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Dedicated oven for optical resonator heating process

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ABSTRACT

Optical resonators are useful to achieve optoelectronics oscillators or frequency combs. High-Q factor resonators for photonics applications are obtained by polishing. To gain in terms of performance, a way is to perform a controlled annealing process to improve the roughness of resonator's surface down to the nanometer scale. We present the setup and explain it.

KEYWORDS

Oven, thermal annealing, nichrome, resonator, CFD fluid module, ANSYS

1. INTRODUCTION

In order to have stable frequency signals, it is possible to choose frequencies in the radio frequency domain. Quartz performances have long been known and reproducible [1 – 3]. In recent years, however, there has been no significant progress in terms of stability of Frequency or phase noise [4]. For more than twenty years, efforts have been made to make optoelectronic oscillators [5]. In our laboratory, we have made delay line-based optoelectronic oscillators and crystal resonators [6 – 9]. These oscillators can be characterized with special benches [10 – 12]. They perform well in terms of quality factors.

Let us return here to the question of how to improve the quality factor of ultra-stable crystalline resonators. There is a two-step manufacturing process [13]. But we see that it is necessary to introduce an annealing stage. In fact, the outer surface of the optical resonator is subjected to numerous stresses during polishing. We must ensure that the state of constraint is relaxed. This will ensure that the roughness will be as low as possible. For the best resonators, aim for a roughness of the order of the nanometer.

For this purpose, we have developed a special annealing oven. The oven operates from room temperature up to almost 700°C. Of course, we could have used a commercial oven, but we were guided by the need for a specific oven. In fact, it is necessary to be able to heat a resonator that is relatively small by controlling the temperature as much as possible. An oven cavity that is too large is too difficult to control. No need to have a big oven as the diameter of the resonator is only about 5 to 6 mm. Free spectral range in X-band dictates the choice of this diameter.

In the following section, we will therefore look at the main elements of the furnace. Then we will look at the simulations.

2. WHAT ARE THE TIPS FOR MAKING THE ANNEALING OVEN?

The main lines of the oven principle that we have achieved are given in the following references [14,15]. This reference can be consulted for furnace electronics [16]. The important thing with the electronic control of the current injected into the NiChrome wires is to control the rise time. A too fast ramp would almost inevitably damage the surface of the resonator to be annealed. On the contrary, the temperature rise ramp must be soft enough to allow relaxation of all kinds of stresses and to ensure an improvement in the quality factor of the resonators. Wires for heating are in Nichrome which is made of nickel, chromium and a bit of iron. Thermal expansion is $14 \times 10^{-6} \text{ m/m/}^\circ\text{C}$. Its Specific heat capacity is $450 \text{ J/kg}^\circ\text{C}$. It is recalled that the most important was the idea of using NiChrome threads intertwined in clay. It may be surprising that Clay is used. But this material has properties that are favorable for this type of use. On the one hand, the clay is easy to model to give it the shape to accommodate the foot of the resonator. On the other hand, Clay has self-repairing properties. It is therefore better able to withstand successive annealing cycles, although it is necessary to replace the supports after several cycles if the rise or fall in temperature has been too rapid, causing a heat shock. Finally, the other idea was to surround this clay support with Basalt Fiber [17]. The type of the basalt is "BAS NW 10MM" manufactured in Wevegem in Belgium by Basaltex SA. "NW" means No woven ". Non woven mats are made of 100% bulk continuous filament (BCF) fibers with high thermal insulation properties, high thermal and chemical resistances. Characteristics of sensors such as platinum resistance thermometers, thermistors and thermocouples can be found in reference [18]. A variety of techniques is reminded in reference [19]. The shape of the support is made for resonators to be in a miniature for a better thermal control. The principle of this annealing is to send a 1 to 6 A DC electric current inside the alloy.

