of the mass.	In clean-room	10 min	2	Ergo-arm
17	Clean the side of the mass again with cerium oxide and bicarbonate of soda as discussed in section 2.4 in the procedure above. It is likely that a more thorough clean with cerium oxide is necessary in particular along the edges of the old bond, because remnants of bonding solution are likely to be visible.	In clean-room	19 min	2	Optical wipes, cerium oxide, bicarbonate of soda, methanol, dry nitrogen
18	Select a new ear and repeat the bonding procedure from step 1 in section 2.1	In clean-room	1 min	1	

### 6.3 Removing a prism and magnet base

In the case that a prism is not aligned to the required accuracy or the adhesive has not cured well, it will be necessary to remove the prism. This can be done at any time using the procedure in E1200821.

### 6.4 Applying/removing First Contact

See T1200321 for general policy on when to apply and remove First Contact, and E1000079 for a detailed procedure.

## 6.5 Drag-wiping

See E1000079.

## 6.6 Disposal of old sodium silicate solution

Step	What	Where	Time	People	Tools
1	TBC Gerardo Moreno				

## 7 Remarks

The old bonding procedure document E050228 uses a 1:4 ratio between sodium silicate solution and water instead of 1:6. This has been changed by the findings of Elliffe et al. and confirmed by ourselves in recent tests as the average strength of 1:6 bonds is somewhat higher and the standard deviation of the strength is lower.

The old procedure doesn't use a centrifuge to get rid of large particles. We do.

The old procedure uses pipetting to take solution out of the bottle. We do not normally use this technique. We normally pour the solution into the 15 ml centrifuge tube.