LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Bonding & visual inspection of preliminary test ears (serial numbers 0021 to 0030)

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1 Introduction

Preliminary test ears for the ETM/ITMs were fabricated to drawing number D050169-06 for initial bonded ear strength testing and visual inspection. The ears are Heraeus Suprasil 2 and have a bond area of 1.77 cm^2 in accordance with the allowable limit set by thermal noise considerations[1]. They are designed in such a way as to accommodate a lap welded ribbon.

The Suprasil 2 ears were bonded to Suprasil 2 disks using two different volumes of bonding solution. This was done with a view to undertaking a preliminary study into bond strength versus thickness at a future date.

The silica disks were manufactured to drawing number D050192-01 with ϕ = 50 mm and t = 7 mm.

2 Bond configurations

The ears described here are 'replacement ears' bonded to 'replacement disks' supplied by *Vendor 'A'*, that is, they are replacement parts for those previously supplied outwith the requested material specification (see LIGO reports T050121-00-K, T050209-00-K and T050210-00-K).

Half of the samples (serial numbers 0021 to 0025) were bonded using the 'standard volume'[2] (or more correctly 'standard volume per unit bond area') of bonding solution (0.4 μL/cm^2) i.e. for bond area 1.77 cm^2 used 0.7 μL of fluid (setting 0700 in pipette). These pieces were bonded on 21st November 2005.

The remaining batch (serial numbers 0026 to 0030) were bonded using 'half of the standard volume' of bonding solution (0.2 μL/cm^2) i.e. for bond area 1.77 cm^2 used 0.35 μL of fluid (setting 0350 in pipette). These pieces were bonded on 24th November 2005.

Prior to this two pairs of Spectrosil 2000 disks (ϕ = 50 mm) also supplied by *Vendor 'A'* were bonded on 16th November 2005:

- Disks 0001: 'standard volume' of solution (0.4 μL/cm^2) i.e. bond area 19.6 cm^2; 7.8 μL of fluid
- Disks 0002: 'half-standard volume' of solution (0.2 μL/cm^2) i.e. bond area 19.6 cm^2; 3.9 μL of fluid.

The proposal was that each of the bonded disk pairs would be sliced and polished at a later date and the bond thickness measured using an AFM (or alternative).

Table 1 provides an overview of the volumes of bonding fluid used in each case.

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[1] Cantley et. al., "*Ear Bond Area Limit for ETM/ITM Optics from consideration of Thermal Noise*", T050216-00-K.

[2] 'volume per unit area' used in GEO and for previous bonding tests including LIGO reports T050121-00-K; T050209-00-K; T050210-00-K.

Date	*Sample description*	*Diameter (m)*	*Area (m^2)*	*Standard Volume (μL)*	*Half Standard Volume (μL)*
Historical (from SR)	Large samples for Q tests	0.062	3.02E-03	12.0	N/A
Historical (from SR)	1" diameter flats	0.0254	5.07E-04	2.0	N/A
Nov' 05	Adv LIGO test ears	N/A	1.77E-04	0.7	0.35
Nov' 05	Spectrosil 2000 disks	0.05	1.96E-03	7.8	3.9

Notes:

'standard volume per unit bond area' is 0.4 μL/cm^2 with 'half-standard volume per unit bond area' 0.2 μL/cm^2.

Table 1 Summary of bonding solution volumes used and historical data

To allow for adequate curing of the bonds any bond strength testing would be conducted a minimum of four weeks after bonding. Bond strength tests for these samples and bond thickness measurements will be the subject of future reports.

3 Bonding

Fresh silicate bonding solution was made up on 16th November 2005 using the Advanced LIGO bonding procedure[3] (i.e. silicate bonding solution of concentration of 1 part commercial sodium silicate solution (14% NaOH, 27% SiO2) to 6 parts De-I water). Further to initial mixing and filtering according to the procedure the solution was subject to further centrifugation on each subsequent day of use (21st November and 24th November). On the last of these days the 2nd sealed vial of the two vials initially created on the 16th November was used.

Before cleaning, the global flatness of the disks was assessed using a Logitech LI10 interferometer. A typical interferogram is shown in Figure 1.

Figure 1 Typical disk interferogram

[3] Armandula, *"Silicate Bonding Procedure (Hydroxide-Catalysis Bonding)"*, E050228-00-D.

Before cleaning, the global flatness of each of the ears was also assessed.

