Characterisation Setup of SAW Devices at High Temperatures and Ultra High Frequencies

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***Abstract*—A HT stable measurement setup for SAW devices operating at UHF has been developed. It is based on a ceramic chip carrier clamped on a metal ground plate that can be inserted into a tube oven and interrogated via coaxial cables. All interconnections except for the SAW device itself are clamped with metallic springs. Thus, the chip carrier can easily be inserted and removed from the measurement setup. The selected geometry and materials allow a simultaneous operation up to frequencies of 3.5 GHz and temperatures of 1000°C. To introduce the coaxial cables into the quartz glass tube, a vacuum tight feed through is used. So, influences of different atmospheres like laboratory air, inert gases or vacuum on the behavior of the SAW devices can be studied. Four similar test units can be inserted into the tube allowing in-situ measurements of up to four two port devices. The design aspects of the setup and first measurements of SAW test devices on langasite are presented.**

I. Introduction

Surface acoustic wave (SAW) devices are perfectly suited for applications in wireless sensor and radio frequency identification (RFID) systems in harsh industrial environments as they can withstand extremely high temperatures in comparison to silicon based devices [1], [2]. As SAW sensor devices need a rather large bandwidth to operate, only a few license-free ISM bands - mainly in the UHF regime - are of use. If CDMA or TDMA is considered, either for accessing multiple devices or for realization of RFID tags with large code size, the ISM-band at 2.45 GHz is most suitable. Existing measurements cover temperatures up to 1000°C and frequencies up to 200 MHz. For SAW devices operated at high temperatures (HT) and ultra high frequencies (UHF) at the same time, hardly any data exists. This is mainly due to the high demands on the interconnections for these environmental conditions.

In scientific publications about high-temperature chip measurements, the focus is mostly on the measurement results and their interpretation. A description of the measurement setup is normally very brief or missing [3]–[5]. After several years of research in the field of high-temperature surface acoustic wave (SAW) sensing, the authors would like to present a newly developed measurement setup that allows to obtain reproducible and reliable measurement data.

II. Setup requirements

The measurement setup had to accomplish the following needs:

- In situ measurements of four two-port measurement UHF channels.
- Temperature monitoring via reference sensors as close as possible to the SAW devices (device under test, DUT).
- Modular design to change and contact the SAW DUT easily - in this case with platinum (Pt) bond wires.
- Air-tight enclosure of the DUT holders so that different atmospheres like vacuum, argone or nitrogene can be established to investigate its influence on the devices' behavior.
- Stable, reuseable interconnections, capable for UHF signals transmitted between the DUT, the chip carrier and the signal transmission cables.
- Low influence on the measurement signal, possibly induced via changes in cable/interconnection impedances during measurements at elevated temperatures.
- The whole measurement setup has to resist temperatures of up to 1000°C for several hours without degradation of electrical contactivity and must have a stable signal quality at different temperature levels.
- To reduce maintenance time, it is not convenient to disassemble the measurement setup for cleaning after each use so the electrical contacts should be stable for many measurement cycles.

In the following, the components of this measurement setup are described.

A. Cables

To meet the requirement of high-temperature stability and good signal transmission, the cables tested were all 'semi-rigid' with a steel mantle, ceramic powder dielectric and copper or steel conductor. Figure 1 shows the transmission parameters (S_{21}) of two tested cables, one with a steel center conductor and magnesium oxide dielectric (red line) and one a with a copper center conductor and silicon dioxide dielectric

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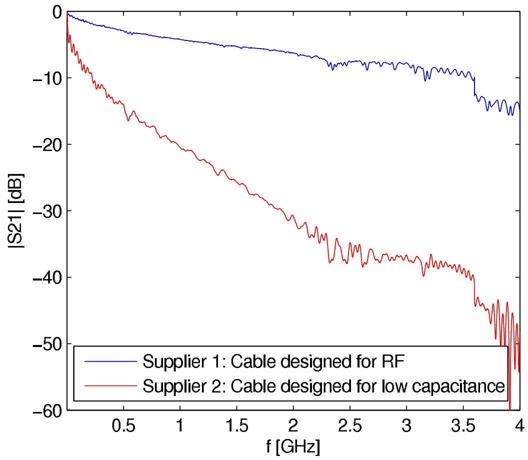


Fig. 1: S_{21} signals of two cables at room temperature.