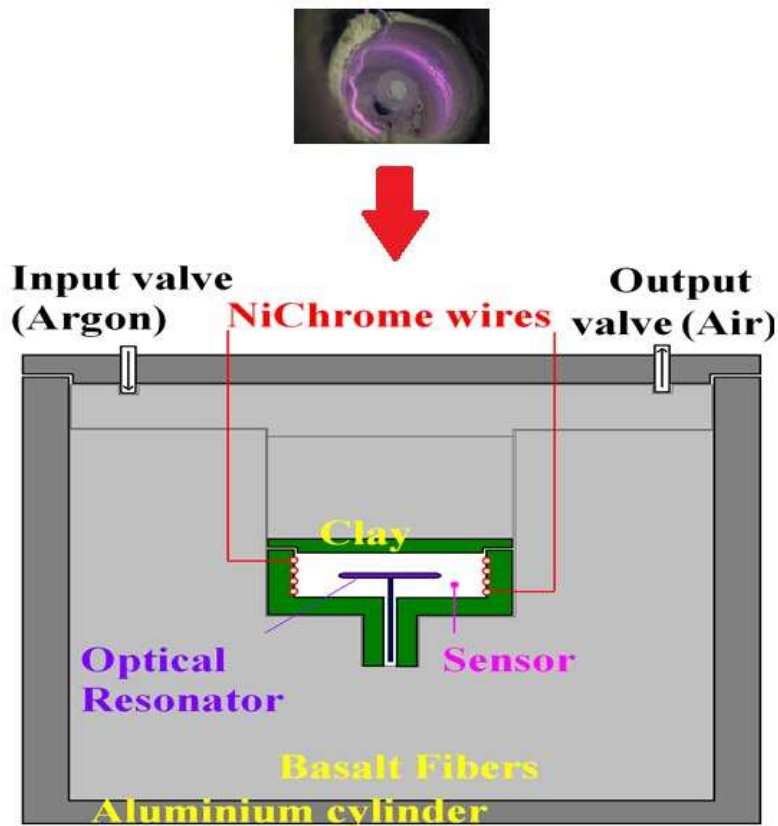


Fig. 1. structure of the oven

3. FINITE ELEMENT SIMULATION

To understand the residual stresses inside the resonator, we have simulated the heating process in the oven using the finite element code ANSYS© and CFD fluid module [20]. The resonator is in the middle of a cylinder with uniform distribution of the temperature all around the part. For this simulation, we neglect the dissipation through the support that link the base and the resonator. Due to the symmetry along the two axis, only $\frac{1}{4}$ is used for the thermal analysis. For better accuracy, we have used 20840 nodes and 77685 (3D) finite elements within ANSYS Workbench. It is shown on Figure 2.

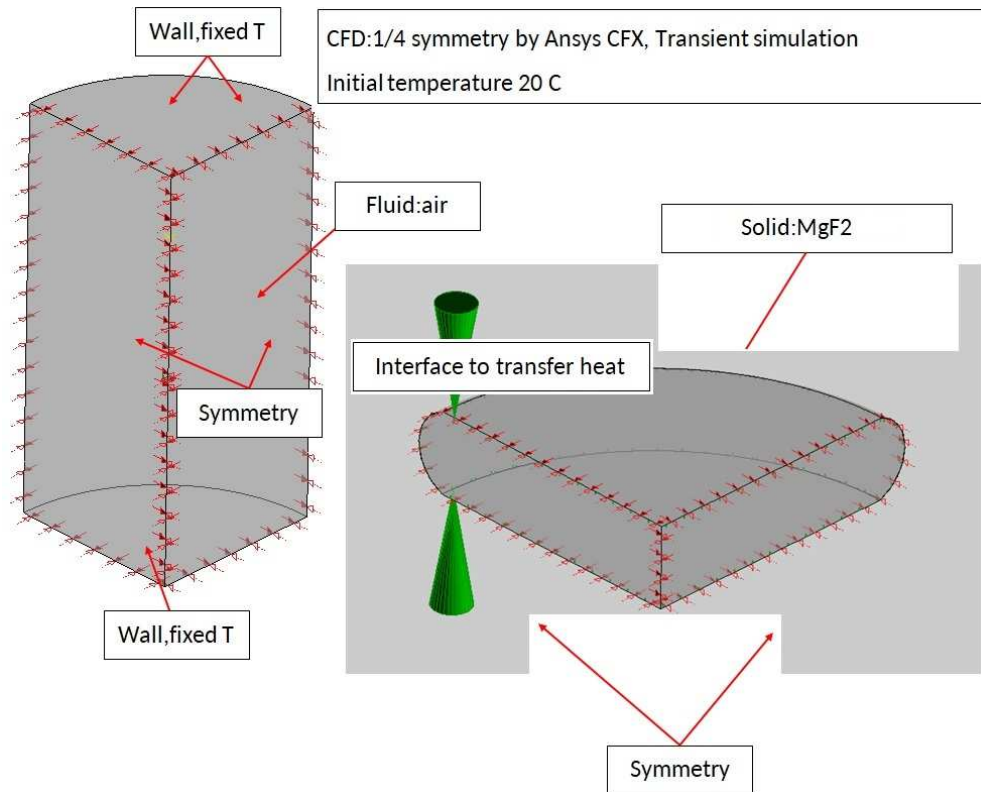


Fig. 2. Due to the symmetry, finite element analysis is reduced to $\frac{1}{4}$ of the structure (initial temperature is set to 20 degree)

In the following figures 3 and 4, we can see the thermal diffusion inside the resonator at different times (at $t=10s, 20s, 50s$ and $100s$) for three input temperatures. We focus on these two main temperatures (100 and $700^{\circ}C$) because it has been proven that MgF2 resonator start relaxing at this rang. We can notice the speed of the diffusion along the disk increase with the increase of temperature. The curved shape at the edge of resonator cumulate more thermal energy at the first stage, and relaxed during heating. This process allowed us to decrease the internal residual stresses related.

