Technological process and resonator design optimization of Ir/LGS High Temperature SAW Devices

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***Abstract*—Photolithography together with ion beam etching was used for fabrication of high temperature SAW devices. Ir thin film of 0.3 µm thick was deposited by magnetron sputtering without additional adhesion layers and than Ir film was annealed after electrode patterning in different conditions. The resistivity of magnetron sputtered thick Ir films drops noticeably after annealing. However, this process requires special care in order to avoid delaminating of the film due to developing high stress during such procedures. We have annealed the substrates with Ir films in different regimes and in different gas/vacuum conditions. The results of these studies have shown that annealing in air up to about 500 °C decreases the Ir film resistivity 1.5-2 times. Vacuum annealing did not show much improvement in comparison to open air annealing. Magnetron sputtered thin Ir films have somewhat porous structure allowing oxygen to diffuse from the substrate surface through Ir films. Resonator structures with thick Ir electrodes were prepared and tested. Examples of the resonator structures show very promising properties, such as high conductance and high Q-factor.**

Keywords—LGS; high temperature SAW devices, Ir film; Q factor; magnetron sputtering

I. Introduction

Ir metallization has been established as a promising candidate for high temperature SAW devices based on LGS. Useful cuts for temperature sensing applications have been reported. However device production and stability are still a challenge. We report on successful approaches in the preparation technology and on the design of one-port resonators for use on different cuts of LGS. SAW resonators were designed in a way to obtain a single resonance peak for different orientations of LGS wafers and different angles of SAW propagation.

II. Sample Preparation

A. *Initial Approaches*

In early publications on Ir/LGS application for high temperature sensors combination of “lift-off” and Ir magnetron sputtering allowed preparing 200 MHz devices with very low yield [1]. Photoresist sidewall coverage by Ir was obviously preventing from increasing the working frequency. Only the brittleness and the high rigidity of Ir permitted to rub the devices surface to successfully remove the lose electrode edges. With this badly repeatable process the usefulness of Ir metallization has been proven, its robustness to heating was demonstrated, no need for adhesion layers was confirmed and the improvement of Q factor after the first annealing has been found.

In an unpublished attempt made together with SAW Components, Dresden, Ir was deposited by e-beam evaporation and the “lift-off” went with regular high yield. However, the heating of patterned devices led to complete destruction of Ir conductivity in bus bars because of film cracking and formation of separate islands with noticeable shrinking. The effect was less pronounced on narrow features, such as IDT and grating electrodes where the total volume of shrinking Ir was smaller. This work has proven the important role of magnetron sputtering for high temperature application of Ir thin films on LGS.

Magnetron sputtering of Ir layer on LGS substrate leads to fabrication of texture with mechanical stress, while the electron-beam evaporation of Ir leads to fabrication of amorphous layer.

B. Adopted Sample Preparation Process

As a noble metal Ir is perfectly machined by Ar ion beam. Thus magnetron deposition of blanked Ir film has been combined with the positive photolithography process together with Ar ion beam etching. Photoresist has several times lower etching rate than Ir, as well as the substrate. However, substrate etching can still occur when the process finishes after complete Ir removal.

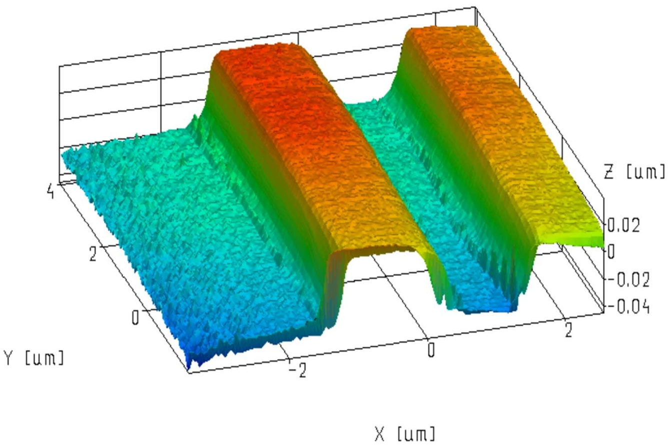

Fig. 1. Structure of thick Ir electrodes measured using AFM.

