Non-destructive bond thickness and refractive index values from measurements of the optical reflectivity of hydroxide-catalysis bonds

Valentina Mangano and Mariëlle van Veggel
on behalf of the *Institute for Gravitational Research* (University of Glasgow)

Introduction

Jointing parts is an inevitable step in assembling high performance (optical) devices. **Hydroxide-catalysis bonding** has been demonstrated to show excellent performance in stability, precision and strength in many mainly mechanical applications [van Veggel, Killow – 2014]. In this project we explore the **suitability of hydroxide-catalysis bonding in optical applications as well as developing a technique to determine bond thickness in situ non-destructively** to more accurately determine thermal noise caused by bonds in mirror suspensions**.**

To these ends, a **non-destructive technique** to measure **reflectances of bonds** and **mathematical optical models** to extract information on **bond refractive index and thickness of bond from reflectance data** have been developed.

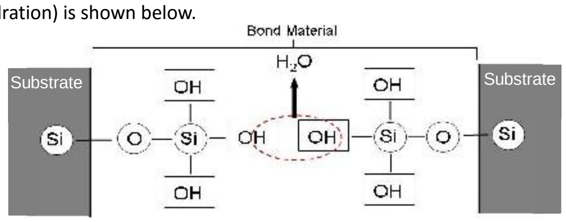
Hydroxide-catalysis bonding

It is a reliable **jointing technique** created at **room temperature** and characterized by:

- **very thin bonds (of order 100 nm) that introduce low levels of thermal noise;**
- **high strength (16 MPa for silica);**
- **high precision alignment (of order 1 μrad).**

The gravitational wave detector **GEO** tested this technique, patented by **Gwo** [Gwo - 1998], obtaining good results: it is now used in the ultra-low loss and quasi-monolithic fused silica mirror suspensions of the advanced detectors.

It can be applied to any combination of materials, provided that a **silicate-like network** can be formed between them. The final stage of the bonding process (polymerisation and dehydration) is shown below.

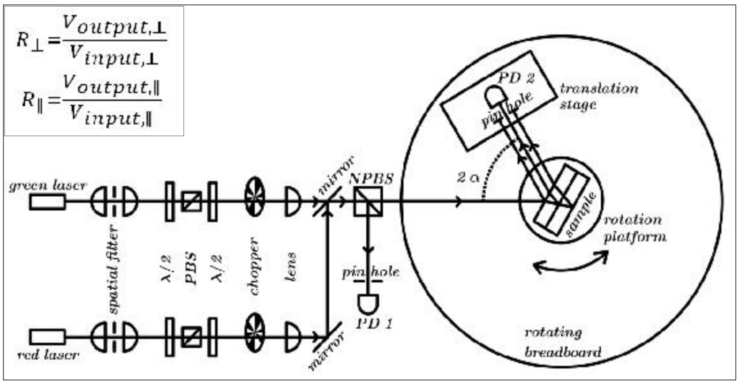


Measurement method

The **incident and reflected powers** of the green and red laser beam are measured as a function of angle of incidence at ⊥ and // polarisation, and the corresponding **reflectances of bond** are determined.

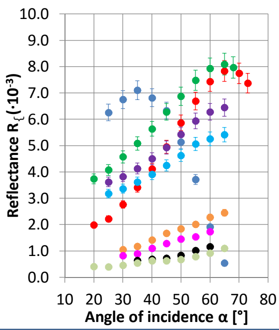
$$R_{\perp} = \frac{V_{output,\perp}}{V_{input,\perp}}$$

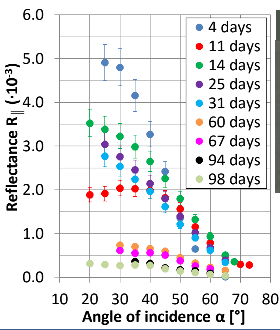
$$R_{\parallel} = \frac{V_{output,\parallel}}{V_{input,\parallel}}$$

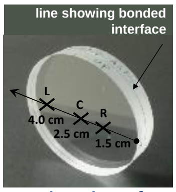


Measurements results: reflectances

The **bond reflectivity as a function of curing time** is shown for the center position on a **fused silica sample 1** bonded with **sodium silicate solution**: the measurements have also been taken at the other two points and similar results were obtained. The left image shows the results for ⊥ polarisation, the right for // polarisation.