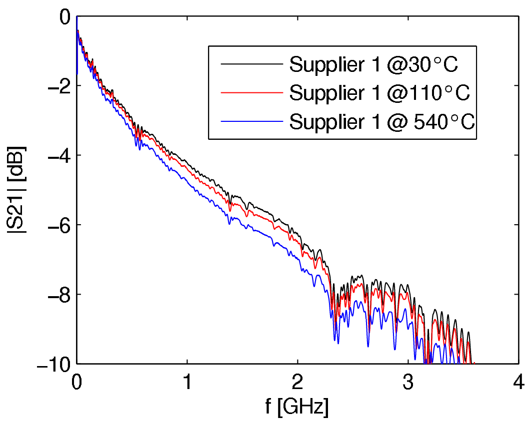


Fig. 2: S_{21} signals of the chosen cable at several temperatures.

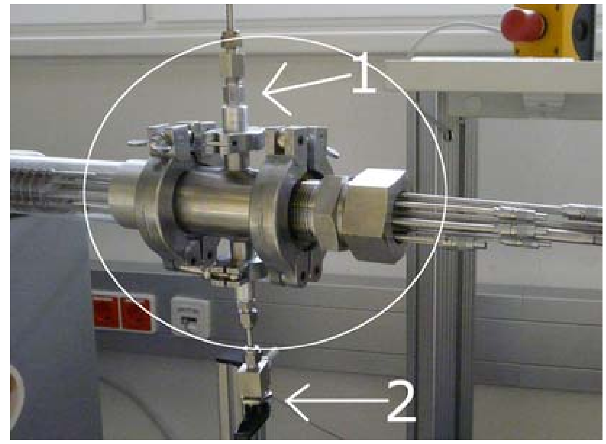


Fig. 3: Cable feedthrough and gas control.
1: Security valve; 2: Vacuum access

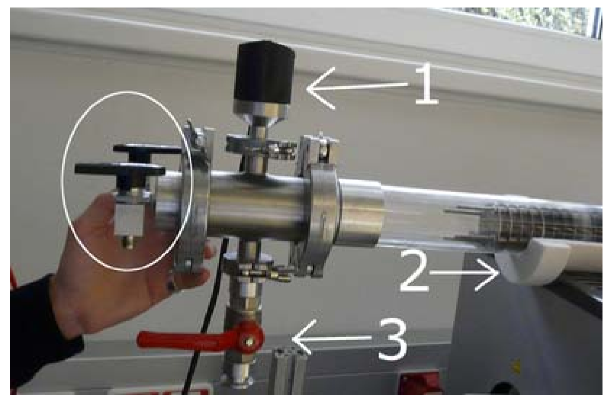


Fig. 4: 1: Gas intakes; 2: Ceramic spacer;
3: Security gas opening

(blue line). The first was assigned as low-capacitance cable, the latter was designed for radio frequency (RF) applications with an impedance of 50 ohms and showed appropriate performance. In figure 2, the S_{21} signals of that cable at room temperature, 110°C and 540°C are shown. The signal degrades about 1.5 dB between 30°C and 540°C.

To connect a two-port network analyzer with four two-port channels, a RF-switch routes the signal from the NWA to the active channel. This switch leads to a discontinuity at 3.5 GHz (figure 1) which limits the upper operation frequency of the measurement setup.

To get a good electrical contact between cable and chip carrier, the copper conductor is plated with Pt foil of 200 µm thickness by laser welding. A formerly tested rhodium electroplating with a film thickness of several microns vanished after annealing.

