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# A Study of Al-Alloy Electrodes for High Power SAW Filters

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Durability of aluminum-alloy electrodes for high power SAW filters which are used for antenna duplexers in cellular portable telephones is experimentally investigated. Titanium added aluminum is deposited by DC magnetron sputtering. The new alloy expands the limitation on the driving power of the filters. Temperature, particularly, accelerates the degradation of the high power filters, the film resistance causes an even greater increase in temperature. Thus, optimum value for titanium of 0.4 wt.% can be achieved for high durability filters.

## §1. Introduction

A high power surface acoustic wave (SAW) filter for a 1.6 W antenna duplexer has been developed to miniaturize a 800 MHz cellular portable telephone.[1)] This filter is composed of about 1 $\mu$m width electrodes on 36° rot. Y-X $LiTaO_3$ substrate, and evaporated aluminum-copper alloy is adapted to obtain high durability.

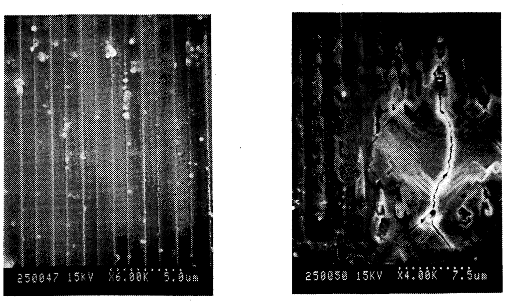
The film is inadequate, however, for higher power systems of 3 ~ 6 W, which are required for the class I cellular radio in USA and Japanese automobile telephone systems. A new film is therefore necessary which will not be damaged by strong electric current and mechanical stress of surface wave propagation.

In this paper new aluminum-alloy electrodes subjected to power and temperature acceleration tests are described. In particular, the rise in temperature caused by film resistance is studied in the high power filter.

## §2. Degradation of SAW Electrodes

Degradation of electrodes was observed in a SAW resonator and a high power SAW filter.[2,3)] Figure 1 shows the damaged electrodes in the high power filter for the antenna duplexer.

The process of degradation of the electrodes is as follows. At last, hillocks grow on the electrode in the SAW propagation path. Neighboring electrodes are short-circuited as the hillocks grow larger. Finaly, electrodes are melted by large momentary electric current. When this happens, as shown in Fig. 1(b), the piezoelectric substrate is often cracked or broken. The electrode degradation was considered to be mainly caused by the large mechanical stress, because the hillocks grow periodically on the electrodes corresponding to the SAW wavelength.



(a) (b)

Fig. 1. SEM photograph of degraded electrodes. (a) hillocks (b) cracks.

Table I. Time to failure (*TF*) of SAW resonator and SAW filter.

| Sample | *TF* (Resonator) | *TF* (Filter) |
|---|---|---|
| Pure Al | 1 | 1 |
| Al–3.8 wt.%Cu | 3.1 | — |
| Al–0.9 wt.%Ti | 29.3 | 11.3 |

Table II. Damage parameters and their influence.

| Parameter | Influence |
|---|---|
| mechanical stress | stress-migration |
| electric current | electro-migration |
| electric current + resistivity | temperature rise (accelerates both migrations) |

Table I shows time to failure (*TF*) of SAW resonators and SAW filters made of several kinds of Al alloys: pure aluminum, aluminum-3.8 wt.% copper and aluminum-0.9 wt.% titanium. An electrode film of 0.1 $\mu$m thickness is deposited by DC magnetron sputtering equipment (ANELVA SPF 420 HL).

The test conditions are as follows. Input power and temperature are, respectively, 100 mW and 120°C for the resonators, and 2.5 W and 80°C for the filters. Each *TF* is normalized by time to failure *TF* of pure aluminum; titanium alloy is the most durable. *TF* of the SAW filters is about one third that of the SAW resonators, indicating that other parameters than the electrode material are involved in the degradation of the filters.

Here, we suppose the parameters of degradation, to be as shown in Table II. One is mechanical stress which directly damages the electrodes. The other is electric current which accelerates the degradation as the temperature rises.

