SPACE QUALIFICATION OF A THIN WAFER LITHIUM NIOBATE ETALON FOR THE VISIBLE LIGHT IMAGER AND MAGNETOGRAPH (VIM)

U. Schühle(1), S. K. Mathew(2), M. Wedemeier(1), H. Hartwig(1), E. Ballesteros(3), V. Martinez Pillet(3) , S. K. Solanki(1)

(1) Max Planck Institut für Sonnensystemforschung, Max-Planck-Str. 2, 37191 Katlenburg-Lindau (Germany)
Email: schuehle@mps.mpg.de, wedemeier@mps.mpg.de, hartwig@mps.mpg.de, solanki@mps.mpg.de

(2) Udaipur Solar Observatory, P. O. Box 198, Badi Road, Udaipur – 313001, Rajasthan, (India)
Email: shibu@prl.res.in

(3) Instituto de Astrofisica de Canarias c/ Via Lactea s/n, La Laguna, 38200, Tenerife, (Spain)
Email: vmp@iac.es, ebr@iac.es

ABSTRACT

For the Visible Light Imager and Magnetograph (VIM) a high-resolution filtergraph is under design. The system takes advantage of a lithium niobate ($LiNbO_3$) crystal which can be used as a scanning filter using high voltage for tuning. We have undertaken first studies to qualify a lithium niobate wafer of 70 mm aperture size for deployment and use in space. We show the results of the mechanical mounting and vibration and thermal cycling tests as well as stability tests under fast voltage tuning in vacuum. Although these tests have all been very successful, further environmental testing is necessary to fully space-qualify the filter for the Solar Orbiter mission.

1. INTRODUCTION

To map the magnetic field at the solar photosphere a magnetograph is needed with a narrow band spectral filter that can be tuned within the spectral width of a strong photospheric line. To achieve the spectral filter with the necessary resolution, a Fabry-Pérot etalon can fulfill the requirements, if combined with other narrow band filters. Typically, a couple of etalons are needed with spacings in the submillimeter range. Technically, solid wafers with the appropriate thickness have certain advantages over air-spaced etalons due to their much lower mass and volume requirements [1]. In addition, a lithium niobate crystal wafer, polished to a high finesse and with conductive coatings on both surfaces, can provide the ability to tune electrically within the required spectral range without using any moving parts [2, 3]. For this purpose, single-crystal $LiNbO_3$ wafers are needed that are cut along one of the principal optical axes ("z-cut" or "y-cut"). Finally, not unimportantly, the high refractive index of $LiNbO_3$ allows a much higher acceptance angle with a much smaller volume needed, as compared to an air-spaced etalon.

In order to achieve the free spectral range needed for tuning and compensation of Sun-spacecraft relative motion, the filtergraph of VIM requires a double etalon in series, such that the second etalon blocks the secondary transmission maxima of the first [4, 5]. The filtergraph may be designed in telecentric or collimated configuration and in either case it will need an aperture size of approximately 50 to 60 mm, depending on the final optical design of the VIM instrument. A similar filtergraph, with a $LiNbO_3$ etalon in double-pass configuration [6], is presently under development for the SUNRISE balloon mission. We have undertaken first steps to space qualify such wafer etalons in view of the Solar Orbiter mission.

