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AlN-based solidly mounted resonators at 400ºC: in-situ performance monitoring

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***Abstract*—Acoustic wave sensors, particularly surface acoustic wave (SAW) devices, have been one of the most studied options for high temperature applications. Although they present the big advantage of simple wireless interrogation, they also have disadvantages. These disadvantages include the destructive agglomeration of their metallic thin electrodes. To overcome these issues, AlN-based solidly mounted resonators (SMRs) appear as promising alternatives. Our previous studies have shown they sustain temperatures as high as 1000ºC, however their in-situ performance at high temperature during a long period of time has not been performed yet. With this work we continue our previous investigations and we test in real time the performance of SMRs at 400ºC during 7 hours.**

Keywords—AlN, solidly mounted resonator, high temperature.

I. INTRODUCTION

Many industrial applications demand for sensors operating in harsh environments, particularly at very high temperatures, for real-time monitoring of different physical quantities and chemical targets. Acoustic wave sensors have proven to be adequate candidates for such purpose [1]. Most of the published works have focused on the development of surface acoustic wave (SAW) devices for these applications, mainly due to their ease of wireless excitation [2]–[4]. One of the biggest disadvantages of SAW devices is the transducer topology based on interdigital transducers (IDTs). At high temperatures the IDTs, composed of long and narrow metallic strips, suffer from destructive agglomeration, hence special metallic composites need to be used [5]. One of the most promising alternatives are solidly mounted bulk acoustic resonators (SMRs) based on thin AlN piezoelectric films [6]. SMRs can overcome the electrodes and power handling limitations of SAW resonators. Recent studies have demonstrated they can sustain very high temperatures up to 1000ºC with little degradation of their electrical response after the heat treatment [7], [8]. However, the in-situ response during the heat treatment has not been assessed. This is pivotal as their sensing capability at high temperatures depends of the performance they show in the harsh conditions. In this work we continue our previous investigations on the high temperature performance of SMRs [9] by monitoring their response at 400ºC for several hours.

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II. DEVICES

The structure of the SMRs consisted of a piezoelectric AlN film sandwiched between two electrodes deposited on an acoustic reflector made of five alternating layers of SiO_2/Mo, 620 nm-thick and 629 nm-thick respectively. As bottom electrode we used a 120 nm-thick Ir film and as top electrode a 100 nm-thick Ir film covered with 20 nm-thick Au. The devices were tested in air, hence the choice of the top electrode materials to avoid excessive oxidation. The designed structure provides a 2.5 GHz resonance.

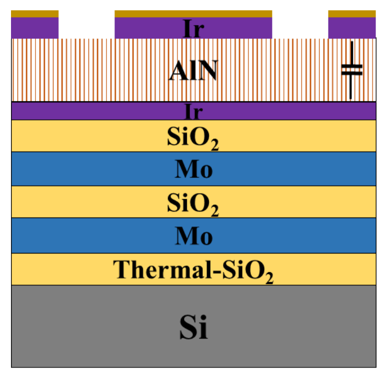

Fig. 1. Structure of the AlN-based SMR.

III. HIGH TEMPERATURE SET-UP

The electrical response of the devices was directly monitored through an RF probe connected to a network analyzer. In order to sustain temperatures as high as 400ºC, the RF probes were adapted with and attached Cu heat spreader to allow for higher power dissipation (Fig. 2). As heater we used a homemade stainless steel holder housing a double coil of Inconel sheathed heating cable. A Cu cap was used to cover the device during heating to prevent high temperature dissipation. The temperature was controlled through a thermocouple and a PID algorithm.

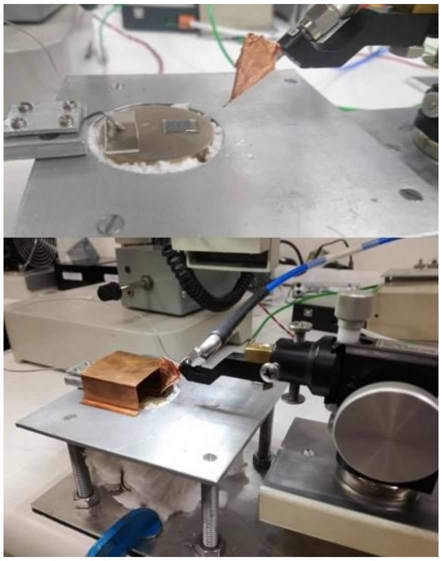

Fig. 2. RF probe station modified for high temperature operation. A Cu cap is used to prevent temperature dissipation (bottom picture).