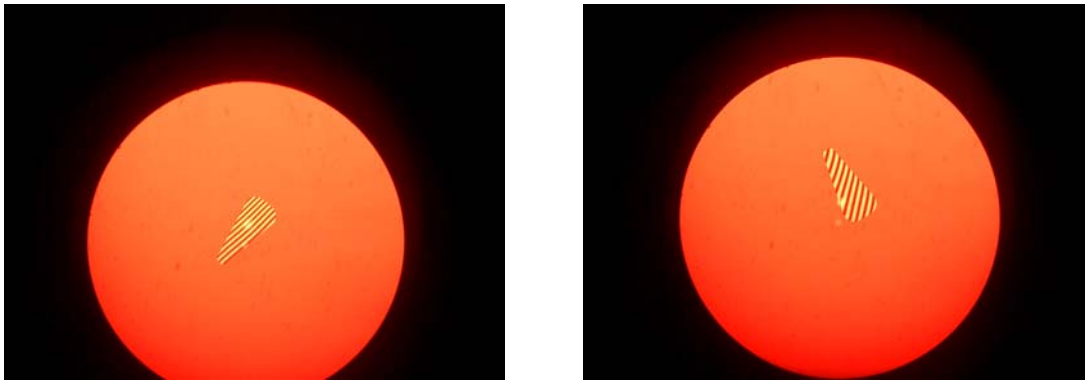

Figure 2 Interferogram of ears SN 0021 (left) & SN 0022 (right)

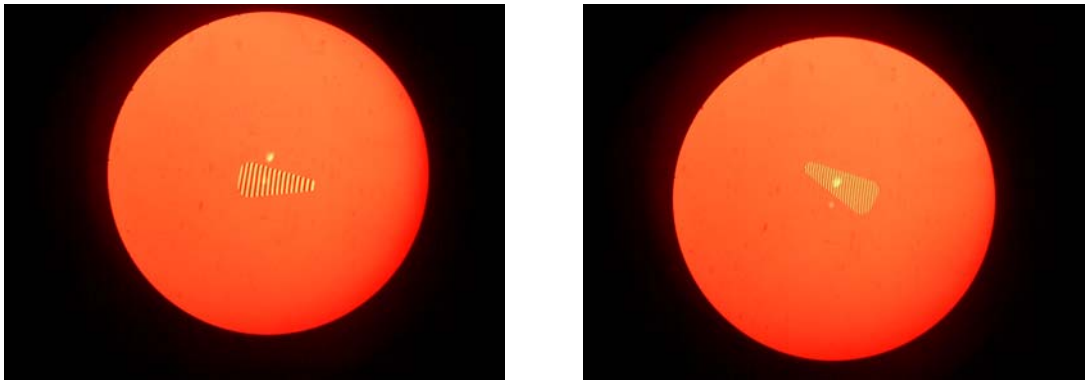

Figure 3 Interferogram of ears SN 0023 (left) & SN 0024 (right)

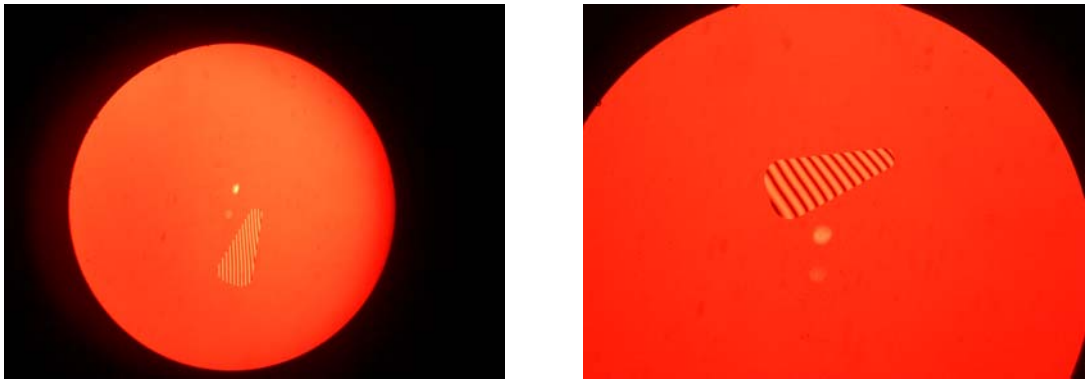

Figure 4 Interferogram of ears SN 0025 (left) & SN 0026 (right)

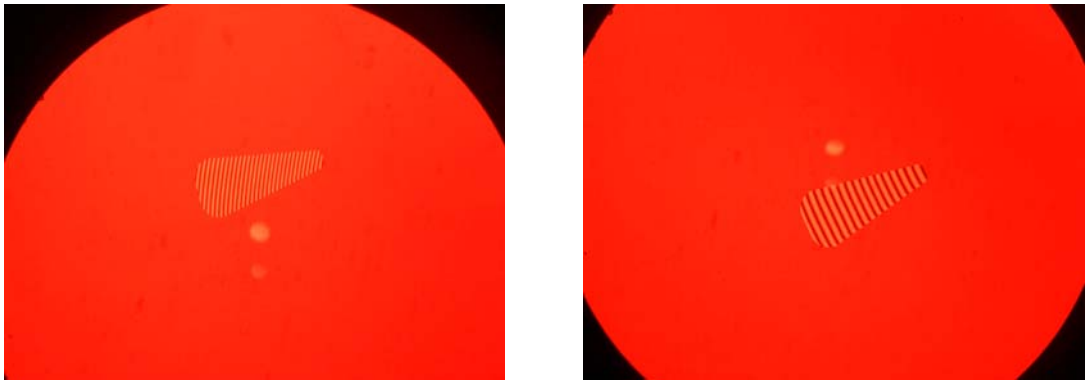

Figure 5 Interferogram of ears SN 0027 (left) & SN 0028 (right)

