Updated BVD Modeling of AlN-based Solidly Mounted Resonators Working at Cryogenic and High Temperatures

From -160 °C up to 130 °C

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***Summary*—In this work we theoretically and experimentally assess the behavior of AlN-based Solidly Mounted Resonators (SMR) at cryogenic and high temperatures. This study can be useful for precise behavior prediction of SMR sensors working as gas detectors in the food preservation industry, or the industrial and automotive ones. We have subjected SMRs to temperatures from -160°C up to 130°C in high vacuum conditions (6x10^{-7} mBar) and compared their experimental performance to a modelled one. We employed an updated mBVD model that includes low temperatures effects, and we show good accuracy between data. Our SMRs have fairly preserved their quality factors and electromechanical coupling factors at both cryogenic and high temperatures: Qa= 482, Qr = 288 and k_{eff} = 6.30% at -160ºC to a Qa = 477, Qr = 265 and k_{eff} = 6.39% at 130ºC.**

Keywords—SMRs; AlN; low temperatures; high temperatures; BVD model

I. Introduction

During the last years, Film Bulk Acoustic Resonators (FBARs) have been widely studied as active components in RF filters and gravimetric sensors [1]–[4]. One field of study has been their application in harsh environments, where they have shown good capabilities. Therefore, they can be used as mass detectors in fields like the automotive one or in the chemical industry for detection of gases like CO_2, CO and O_2 [5]–[7], and also in the food industry where optimal preservation at specific temperatures is pivotal. For example, the decomposition of some food like fish, produce certain gasses that indicate decomposition, also in the food distribution chain for fruits and vegetables Although their application at high temperatures has been thoroughly assessed these last years, only few studies exist at low temperatures [8]. Additionally, widely employed models for FBAR design do not include low temperature effects. In this work, we present an updated Butterworth Van Dyke (BVD) model that considers very low temperature effects, and we compare it with experimental results on AlN-based Solidly Mounted Resonators (SMR) operating at 2.4 GHz. We have submitted SMRs at temperatures ranging from -160°C up to 130°C and compared them with theoretical predictions finding good agreement between them. At low temperatures, we could use this technology in the food preservation.

II. Methods/Results

We measured SMRs in a vacuum chamber (6x10^{-7} mBar) where temperature conditions could be set from -160 °C up to 130 °C. To control the temperature on the chuck and the sample we used a precision controller and a high-performance silver paste that ensures excellent electric and thermic conductivity all this to ensure good results for different temperature measurements. The electrical response of the devices upon temperatures variations has been tested using an RF probe Z40 -XV-GSG 150 and a vector network analyzer. Fig. 1 shows the impedance moduli at different temperatures where we can clearly observe the negative temperature coefficient of frequency (TCF) effect on both, resonance (fs) and antiresonance (fp) frequencies. Fig. 2 shows the fair performance preservation of the device at both, low and high temperatures, by means of their quality factors. We can observe how Ohmic losses increase when the temperature increases and how at very low temperatures (below -160 °C) the resonator suffers a saturation effect. In addition, in Fig. 3, we present the modelled and experimental response at some specific temperatures. The employed model is a modified mBVD electric circuit previously described in [7].

III. Conclusions

We have modeled and experimentally tested SMRs at temperatures ranging from -160°C up to 130 °C. The presented model is a modified mBVD electric circuit that accounts for extreme temperatures effect. Results have shown good agreement between theoretical and experimental data. In a future work, the studied effects will be additionally included in a 1D Mason model for more precise behavior prediction of SMR sensors working in harsh environments. Additionally, sensors behavior and environmental side effects will be studied at atmospheric pressure in air to simulate more realistic applications.

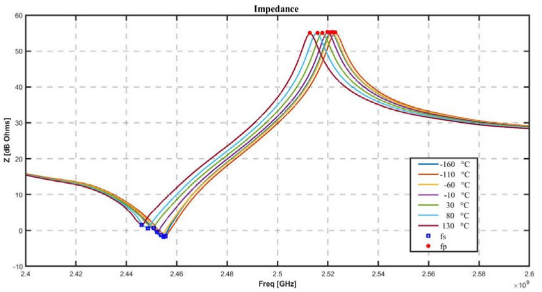

Figure 1. Electric impedance (Z) at different temperatures from -160 °C up to 130°C.

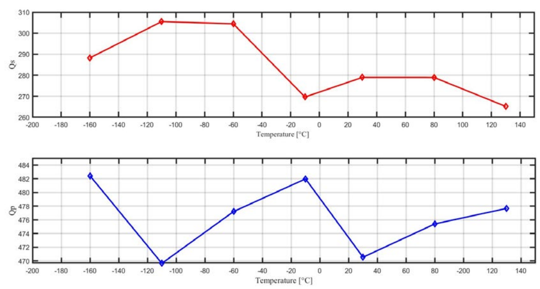

Figure 2. Qs and Qp at different temperatures from -160 °C up to 130°C, Qs is the red line and Qp is the blue one.

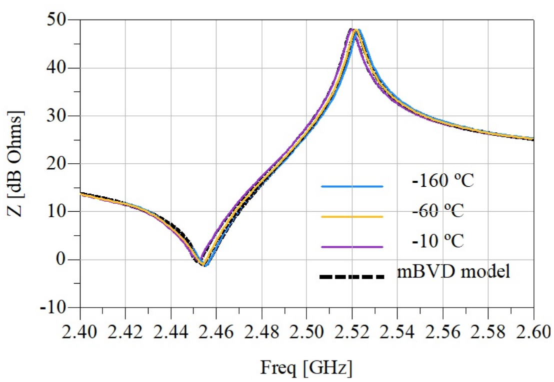

Figure 3. Impedance modulus (Z) at low temperatures from -10°C up to -160°C. The black dash curve represents the mBVD model and the solid lines represent the measurements.

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