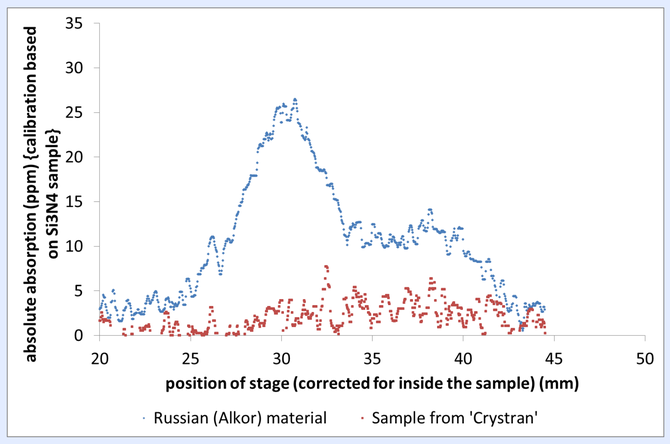
Surface absorption in Silicon at 1550 nm

Angus Bell[1], Jessica Steinlechner[1], Liam Cunningham[1], Sheila Rowan[1], Jim Hough[1], Roman Schnabel[2], Alexander Khalaidovski[2], Harald Lück[2] and Iain Martin[1]
[1] Institute for Gravitational Research, SUPA, University of Glasgow, Glasgow, G12 8QQ
[2] Max Planck Institute for Gravitational Physics (Albert Einstein Institute) and Institute for Gravitational Physics of the Leibniz Universität Hannover, Callinstraße 38, D-30167 Hannover

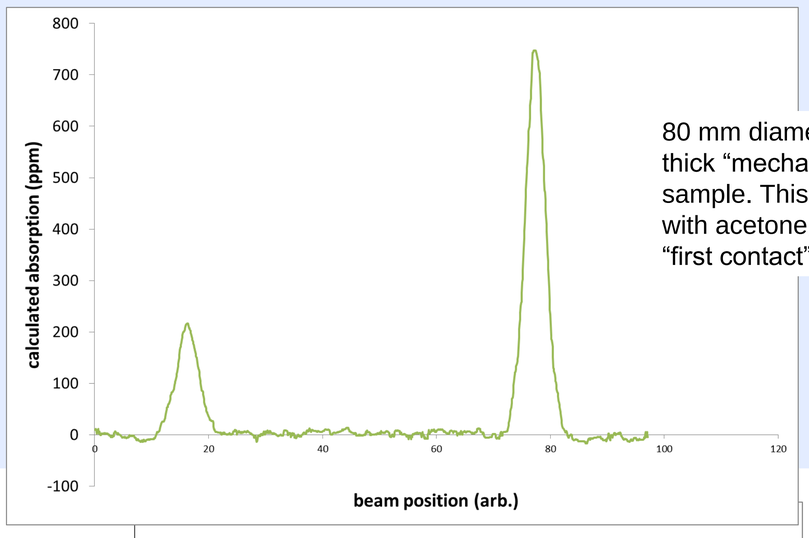
Introduction

The need to reduce the thermal noise in future detectors below the levels in the design of aLIGO and AdVirgo will almost certainly require cryogenic operation, and therefore a crystalline test mass. As silicon is a crystalline material that can be obtained in high purity and in large single crystals, with low mechanical loss at low temperatures, it is an obvious candidate for test mass material. Initial work on optical absorption in silicon seems to indicate that it will have a performance at 1550 nm that will be acceptable for the design concepts of future detectors. However, it has been noticed that some silicon samples showed surface absorption that appeared to be at levels high enough (> 100 ppm) for it to become an issue.

