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REALIZATION OF HIGH-Q FREQUENCY-TEMPERATURE COMPENSATED RESONATOR WITH SPURIOUS MODE FREE REGION

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Abstract **- In this paper, we present results for a high–Q frequency-temperature compensated dielectric resonator in the framework of the PHARAO project. This design and this analysis of performance are based on a two dimensional Finite Element method (FEM), with a good agreement between theory and experiment. This study shows that a good isolation between the whispering gallery mode and spurious mode is necessary to obtain good performances. A compensation temperature of 71.8 K for a high quality factor of 10.7 millions is measured. This device is generally used in oscillator applications, but in the filter domain, high-Q frequency-temperature compensated dielectric resonator can be interesting.**

Keywords **- Compensated sapphire resonator, whispering gallery modes, Finite element method**

I. INTRODUCTION

High-stability microwave resonator oscillators based on sapphire Whispering gallery (WG) modes resonators have become important devices for metrological applications. To confine the field within the sapphire and get a high-Q, it is necessary to excite Whispering gallery modes. The high-Q factor has enable the lowest phase noise [1] and most frequency stable [2] oscillators in the microwave domain. Sapphire is an extremely low loss material at liquid nitrogen temperature but his permittivity presents a large temperature sensitivity leading to a frequency temperature sensitivity. In order to create an oscillator with frequency stability, the resonator must have the frequency-temperature dependence annulled

To compensate this dependence at liquid nitrogen temperature, we chosen the technique of dielectric compensation : we design a composite resonator with rutile which have low loss and opposite sign of its temperature coefficient of permittivity (TCP), compared that of sapphire (figure 1).

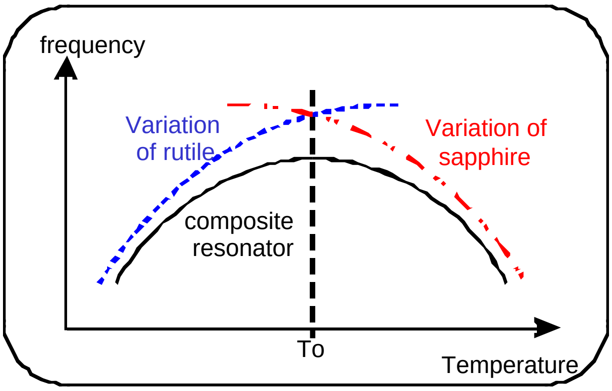


Fig. 1: Dielectric compensation

II. RESONATOR DESIGN

To compensate the temperature coefficient of permittivity for sapphire, thin rutile rings, with opposite TCP, are placed coaxially at the end faces of a sapphire cylindrical resonator operating in WG mode [3], [4]. Rutile has been choosen because it's also a low loss dielectric material. Moreover, Bragg reflection occurs between layers of rutile and sapphire and most of the energy is confined into the sapphire. The topology of a rutile ring was used because the Q-factor may be larger and spurious modes may be eliminated. The inner diameter of the rutile rings has to be greater than the caustic radius of the whispering gallery mode excited in the structure, in order to reduce the strength of interaction between the two materials.

Two kinds of whispering gallery modes can be excited in the device (figure 2): WGE modes with transverse electric fields and WGH modes with axial electric fields.

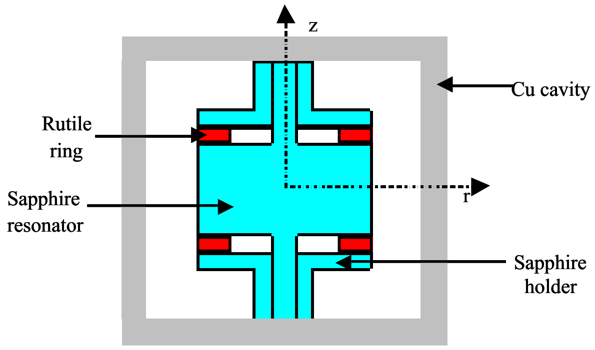


Fig. 2: Sapphire-rutile resonator

For the following reasons, we have chosen to work with WGE modes. First, because the electric field is tangential at the rutile interface, no air gap problems can occur.
The second reason is due to the Bragg reflections that occurs at the interface between the sapphire and the rutile. An anti-resonance appears in the rutile and forces most of the energy into the sapphire resonator and out of the rutile. The annulment temperature is weakly dependent on the thickness of the rutile rings in the anti-resonance regime [4]. The former allows for good design, which respects the manufacturing tolerances. The third reason is less energy is required in the rutile for compensation. Thus, the losses, due to rutile, are lower and the Q-factor is larger.

