A Study for the Relationship between Drive level and the Activation Energy in Arrhenius Accelerated Aging Model for Small Size Quartz Resonators

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Abstract—Aging performance as long-term stability is one of the most important characteristics of quartz resonators. It is usual to use higher temperature accelerated aging experiment results and Arrhenius accelerated aging model to estimate the product lifespan. In this paper, an approximated mathematical expression of apparent thermal $E_a$ (Activation Energy) which could describe the aging model that both considering drive level and temperature for small size quartz resonators. The apparent thermal $E_a$ value is 0.730eV under 100μW, when drive level higher to 1000μW the apparent thermal $E_a$ become smaller to 0.233eV and shows a saturated tendency. Our works make sure the drive level did contribute to aging acceleration and cannot be neglected, especial for the estimated life of small size quartz resonators.

Keywords—$E_a$(Activation Energy); Aging Model; Quartz Resonators

I. INTRODUCTION

The activation energy value is critical for the lifespan estimation, and some researches published [1,2] for SMD seam type quartz resonators. When the size of the crystals becomes smaller, the drive level effect cannot be neglected and will affect aging behavior. Which means the accelerated aging model needs to include drive level effects. For the quartz resonators’s $E_a$ studies, some classic earlier researches done more than 20 years ago [3, 4, 5] but all ignore the effect of non-thermal item such as Current, Voltage and Power. However, the relationship between $E_a$ and drive level effect still lack of published studies. This paper tried to establish the relationship through accelerated aging experiments with controlled drive level and temperature conditions. The size for quartz resonators in this paper is 2.5 x 2.0 mm.

II. EXPERIMENT

A. Drive Level Define

The derive level definition was well known[6, 7]. The construction of oscillation circuit was show as Fig. 1. Fixing the same capacitor for $C_g$ and $C_d$, through changing the resistance $R_d$ and use current meter to measure the front into current A. Finally as the TABLE I the derive level could be calculated.

![Oscillation circute and construction for drive level defination](image)

**TABLE I. DRIVE LEVEL CALCULATION FOR 2.5MM X 2.0MM 26MHZ FOUNDMENTAL SEAM TYPE QUARTZ RESONATORS**

<table>
<thead>
<tr>
<th>Oscillation Circute Current</th>
<th>$R_d$ (Ω)</th>
<th>$C_g=C_d$ (pF)</th>
<th>$D. L.$ (μW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1500</td>
<td>2.00</td>
<td>2.52</td>
</tr>
<tr>
<td></td>
<td>2500</td>
<td>6.00</td>
<td>4.57</td>
</tr>
<tr>
<td></td>
<td>310</td>
<td>20.00</td>
<td>10.22</td>
</tr>
<tr>
<td>2.5mm x 2.0mm Quartz Resonator</td>
<td>26MHz Fundamental Effective Resistance (Ω)</td>
<td>D. L. (μW)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.57</td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200</td>
<td></td>
</tr>
</tbody>
</table>

B. Biased Aging Conditions

Aging facility was use commercial QAS-2000 that was co-developed by TXC(NINGBO) and QTS CORPORATION. QAS-2000 uses eight independent controlled ovens and with separated oscillation circuit and quartz resonators. This design not only overcomes the temperature limit of maximum 125℃ for old all in one oven design, but also make sure the temperature only effect on quartz resonators, hence the oscillation circuit was suffer minimum temperature noise.
There are three temperature conditions include 85°C, 125℃, and 150°C, and three defined drive level 100μW, 200μW and 1000μW, total nine combinations were used for this study. Size of the metal seam sealed quartz resonators is 2.5mm × 2.0mm, and the frequency is 26MHz fundamental. The aging frequency shift use average value of 30 pieces samples for each condition evaluation, and frequency were measured daily for 500hrs (about 21days). The aging frequency shift results are total shown as Fig. 2.

**III. ACTIVATION ENERGY ESTIMATION THROUGH ARRHENIUS ACCELERATED AGING MODE**

**A. Aging Frequency Shift Effect by Drive Level**

In order to clearly see how drive level and temperature affect the aging behavior, Fig. 3, Fig. 4 and Fig. 5 was individual plots by 100μW, 200μW and 1000μW. It’s obviously to see the aging frequency shift not only change by temperature, but also affected by drive level, even the aging frequency shift shows drive level with bigger effect than temperature.