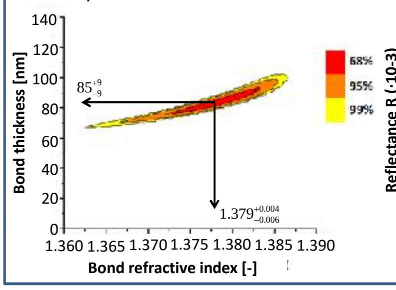


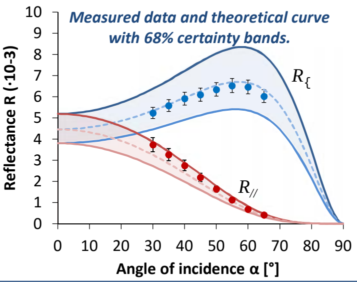


The values of bond reflectivity are less than 10^{-5} after three months.

Analysis method: Bayesian likelihood

Using a **mathematical model** for the reflectances of bond (Fresnel equations and effects of thin film interference were considered) and a **Bayesian likelihood analysis** based on the least squares method, the **refractive index and thickness of bond** are extracted from the **reflectance measurements**. The **confidence levels of probability provide constraints on the refractive index and thickness of the bond.** An example of this analysis is shown below.

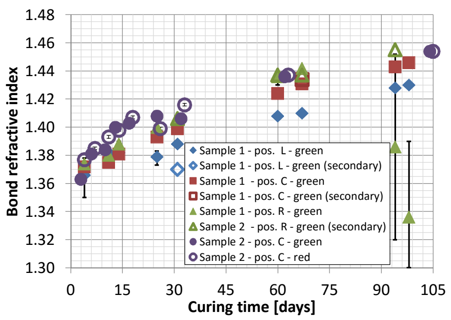




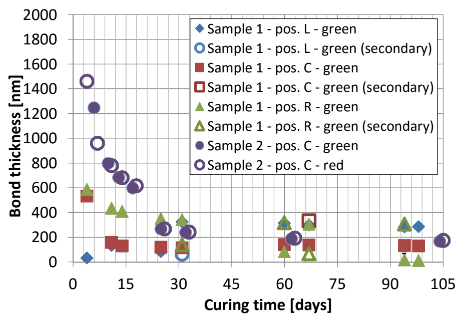
Analysis results: refractive index and thickness

Measurements of refractive index and thickness of a bond as a function of the curing time are reported. For this analysis, **two fused silica samples** were bonded using **sodium silicate solution (1:6)**. For sample 1 three positions on its surface were measured with green laser light. For sample 2, the center location only is analyzed using the green and red laser light. There is a **good agreement** between results obtained from these two samples.

The refractive index increases with time approaching that of fused silica. The bonds obtained by means of this technique are **highly optically transparent at the visible and infrared light**, allowing light to pass through the material.



This is a powerful and non-destructive method for measuring both refractive index and thickness of a bond based on the characterization of the light reflected from bonded interface.



The bond thickness decreases with time until it stabilizes at a constant value. The water migrates or evaporates in time until a **strong and very thin bond** is formed, **minimising its contribution to thermal noise.**

Conclusions and next steps

These results have allowed having information not only on **magnitude of the light that is reflected from the bonded interface** between two fused silica discs, jointed using sodium silicate solution, but also on **refractive index and thickness of the hydroxide-catalysis bond**.

This method will allow us to investigate **how the optical properties of hydroxide-catalysis bonding can be altered by the chemistry of different bonding solutions and substrate materials.** It could also be developed to allow us to **non-destructively determine bond thickness of actual bonds in mirror suspensions to allow more precise determination of thermal noise** caused by these bonds.

We will continue and analyse fused silica samples in which parameters like concentration, type of hydroxide and heat treatments will varied to study their influence on the final values of thickness and refractive index. Sapphire substrates bonded will be also studied.

This is a first and compulsory step for the realization of future and profitable optical applications of interest for research institutes and industries.

LIGO-G1601717
LVC Meeting, 29 August – 1 September 2016, Glasgow