Data retention performance of 0.13-µm F-RAM memory

Abstract

F-RAM (Ferroelectric random access memory) is a non-volatile memory that uses a ferroelectric capacitor for storing data. It offers higher write speeds over flash/EEPROM.

This white paper provides a brief overview of data retention performance of F-RAM memory.

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1   Introduction

This document provides details on the data retention specifications of AEC-Q100 Grade 3, Grade 2, and Grade 1 (0.13-µm) F-RAM memory products. If operated within the product specification and with 2T2C cell structure, F-RAM has theoretically unlimited Same State (SS) data retention and limited Opposite State (OS) data retention. The prediction of OS retention time of 0.13-µm F-RAM memory products is based on the reliability test results after extended bakes and the activation energy (Ea) of 1.4 eV. This white paper provides a method to calculate the OS data retention life time for customized temperature profiles.

2   F-RAM retention lifetime

A primary measure of reliability of F-RAM is the retention lifetime of a capacitor cell that has been previously stored in a polarization state for an extended time, and then written to the opposite polarization state. This type of retention is known as Opposite State (OS) retention. The effect of imprint makes the previously stored state, or Same State (SS), more stable with a longer store time. Therefore, F-RAM has an unlimited SS retention life within the specified temperature range.

This white paper focuses on the OS retention performance, as specified in F-RAM product datasheets. The OS retention is often specified as an amount of time the F-RAM device can hold user data at a given constant temperature. Thus, the OS retention (time) specification of AEC-Q100 Grade 3, Grade 2, and Grade 1 F-RAM products for constant temperature profiles are given along with a cumulative scenario of multiple temperature profiles over the life of the product.

3 AEC-Q100 Grade 3 (Automotive-A) F-RAM OS retention

Based on accelerated and extended stress experimental results and Ea of 1.4 eV, 10 years of OS retention at 85 °C is guaranteed. The OS retention time at various temperatures are calculated as shown in **Figure 1**. The OS retention increases exponentially as temperature decreases. For example, it is 38 years at 75 °C and >100 years at 65 °C. Below 65 °C, the OS retention is virtually unlimited.
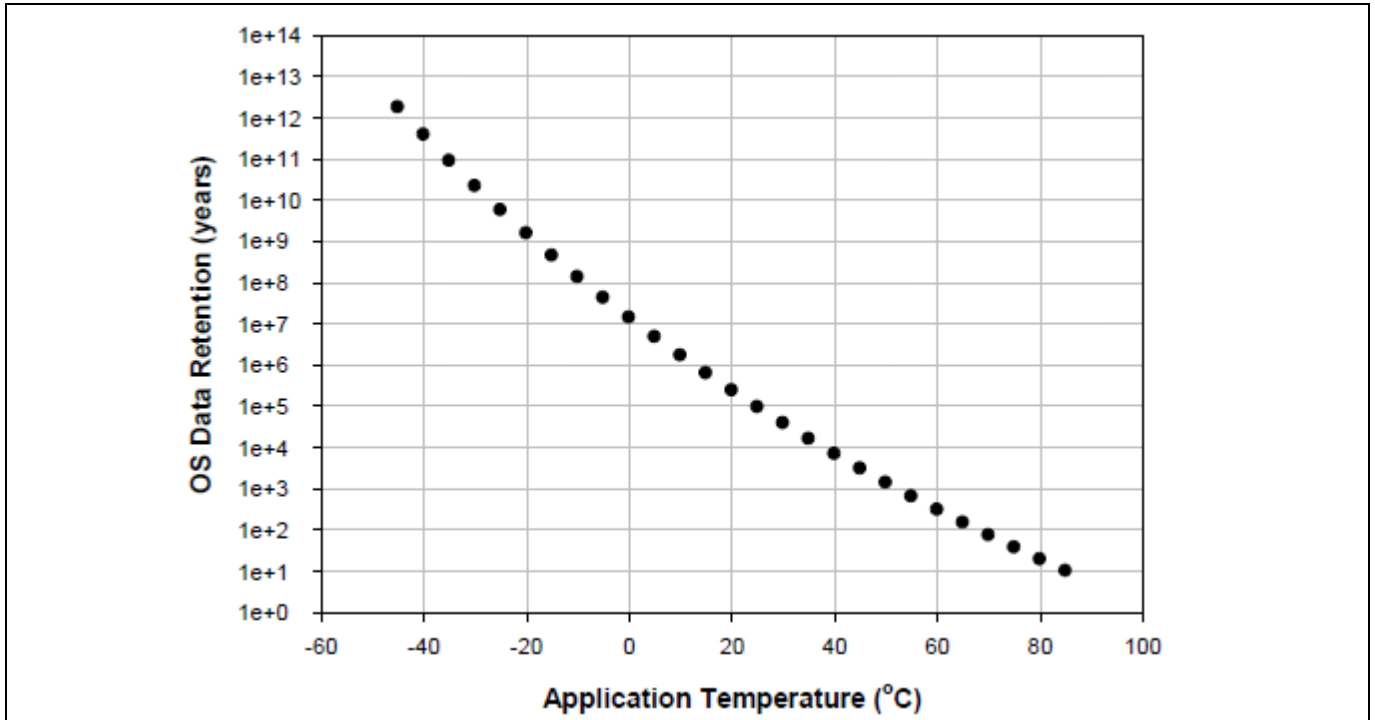