## §3. Power Acceleration Test

Durability of the aluminum alloy electrodes is investigated by power and temperature acceleration tests. We use two port SAW resonators on ST quartz with film thickness of 0.1 μm, loaded $Q$ of about 4000 in 50 Ω systems and center frequency of 696 MHz, and we define *TF* as aging time at which the shift of center frequency reaches 50 kHz. The test conditions are the same as stated in §2.

It is convenient in the experiment that SAW resonators can easily generate large mechanical stress in a low power range and do not rise the temperature.

Figure 2 shows the relation between input power and *TF* for various electrode materials. The E-Gun evaporated aluminum-copper film, which is conventionaly used for SAW resonators, is tested for comparison. The results show that *TF* depends on titanium concentration, with the durability of aluminum-0.8 wt.% titanium electrodes being the highest among the electrodes tested. *TF* is inversely proportional to the cube of input power for every material, so it seems that degradation of all the alloys is caused by the same parameter, that is, the mechanical stress of SAW.

## §4. Temperature Acceleration

Figure 3 shows some relations between film thickness and film resistivity of pure aluminum and its alloy. Resistivity increases abruptly under a thickness of 0.1 μm, and

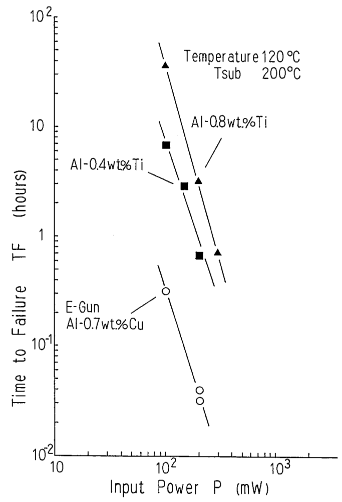



Fig. 2. *TF* versus input power for alloy electrodes.

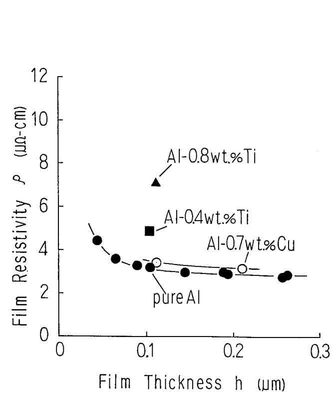



Fig. 3. Resistivity versus film thickness.

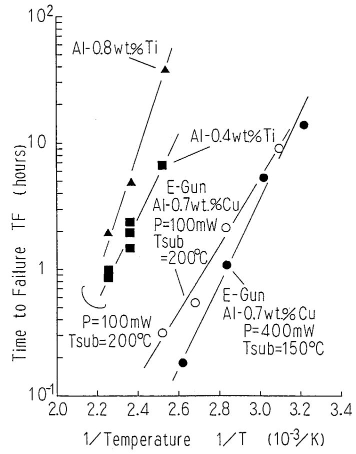



Fig. 4. *TF* versus temperature for alloy electrodes.

an impure addition to pure aluminum increases the resistivity even more. This means that the temperature of aluminum-0.8 wt.% titanium electrodes tends to rise in high power operation.

An acceleration test is performed on the alloy electrodes to estimate temperature influence. The results are shown in Fig. 4, where *TF* is plotted against inverse absolute temperature. Input power of 100 mW is respectively applied to aluminum-0.8 wt.% titanium, aluminum-0.4 wt.% titanium and aluminum-0.7 wt.% copper electrodes which are deposited at a substrate temperature of 200°C; 400 mW power is applied to aluminum-0.7 wt.% copper deposited at 150°C. Aluminum-0.7 wt.% copper electrodes deposited at different substrate temperatures show similar *TF* for different input power. This suggests that *TF* depends not only on electrode material but on film structure.