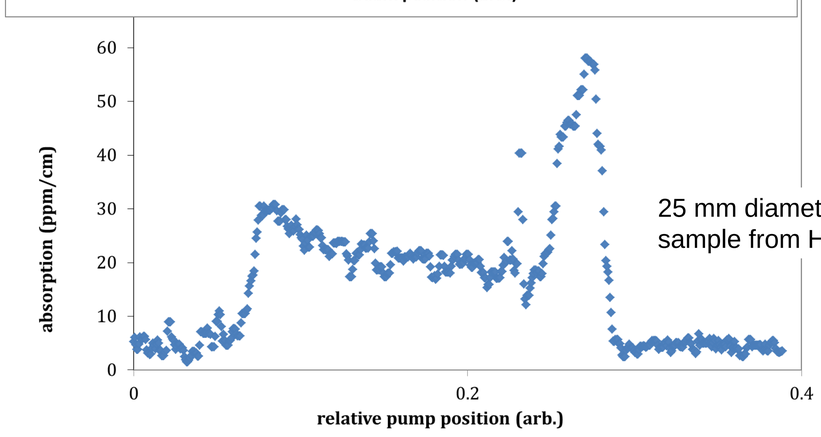
This aim of this work was to identify the origin of this surface absorption and to try to come up with a recipe or set of rules to avoid in the production of mirror substrates and test masses



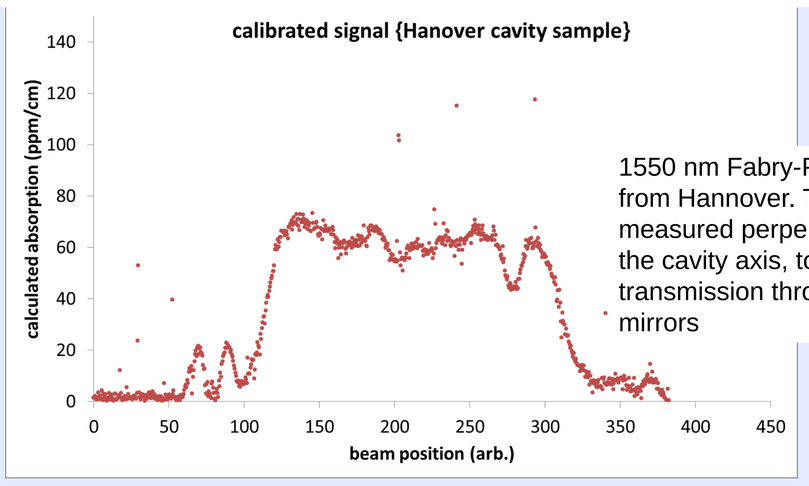
25 mm diameter, 10 mm thick samples, one showing surface effect, the other not. These samples are drag wiped with acetone and methanol before measuring



80 mm diameter, 100 mm thick “mechanical loss” sample. This is after cleaning with acetone, methanol and “first contact”



25 mm diameter, 98 mm thick sample from Hannover.



1550 nm Fabry-Perot cavity from Hannover. The sample is measured perpendicular to the cavity axis, to avoid transmission through the HR mirrors

Figure 1. Different levels of surface absorption on a number of samples

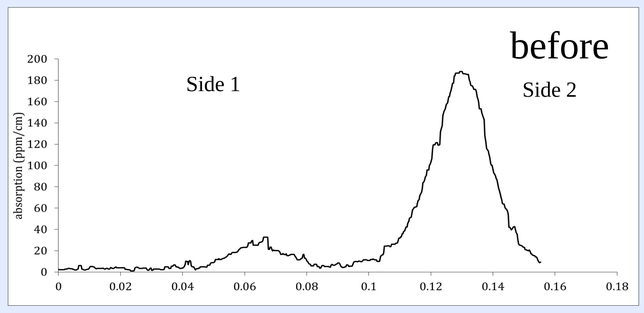
Material removal stages

To try and determine where exactly in the material the absorption was located, we looking at using a several step process.