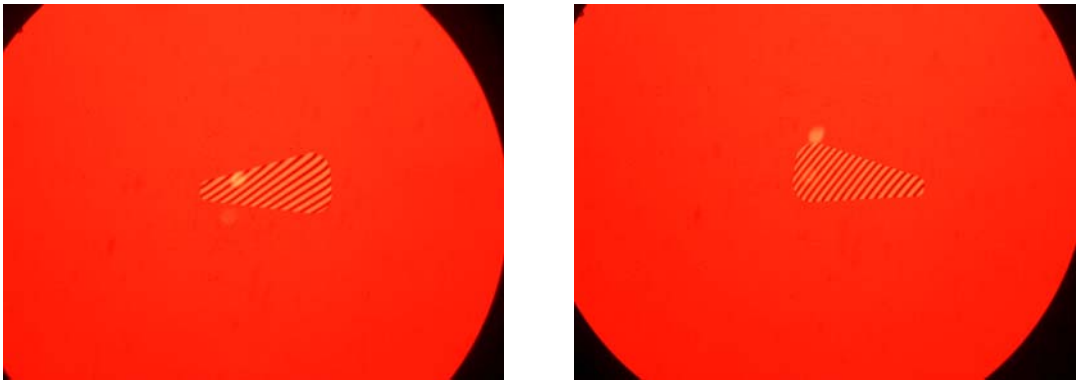

Figure 6 Interferogram of ears SN 0029 (left) & SN 0030 (right)

The interferograms of all ears and flats seemed reasonable (specification λ/10).

The ears and flats were all cleaned using the procedure detailed in the Advanced LIGO bonding procedure[3].

To bond each ear/flat pair the same procedure was followed:

- A single drop of the chosen volume of bonding solution was dispensed onto the surface of a flat using a biological pipette ensuring the tip of the pipette did not make contact with the bonding surface.
- An ear was then placed by hand over the drop and lowered until it touched the drop and flat beneath with the drop spreading out to fill the entire bonding surface

All bonds were initially left on the clean bench to cure for ~ 1 hour (or more) before transporting them to an office for storage.

Additional Comments:

(A) – Surface finish of ears

The specified flatness for the bonding surface on the ears was λ/10. The remaining surfaces of these preliminary ears were specified as ground finish.

The ground finish was not ideal from two perspectives:

Bonding

1) the ground ear surfaces hindered inspection of the cleanliness of the polished bonding surface of the ear
2) the ground ear surfaces meant that the bonded interface could not be observed when the ear was put in place on the flat. Therefore it was not possible to check that the bonding fluid had spread out correctly from above. However inspection could be carried out through the disk/flat after initial bonding.

Stress concentrations

3) Aside from causing visibility problems with respect to assessment of bond quality, it was considered that the ground finish could lead to undesirable concentrations of stress on the surface/edges of the ears when loaded. This was further investigated during loading tests on the bonded samples. It was demonstrated that in the existing bonded test ears the surface quality could be improved by flame polishing and this increased the strength of the ear itself[4]. Potential issues of degradation of bond quality due to heating by flame polishing would require further investigation if this approach were ever adopted. Instead it is planned that future ears will be fabricated with an inspection polish finish to remove problems of stress concentration within the ear and to aid in visibility of the bond during bonding.

(B) – Effect of volume of bonding fluid on apparent ease of bonding

1) Bonding of disks 0001 ((‘standard volume’ of solution (0.4 μL/cm^2) i.e. bond area 19.6 cm^2; 7.8 μL of fluid): Floated for some time (~30 seconds) before the bond started to set. Some bubbles and fringes were visible immediately after bonding. This volume is clearly more than enough solution to fill the area to be bonded.
2) Bonding of disks 0002 ((‘half-standard volume’ of solution (0.2 μL/cm^2) i.e. bond area 19.6 cm^2; 3.9 μL of fluid): The bond set more quickly (perhaps half the time). Some bubbles and fringes were more visible immediately after bonding but more localised and less than for the 0001 bond.

[4] Cantley et al., *“Bonded ear strength tests (Serial numbers 0001, 0002 and 0011 to 0014”*, T050211-00-K.