Measurements of ultra-stable langatate crystal oscillators

J. Imbaud, S. Galliou, J. P. Romand, P. Abbé and R. Bourquin
FEMTO-ST institute, Frequency and Time department
Besançon, France
joel.imbaud@gmail.com

***Abstract*— The use of the langatate (LGT, $La_3Ga_{5.5}Ta_{0.5}O_{14}$) crystal for the realization of ultra-stable oscillators is very recent. This material proved that it is capable of giving stability results as good as those achieved by quartz crystal. To the knowledge of the authors, until now there was no substitution material for the quartz crystal, for low noise applications. Indeed, investigations had proved that LGT is a good alternative.**

This paper describes quickly all the essential manufacturing steps related to the development of an oscillator using this pure synthetic crystal. It shows that the performances looked for, in terms of noise, are those obtained with the quartz crystal.

Its content is as follows. It begins with the description of the resonator manufacturing, the resonator being the heart of the oscillator. Then, the development of the related electronics is discussed and noise measurements are given as a conclusion. Very first ageing measurements of a set of LGT crystal oscillators are also emphasized.

Noise results are given in terms of standard Allan deviation as well as in power spectral density of phase fluctuations. These results are analyzed and finally compared to those of quartz crystal oscillators.

I. INTRODUCTION

Langasite (LGS) material family (class 32) has been discovered in Russia approximately 30 years ago [1]. These kinds of pure synthetic crystals possess interesting piezoelectric properties like its intrinsic high quality factor. Since few years a particular attention is paid to these crystals (essentially on the langatate) to realize ultra-stable oscillators (USO).

The material has to be selected with care. Indeed, it is obvious that only a high quality crystal permits to obtain the best results. Studies of quality factors versus suppliers and crystal defects proved that big quality differences exist from a boule to the other [2-7]. Anyway, an adapted machining process is needed to realize high grade resonators [8-10].

Until now, quartz crystal was the only material usable in the field of RF USO applications. From a few years, first investigations have proved that langatate crystal is a good challenger [11-13].

This paper complements the study on USO equipped with LGT crystal resonators. Specially, the results on aging of the five first prototypes are reported below.

II. MANUFACTURING OF THE OSCILLATORS

The best langatate crystal resonators have been selected on the overall manufactured batch. This gave birth to five oscillator prototypes. They are the prototypes analyzed all along this paper.

A. About the resonators

To realize a high grade resonator, many steps of machining are needed. All of the methods usually used for quartz crystal cannot be applied in the case of the langatate crystal. Specific grinding and polishing machining based on the use of an abrasive diamond powder have been developed for this crystal [9].

It is also proved that langatate can exhibit volume or structure defects. In order to avoid this problem, the highest quality crystal has been used to make those resonators. It has been selected after an infrared absorption test [13].

Three kinds of resonator topologies have been used in these first prototypes of oscillators. The first one is the conventional one, the second one has an insulated active part fulfilled by bridges (BVA4) and the last one is the electrodeless version (BVA). Their pictures are visible in Fig. 1. All the tested resonators are Y-cut resonators working on their 5th overtone C-mode (the conventional thickness shear mode in metrology). The thickness at the resonator center is about 690 µm for a resonance frequency of about 10 MHz. The main geometrical characteristics of each type are outlined in Tab. 1.

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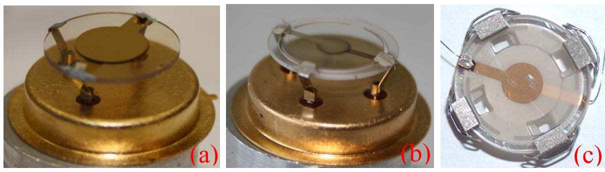

Figure 1. Three types of resonators used in the prototypes: (a) electrode deposited, (b) electrode deposited with bridges (BVA4) and (c) BVA.

TABLE I. MECHANICAL PARAMETERS OF RESONATORS REFERED TO EACH OSCILLATOR.