B. Flange area and atmospheric control

All flanges are of the Swagelock® type (figure 3). Two gas inlets are mounted to allow the mixture of two different process gases like oxygen, nitrogen, argon or air if needed (figure 4). Additionally, a vacuum (about 0.5 mbar) can be applied if atmospheric influence has to be reduced. A pressure sensor, a security valve and a security gas inlet allow to control and monitor the pressure inside the quartz glass tube enclosing the whole measurement setup. The cables penetrate a specially designed feedtrough with rubber/neoprene seals. This increases the flexibility to adjust the cable lengths at the cable tips. To keep the temperatures below 70°C at the ends of the quartz glass tube, radiation reflectors (figure 5) are placed inside 30 cm from the tube ends. Further, they stabilize the cables and hold them in place. Thus, the aluminum flanges mounted on the quartz glass tube can be glued with standard epoxy adhesive, the flange seals can be made of ordinary rubber and the gas tubes are of standard plastic. As can be seen in figure 5, the reflector plates show the tempering colours from the inside to the outside indicating the temperature levels at each reflector plate. The outer plates look still metallic and shiny as do the cables, so the temperature at these plates was much below the temperature at the inner plates.

C. Device holders

1) Main block: A fully equipped measurement setup with four test devices and two temperature reference sensors can be seen in the photography of figure 6. This part holds

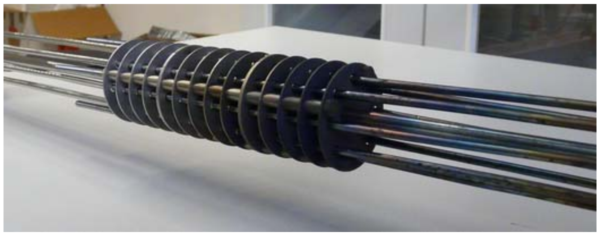


Fig. 5: Photography of the reflector.

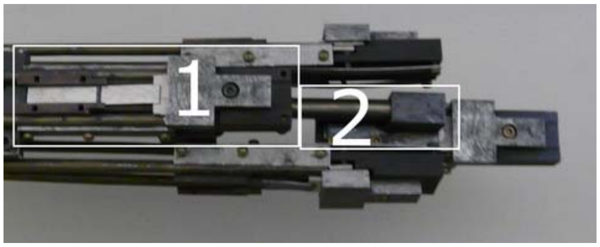


Fig. 6: Completely equipped measurement setup.
1: Single device holder
2: Temperature reference sensor

all the screws, springs and cables in place and allows the interconnection between cables and chip carrier. Figure 7 shows the single block without any other part mounted and figure 8 the additional parts in position. For the block, two materials were tested: niobium and 1.4305 steel.

2) Springs and cap: These molybdenum parts fix the cable and chip carrier to the main block. The cap pushes the carrier down to make an electrical contact with the cable tips (figure 8).

3) Chip carrier: This part (figure 9) is made of Rescor®960, a machineable ceramic and has the following functionalities:

- to hold the chip in place during the measurement,
- to provide electrical contact between cable tip and chip,
- to allow an easy change of the chip and make an electrical contact via wire bonding,
- to keep the ”open” signal path between the cable tips and the DUT as short as possible for adequate UHF signal quality,
- to ensure convenient handling with nitrile gloves.

The main design goal was to find a compromise between a short signal path and an adequate handling possibility (figure 9). Pt straps are wound around three positions of the chip carrier. They establish the electrical connection between the cables and bond wires of the test device. The lower Pt strip contacts mass, the upper left and right Pt strips connect the signal pins of the SAW device with the coaxial cables. To keep the chip in place during bonding, a hole is drilled into its center to apply vacuum. For a stable electrical connection, two bonds per pad are attached with a Pt wire of 25 µm in diameter. Figure 10 shows a SAW delay line chip mounted on a chip carrier, held in place and electrically connected via Pt bonds. The whole carrier is about 30mm x 30mm x 3mm

