HIGH POWER DURABLE RESONATORS FABRICATED WITH ALUMINUM-SCANDIUM-ALLOYS

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To investigate fatigue of aluminum-scandium (AlSc) alloys in thin films under cyclic mechanical stress, 860 MHz nano resonators with AlSc electrodes have been fabricated. The Sc content in the alloy has been varied from 0 % to 2,5 %. The resonators have been operated with heavy load at high frequencies and power durability has been determined. Devices with AlSc electrodes exhibit an increased power durability compared to conventional aluminum metallized devices. All films have been investigated by means of electron backscatter diffraction (EBSD) and atomic force microscopy (AFM) to obtain texture and grain structure. Degradation of electrodes has been visualized by scanning electron microscopy (SEM). The enhanced mechanical stress durability of electrodes fabricated with AlSc alloys is contributed to the refined grain structure in these alloys.

With higher operation frequencies and shrinked device dimensions the requirements for the power durability of SAW devices have increased rapidly. Although these devices are driven electrically they may fail mechanically. Surface acoustic waves propagating perpendicular to the electrodes of the device induce heavy cyclic stress in the metal. Thus, material fatigue depending on applied load occurs with operation time. A decrease of resonance frequency reveals a loss of electrodes stiffness which leads to device failure.
Scandium is a light metal with a density of 2,985 g/cm^3. This is close to the density of aluminum (2,7 g/cm^3), which makes it preferable for SAW applications. Scandium is known for improving the mechanical properties of Al, if alloyed in small concentrations. Due to its high price its use as an alloying element is limited to a small sector of applications, e.g. bicycle frames and baseball bats.
Starting with a piezoelectric substrate ($LiTaO_3$, 42° Y-X-Cut) four samples have been prepared with lift off technique. After a short pre-clean with O_2 plasma sample metallization has been deposited by co-evaporation of Al and Sc at ultra high vacuum conditions ($p < 10^{-9}$ mbar). Al has been evaporated by means of electron beam and Sc has been evaporated out of a high temperature effusion cell. Sc sublimates at approximately 1525 °C with a stable rate, thus flux and scandium content in the alloy have been controlled via the temperature of the cell. Sample preparation ended with a lift off step in an ultrasonic bath of acetone solution.
A measurement setup, which kept the electrical load constant while the resonance frequency decreases, has been used to determine power durability (PD). In our experiments the device failure criterion was fulfilled when the original resonance frequency was shifted by 1000 ppm, i. e. 860 kHz for our 860 MHz test devices. PD has been quantified in dB units. Pure aluminum (0 % Sc) has been defined as reference value (0 dB). This value represents the input power a device can endure until its failure criterion is reached after one hour of loading.
Results of thin film analysis by AFM and EBSD are shown in Fig. 1 and Fig. 2. The sample without scandium exhibits a grain size of 200 nm in average, as shown by the AFM measurement in Fig. 1a. Since a vertical <111> axis is energetically advantageous, aluminums out of plane texture is close to <111>, as shown by the large blue areas in the EBSD map in Fig. 1b and by the inverse pole figure in Fig. 1d.
With increasing Sc content the Al grains get more refined, as shown by AFM measurements and EBSD maps in Fig. 2a and b. The orientation of the refined grains changes from <111>

axis vertical to randomly oriented grains. AFM measurements demonstrate small grains in the samples with AlSc. The refinement of grains in AlSc alloys is contributed to the formation of Al_3Sc particles. A scandium content of 2,5 % increases PD by approximately 10 dB, as illustrated in Fig. 3. This represents an input power increase by one order of magnitude.

The decrease in resonance frequency for the AlSc devices is lower than for the pure Al devices, if the same electrical load is applied. This indicates a slower loss of electrode stiffness, i.e. a higher resistivity to mechanical stress. We contribute this to the enhanced material properties of the AlSc alloy. The improved PD, as shown in Fig. 3, can be explained by the refined grain structure of AlSc alloys. Measuring power durability we observed long aluminum extrusions out of the AlSc electrodes as operation power exceeded a certain value. These extrusions can span the gap between two electrodes (Fig. 5) and thus may lead to a short circuit. This would explain the sudden drop of resonance frequency, as shown in Fig. 4. As a result the entire device can be destroyed, as illustrated in Fig. 5d.

References:

[1] J. Royset, "Scandium in aluminum alloys," International Material Reviews Vol. 50, 2005, pp. 19-44.

[2] Y. Leipikh, "Strain effects in surface acoustic wave elements with a piezoelectric acoustic line and sensors based on this effect," Semiconductor Physics, Quantum electronics and optoelectronics, Vol. 3, No. 1, 2000, pp. 91-93.

Figures:

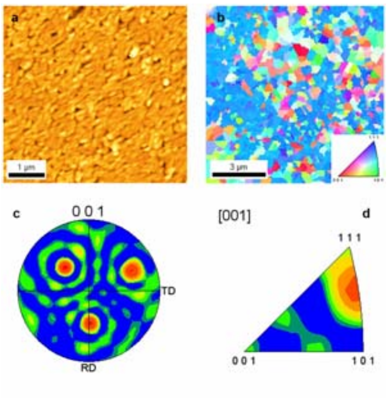

Fig. 1. Surface morphology (a), out of plane grain orientations (b) and texture (c and d) of aluminum film with **no scandium** deposited on blank $LiTaO_3$.

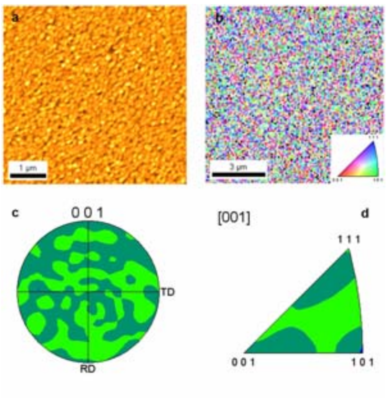

Fig. 2. Surface morphology (a), out of plane grain orientations (b) and texture (c and d) of aluminum film with **2,5% scandium** deposited on blank $LiTaO_3$.

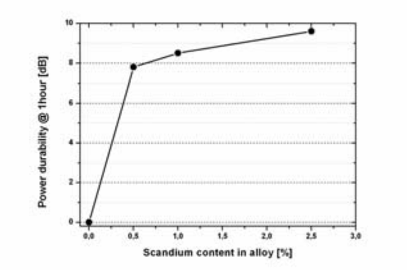

Fig. 3. Power durability versus scandium content of the test devices.

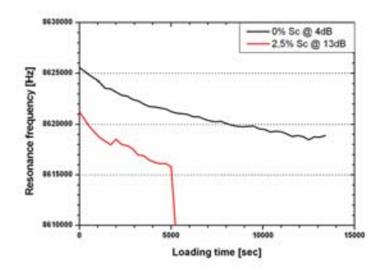

Fig. 4. Drop of resonance frequency in devices under heavy load with no scandium (black curve) and with 2,5% scandium (red curve).

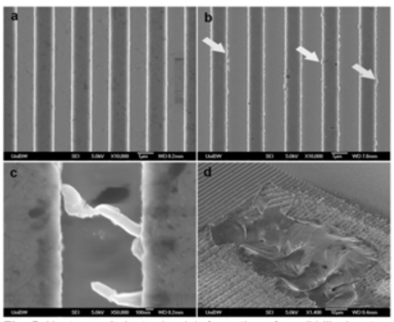

Fig. 5. Unstressed electrodes (a), formation of small hillocks at low load on pure Al electrodes (b), formation of long extrusions at high load on AlSc electrodes (c) and destructed device after shortcut of electrodes (d).