Figure 1 OS retention time of Automotive Grade 3 F-RAM at various temperatures

4   AEC-Q100 Grade 2 F-RAM OS retention

Based on accelerated and extended stress experimental results and Ea of 1.4 eV, 5 years or 43,800 hours of OS retention at 105 °C is guaranteed. The OS retention time at various temperatures are calculated as shown in **Figure 2**. This specification can be converted to more common temperatures. For example, it is equivalent to 43,000 hours at 105 °C plus 64 years at 55 °C. The life time prediction for specific application temperature profiles will be discussed in a later section.
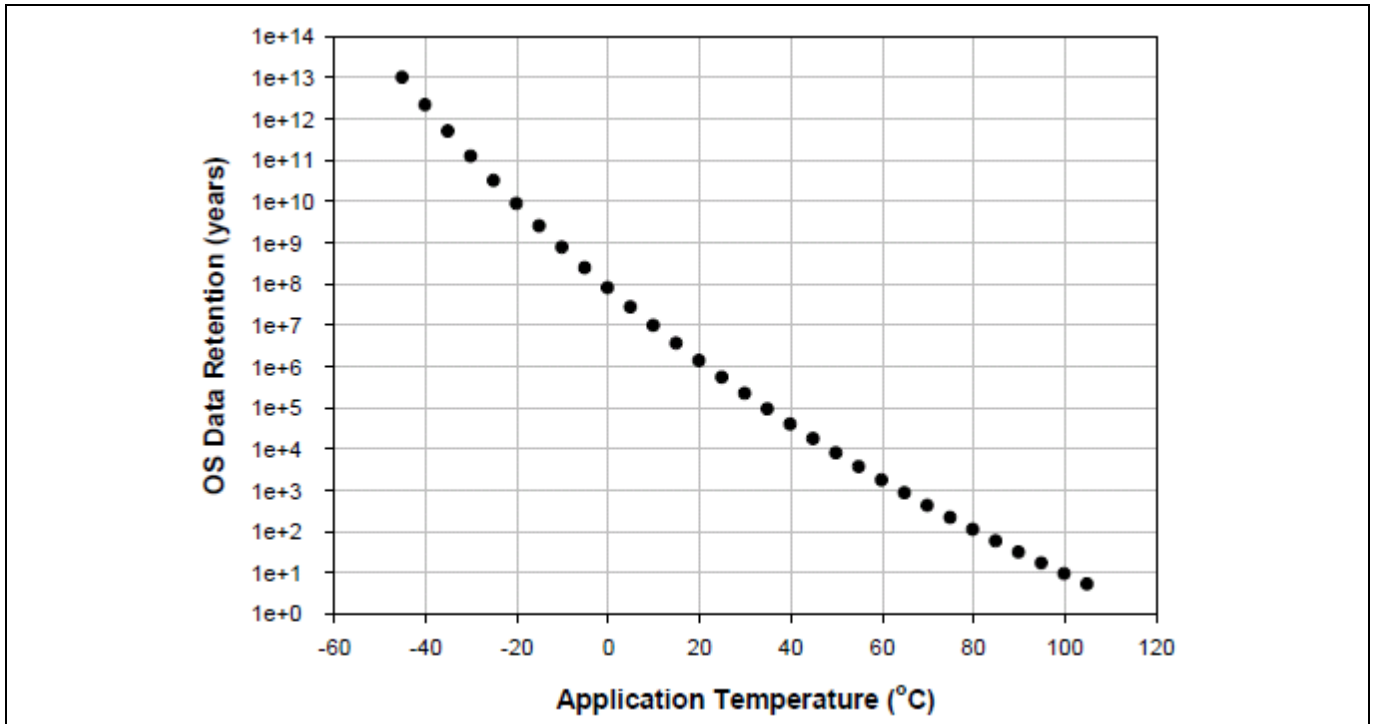