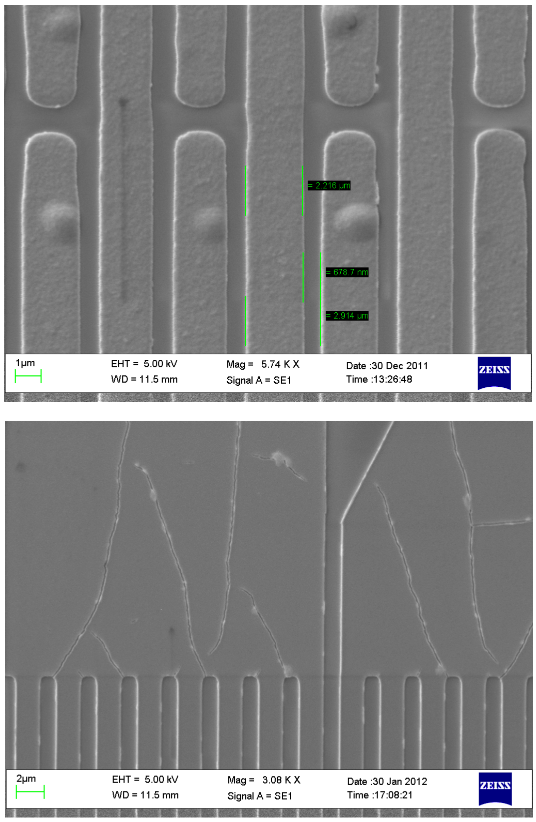

Fig. 2. SEM images of SAW resonators fabricated using Ir magnetron sputtering (a) and Ir e-beam evaporation after annealing at 500 °C during 100 hours.

Figure 1 shows the AFM profile of an electrode structure made with very thick Ir (close to 0.5 microns) that could be prepared by means of ion-beam milling. The thickness to wavelength ratio in this sample reaches 8%.

Figure 2 illustrates the 500 °C annealing impact on magnetron sputtered Ir, and on e-beam evaporated Ir at low substrate temperature (patterned by lift-off). Dome-like delamination shows in the former sample, while cracks develop in bus-bars of the latter sample.

Figure 3 reveals the reason for different behavior, magnetron sputtered films have a texture, while e-beam evaporated films are amorphous.

As previously noted [2], the resistivity of magnetron sputtered Ir films drops noticeably after annealing. However, this process requires special care in order to avoid delaminating of the film due to developing high stress during such procedures. We have annealed the substrates with Ir films in different regimes and in different gas/vacuum conditions. The results of these studies have shown that annealing in air up to about 550 °C decreases the Ir film resistivity 1.5-2 times (up to 1.3 Ω/□). With increasing annealing temperature above 600 °C, the resistivity of Ir film begins to grow, because we reach the temperature when Ir oxides start to form on the film surface. Further temperature rise in air up to 1000 °C leads to Ir film degradation. Vacuum annealing did not show much improvement in comparison to open air annealing. We suppose that reason for this effect is that the magnetron sputtered thin Ir films have somewhat porous structure allowing oxygen to diffuse from the substrate surface through Ir films

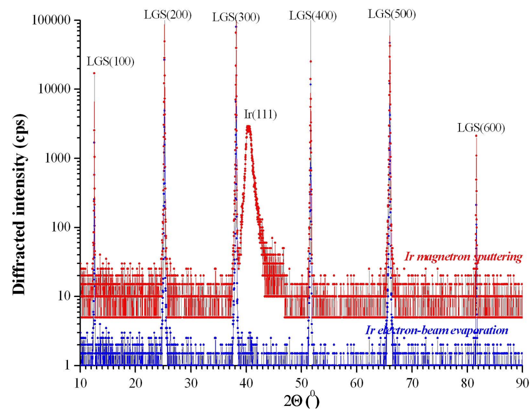

Fig. 3. XRD spectra of the Y-cut of an LGS crystal covered by Ir-layer with thickness of 1000 Å: magnetron sputtering (texture), electron-beam evaporation (amorphous layer).

III. Resonator Design

As useful LGS cuts demonstrate noticeable phase of the reflecting coefficient from Ir gratings (in this work we used an orientation (0, 138.5°, 26.6°) with NSPUDT effect), the use of synchronous single port resonator design usually results in electrical response with two resonances. For this reason, a semi-synchronous design [3] with an additional gap between the IDT and one of the reflectors was adopted.

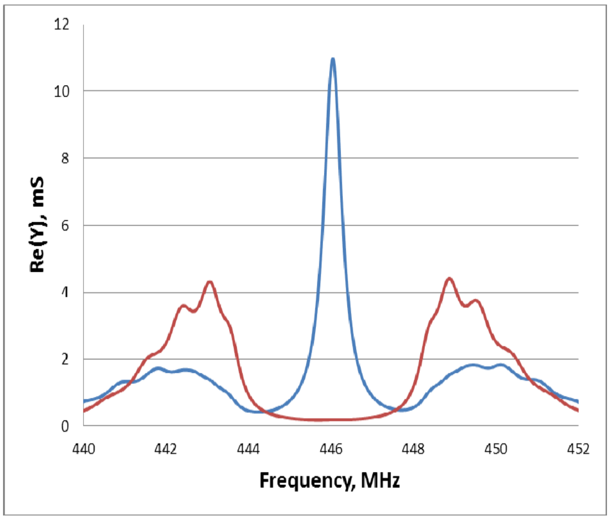

Fig. 4. Simplified calculation of the resonator response with the quarter-wavelength gap on the right side of the IDT (blue) and on the left side (brown).