**B. Aging Model Considering Temperature and Drive Level**

Like common microelectronic devices, the function of aging frequency change can be expressed as (1), which relates with non-thermal, thermal, and time [8]

\[
\frac{\Delta f}{f}(i,T,t) = R(i) \cdot R(T) \cdot R(t)
\]

(1)

\[
R(T) = C \cdot e^{\frac{-E_a}{K_BT}}
\]

(2)

\[
R(t) = \ln(1 + bt)
\]

(3)

Where \(R(i)\) is the non-thermal item, and further combine Arrhenius accelerated model, the thermal item \(R(T)\) can be expressed as (2), and for a specified time \(R(t)\) can be expressed as (3), The relationship of frequency change versus to non-thermal and thermal turns into (4).
\[
\frac{\Delta f}{f}(i, T, t) = R(i) \cdot C \cdot e^{\left[ \frac{-E_a}{e^{KT}} \right]} \cdot \ln(1 + bt) \tag{4}
\]

Where \(C\) and \(b\) is constant, \(K_b\) is Boltzmann’s constant= \(8.616 \times 10^{-5}\)(eV/K), \(E_a\) is activation energy(eV)

This paper proposes an apparent thermal \(E_{a\Phi}\) to express how non-thermal item such like current, voltage, even power effect on the aging model, that express as (5).

\[
\ln T \frac{\Delta f}{f} = \left( \frac{-E_{a\Phi}}{K_b} \right) \frac{A}{T} + B \tag{5}
\]

Where \(A\) and \(B\) is constant, \(E_{a\Phi}\) is activation energy(eV)

\[
E_{a\Phi} = 0.1984 \cdot \exp^{127.83 \cdot \frac{1}{T}} \tag{6}
\]

An approximated mathematical apparent thermal \(E_{a\Phi}\) versus drive level could be calculated by experiment results and further express as (6). The apparent thermal \(E_{a\Phi}\) in different drive level was summary as TABLE II. It reveals small size quartz resonators cannot neglect high drive power effects, especially when drive level over 100\(\mu\)W, the activation energy will dramatically decrease form 0.730eV to 0.355eV, that directly reduce the estimated life of quartz resonators. Fig. 6 even shows when drive level over 1000\(\mu\)W, the apparent thermal \(E_{a\Phi}\) exhibits a saturated tendency with a minimum value 0.233eV.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Drive Level ((\mu)W)</th>
<th>Apparent Thermal (E_{a\Phi}) (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>85°C (358K)</td>
<td>100(\mu)W</td>
<td>0.730 eV (slop = -8473.2)</td>
</tr>
<tr>
<td>125°C (398K)</td>
<td>200(\mu)W</td>
<td>0.355 eV (slop = -4117.2)</td>
</tr>
<tr>
<td>150°C (423K)</td>
<td>1000(\mu)W</td>
<td>0.233 eV (slop = -2709.8)</td>
</tr>
</tbody>
</table>

Aging Model Considering Temperature & Drive Level

\[
\ln T \frac{\Delta f}{f} = \left( \frac{-E_{a\Phi}}{K_b} \right) \frac{A}{T} + B = -0.1984 \cdot \frac{K_b}{T} \cdot \exp^{127.83 \cdot \frac{1}{T}} \tag{6}
\]

- \(E_{a\Phi}\) (eV) is the apparent activation energy which accelerated under temperature and drive level
- \(T\) (K) is the temperature of acceleration environment
- \(P(\mu\)W) is the drive level
- \(K_b = 8.616 \times 10^{-5}\)(eV/K) — Boltzmann’s constant

### IV. CONCLUSION

For small size crystal resonators, the drive level effects for the lifetime estimation cannot be neglected and will affect the activation energy \(E_a\) value in classic Arrhenius accelerated aging model. This paper provides an initial step about the study for the relationship between \(E_a\) and drive level. More studies for the mechanism and more conditions will be needed to get clearer picture for drive level effects on quartz resonators aging in the future. It looks the relative contributions for drive level to \(E_a\) will be saturated when drive level high enough. It can be explained as the drive level also contribute to aging acceleration, and when the drive level becomes higher, the relative thermal contributions for \(E_a\) get lower.

### REFERENCES