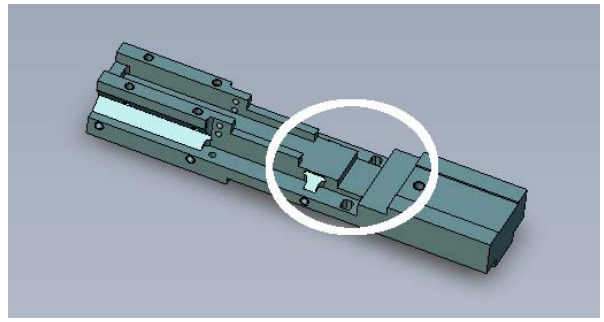


Fig. 7: 3D-model of the main block. The circle indicates the position of the chip carrier.

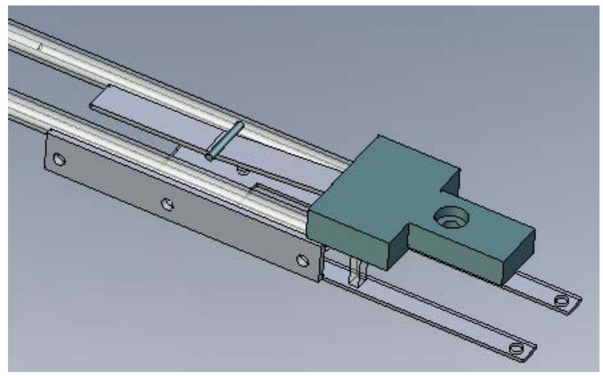


Fig. 8: 3D-model of prings and cap in position as if mounted.

and fits into a small clamp placed on the bonding chuck. A completely mounted device holder is shown in figure 11. The cap was removed for better visibility of the DUT, so the Mo spring presses the chip carrier slightly upwards.

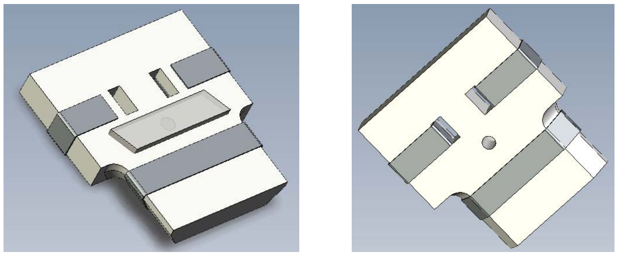
D. Screws, axes

Niobium and steel screws were tested. The Nb screws work best with the steel main block, but must be avoided when using the Nb main block because they get irreversibly and reproducibly stuck in the thread. The combination Nb-steel or steel-Nb works fine. The axes of the top Mo springs (figure 8) were always made of Nb.

E. Quartz glass tube and oven

As mentioned above, the completely mounted device holder is placed inside a quartz glass tube for the following reasons:

- Due to its transparency, it is possible to notice contaminations inside the tube very easily.
- Thus, the tube can be cleaned using standard chemical cleaners like acetone or isopropanol and more aggressive cleaning methods including sulphurous or nitric acid. This is not possible with a steel tube.
- To be able to clean the tube, it can be removed from the alumina oven tube in which it is placed on ceramic spacers (see figure 4, number 2).
- Because quartz is chemically very stable, it will not influence the measurements by contaminating the atmosphere.



(a) Top side of the chip carrier. (b) Bottom of the chip carrier.

Fig. 9: Top and bottom view of the chip carrier.

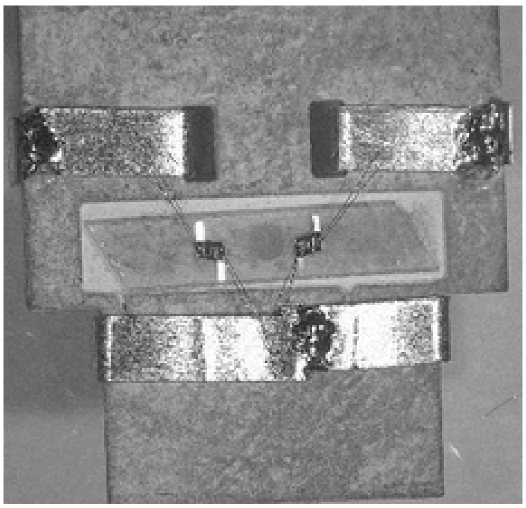


Fig. 10: Photography of a SAW chip mounted on the carrier.