Oscillators	Topology	Ø electrodes (mm)	Radius of curvature (mm)	Ø of the active part (mm)
#1	BVA	3.5	100	10.3
#2	Electrodes deposited with bridges (BVA4)	7	100	10.3
#3	BVA	3.5	100	10.3
#4	Electrodes deposited	7	115	13.2
#5	Electrodes deposited	7	230	13.2

B. About the electronics

The oscillator used in each prototype is based on the Colpitts-type sustaining electronics. It is followed by a common collector amplifier and a cascode output stage which also performed the output impedance matching. A selective filter is inserted into the loop to permit the starting of the oscillations only on the desired 5^{th} overtone. The loaded Q-factor is optimized by a simulation method [14] to be higher than 50% of the unloaded Q-factor. Most of electrical parameters are resumed in the Tab. II.

TABLE II. ELECTRICAL PARAMETERS FOR EACH RESONATOR IN OSCILLATOR.

Oscillators	Resonator Q-factor (10^6)	Loaded rate of Q-factor (%)	Motional resistance (Ω)	Parallel capacitance (pF)
#1	1.62	52	16	8
#2	1	40	13	7
#3	1.67	53	15	8
#4	1.3	54	8	15
#5	1.4	53	6	15

The drive level of resonators in all the oscillators has been chosen at about 50 µW. This value is comparable with that used in usual USO. Remind that langatate crystal resonators have a lower drive level defect in comparison with that of the quartz resonators.

All the electronics has been realized meticulously in the spirit of low noise techniques.

C. About the thermal regulation and the packaging

Double ovens oscillators have been used as prototypes to evaluate the first noise performances of langatate crystal resonators (Fig. 2 gives the details).

The resonator is inserted into the core oven whose temperature is adjusted at the turnover point of the resonator characteristic (between 65 and 85°C). The core oven, the temperature-controller electronics and the oscillator sustaining electronics are fitted into a copper housing temperature-controlled at about 50°C.

The copper box itself is inserted in an insulating thick foam contained in an aluminum box. The thermal gain of this structure has been measured higher than 300.

Figure 2. The oscillators prototypes are composed of two temperature controlled ovens in a copper housing (a) & (b). This last one is inserted in a thermal insulating thick foam (c). The overall is inside an aluminium housing (d).

III. NOISE AND AGING MEASUREMENTS

Results presented below have been performed against a 10 MHz H-maser reference with the automatic measurement bench Symmetricom 5120A in the best environment setup, see Fig. 3.

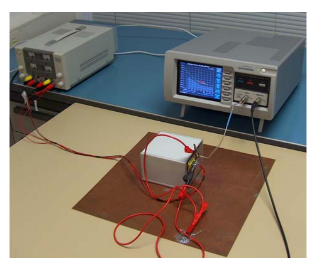

Figure 3. Measurement setup.

A. Power spectral denstity of the phase fluctuations

The best results in term of noise exhibit a power spectral density (PSD) of phase fluctuations of about -110 dBc/Hz at 1 Hz from the carrier (Osc. #4) and a noise floor of about -150 dBc/Hz above 10 kHz from the carrier(Osc. #5), see Fig. 4.

The spurs visible between 10 and 1 kHz are essentially due to the environment. The five usual slopes can be identified on the PSD graph. Table III reminds the five slopes and their equivalent in terms of PSD of fractional frequency fluctuations and Allan deviation.

TABLE III. USUAL NOISE SLOPE OF PHASE FLUCTUATIONS PSD

Noise origin	$S_\Phi(f)$	$S_y(f)$	$\sigma_y(\tau)$
Frequency random walk noise	f^{-4}	f^{-2}	$\tau^{+1/2}$
Frequency flicker noise	f^{-3}	f^{-1}	τ^{0}
Frequency white noise	f^{-2}	f^{0}	$\tau^{-1/2}$
Phase flicker noise	f^{-1}	f^{+1}	τ^{-1}
Phase white noise	f^{0}	f^{+2}	τ^{-1}