The frequency of the resonator has to be 9.2 GHz. It operates in the $WGE_{7,0,0}$ mode. The choice of azimuthal mode number (n=7) was made because of the size limitation of available rutile rings.

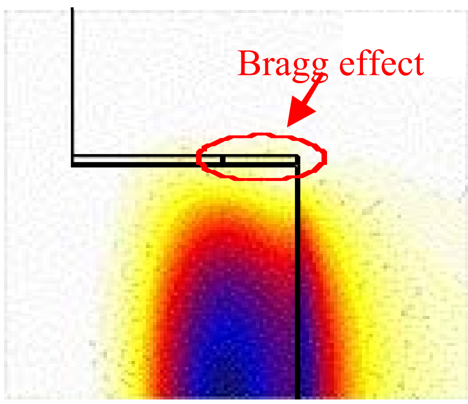


Fig. 3: Electric field density for WGE mode

The sapphire-rutile cavity was analysed by Finite Element (FE) software [5]. We use the anisotropic permittivity of sapphire and rutile [6] to calculate the characteristic of the sapphire-rutile resonator as a function of temperature. Because of the symmetry of a cylindrical resonator, only _ of the resonator was needed for the FE mesh.

The figure 3 shows the electric density for a WGE mode. It's evident from this plot that most of the field is confined into the sapphire dielectric.

Calculation by FEM software is shown in figure 4 for the frequency and unloaded Q-factor.

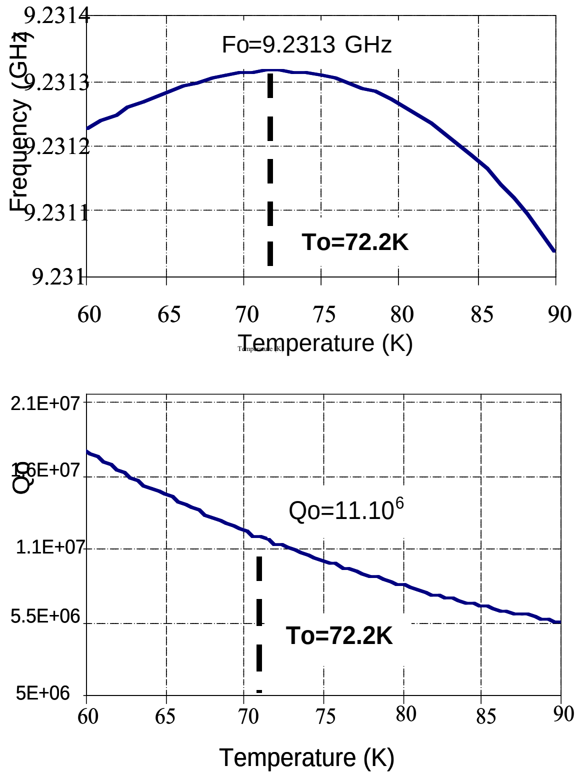


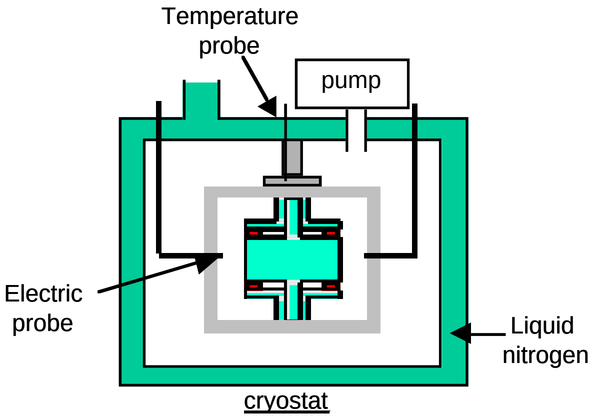
Fig. 4: Calculated frequency-temperature dependence and Q-factor dependence

The $WGE_{7,0,0}$ was calculated to have an annulment temperature of 72.2 K and a Q-factor of 11 millions at 9.2313 GHz .

III. MEASUREMENTS

The sapphire rutile resonator was placed in the center of a cylindrical copper cavity. The coupling of the resonator is accomplished with two electrical probes. Then the device was placed in an evacuated can and was cooled with liquid nitrogen at 77 K and cooled to 60K by pumping on the liquid. (figure 5).