- The large temperature gradient in the reflectors' area of about 600 Kelvin over 20 cm (length of the reflectors) does not induce cracks to the quartz glass tube.

The whole measurement setup inside the oven is equally heated from all sides over a length of 80 cm. Outside of this area, the radiation reflectors are placed to ensure a temperature below 70°C at the flanges (figures 3 and 4).

The maximum oven temperature is 1200°C. Due to radiation and convection losses, the maximum temperature at the main block is reduced to about 1000°C. To monitor the measurement setup's temperature, two K-type thermocouples are mounted close to the main blocks as reference sensors. To achieve a good thermal contact, the reference sensor tips are placed within metallic supports (see figure 6, number 2).

For preliminary tests the measurement setup was operated at three temperature levels (300°C, 600°C and 900°C), each held for 2 hours. Heating up takes nearly 12 hours, cooling down needs about 14 to 16 hours as no active cooling unit is used. An overview is shown in figure 12. For a better visibility, the quartz glass tube is placed outside the oven tube so the device holder can be seen at its mounted positions (top view of figure 12).

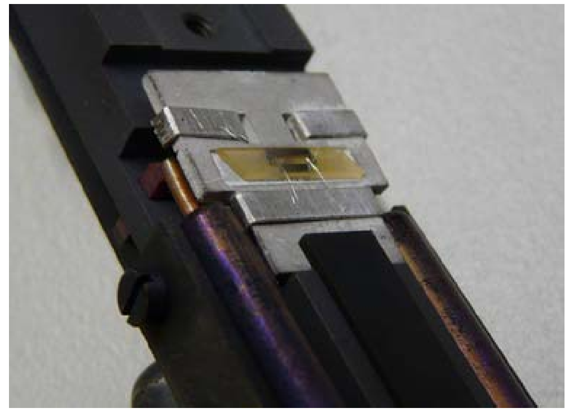


Fig. 11: Photography of a langasite chip on a device holder.

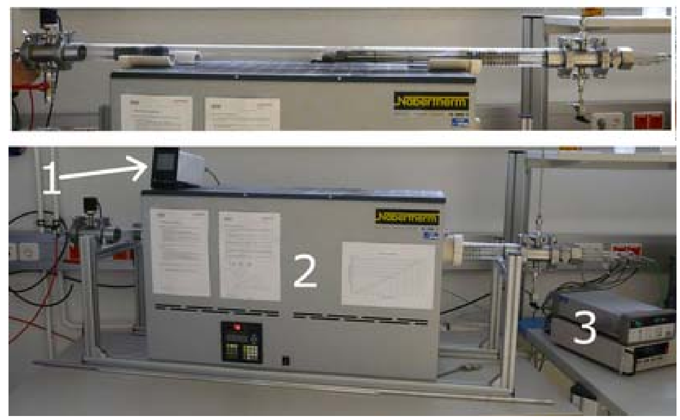


Fig. 12: Complete view of the measurement setup.
1: Pressure sensor display;
2: Oven;
3: DC and RF switch

III. Performance

To get reproducible results, all parts of the measurement setup were annealed at about 800°C in Ar atmosphere for 3 to 5 hours.

The Cu conductor and the steel tube of the semirigid cable get a dark patina degrading the electrical contact quality from one measurement to the next. After 3 to 4 annealing runs, the cables were polished to recover good electrical contact. After plating with Pt, this was no longer necessary. The cable endings were sealed with a ceramic based glue, e.g. magnesium oxide or circonium oxide to avoid the trickling out of dielectrical isolation powder. It was necessary to use (nitrile) gloves during assembling to avoid contamination by hand perspiration.

