很多汽车电子产品有基于快闪的微处理器。汽车公司或EMS经销商最不想见到喜欢的就是因由于控制模块中的数据保存出现问题而回收产品。因此，一些工程师不愿意更新从较慢（而且昂贵）的在系统编内程序设计方法进行更新，因为这些方法允许进行焊接后编的程序设计。本文通过考虑在无动力装置中发生升温时的漏电，说明非易失性存储器（NVM）装置的可靠性物理性质。我们发现，在对非易失性存储器装置进行编程序设计后焊接的情况下，对数据保存的影响是可以忽略的。

Manufacturing Effects on Data Retention of Nonvolatile Memory Devices

Kelly Hirsch

Can heat from wave or reflow soldering cause premature data loss?

Charge is stored on floating gates, and heat coupled with a loss of charge can cause a "bit-flip." Is this a significant problem?

Many automotive electronics have flash-based microcontrollers in mission critical applications. The last thing an automotive company or EMS vendor wants is a recall due to problems with data retention in one of the control modules. As such, some engineers are reluctant to upgrade from slow (and costly) boundary scan or other in-system programming methods because they permit post-soldering programming.

Our position: it's not a problem. Let's review why.

Every semiconductor manufacturer that produces non-volatile memory (NVM) has to verify that data retention for a new design is sufficient and establish a quality procedure for monitoring data retention in production. Typically they will test for loss of data at elevated temperatures; then, using a relationship called the T-Model, calculate the equivalent lifetime for normal temperature ranges.

The T-Model is used because it takes into account both temperature and voltage effects. This is appropriate because the semiconductor manufacturer is trying to determine the data retention for NVM used in an application where heat and power are applied at the same time. (An automotive application is a good example of a NVM device used at elevated temperatures.)

The T-Model is defined as

$$A_f = \exp\left[\frac{T_t - T_u}{To}\right]$$

where A_f is the acceleration factor, T_u is the temperature of the normal environment and T_t is the elevated temperature where failures are induced at an accelerated rate. (Note both of these temperatures are in degrees Kelvin.) *To* is the characteristic temperature for data retention that embodies dielectric, field strength and charge loss effects. For EPROMs using an oxide-nitride-oxide process, one manufacturer empirically determined *To* to be 21°K for the floating gate.

To continue the example, let's say we are trying to determine the data retention for an automotive application where a microcontroller (with embedded EPROM) sees a junction temperature of 125°C. For one of the tests, we might measure data retention for 450 hrs. at 250°C. (Obviously, this is at wafer burn-in; the plastic encapsulant used in SMT packages cannot withstand this temperature.) Using the T-Model, we would calculate the acceleration factor as

$$A_f = \exp\left[\frac{523 - 398}{21}\right] = 384$$

An acceleration factor of 384 means that if the data lasted for 450 hrs. at 250°C, they would last

384 times longer at 125°C, or about 20 years. This is certainly sufficient for any automotive application.

But when we think about our perennial question – Does the heat from reflow hurt the data? – there is no voltage applied to the embedded flash; the device is off. So how do we model this?

If we are trying to model temperature effects alone, then we can use the famous Arrhenius relationship. This model describes the effect that temperature has on a chemical process with a certain activation energy. Like the T-Model, it produces an acceleration factor for a system exposed to an elevated temperature. The relation is

$$A_f = \exp\left[\frac{E_a}{k}\left(\frac{1}{T_u} - \frac{1}{T_t}\right)\right]$$

where A_f is the acceleration factor, E_a is the activation energy (in eV), k is Boltzman's constant (in eV), T_u is the temperature of the normal environment and T_t is the elevated temperature. (Again, these temperatures are in degrees Kelvin.)

The effect of soldering programmed NVM devices is negligible.

But to use the Arrhenius relationship, we need to empirically determine the activation energy by fitting a curve to some experimental results at different temperatures. The activation energy is a critical parameter for attaining meaningful results. A typical activation energy is 0.8 eV for effects related to charge loss when no voltage is applied to the device.

As another example, consider a guided munitions application for which an electronics module might sit in storage in the desert. Assuming the internal temperature of the shell reaches 125°C, will the data retention in the embedded flash be compromised? In this case, we would use data from a test where we measured data retention at wafer burn-in with no power applied to the circuit (other than brief intervals to read the data and make sure it was still in order). Let's assume we measured good retention for over 1000 hrs. at 250°C. (This is typical of today's NVM.) Using the Arrhenius relationship, we would calculate the acceleration factor as

$$A_f = \exp\left[\frac{0.8}{8.6171\,x\,10^{-5}}\left(\frac{1}{398} - \frac{1}{523}\right)\right] = 263$$

With an acceleration factor of 263, the data retention in the application (at 125°C) will be more than 263,000 hrs. (263 x 1000), or over 30 years. The U.S. Army should be happy with this result.

Reflow Considerations

This same process can be applied to data retention effects from heat exposure during soldering. Peak temperatures of 235°C are typical, but the durations are much shorter. Let's use the Arrhenius relationship to calculate how much of the "life" we are using by heating a NVM device after programming.

Vapor phase reflow is used with a peak temperature of 235°C for 60 sec. The thermal profile also includes ramping up to 125°C for a few minutes (we have already shown that there is negligible effect at this temperature).

The worst-case assumption would be that the thermal mass of the NVM device is so small that the die temperature is tracking the ambient temperature. Using the same data point as in the previous example, we can calculate the acceleration factor between non-powered data retention tests and the SMT vapor phase reflow temperature as

$$A_f = \exp\left[\frac{0.8}{8.6171\,x\,10^{-5}}\left(\frac{1}{508} - \frac{1}{523}\right)\right] = 1.69$$

We are saying that very little difference exists between charge loss at 250°C compared to 235°C; only a factor of about 1.7. So if we spend 1 min. at 235°C, what have we done to the average data retention time? To find out, divide 1 min. by 1000 hrs. times 1.7. This calculates to about 10 ppm or 0.001% of the calculated life.

Referring back to the guided munitions application, the effect of programming before SMT reflow reduces the data retention lifetime from 30 years to 29.9997 years. Big deal.

Most datasheets for SMT devices have a list of Absolute Maximum Ratings. Included in these parameters is usually the maximum heat exposure a part can withstand during soldering and still be reliable. But this maximum rating is mostly due to the thermomechanical effects. For example, at extreme temperatures the encapsulant will flow and tear off wire bonds. But as we have shown, this brief thermal exposure does not cause a data retention problem.

Note that for a thorough estimate of NVM device reliability, we would also have to include thermomechanical and temperature-humidity effects.

While this example greatly simplifies the reliability physics for NVM devices by solely considering charge leakage at elevated temperatures in an unpowered device, it is the appropriate model to answer our basic question: The effect on data retention by soldering NVM devices after they have been programmed is negligible. ■

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