Fig. 5: Measurement device



Measurements of the resonant frequencies, loaded Q-factor and coupling are made for each temperature. Then we can calculate the unloaded Q-factor. Results for the frequency and Q-factor are presented in the figure 6.

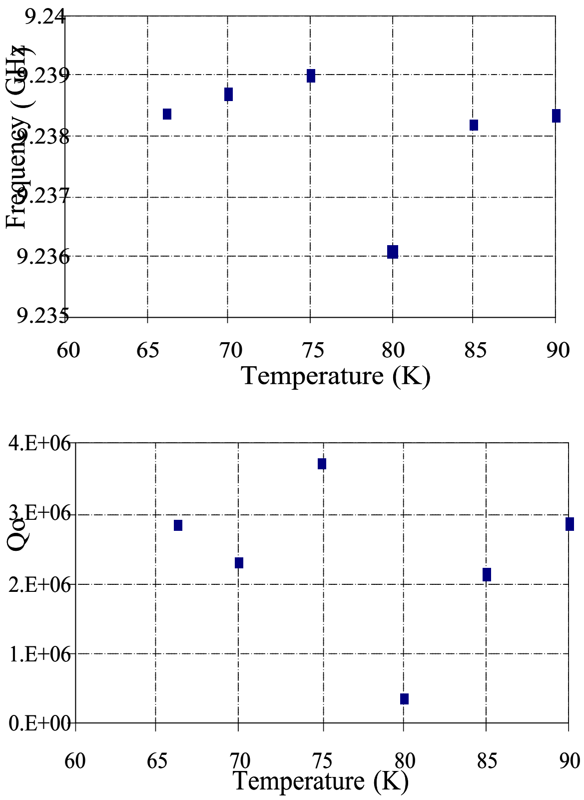


Fig. 6: Measured frequency-temperature dependence and Q-factor dependence

Experimental measurements reveal that the frequency-temperature dependence is not annulled. We also obtain a low unloaded Q-factor. It is 3 to 4 times worse than that predicted between 65 ant 90K. These problems can be explain by interactions between $WGE_{7,0,0}$ mode and spurious modes, corresponding to the empty cavity modes, rutile modes and other sapphire whispering gallery modes (figure 7). With the FE software, we can realized the identification of this spurious modes. We can see three interactions, leading to a perturbation of the resonance frequency and a degradation of the Q-factor for the $WGE_{7,0,0}$ mode.

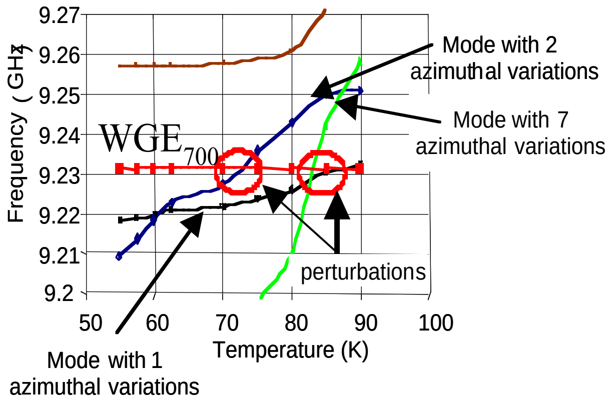


Fig. 7 : Mode interactions

This analysis revealed that the condition of annulment temperature was realized during mode interactions with spurious modes. One solution to minimize this unwanted interaction is to use a mode selection technique for the whispering gallery mode $WGE_{7,0,0}$ [7] [8].

IV. VALIDATION OF THIS COMPENSATION TECHNIQUE

In order to validate this technique of dielectric compensation, we made measurements for other whispering gallery modes, and in particularly for the WGE mode with 9 azimuthal variations.

Comparison between the FE calculation and experimental results is shown in figure 8 for the frequency-temperature dependence and the unloaded Q-factor dependence.