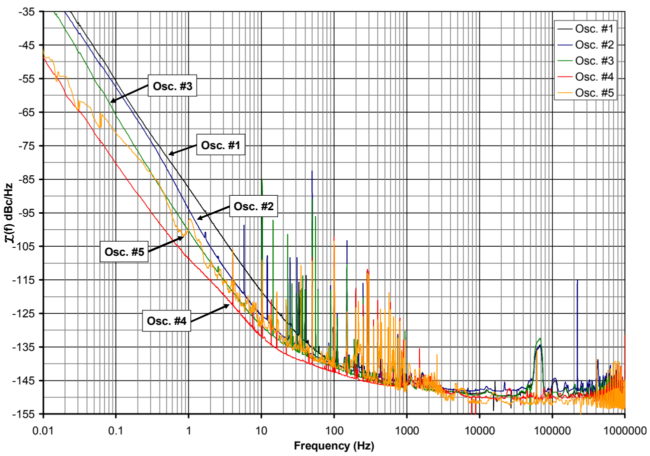

Figure 4. PSD of phase fluctuations of the5 LGT crystal oscillators measured against a 10 MHz H-maser reference.

Best oscillators seem to be prototype #4 and #5. Phase fluctuations of Osc. #5 are a little bit chaotic in the low frequency: a problem happened during the measurement.

B. *Standard Allan deviation*

The best standard Allan deviation floor is of about $5{\cdot}10^{-13}$ between 1 and 20 seconds (Fig. 5). All the usual slopes can be also identified on this standard Allan deviation graph for the best oscillators which are Osc. #4 and #5.

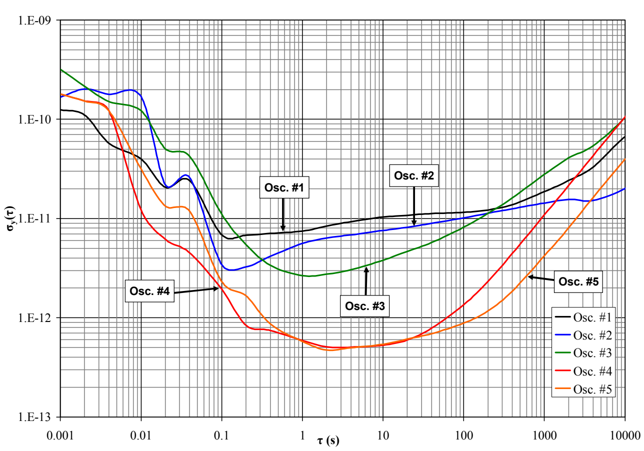

Figure 5. Standard Allan deviation of oscillators equipped with LGT resonators against a 10 MHz H-maser reference.

Curious waves can be observed on the short term domain: Osc. #1 to #3 exhibit unusual disturbances between 0.001 and 0.1 second. These perturbations could be attributed to the PSD to standard Allan deviation conversion in the measurement bench.

C. *Aging*

This is the very first aging measurement of langatate crystal oscillators. Results are shown in Fig. 6. For these five samples, we can observe that aging slope can be positive or negative. The starting is very chaotic but it calms down after some dozens of days.

The most efficient in term of aging is Osc. #2 with a relative shift of about $1.5{\cdot}10^{-10}$ day^{-1} after 250 days of working.

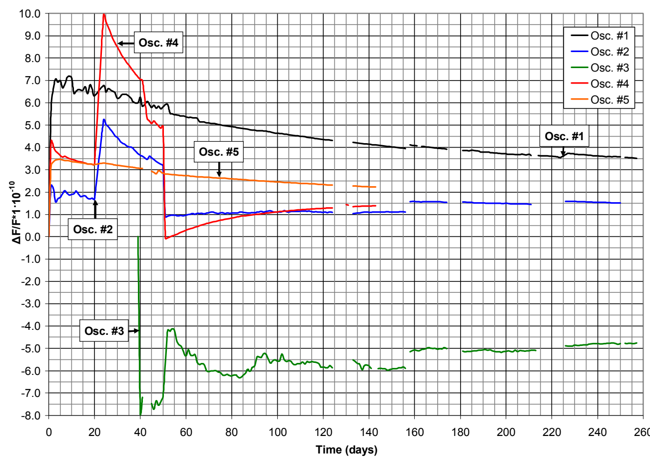

Figure 6. Aging results for each LGT oscillator.

Unfortunately, Osc. #4 and #5 have been tested no longer than 140 days. However Osc. #4 seems to give good performances too.