A. Signals

1) Signal quality: For comparison, a langasite test chip was measured on a wafer prober, then mounted on a chip carrier, placed in a device holder and measured again. Figure 13 shows the S_{21} signals of both measurements. They are of equal

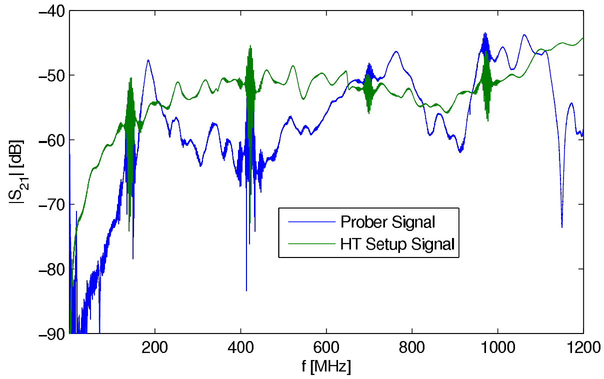


Fig. 13: Signals of a langasite test device, measured on a wafer prober (blue) and the measurement setup (green).

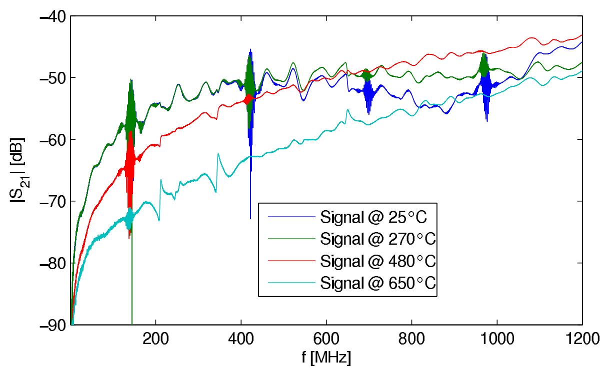


Fig. 14: Signals of a langasite test device at different temperature levels.

quality, so measurements close to the sensitivity of a wafer prober are possible with this HT UHF test equipment.

2) Signal behaviour during annealing: During annealing, the signal changed with temperature. Figure 14 shows the signals of the test chip at different temperature levels. The first three levels gave repeatable results, the last temperature level changed this DUT irrevesibly.

During annealing, several effects happen simultaneously that influence the signal:

- The cables change their impedance. The losses increase to about 3 dB between room temperature and 550°C (holds for both cables shown in figure 1).
- Dependent on the surrounding atmosphere, the contact quality between cable and chip carrier decreases.
- With Pt-plated cables, the contacts even fuse together and have to be separated with a sharp blade afterwards. Here, the surface of the contacts stays metallic and shiny.

When comparing the signal losses induced by the cables during annealing (see figure 2) and the signal degradation of a DUT (figure 14) during annealing, it can be assumed that the devices' degradation is dominant compared to the effects induced by the cables and the device holder.

B. *Influence of atmospheres*

When using corrosive atmospheres like oxygen - nitrogene - mixtures or air, the measurement setup has to be cleaned thoroughly which is time consuming. Doing this mostly leads to a loss of several cm of cable length at the tips.

IV. Conclusion

A multi-channel measurement setup for UHF frequencies and temperatures of up to 1000°C was presented. It allows an easy mounting of the DUT and shows excellent performance at all tested temperature levels. To achieve reliable electrical contacts and to reduce the service time it was very useful to plate the cable endings and mass contact area of the cable mantle with Pt foil.

Acknowledgment

The authors would like to thank David Eisele from the institute of microsystem technology in Freiburg (IMTEK) for fruitful discussions and helpful suggestions. Finally, the authors thank Martin Kraft (CTR) for his help in servicing the quartz tube and other parts of the measurement setup.

This work was partly funded within the COMET program, coordinated by the Austrian Research Promotion Agency (FFG).

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