Figure 2   **OS retention time of Automotive Grade 2 F-RAM at various temperatures**

5   AEC-Q100 Grade 1 (Automotive-E) F-RAM OS retention

The accelerated and extended stress experimental results suggest that the OS retention time of Grade 1 F-RAM products is >11,163 hours at 125 °C. This result supports the specification of 11,000 hours (~1.25 years) at 125 °C. The specified OS retention time at various temperatures within the specified temperature range (-40 °C to 125 °C) are calculated as shown in **Figure 3**. The specification can be converted to other temperature profiles.

The life time prediction of specific application temperature profiles is illustrated in the next section.
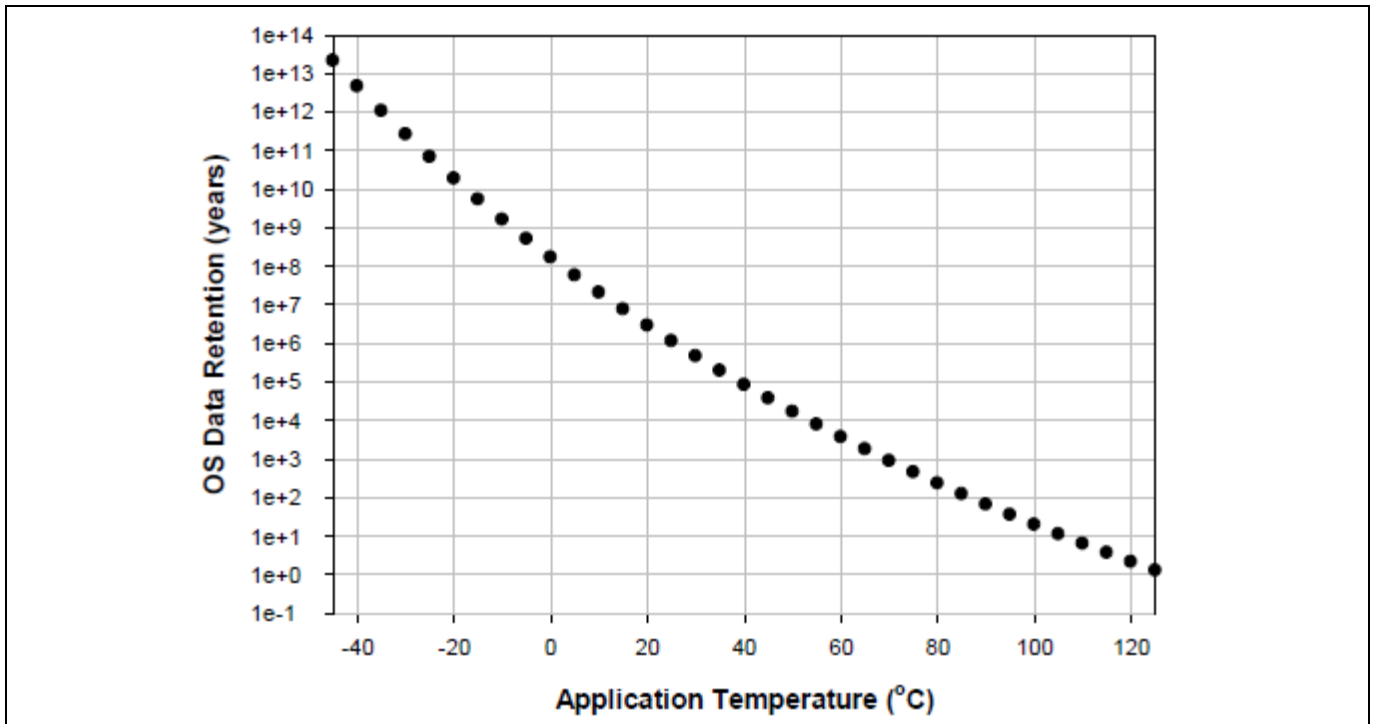