IV. RESULTS AND DISCUSSION

The SMRs were heated up to 400ºC and maintained at that temperature for several hours. Fig. 3 shows the electrical impedance of an SMR during seven hours. We can observe a conservation of the performance during the seven hours with very small variation of the resonant and antiresonant frequencies.

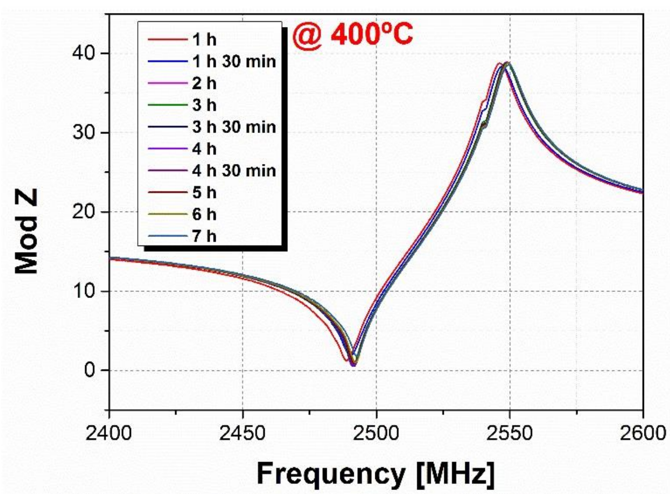

Fig. 3. Electrical impedances of an AlN-based SMR heated up to 400ºC and maintained for seven hours.

Fig. 4 compares the response of the same device before and after the entire process, once the device was cooled down. While the quality factor of the device was degraded to half its value, from 750 to 362 at resonance and from 1150 to 460 at antiresonance, the electromechanical coupling factor degradation was not that pronounced (from 6.29% to 5.58%). This means the piezoelectric quality of the AlN is preserved during high temperatures, however other materials composing the devices suffer more degradation. That is the case of the top electrode, on which at around 300ºC formed small dots (Fig. 5). This could be due to the occlusion of gas during the heating process which promotes the formation of bubbles. The unavoidable formation of an oxide layer on the top electrode is also responsible of the quality factor degradation, mainly at resonance as it increases the sheet resistance. These effects, detrimental to the performance of the SMRs, could be avoided by adequately capping the top electrode.

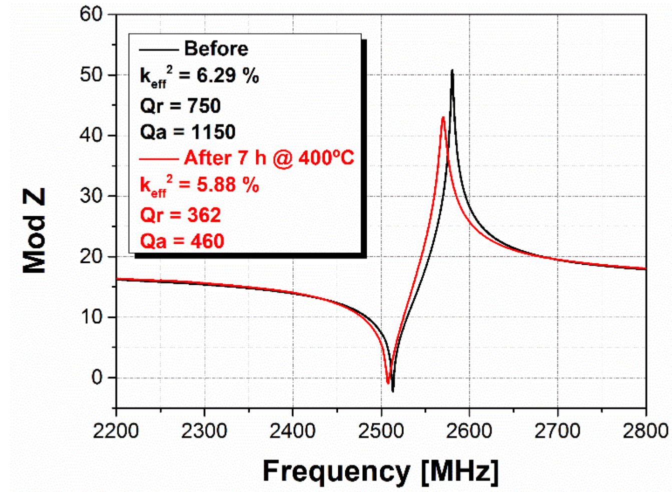

Fig. 4. Electrical impedance of the same SMR before and after the high temperature impact described in Fig. 3.

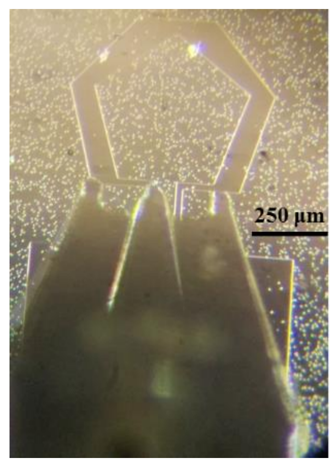

Fig. 5. Optical microscope image of the probed SMR during the 400ºC test. The image shows the effect of the high temperature on the Ir-Au top electrode.

V. CONCLUSIONS

We have tested the real time performance of AlN-based SMRs while heated up to 400ºC. The devices were maintained at this temperature for several hours proving their performance is preserved during the entire process. Although they suffer a considerable degradation in quality factor, their electromechanical coupling factor is less affected. Nonetheless, they still provide enough performance to be used as sensors in harsh environments. The considerable degradation in quality factor arises due to the fact that they are heated up in air, hence considerable oxidation of the top electrode occurs. This could be solved by employing optimized capping layers.

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