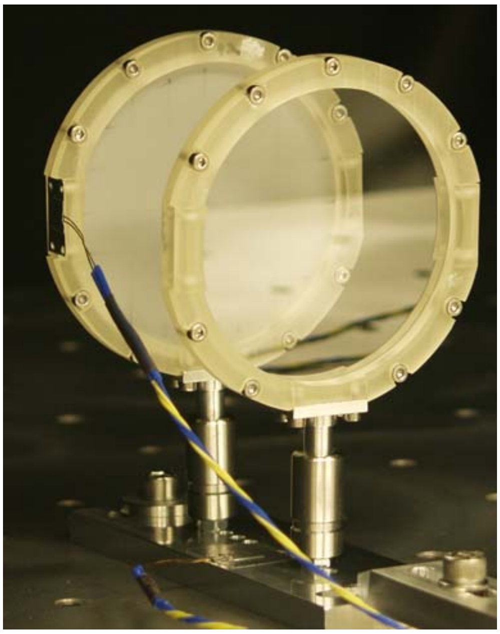

Figure 1: Two LiNbO3 test wafers in dual-etalon configuration

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2. TESTS AND MEASUREMENTS

The VIM filtergraph requires a dual etalon configuration with one fixed etalon and the other adjustable by tilting for initial adjustment of their transmission maxima. Both have to be mounted in a temperature stabilized oven. One major concern for space flight is the stability of such thin, brittle devices under vibrational launch loads and under thermal cycling.

2.1 Preliminary mechanical qualifications

As representative placeholders for preliminary mechanical qualification tests, two 3“ size LiNbO3 wafers (z-cut) have been used with a thickness of 0.250 mm (see Figure 1). The wafers have been mounted into retainers with 70 mm free aperture, to test the stability of wafers and the holder under vibrational loads. The stress-free mounting frame was made of hard polyimid material (VESPEL SP-1). To prevent rotation of the etalon inside the retainer during launch vibrations, an annular spring was designed to keep the etalon in position, holding it down by pressure. The vibration tests were carried out at MPS, and the etalons were subjected to acoustic and sine vibration tests including resonance searches in all three axes.

The test levels were 12 g RMS for the random vibration and 10 g for the sine tests. Note for a Sojus-Fregat launch of a 30 kg instrument the 12 g RMS random excitation is representative. The sine vibration load requirements of that launcher are actually higher, so that an extension of this test is necessary to finalize the mechanical qualification.

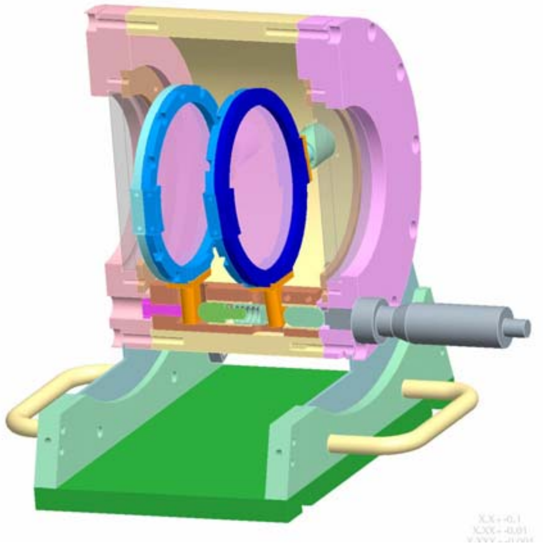

Figure 2: Design of the temperature stabilized housing used for testing the dual-etalon arrangement

2.2 Thermo-mechanical qualification tests

The thermo-mechanical qualifications consist of a vibration test, as described above, and a thermal-vacuum cycling test with an optically polished lithium niobate etalon wafer.

A housing was designed to align the two etalons with respect to each other and to provide temperature stability. The design is shown in Figure 2. The thermo-mechanical qualifications were done with the etalons inside this housing. In Figure 3, the housing is mounted on the shaker at MPS for vibrational testing.

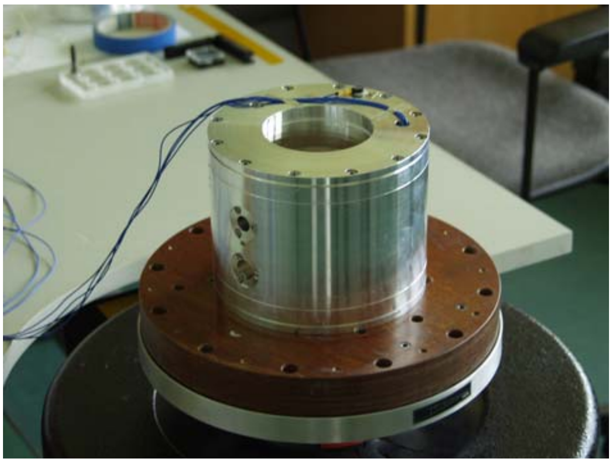

Figure 3: The etalon in its housing, mounted on the shaker at MPS. The vibration sensors are mounted on the etalon retainers inside the housing.