Figure 3   OS retention time of Automotive Grade 1 F-RAM at various temperatures

6 OS retention life prediction for customized temperature profiles

Most of the previous sections focused on the OS data retention specification of AEC-Q100 Grade 1, Grade 2, or Grade 3 F-RAM at a fixed temperature. However, it is rare for an application to actually operate under a steady temperature for the entire usage life time of the application. Instead, an application is often expected to operate in multiple temperature environments throughout the application's usage life time. Accordingly, the retention specification for F-RAM in applications often needs to be calculated cumulatively.

For example: Assuming an application uses Grade 1 F-RAM at different temperature profiles over the following usage life time:

Temperature 1 = 125 °C for 10% of time (t1)

Temperature 2 = 105 °C for 15% of time (t2)

Temperature 3 = 85 °C for 25% of time (t3)

Temperature 4 = 55 °C for 50% of time (t4)

Following the Arrhenius equation, the acceleration factor A between T and Tmax is:

$$A = \frac{L(T)}{L(Tmax)} = e^{\frac{Ea}{k}\left(\frac{1}{T} - \frac{1}{Tmax}\right)}$$

Where 'k' is the Boltzmann constant 8.617×10^{-5} eV/K, 'Tmax' is the highest temperature specified for the F-RAM product, and 'T' is any temperature within the F-RAM product specification. All temperatures are in kelvin (K) in the above equation. The acceleration factors are calculated and listed in **Table 1**.

Table 1   Acceleration factors

Temperature	Time factor	Acceleration factor w.r.t Tmax	Profile factor	Profile life time
(T)	(t)	(A)	(P)	L(P)
T1 = 125 °C	t1 = 0.1	A1 = 1	$P=\dfrac{1}{\dfrac{t1}{A1}+\dfrac{t2}{A2}+\dfrac{t3}{A3}+\dfrac{t4}{A4}}$ = 8.33	$L(P) = P \times L(Tmax)$ = 10.46 years
T2 = 105 °C	t2 = 0.15	A2 = 8.67		
T3 = 85 °C	t3 = 0.25	A3 = 95.68		
T4 = 55 °C	t4 = 0.5	A4 = 6074.80		

The Profile factor P is determined by:

$$P=\frac{1}{\frac{t1}{A1}+\frac{t2}{A2}+\frac{t3}{A3}+\frac{t4}{A4}}$$

The OS retention life time prediction of a temperature profile, L(P), is given by:

$$L(P) = P \times L(Tmax)$$

Where L(Tmax) is the specified OS retention time 11,000 hours at 125 °C. The calculation process and results are listed in **Table 1**. It can be observed that the life time of a profile is dominated by the highest usage temperature and its time factor. Note that in the calculation, T is equal to or lower than Tmax. It is mathematically correct to use in equations when T > Tmax, and T < Tmin; however, Infineon does not guarantee the parts working properly when T is out of the temperature specifications.

7 Summary

Table 2 summarizes the Tmax, the OS retention life time specification at Tmax i.e., L(Tmax), and OS retention life time calculation of a general temperature profile.

Table 2   Summary of OS retention

F-RAM product	Tmax	OS retention at Tmax	OS retention life time of temperature profile determined by customers
Grade 1	125 °C	11,000 hours	
Grade 2	105 °C	5 years	$P = \frac{1}{\Sigma\frac{t}{A}}, \qquad L(P) = P \times L(Tmax)$
Grade 3	85 °C	10 years	

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