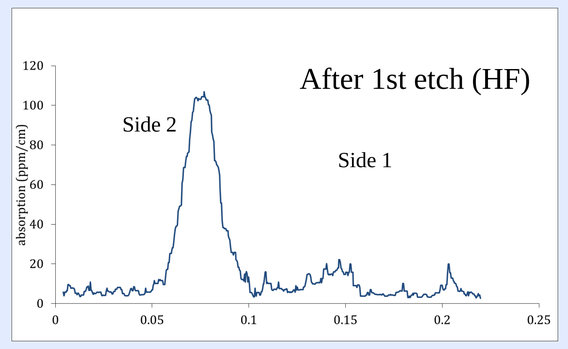
1. HF etch (would remove up to 5 nm SiO or more SiO_2)
2. KOH etch (< 10 nm Si)
3. HF then immediate KOH. (~100 nm Si)
4. Mechanical polish

During the first two stages some general improvement in the sample surface cleanliness was observed but without changing the clear surface effect. It should also be noted that the variation in the absorption across the surface was significant. The beam size in this measurement was ~ 1mm. Previous measurements with a 50 micron beam had shown large variations in absorption over several tens of microns.

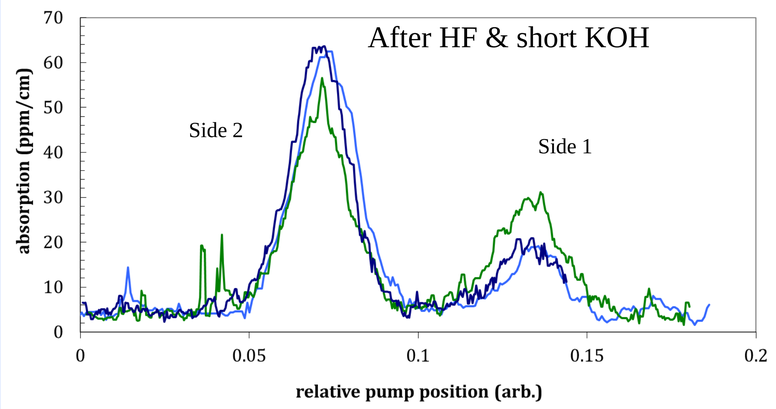
Hannover sample piece (32 mm long Si cylinder, 25 mm diameter)

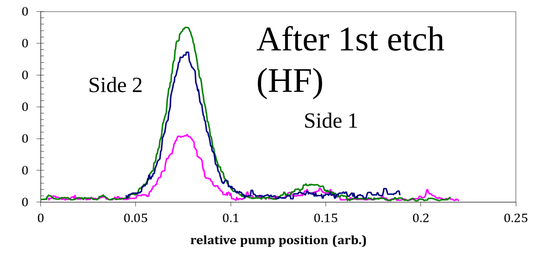


Note that the peaks are reversed in some scans due to the sample being reversed. The large peak is always at the same end of the sample.

