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

Chun-Nan Shen, Jun Jun Xu and Min-Chiang Chao
TXC(NINGBO) CORPORATION
Ningbo Zhejiang, China
E-mail: [obi-wan,njunjunxu,chaomk]@txc.com.tw

***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 Ea_{Φ}(Activation Energy) which could describe the aging model that both considering drive level and temperature for small size quartz resonators. The apparent thermal Ea_{Φ} value is 0.730eV under 100μW, when drive level higher to 1000μW the apparent thermal Ea_{Φ} 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—Ea(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 Ea 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 Ea 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 Cg and Cd, through changing the resistance Rd and use current meter to measure the front into current A. Finally as the TABLE I the derive level could be calculated.

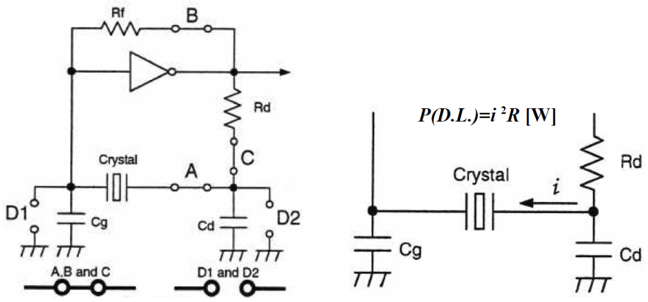

Fig. 1. Oscillation circute and construction for dreive level defineation[6, 7]

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

Oscillation Circute		Current
Rd (Ω)	Cg=Cd (pF)	*i* (mA)
1500	2.00	3.23
2300	6.00	4.57
210	20.00	10.22
2.5mm x 2.0mm Quartz Resonator 26MHz Fundamental Effective Resistance (Ω)		D. L. (μW)
9.57		100
		200
		1000

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.

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There are three temperature conditions include 85℃, 125℃,and 150℃, 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.

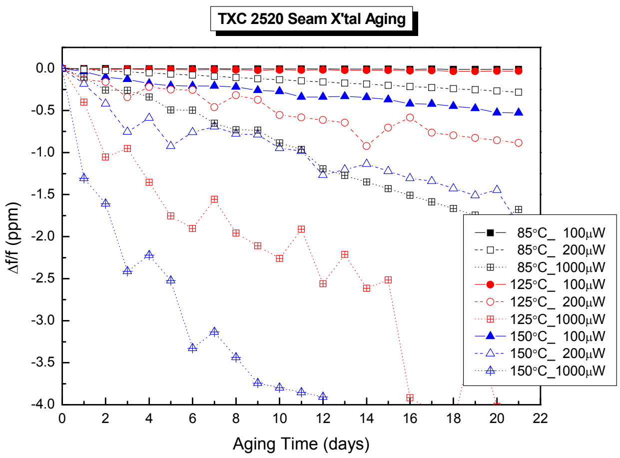

Fig. 2. Aging frequency shift of 2.5mm x 2.0mm Seam Quartz Resonator s under different drive level and temperature.

III. Activation Energy Estimation through Arrhenius Accelerated Aging Modle

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.

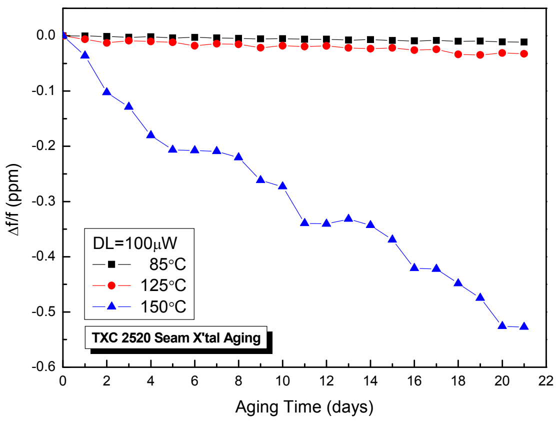

Fig. 3. Aging frequency shift of 2.5mm x2.0mm Seam Quartz Resonator s under 100µW drive level versus diffferent temperaute.

