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Accelerated Life Tests for Determining the Expected Lifetime – Test Strategy for IR-MEMS-Emitter

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Summary:
A procedure for estimating expected lifetime of IR-MEMS-emitters was developed. A pre-test to examine the main influencing factor that limits lifetime has been carried out. Membrane temperature of the IR-MEMS-emitters was identified as the main influencing factor for electromigration, reducing lifetime. For this reason, the Arrhenius life stress model, a temperature based physical model, is used for calculating expected lifetime at nominal conditions.

Keywords: IR-MEMS-Emitter, Arrhenius life stress model, expected lifetime, membrane temperature

Background and Motivation

IR-MEMS-emitter are silicon-based hotplate infrared sources with an optimized emission in mid-infrared range between 2 and 15 µm wavelength. The emitter is a multilayer system, whereby the emission layer on the top side determines the emission range. The heating layer defines the resistance of emitter types. If an input voltage is applied, membrane temperature of heating layer rises and the hot resistance increases with defined temperature coefficient. Resistance, emission spectrum and temperature distribution over the membrane are the most important quality properties of IR-MEMS-Emitters. Stressed emitters show shifts in emission spectrum and a material shift in heating layer, which is called electromigration, and changes membrane temperature distribution. Resistance of emitters increases as electromigration continues. To better assess the effects of influencing factors on emitter lifetime, a test strategy has been developed that enables a statement of lifetime via accelerated lifetime tests. A test to evaluate expected lifetime based on an Arrhenius life-stress model was conducted. In addition, the correlation between electromigration and emission shift has been numerically quantified.

Arrhenius life stress model and Weibull-distribution

Prior testing to identify whether membrane temperature or strength of electrical field is the main influence factor of electromigration has been done. These tests showed that there is a strong correlation between emitter failure and high membrane temperatures. On the other hand at the evaluated operating point ranges, there was no connection between strength of electrical field and emitter failure observed. Therefore, simple Arrhenius life-stress model can be applied. This model is a physics-based model derived from temperature dependence [1], used for temperature-accelerated tests. From of at least two test groups with higher working temperatures the expected lifetime under normal conditions can be calculated. The membrane temperature is a function of the electrical input power and was measured by a suitable IR-camera. To estimate the characteristic lifetime of higher stress groups the 2-parameter Weibull distribution was used [2]. The 95 % confidence interval and median of parameters is determined via non-parametric bootstrapping, with 20,001 resamples.

Test setup

Tab. 1: Example distribution of test groups

Power [W]	#Samples Not IM	#Samples IM
0.65	32	8
1.05	48	8
1.2	48	8
1.35	48	-

For calculating expected lifetime, the resistance change of several emitters, running continuously at different power inputs and therefore temperatures, was measured in a special emitter test chamber. Furthermore, emission spectrum via FTIR-spectroscopy with a special external

emitter input and membrane temperature distribution via IR-camera were measured at regular intervals for a subset IM (intermittent measurements) of emitters. Tab. 1 shows the resulting test groups.

Results - Expected Lifetime

Based on Weibull distribution, the characteristic lifetimes of the temperature stressed test groups were calculated with results shown in Tab. 2.

Tab. 2: Example characteristic lifetimes of stressed test groups

P [W]	T_{mem} [K]	Characteristic Lifetime[h]
1.05	1026	4194
1.2	1111	679
1.35	1152	210

Logarithmizing the Arrhenius life-stress model leads to

$$ln\left(Lifetime(T_{mem})\right) = ln(C) + \frac{B}{T_{mem}} \qquad (1)$$

with parameters B and C obtainable via linear regression. Using *(1),* expected lifetime at nominal power has been determined. A service lifetime of minimum 1e5 hours at nominal input power of 650 mW was reached (Fig. 1).

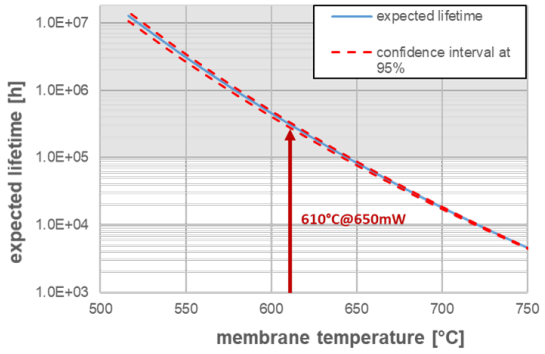

Fig. 1: expected lifetime of CMOSI500 vs. membrane temperature: nominal input power 650 mW @ 610 °C is marked

Electromigration

Electromigration was numerically quantified by IR-pictures showing membrane temperature distribution. Over the operational time of an emitter, position of the hot spot on the membrane and shape of the hot spot, defined by calculating the ratio of height and width (shape ratio) of the 10 % highest temperature pixels, were determined. While there is no change in location and shape ratio of the hot spot in test groups with nominal power, in stressed test groups the hot spot moves in one direction until some upper boundary. Afterwards the hot spot becomes more elliptic, indicated by an increasing shape ratio.

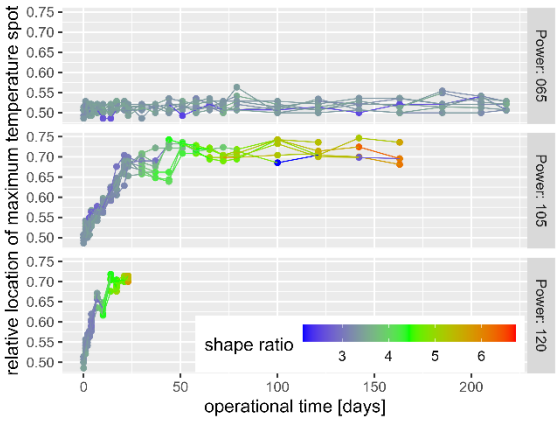

Fig. 2: numerical evaluation of IR-pictures

Emission shift

In four wavelength intervals, change of amplitude was measured by FTIR-spectroscopy. In higher stress groups there is a change of around 10 % in every wavelength interval, while in nominal power there is no change over operational time.

Discussion

To verify if there is a correlation between emission shift and electromigration the amplitude change of measured spectrometer data in the different wavelength were compared to calculated spectra of the temperature distribution measured by IR-camera. For every temperature pixel a Planck spectrum was calculated and summarized to a total spectrum. Both calculated and measured amplitude change are showing the same behaviour over time. This proves the correlation between emission shift and electromigration. Long-term tests had shown the main force that limits lifetime of IR-MEMS-emitter is electromigration, which can be attributed to a high membrane temperature. The material shift leads to changed radiation characteristics in emission spectrum caused by hot spot displacement and changes in hot spot shape. Finally the material shift leads to a rupture in membrane. The AC-Mode of IR-MEMS-emitters should contribute to the reduction of migration effects and thus to lifetime extension, which needs to be evaluated in further long-term tests.

References

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