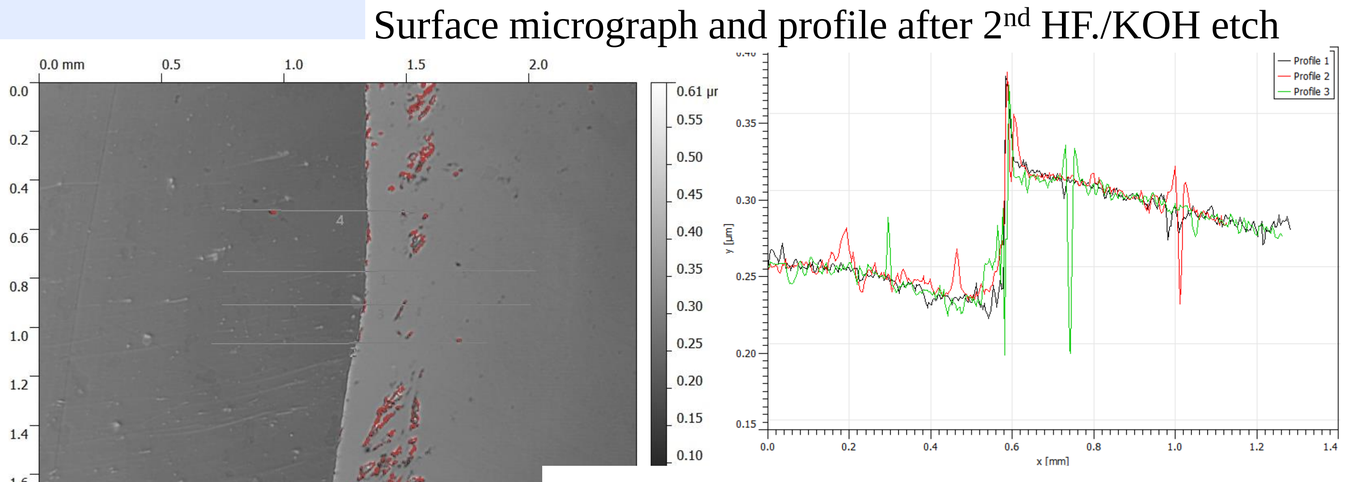


absorption measured at different spatial positions





Surface micrograph and profile after 2nd HF./KOH etch



After 2nd round of HF & KOH etching

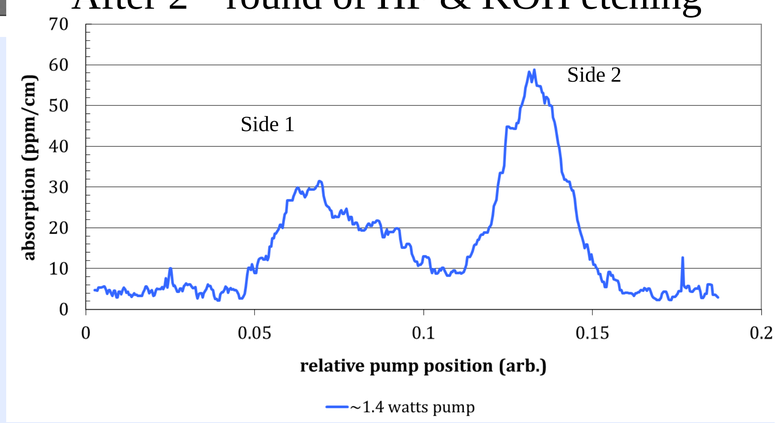
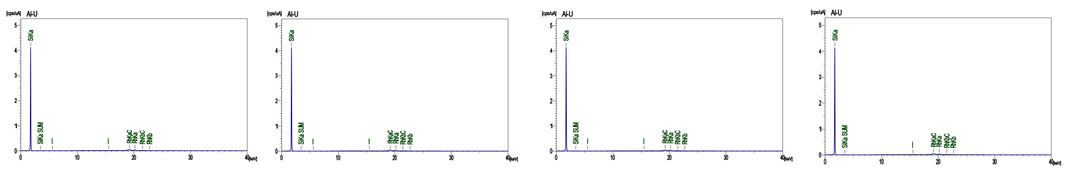


Figure 2. the same sample measured during the etching processes

X-ray spectroscopy results



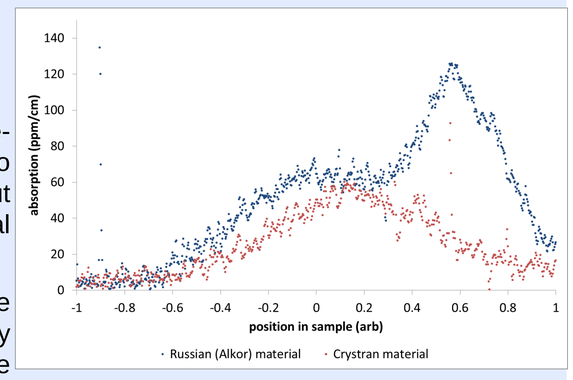
The samples were all tested in an XPDS machine. No evidence of specific contaminants were found but the levels required are around 100 times less than easily observable wit this machine.

After mechanical polishing

Several of the samples were sent to Crystran for re-polishing. They were treated nominally identically to the samples originally sourced from Crystran, but with the proviso that as small an amount of material as possible be removed.

All the repolished samples showed surface absorption of around 15 ppm. Crystran is currently repolishing two of these samples again, this time specifically aiming to avoid any surface absorption.

Figure 4. Two samples measured after mechanical polishing



These are the same samples as in fig 1 but the orientation is reversed