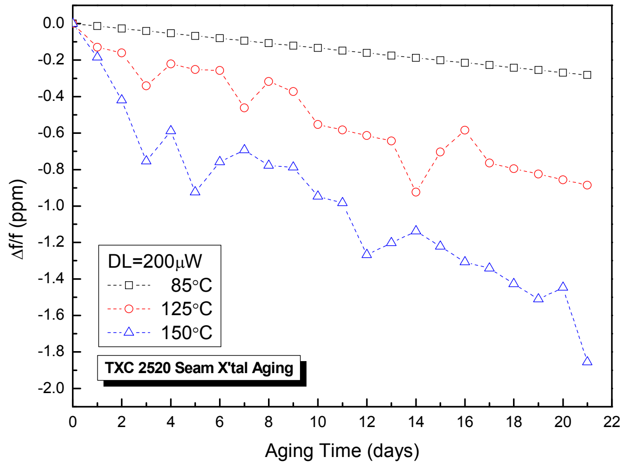

Fig. 4. Aging frequency shift of 2.5mm x2.0mm Seam Quartz Resonators under 200µW drive level versus diffferent temperaute.

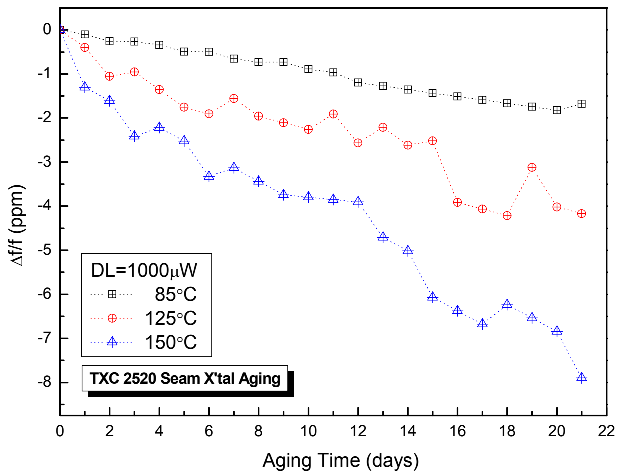

Fig. 5. Aging frequency shift of 2.5mm x2.0mm Seam Quartz Resonator s under 1000µW drive level versus diffferent temperaute.

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]

$$\frac{\Delta f}{f}(i,T,t) = R(i)\cdot R(T)\cdot R(t) \tag{1}$$

$$R(T) = C\cdot e^{\left(\frac{-Ea}{K_B \cdot T}\right)} \tag{2}$$

$$R(t) = \ln(1+bt) \tag{3}$$

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).

$$\frac{\Delta f}{f}(i,T,t) = R(i)\cdot C\cdot e^{\left(\frac{-Ea}{K_B\cdot T}\right)}\cdot \ln(1+bt) \qquad (4)$$

Where C and b is constant, K_B is Boltzmann's constant= 8.616 × 10^{-5}(eV/K), Ea is activation energy(eV)

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

$$\ln T\frac{\Delta f}{f} = \left(-\frac{Ea_\phi}{Kb}\right)\cdot\frac{A}{T} + B \qquad (5)$$

Where A and B is constant, Ea_Φ is activation energy(eV)

$$Ea_\Phi = 0.1984\cdot EXP^{127.62\frac{1}{P}} \qquad (6)$$

An approximated mathematical apparent thermal Ea_Φ versus drivel level could be calculated by experiment results and further express as (6). The apparent thermal Ea_Φ in different drive level was summary as TABLE Π. It reveals small size quartz resonators cannot neglect high drive power effects, especially when drive level over 100µW, 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 1000µW, the apparent thermal Ea_Φ exhibits a saturated tendency with a minimum value 0.233eV.