The resonator response shown in Figure 4 relates to 100 nm thick Ir electrodes. Here a high propagation loss has a realistic figure reflecting low conductivity of thin Ir.

IV. Measurement Results

Typical resonator response with Al electrodes on a substrate with the orientation (0, 138.5°, 26.6°) is shown in Figure 5.

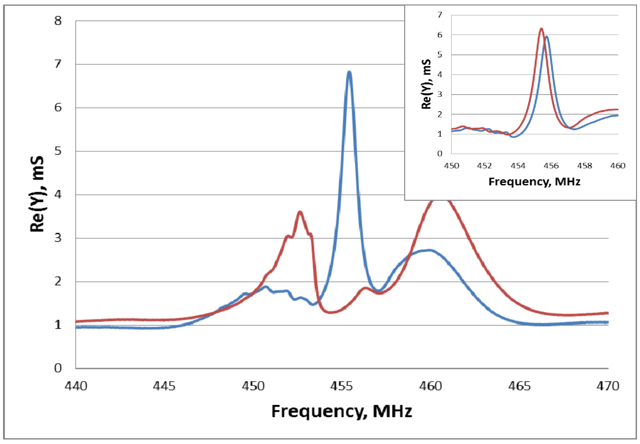

Fig. 5. Measured resonator response with the quarter-wavelength gap on the right side of the IDT (blue) and on the left side (brown). Al electrodes. The inset shows measured resonator response before (brown) and after annealing at 500 °C (blue). Al electrodes.

Annealing of a resonator with Al electrodes at 500 °C is possible, as it does not damage the electrodes too much as shown in Figure 5. The Q factor remains almost the same. The resonator response with Ir electrodes that were about 0.05 μm, two times thinner than expected, demonstrates the resonance frequency that is higher than calculated, we observe a slightly lower reflection coefficient that defines the Bragg bandwidth, and the response shape distortion related to high electrode resistance.

The annealing of this resonator results in slight frequency increase with a noticeable improvement of Q factor, as shown in Figure 6.

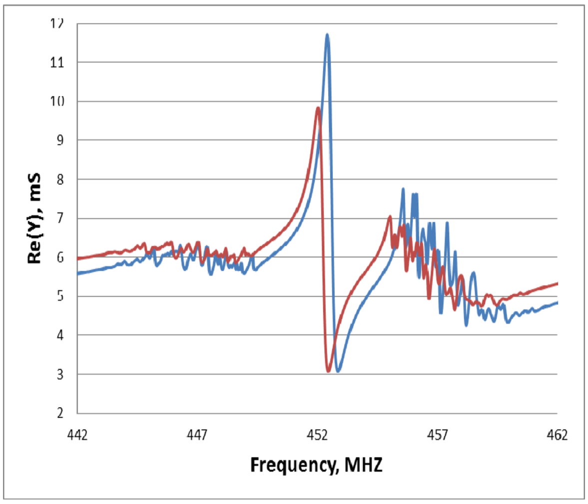

Fig. 6. Measured resonator response before (brown) and after annealing at 500 °C (blue). Thin Ir electrodes.

We were lucky to prepare a wafer with a very thick Ir layer close to 500 nm; this makes about 8% of the wavelength at the frequency in the middle of the Bragg band. First, we could prove that Ar ion milling could etch thought such a thick layer, however photoresist layer was slightly affected; that gave very high frequency scatter over the wafer area. One of the resonators has demonstrated a spectacular Q-factor increase from 700 to 3800 after annealing at 500 °C for half an hour.

The comparison of this resonator response before and after annealing is shown in Figure 7.

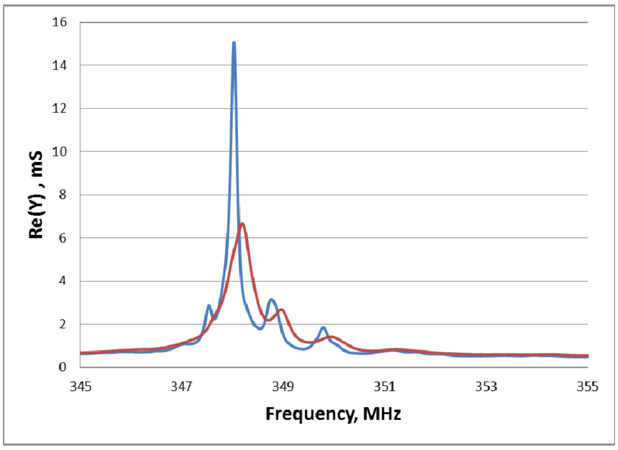

Fig. 7. Mesured resonator response before (brown) and after annealing at 500 °C (blue). Thick Ir.