We can assume an experimental equation which expresses the relation between *TF* and temperature, and it is obtained from the analogy of Arrhenius:[5]

$$TF = A \exp\{E/(kT)\} \quad (1)$$

where $A$ is a parameter depending on film structure, electrode material, geometry of electrodes and the substrate, $k$ is Boltzmann's constant, $T$ is absolute temperature, and $E$ is activation energy concerned with the migration process in SAW devices. Here, $E$ is calculated from the slope: it is 0.92 eV for aluminum-0.8 wt.% titanium and 0.62 eV for aluminum-0.4 wt.% titanium. The results suggest that the migration process obeys the Arrhenius equation in the experimental temperature range.

The rise in temperature is estimated from the frequency shift of the filter, because it is difficult to measure surface temperature of the substrate directly. Figure 5 shows a block diagram of the measurement circuit for temperature rise. The voltage controlled oscillator generates a 835 MHz signal, which is the center frequency of the filter. The output signal level and its frequency are monitored by a spectrum analyzer (TAKEDA-RIKEN TR-4133). The frequency change of the SAW filter is measured by a network analyzer (HEWLETT-PACKARD HP-8505A).

The results are shown in Fig. 6, where temperature rise is plotted against output power. Aluminum-0.7 wt.%

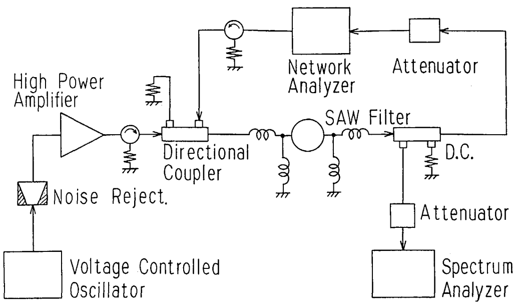



Fig. 5. Block diagram to measure rising temperature.

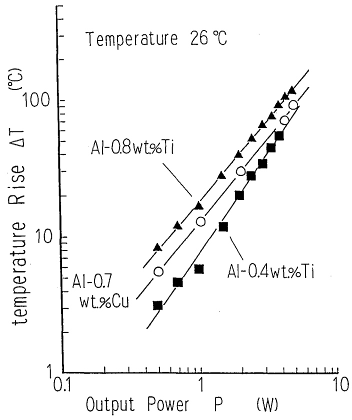



Fig. 6. Rising temperature versus output power.

Table III. Results of acceleration test on SAW filter (temperature 100°C).

| Sample | Output Power (W) | *TF* (hr) |
|---|---|---|
| Al-0.4 wt.%Ti | 7.0 | 60 |
| Al-0.8 wt.%Ti | 6.5 | 27 |
| Al-0.7 wt.%Cu | 7.0 | 2 |

copper shows medium temperature rise, though it has a lower resistivity. The reason for this is now being investigated.

Aluminum-0.8 wt.% titanium shows a temperature rise of 66°C at output power of 3W and its migration is accelerated about 1000 times, from eq. (1). On the other hand, aluminum-0.4 wt.% titanium shows a temperature rise of 34°C at the same output power, with a migration that accelerates about 14 times. Thus, titanium addition increases film durability for mechanical stress, however, it considerably rises temperature. Temperature rise accelerates the migration, so it is assumed that the electrodes of high power filters are less durable than the resonators for the same aluminum alloy.

Temperature and power acceleration tests are conducted to evaluate the durability of the alloys in high power operation. The results are listed in Table III. Since temperature greatly affects *TF*, aluminum-0.4 wt.% titanium has better durability than aluminum-0.8 wt.% titanium.

## §5. Conclusion

Aluminum-alloy electrodes for high power SAW filters were experimentally investigated. To achieve high durability, titanium added aluminum was deposited by sputtering. The degradation of the electrodes was mainly caused by mechanical stress of SAW and is remarkably accelerated by temperature.

Temperature and power acceleration tests were performed to measure the durability of the high power filters. Addition of titanium increased their durability, however it considerably rised their temperature. It was learned that aluminum-0.4 wt.% titanium is more durable than aluminum-0.8 wt.% titanium.

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