TABLE II.
AN APPROXIMATED MATHEMATICAL EA EXPRESSION FOR 2.5MM X 2.0MM SEAM TYPE QUARTZ RESONATORS

Arrhenius Accelerated Aging Model		
Temperature	Drive Level	Apparent Thermal Ea_Φ
85℃(358K)	100µW	0.730 eV (slop = -8473.2)
125℃(398K)		
150℃(423K)		
85℃(358K)	200µW	0.355 eV (slop = -4117.2)
125℃(398K)		
150℃(423K)		
85℃(358K)	1000µW	0.233 eV (slop = -2709.8)
125℃(398K)		
150℃(423K)		
Aging Model Considering Temperature & Drive Level		
$\ln T\frac{\Delta f}{f} = \left(-\frac{Ea_\phi}{Kb}\right)\cdot\frac{A}{T} + B = -\frac{0.1984}{Kb\cdot T}\cdot EXP^{127.62\frac{1}{P}}$		
— Ea_Φ (eV) is the apparent activation energy which accelerated under temperature and drive level — T (K) is the temperature of acceleration environment — P (µW) is the drive level — Kb = 8.616 × 10-5(eV/K)—Boltzmann's constant		

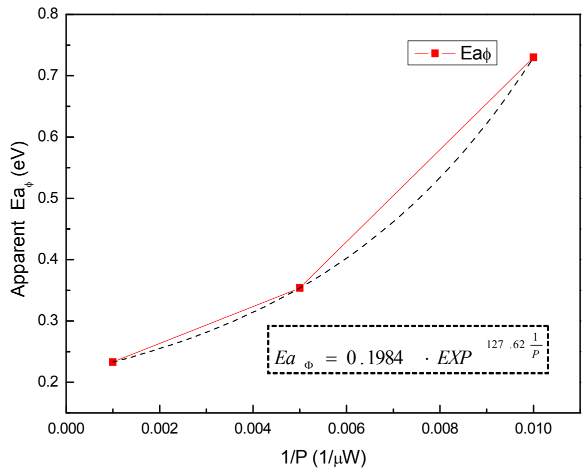

Fig. 6. Apparent thermal Ea_Φ versus drive level

IV. CONCLUSION

For small size crystal resonators, the drive level effects for the lifetime estimation cannot be neglected and will affect the activation energy Ea value in classic Arrhenius accelerated aging model. This paper provides an initial step about the study for the relationship between Ea 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 Ea 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 Ea get lower.

REFERENCES

[1] C.N. Shen, X. W. Yang, C. Chang and M. C. Chao, "The Study of Activation Energy(Ea) by Aging and High Temperature Storage for Quartz Resonators's Life Evaluation", Pro. 2010 Joint Conference of the IEEE Int'l Frequency Control Symp. & European Frequency and Time Forum, San Francisco, pp. 144-146, May 2011.

[2] C. S. Lam. Partik Lin, Sally, Cheng and C. N. Shen, "Aging Performance of Small size MHz Quartz Crystal under High Drive", 2011 IEEE Piezoelectricity, Acoustic Waves and Device Applications Symp., Shenzhen, Dec 2011.

[3] R. Filler et al, "The aging of resonators and oscillators under various test conditions", Proc. 38th AFCS , pp. 444, 1987

[4] A. A. Feinberg, "Parametric failure rate model for quartz crystal device aging with application to surface acoustic wave filters", Proc. 41th AFCS, pp. 360, 1987

[5] M. R. Miljkovic, G. L. Trifunovic, V. J. Brajovic, 42th AFCS, pp.404, 1988

[6] J. R. Vig , "Quartz Crystal Resonators and Oscillators - For Frequency Control and Timing Applications - A Tutorial", May 2013

[7] EPSON, "Oscillation Circuit Design Guide", Technical Note, Apr 1995.

[8] D. Epstein, "Application and use of acceleration factors in microelectronics testing", Solid State Tenchnology, pp. 116, 1982