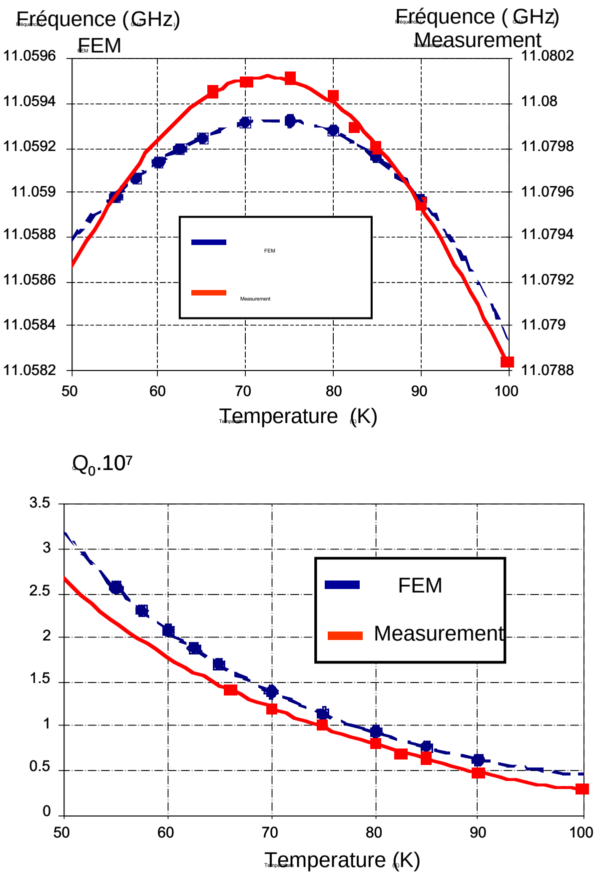


Fig. 8: Calculated and measured frequency-temperature dependence and Q-factor dependence

Table 1 presents the main characteristic parameters for the composite resonator.

	To	fTo (GHZ)	Qo (To)
FEM	68.5	11.0712	$16{,}12.10^{6}$
Measurements	71,8	11,0801	$10{,}71.10^{6}$

Tab 1 : FE calculations and experimental results

There is a good agreement between Finite Element calculation and experimental measurements.

A high-Q factor of 10,7 millions was measured with an annulment temperature of 71.8 K for a frequency of 11.08 GHz.

In the figure 9, we present the evolution of the spurious modes between 60 and 100K. We can check a good spectral isolation around the $WGE_{9,0,0}$ mode. Thus, there is no interactions between WGE modes and spurious modes.

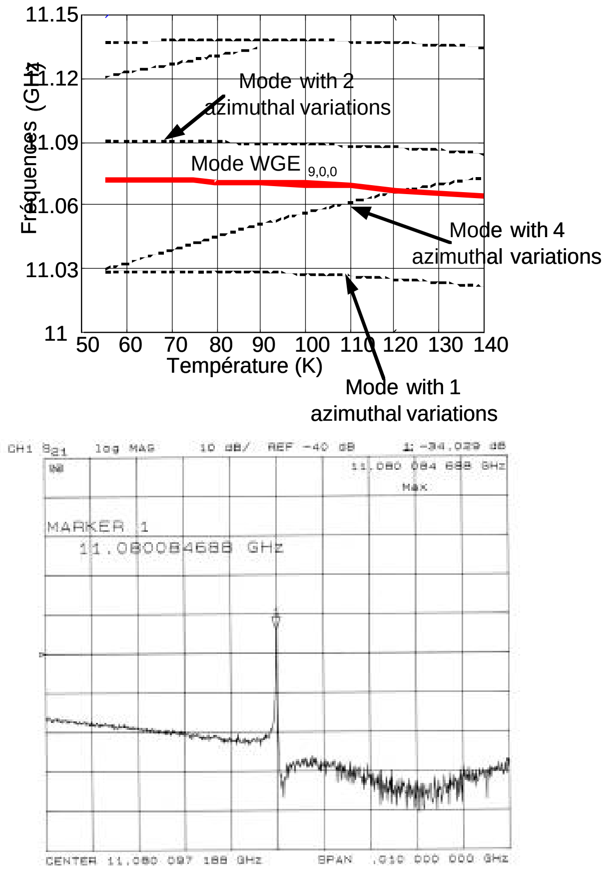


Fig 9 : Isolation around $WGE_{9,0,0}$ mode

IV. CONCLUSION

We have presented the design of a sapphire-rutile cavity to get a high-Q frequency-temperature compensated dielectric resonator. With the measurements for $WGE_{7,0,0}$ mode, interactions appeared between this modes and 3 spurious modes. Thus, the condition of annulment temperature is not realized and there is a degradation for the unloaded Q-factor.

Then, we realised the measurements for the $WGE_{9,0,0}$ mode. Calculations from Finite Element software have been compared to measured temperature characteristics with a good agreement. A high-Q factor of 10,7 millions was measured with an annulment temperature of 71,8 K. We have checked a good isolation around the Whispering Gallery mode.

The next step will be to build an oscillator with this composite resonator using the $WGE_{9,0,0}$ mode and to check the reduction of the phase noise in oscillator.

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