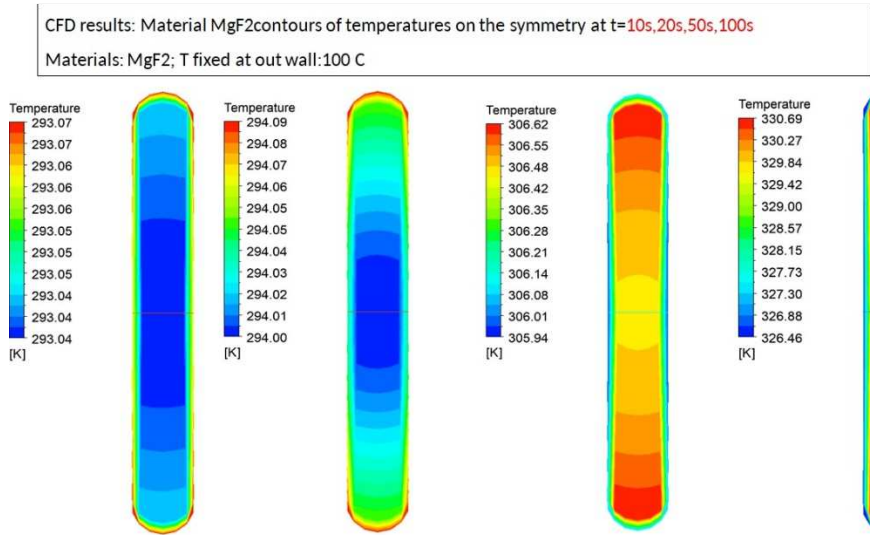


Fig. 3. FE simulation of the thermal diffusion for MgF₂ resonator at t=10s, 20s, 50s, 100s and the temperature T is fixed at out wall at 100 °C.

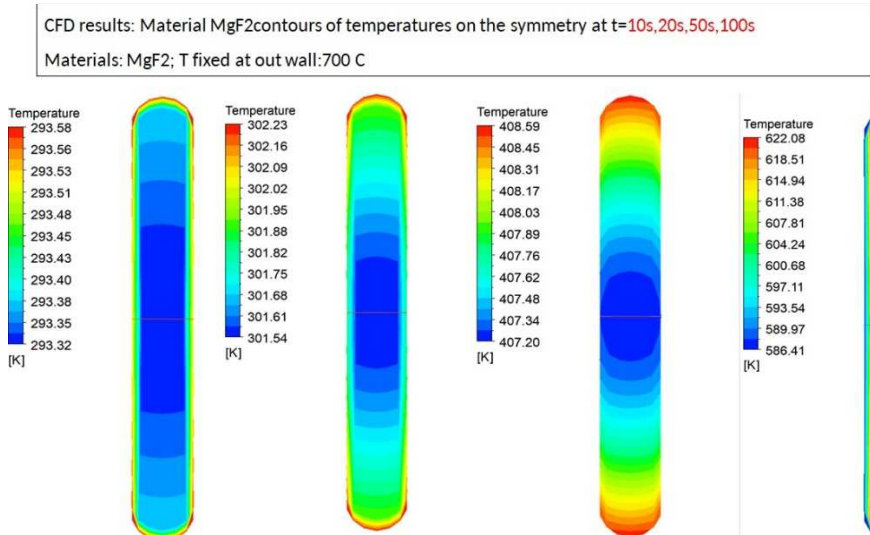


Fig. 4. FE simulation of the thermal diffusion for MgF₂ resonator at t=10s, 20s, 50s, 100s and the temperature T is fixed at out wall at 700 °C.

4. CONCLUSION

In this paper, we provide the main element of the oven and of the holder for resonators heating process. nichrome resistant alloy wires and special chopped basalt fibers for thermal isolation are essential elements of the realized oven. In this paper, we have also performed a finite element simulation of the heating using ANSYS code to describe the thermal diffusion within the resonator at different times and temperature. It is clear that the process described below allows decreasing the internal residual stresses. However, further investigation is running to measure the roughness before and after the heating process using non-indentation technics and X-ray imaging. This should help us to better quality our resonator.

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