IV. CONCLUSION

To the knowledge of the authors, there was no material so far able to replace the quartz crystals in the low noise oscillator applications. We can now suggest that the langatate crystal is a serious candidate. This work brings the first results on the aging, nevertheless only few prototypes were tested. Up to now, the best achieved results are:

- **-110 dBc/Hz** at **1 Hz** from the carrier
- a **floor** of about **-150 dBc/Hz** after 10 kHz
- **aging** of $\mathbf{1.5{\cdot}10^{-10}}$ $\mathbf{day^{-1}}$

The most efficient prototype (Osc. #4) is equipped with the most trapped resonator; this best one has achieved the lowest noise as well as one of the lowest aging performances.

We can expect better results by the use of this pure synthetic crystal to realize ultra-stable oscillators. So, works on langatate have to be continued to answer the question: is the langatate crystal can permit to build more stable oscillators than quartz crystal?

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AUTHORS

Joël Imbaud (M’07) was born in Riom, in France. He received the engineer degree in mechanical and micro-technical sciences and the Master degree in electronic and optical sciences from the Ecole Nationale Supérieure de Mécanique et des Microtechniques (ENSMM) of Besançon, France, in 2005. In 2008 he received the Doctor degree in engineering sciences of the Franche Comté University in France. He currently works for the Centre National d’Etudes Spatiales (CNES) in the Frequency and Time department of the FEMTO-ST institute of Besançon.

Serge Galliou received the mechanical engineering degree from the Ecole Nationale Supérieure de Mécanique et des Microtechniques (ENSMM) of Besançon, France, in 1980. In 1982, he received the Doctor Engineer Degree in vibrations and oscillators. He joined the Laboratoire de Chronométrie d’Electronique et de Piézoélectricité (LCEP) of Besançon in 1980 and, since 1985, he also has been teaching electronics and signal processing at ENSMM, where he is now Professor. His research interests include topics such as precise temperature control, noise reduction and design of various types of crystal oscillators (miniature oscillators, dual mode oscillators, ultra stable oscillators). Industrial partners who partly support these research topics are European manufacturers of ultra stable resonators and oscillators and institutions like the Délégation Générale pour l’Armement (DGA) and Centre National d’Etudes Spatiales (CNES) whose needs include radar applications or measuring and positioning systems, dedicated to onboard or ground uses… He currently manages the team Piezoelectric Resonators and Ultrastable Oscillators, in the department LCEP of the FEMTO-ST Institute of Besançon.

Jean Pierre Romand received the Superior Technician degree from the Lycée Victor Berard of Morez, France,in 1987. Since 1992, he is specialized in precision grinding and polishing and also in the manufacture of very high quality crystal resonators. Under contract since 2000 with the Laboratoire de Chronométrie d’Electronique et de Piézoélectricité (LCEP) as the technician for manufacturing.

Philippe Abbé received the Superior Technician degree from the Lycée Victor Hugo of Besançon, France, in 1995. In 2000, he received the Assistant Engineer degree. He joined the Laboratoire de Chronométrie d’Electronique et de Piézoélectricité (LCEP) which became Frequency and Time department of the FEMTO-ST Institute of Besançon in 2004. He is working on the associated measurements and metrology of ultra-stable oscillators and more recently cryogenic oscillators.

Roger Bourquin (M’97) was born in Valentigney, France, in 1947. He received the M.S. in 1969, the Doctorat of University in 1971, and the Doctorat d’Etat in 1979 from the University of Franche-Comte, France. In 1970, he joined the Ecole Nationale Superieure de Mecanique et des Microtechniques (ENSMM) as an assistant professor and was appointed as a professor in 1989. From 1969 to 1971, he was with the Laboratory of Atomic Clock (CNRS) of Besancon where he worked in the field of electron spin resonance instrumentation and in 1971, he joined the Laboratory of Chronometry, Electronics, and Piezoelectricity (LCEP) of ENSMM. Since 2004 he his with the FEMTO-st Institute (University of Franche-Comte / CNRS / ENSMM) as head of the Department of the LCEP Department. He is currently working on non-linear effects in piezoelectric crystals and devices, and on piezoelectric resonators and their use as frequency output sensors.