Note, that for this particular sample the resonance frequency has decreased after annealing, while it usually increases for thinner Ir samples. Another feature that was very different from the response of thinner Ir resonator is the almost 80 MHz resonance frequency shift from the value related to velocity decrease by this thickness of Ir film.

Evaluation of COM-parameters based on modified FEMSDA [4] has revealed that the reflection coefficient from one Ir strip is above 50% at this thickness. So that the observed resonance is related to the left side of the Bragg band, that has an almost 140 MHz width. Such large reflection is rarely observed in experiments, and it results in very strong internal reflection inside the IDT that defines the frequency response, so that the outer reflectors almost do not influence the response. Thus, the experimental response shapes of semi-synchronous resonators with an additional quarter-wavelength gap on the left and on the right of the IDT practically do not differ.

As the reflection phase on this cut is close to 90° even at this Ir thickness there is a resonance on the right side of the Bragg band, however it is almost suppressed by bulk wave generation. We also can observe a small pick close to the middle of the Bragg band (Figure 8).

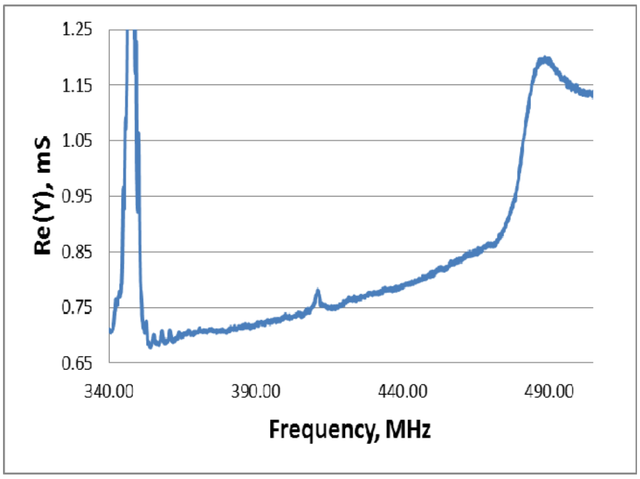

Fig. 8. Wideband detailed measurement of the resonator response. Thick Ir.

The modeling of this structure predicts that the use of long reflectors together with a semi-synchronous design only introduces distortion in the resonance shape for such a thick Ir film, as shown in Figure 9.

These findings mean that it is possible to make high Q resonators with thick Ir films on langasite; however, the design procedures need to take into account specific features of the high reflection from thick Ir films. Notably, there is no more need in semi-synchronous design, besides, modeling shows that reflectors in synchronous design do not improve the Q factor of the resonator either, the response of the IDT alone is preferable for the number of IDT electrodes higher than 50. With decreasing the number of IDT electrodes to about 5 the resonance in the center of the Bragg band becomes more pronounced, and can serve as the main resonance, however it requires substantial aperture increase together with IDT frequency shift as in [5]. Very clean resonance shape together with high Q factor is predicted in modeling, however such design may require presently unachievable preparation accuracy for such a thick Ir film.

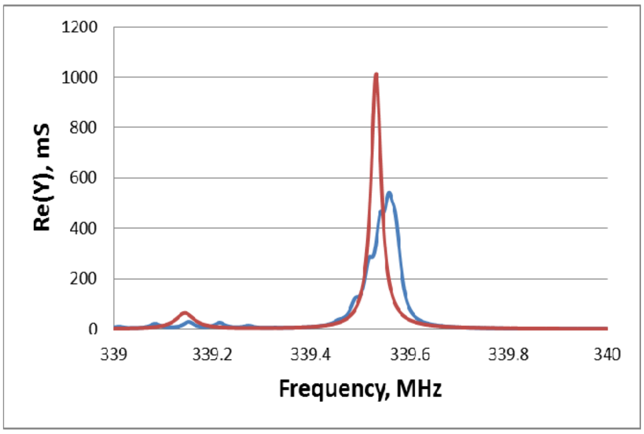

Fig. 9. Modeled response of the IDT alone (brown) and of the semi-synchronous resonator with the same IDT and reflectors, The quarter-wavelength additional gap is on the right of the IDT (blue). Thick Ir.

V. Conclusion

High Q-factor is achievable in resonators intended for use as sensors at high temperatures. This requires very thick magnetron sputtered Ir films patterned by direct photolithography followed by ion-beam milling. The layout should use synchronous resonator design, with short reflectors or even without them. The resonance frequency shift from the middle of the Bragg band may easily reach 20% that defines large scatter of resonance frequencies in this approach.

Acknowledgment

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