For these qualification tests, one etalon with a finesse high enough for optical testing was used, so that optical tests could be performed before and after the thermo-mechanical tests. For this purpose a wafer etalon was procured, fabricated by Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia. A y-cut LiNbO$_3$ wafer of 73 mm diameter was polished by CSIRO on both sides at a thickness of 0.22 mm. For this exercise, no conductive coating for voltage tuning was applied, but a temporary silver reflective coating was deposited for the optical testing of the etalon.

This etalon was mounted inside the retainer described above, which was then mounted inside the housing (temperature stabilized oven) and subjected to thermal cycling in a thermal vacuum chamber between -80 °C and +100 °C.

Optical testing of the etalon, by monitoring the fringes obtained with an expanded, frequency stabilized, He-Ne laser, was performed before and after the tests, as well as visual and microscopic inspection for any possible damage.

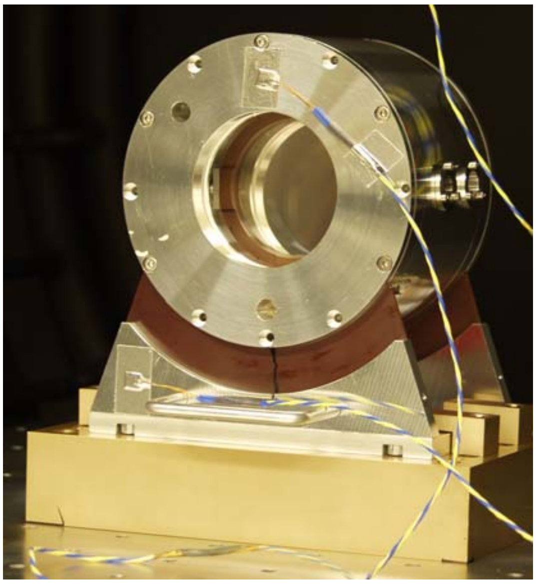

Figure 4: The etalon and the housing inside the thermal-vacuum chamber with mounted temperature sensors

2.3 Fast voltage tuning

The fast voltage scanning was tested with another LiNbO3 etalon of approximately the same size procured for the IMAX Magnetograph of the SUNRISE balloon project [6]. The etalon was scanned with 8 tuning positions (each position was retained for 5 s, see Figure 5) with a fast change of voltage of 3000 V/s.
The test was run for a full duration of 15 days while detecting with a photodiode the modulated light of a passing-through laser. As a result of this test, no change of performance was detected.

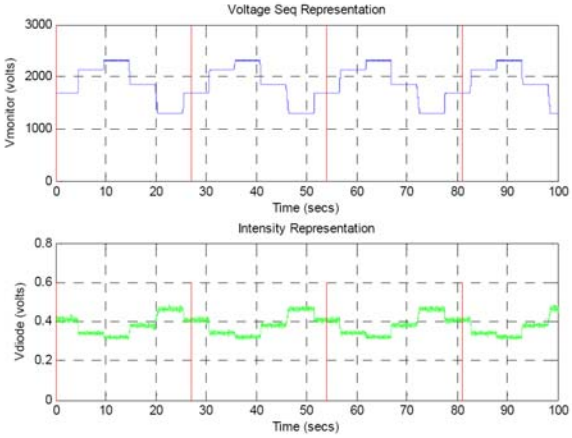

Figure 5: voltage tuning sequence and response (photodiode signal) of the etalon during a long-term test with fast voltage changes.

3. CONCLUSIONS AND OUTLOOK

The thermal, mechanical, and electrical tests have been successful so far. However, one major stepping stone is the test of hardness against high-energy space radiation during high voltage operations. A radiation test under representative conditions of the Solar Orbiter mission is necessary to fully qualify this solid wafer etalon for use in space.

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